Comparative study on wood characteristics of *Carapa guianensis* Aubl. from two plantations and a natural site in Central Amazonia

J. Bauch,[1] O. Dünisch,[2] F. Schuster,[1] L. Gasparotto,[3] and C. P. de Azevedo[3]

[1] Institute of Wood Biology, Hamburg University, Hamburg
[2] Institute of Wood Biology and Wood Preservation, Federal Research Centre of Forestry and Forest Products, Hamburg
[3] EMBRAPA Amazônia Ocidental, Manaus, AM, Brazil

Summary

The study has shown that, especially for the recultivation of degraded land areas, a small portion of long-lived trees for high quality timber production might contribute to the stabilization of mixed culture plantation systems. Nevertheless, the environmental influences on high-quality timber production of many tree species are not known in detail.

The present study with *Carapa guianensis* Aubl. was directed to find out the parameters prevalent already in young trees which determine their growth. These parameters could be useful to predict the wood characteristics and the quality of the adult trees, when they will be sufficiently mature for utilization.

The study related to two monocultures at an age of 4 (eight trees) and 17 (two trees) years respectively and to a primary forest (two trees). The growth dynamics of the eight 4-year-old trees selected revealed 11 to 15 increment zones which could not be correlated with the labelling of increment zones by vessel enrichment. The study proved that, already in the 5th year, parenchyma bands indicate the pattern of adult wood. The very early formation of adult wood is traceable in the pattern of the percentual composition of vessels, fibres, and parenchyma (ray and strand parenchyma). Furthermore, the fibre length already reaches its plateau of 1.45 – 1.59 mm at the early growth stage of about four years. It could be shown, as well, that the fibre lengths of plantation-grown trees correspond to those of primary forest trees. Average density also could be demonstrated to correspond with about 0.63 g/ cm^3. Therefore, it can be expected from the growth increment that under plantation conditions, 30- to 40-year-old trees can be harvested. According to the study, *Carapa guianensis* can be recommended for plantations in order to produce timber of high quality.

The findings of the present study on wood formation and wood characteristics of native tree species of the Central Amazon, therefore, can contribute to the development of sustainable landuse systems in this region.

Resumo

Estudo comparativo das caraterísticas da madeira de *Carapa guianensis* Aubl. procedente de duas áreas de plantío na floresta nativa da Amazônia Central

Os estudos têm mostrado que, especialmente, para o recultivo de áreas degradadas, uma pequena quantidade de árvores que produzem madeira de alta qualidade pode contribuir para a estabilização dos sistemas de cultivo misto. Contudo, não são conhecidos detalhadamente as influências do meio ambiente sobre a produção de madeira de alta qualidade de muitas espécies arbóreas.

A pesquisa com *Carapa guianensis* Aubl. objetivou definir os parâmetros existentes, predominantes nas plantas jovens e que determinam o seu crescimento. Estes parâmetros serão úteis para predizer as características e a qualidade da madeira das árvores adultas, quando atingirem a idade de corte.

Os trabalhos foram desenvolvidos em duas áreas de monocultivo, sendo uma, com oito árvores de quatro anos de idade e a outra, com duas árvores de 17 anos de idade, e em floresta nativa, com duas árvores. As dinâmicas de crescimento das árvores com quatro anos de idade revelaram 11 a 15 zonas de incremento, as quais não puderam ser correlacionadas com a marcação das zonas de incremento pelo enriquecimento dos vasos. O estudo provou que no quinto ano, parênquima em faixas indicam o padrão da madeira adulta. A formação muito precoce da madeira adulta está traçada no padrão de composição percentual dos vasos, fibras e parênquima (parênquima radial e longitudinal). Além disso, o comprimento da fibra atinge seu ápice de 1,45 a 1,59 mm no estágio inicial de crescimento aos quatro anos de idade. Verificou-se que o comprimento das fibras das árvores cultivadas é semelhante ao das árvores da floresta nativa. A densidade média foi de 0,63 g/ cm^3. Conclui-se que a *Carapa guianensis* pode ser recomendada para plantio a fim de produzir madeira de alta qualidade, com a expectativa das árvores atingirem a idade de corte entre 30 a 40 anos.

Os resultados dos estudos sobre a formação e as características da madeira de espécies nativas da Amazônia Central podem contribuir para o desenvolvimento de sistemas sustentáveis de uso da terra nesta região.

Introduction

The capital of the Federal State Amazonia, Manaus, at present experiences a high increase in population rates. This in turn leads to an increased pressure of the rapidly growing city on the surrounding tropical primary forest. The population has to be supplied with agricultural products. Additionally, there is a great demand of wood for various utilization aspects.

For this reasons, in Central Amazonia, particularly on the „terra firme", there are projects to establish mixed plantations on sites, where degradation of former forest areas occurred. In this respect, for sustainably managed, mixed plantations, tree species with high-quality timber production should be considered, as well. However, many tree species (such as *Tectona grandis*, *Shorea* spp. or *Pinus strobus*) grown under plantation management produce timber with less wood characteristics and, therefore, produce less valuable wood than under primary forest conditions (comp. BHAT et al., 1989; BOSMAN et al., 1994).

With the plantations on the „terra firme" in the Manaus region, species of the family of *Meliaceae* are favoured for their high-quality wood production. In particular, there will be a considerable demand for *Swietenia macrophylla* King., *Carapa guianensis* Aubl. and *Cedrela odorata* Roxb. for construction wood, furniture production, and veneer quality wood in the future. So far, there have not been biological, chemical, and technological studies on the wood characteristics of these species under plantation conditions on the „terra firme".

In the following study, we try to compare the wood characteristics of plantation trees of *Carapa guianensis* Aubl. in the Manaus region with those of trees from old growth primary forests. It will be attempted to demonstrate the possibilities and limits of predicting the adult wood phase at harvest for wood utilization already from characteristics of the juvenile phase. Moreover, the extent of the sustainable growth of the plantation trees will be calculated from the growth pattern to show the perspectives and limits of this method and to indicate which plantation management should be favoured.

Site and tree selection

In association with the experimental area of 19 ha of the SHIFT-project ENV 23, established in 1992, where *Carapa guianensis* Aubl. was considered for timber production, as well, the Research Centre EMBRAPA Amazônia Ocidental in Manaus planted this species in January 1992 in plots of 25 trees each, with four repeats for the study of wood characteristics and growth behaviour.

At the beginning of this study, it could not be expected that already juvenile plants at an age of only four years would allow predictions of the wood quality to be expected later on, when harvesting is calculated.

Therefore, a comparable *Carapa*-plantation of the INPA (Instituto Nacional de Pesquisa da Amazônia) at an age of 17 years might support this study. Finally, trees from a neighbouring primary forest served as a reference to the wood quality obtainable under the prevalent climatic and soil conditions.

In December 1995, eight trees in total of four plots were harvested from the 4-year-old plantation, and two very similar trees were comparatively selected from the 17-year-old plantation. Finally, two adult trees of the primary forest served as a reference. Naturally, the age of the latter could not be determined, but it certainly amounts to more than 50 years (Table 1).

Table 1: Trees of the species *Carapa guianensis* Aubl., selected from two plantations and a primary forest

Tree No.	Location	Age (years)	Diameter (centimetres)	Height (metres)
1	Plantation EMBRAPA	4	10.7	7.0
2	Plantation EMBRAPA	4	8.8	5.4
3	Plantation EMBRAPA	4	9.2	4.6
4	Plantation EMBRAPA	4	9.4	5.5
5	Plantation EMBRAPA	4	9.4	5.3
6	Plantation EMBRAPA	4	10.8	6.2
7	Plantation EMBRAPA	4	9.1	5.8
8	Plantation EMBRAPA	4	9.8	5.8
9	Plantation EEST (INPA)	17	24.5	16.7
10	Plantation EEST (INPA)	17	19.0	18.2
11	Primary forest	n. d.	26.5	27.8
12	Primary forest	n. d.	37.5	32.0

Experimental

The investigations on the wood characteristics relate to the 12 selected trees: The discs were taken in December 1995 from the freshly cut trees in a height of 1.30 m. For comparison, discs were harvested from the treetop, as well.

Macroscopically determined structural patterns on discs

Photos (1:1) from the polished discs served for the determination of bark, sapwood, heartwood, and pith portion by means of a digital board (HIPAD Plus; company: Houston Instruments). The growth increments were measured by an Eklund machine in all directions.

Microscopical observations

Along the radius in all cardinal directions of the discs, blocks were used continuously from cambium to pith for the determination of the composition (%) of the cell species (vessels, fibres, strand and ray parenchyma). These data were obtained by means of an integration ocular lens and a counting instrument (Leucodiff; company: Boskamp). By this procedure, the structural dynamics from cambium to pith can be illustrated.

The variation of the individual vessel area was measured, as well, on cross sections from 10 – 20 µm thin slides, in order to understand exogenous influences on vessel size during the annual growth.

Other important parameters of wood quality evaluation are the fibre length, the wall thickness, and the cell lumen. The fibre length, the wall thickness, and the cell lumen from cambium to pith were determined after maceration (Jeffrey solution) of small blocks continuously cut out along the radius of the discs. The dimensions of the isolated fibres were additionally determined by using the digital board.

Wood density

Carapa guianensis is, among other uses, commercially important as a wood species suitable for construction purposes. Therefore, wood density is a key parameter in the evaluation of quality. For this purpose, gradients from cambium across the pith to cambium were taken from all discs and subsequently determined gravimetrically (density r_0).

Results

Pattern of growth increments

Carapa guianensis belongs to the tree species in Amazonia which develop distinct growth increments. The parameters responsible for these growth patterns are not yet known. Therefore, it was important from the beginning onwards to determine the growth patterns macroscopically and microscopically for all of the twelve selected trees, as the dynamics of growth to a great extent determines the wood characteristics of the adult tree. The discs of the eight selected trees of the 4-year-old plantation with a diameter of up to 10.8 cm and 7.0 metres height exhibited 11 to 15 growth increments in regular distribution. The selected disc for illustration (Fig. 1) reveals 14 continuously developed zones with two to four additional indications of zones restricted to short dimensions around the disc. It turned out that a synchronization of the growth increments between the eight trees was not possible. It became obvious that individual growth behaviour dominated.

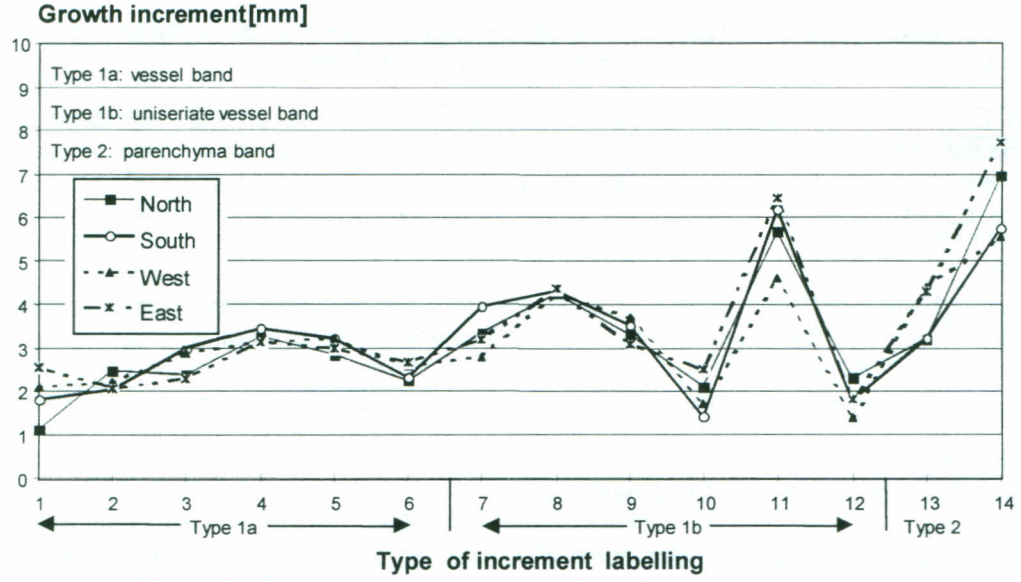

Fig. 1: 14 growth increments of a 4-year-old tree (EMBRAPA)

However, all of the eight trees have in common that at the beginning vessel accumulation (type 1 a) near the pith and one vessel series (type 1 b) labeled the growth zones. But already at a tree age of approximately four years, the parenchyma bands which are typical for *Carapa* appeared (type 2).

In addition, the growth patterns of the trees of the 17-year-old plantation and those of the primary forest coincide with that of the 4-year-old plantation. These corresponding growth patterns of the three different sites indicate that *Carapa* trees change from juvenile phase to adult phase after a tree age of only about four years already. This early change to adult wood structure is of dominant importance for the quality of wood produced under plantation conditions. Moreover, the 17-year-old plantation tree with 24.5 cm diameter and 16.7 metres height already exhibits a high portion of durable heartwood. Corresponding to that tree, the tree from primary forest (37.5 cm diameter, 32 metres height) exhibited a heartwood portion of approximately 50% already. But it is conspicuous that at an age of about four years, their growth rate was only half of the growth of trees grown on the plantation. In addition to the comparison of growth patterns under plantation and primary forest conditions, the composition of the wood from the cell species is of importance for the evaluation of wood characteristics.

Percentual composition of vessels, fibres, and parenchyma

The percentual composition of vessels, fibres, longitudinal and ray parenchyma was determined in all of the twelve selected trees. The average values were printed for the gradient pith to cambium in 20 mm steps, beginning from pith.

It is obvious that the juvenile phase of *Carapa* at all three sites indicates a high ray parenchyma (24%) and a low vessel portion (9%), as illustrated by the EMBRAPA-plantation in Table 2. In an advanced adult phase such as in trees of the primary forest, the vessel portion remarkably increased, whereas the percentages for ray parenchyma decreased.

In Table 2, the total average of the gradient pith to cambium was determined for the two plantations and the primary forest. It is significant that the percentage of the formation of fibre iss almost constant with 59 to 63% throughout the lifetime of the individual trees. The values indicated in the literature coincide with this pattern of cell composition. It can be concluded from cell composition that wood from plantations corresponds in quality to that of primary forest trees.

Table 2: Percentual composition [%] of vessels, fibres, longitudinal and ray parenchyma in the wood of the twelve selected trees of two plantations and a primary forest

Site	Vessels	Fibres	Longitudinal parenchyma	Ray parenchyma
Plantation EMBRAPA (eight trees)	9	59	8	24
Plantation EEST (two trees)	14	63	7	16
Primary forest (two trees)	17	60	9	14

*Percentages in literature: vessels 16%, fibres 60%, longitudinal parenchyma 7 %, ray parenchyma 17%.

Pattern of fibre lengths from pith to cambium

The high percentage of fibres in the wood of *Carapa* to a great extent determines the high quality of this wood species. But for a more detailed interpretation of the wood characteristics, the fibre length, the lumen, and the wall thickness are of importance, as well. The determination of the fibre length occurred continuously from pith to cambium for all of the twelve trees. One example of each of the three sites is indicated in Fig. 2.

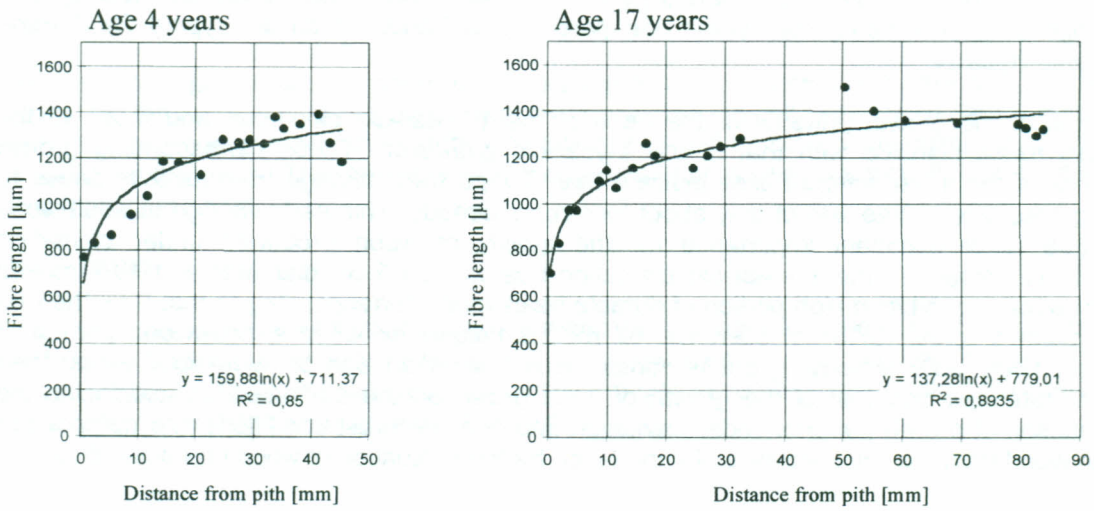

Fig. 2a/b: Fibre length from pith to cambium exemplified for the two plantations

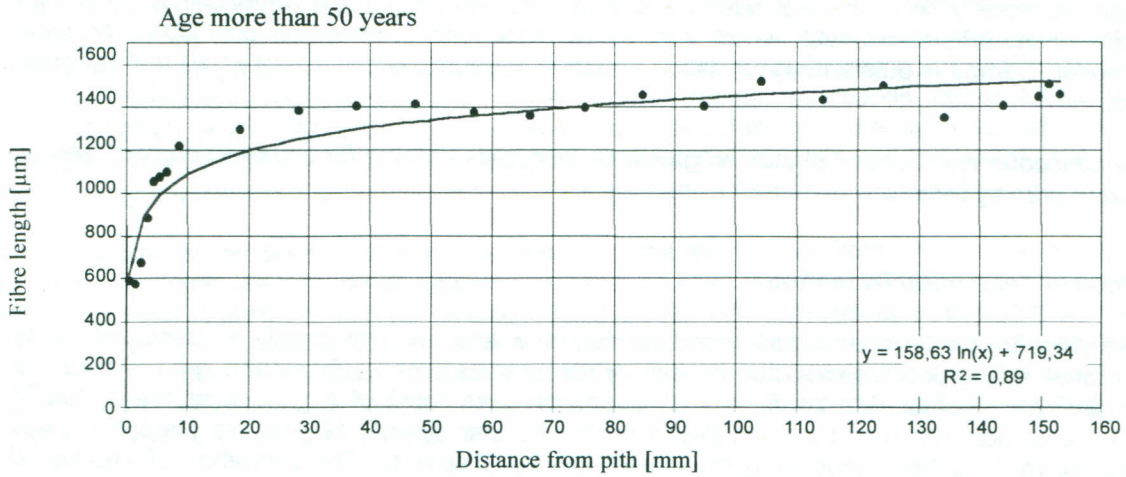

Fig. 2c: Fibre length from pith to cambium for a tree of the primary forest

On the parameter fibre length, the rapid development from juvenile to adult wood can be confirmed, as well. Already after four years growth (which is similar to about 40 mm tree radius), the fibre length of the two plantations tends to a plateau. Due to a lower increment per year of the two primary forest trees, the curve for fibre length indicating the increasing tree diameter is even steeper.

By means of a regression equation, fibre lengths of up to 1.45 to 1.59 mm could be measured for tree dimensions of about 30 cm diameter. From this calculation, it can be concluded that the fibre lengths in plantation-grown wood and of primary forest trees correspond.

Moreover, also wall and lumen dimensions exhibit corresponding values from 3.1 to 4.0 µm wall thickness and 11.0 to 14.3 µm lumen diameter at 40 mm from the pith. These data lead to the conclusion that also wood density is to be expected to be in a corresponding range, which determines the elastomechanical characteristics of the wood.

Wood density

With regard to estimate the elastomechanical characteristics of wood from plantation trees compared to that of trees from primary forests, the density (R_0: g/ cm^3, oven dry wood) is a key parameter for evaluation. Density measurements were carried out for all twelve trees from pith to cambium. In Table 3, selected data are shown for the zone 0 to 40 mm, beginning from pith for all trees, in addition to the thicker trees (EEST-plantation and primary forest) also the outer xylem zone (40 mm, neighbouring to the cambium) was included.

Table 3: Determination of the density [R_0: g/ cm^3] from pith to cambium for twelve selected trees of three sites

Site	Measure [n]	Density [g/ cm^3]	Variation coefficient [%]
Plantation EMBRAPA 0 – 40 mm	145	0.59	5.33
Plantation EEST 0 – 40 mm outer xylem	36 39	0.55 0.63	6.57 5.73
Primary forest 0 – 40 mm outer xylem	37 37	0.59 0.62	7.39 5.94

As a basic result, it can be emphasized that the juvenile wood density with 0.55 - 0.59 g/ cm^3 already is close to the values of adult wood with 0.62 and 0.63 g/ cm^3 respectively. This high density, comparable to beech wood, can be obtained under plantation conditions, as well. Moreover, *Carapa* is outstanding for its low variation in density within a single tree and between trees.

As a consequence, wood of plantation-grown *Carapa* is as suitable for construction purposes as wood of primary forests.

Trends in heartwood formation

In contrast to construction wood, wood for furniture and veneers mainly is classified by its decorative heartwood. In particular, accessory compounds such as flavonoids are the cause of the decorative colour. Monitoring the cross-section area [cm^2] of the discs at breast height (DBH) and their heartwood portion [%], it is striking that already 17-year-old plantation trees show 14 to 17% heartwood of good veneer quality (Table 4). The formation of heartwood increases disproportionally to the tree age. Therefore, a similar portion of heartwood, as in primary forest trees, with 64 and 78% can be predicted for plantation trees of the same age. The decorative character in combination with a high natural durability will guarantee a high economic value with an increasing tendency for *Carapa.*

Table 4: Comparison of the cross section area to its proportional content of heartwood

Site	Cross-section area (disc) [cm^2]	Portion of heartwood [%]
Plantation EMBRAPA	59 - 91	**0**
Plantation EEST	237 and 401	**14** and **17**
Primary forest	511 and 913	**64** and **78**

Discussion

For *Carapa guianensis*, the development from juvenile to adult wood was not yet described. Therefore, comparative histological and histometrical studies on wood from plantations and a primary forest of this species were necessary to predict the quality of adult wood from juvenile wood, as far as wood properties are considered. Whereas in a previous study, the growth dynamics throughout the year were of main interest (SACK, 1998; DÜNISCH et al., 1999), the present study is concentrated in the structural dynamics and the wood quality of the selected twelve trees.

After the cutting of tropical and subtropical plantation trees, in several cases it became obvious that the wood characteristics and the wood quality of these trees do not reach the same high level as the trees grown in the primary forest (BEN DISEN, 1978; ZOBEL, 1985; BRAZIER, 1985). This is due to the fact that fast-growing plantation trees with identical stem diameter develop a higher portion of juvenile wood compared to primary forest trees. This development is independent of tree age, which can vary significantly in the number of years (ZOBEL and BUIJTENEN, 1989).

The variability of the structural dynamics within a tree depends on the endogen triggered ageing of the cambium and on the exogen inputs in the meristem (PANSHIN and DE ZEEUW, 1980). Physiologically, it functions as a sink for water, carbohydrates, nutrient elements, and phytohormones. The structural dynamics from pith to cambium revealed a remarkably rapid development from juvenile to adult wood. There is strong evidence that in the juvenile phase, the scarcely visible increment zones are formed by vessel enrichment as short, tangentially-

oriented bands or by bands continuously developed around the 360° circumference. However, the 11 to 15 bands in a 4-year-old tree of *Carapa* do not reveal any clear relationship with dry and wet seasons. Moreover, already from about a tree-age of four years, the bands are determined by longitudinal parenchyma as is usual for adult wood (comp. VETTER, 1995). Compared with the development of adult wood in other tropical hardwoods (comp. MÜLLER, 1987; BOSMAN et al., 1994), *Carapa guianensis* reaches adult structural dynamics at a very early age. This result, which is a very positive one for the utilization of the wood, can be confirmed by several cell characteristics and by parameters determining wood quality.

The variability of the portion of the cell-species measured across from pith to cambium is relatively low, compared to other species. Even in juvenile wood, about 60% of the wood volume consist of fibres, similar to average adult wood. With increasing tree diameter, the portion of vessels increases to some extent. A corresponding decrease is obvious in the ray-parenchyma portion. This vessel increase is combined with an increasing vessel diameter in the juvenile phase, which could be already demonstrated by OBAYASHI and SHIOKURA (1989) for three fast-growing tropical tree species.

The fibre length, which is strongly genetically determined, represents a suitable parameter for predicting the development from juvenile to adult wood (ZOBEL and JETT, 1995). By means of regression analyses of the development of fibre length from pith to cambium, for *Carapa* a maximum plateau from 1.45 to 1.59 mm can be expected. The fibre-length is genetically determined. This genetical determination can be shown convincingly by the fact that, as to fibre-length, the fast-growing and slow-growing 4-year-old trees in the monoculture and the enrichment system respectively correspond as concerns age, but not as concerns diameter.

The results on the wood-anatomical characteristics of juvenile and adult wood of *Carapa guianensis* indicate that wood from a plantation and a primary forest corresponds in the structural composition. Additionally, the measurements of wood density, which determines the elastomechanical properties, measured across the tree diameter showed a high density already in the juvenile phase with about 0.55 to 0.59 $g \cdot cm^{-3}$ respectively in all twelve experimental trees with a low deviation of the mean values. The slight increase of density up to 0.62 and 0.63 $g \cdot cm^{-3}$ respectively can be explained with an increase of wall-thickness in the adult wood zones. PANSHIN and DE ZEEUW (1980) showed that most of the diffuse porous hardwood species follow this trend. But they could also identify two other types of density patterns across the stem, which were later on confirmed by BHAT et al. (1989). According to these studies, density can increase from pith outwards to the adult wood, as shown for *Carapa*. The density can increase until the cambium even in the adult wood (comp. WIEMANN and WILLIAMSON, 1988). Finally, KURODA et al. (1995) confirmed a third density pattern, where the density increased in younger trees and changed in older trees outwards to a slight decrease.

The relatively high and uniform density of *Carapa guianensis* combined with straight and large trunks on the one hand favours the utilization also for construction purposes. On the other hand, heartwood of *Carapa guianensis* is estimated for veneers, because of its natural durability and its decorative structure.

The 17-year-old plantation of *Carapa guianensis* shows that also under plantation growth conditions, heartwood formation already begins in young trees of this species and that the heartwood portion increases rapidly in volume and colour quality. Considering the distinctly different site factors, such as temperature, soil water supply, light intensity, element supply and insect calamities, in plantations and primary forests respectively, this finding is very promising for high-quality timber production under suitable plantation conditions.

In recent years, several methods of management for sustainable mixed plantations were favoured in tropical regions, in order to decrease the high exploitation pressure on primary forests. With respect to the „terra firme" in the Central Amazon, preliminary results on the management of mixed plantations with fruit, crops, and to some extent high-quality timber production, *Carapa* is one of the favoured species for good harvests concerning quantity and quality. Considering the increasing future demand for high-quality wood in Brazil, high-quality timber production can be highly recommended.

References

BENDTSEN, B. A.: Properties of wood from improved and intensively managed trees. Forest Products Journal, 28, 10 (1978) 61 – 72.

BHAT, K. M.; BHAT, K. V.; DHAMODARANT, T. K.: Radial pattern of density variation in eleven tropical Indian hardwoods. Holzforschung, 43 (1989) 45 – 48.

BOSMAN, M. T. M.; KORT, I. de; GENDEREN, M. K. van; BAAS, P.: Radial variation in wood properties of naturally and plantation grown Light Red Meranti (*Shorea, Dipterocarpaceae*). IAWA Journal, 15, 2 (1994) 111-120.

BRAZIER, J. D.: Juvenile Wood. In: KUCERA, L. J.: Xylorama. Birkhäuser Verlag, Basel, Boston, Stuttgart (1985) 25 – 32.

DÜNISCH, O.; BAUCH, J.; SCHWARZ, Th.: Supply of *Swietenia macrophylla* King and *Carapa guianensis* Aubl. with K, Ca, and Mg in three different plantation systems. BFH Mitteilungen Nr. 193 (1999) 47 – 59.

DÜNISCH, O.; BAUCH, J.; SACK, M.; MÜLLER, M.: Growth dynamics in wood formation of plantation-grown *Swietenia macrophylla* King. and *Carapa guianensis* Aubl., BFH Mitteilungen Nr. 193 (1999) 79 – 96.

KURODA, N.; TUKAU, A.; IBRAHIM, A. W.: Intra-stem variations of basic density and green moisture content of eight species grown in Sarawak. Proc. Inter. Symp. Tree Anatomy & Wood Formation 1995, Wood Anatomy Research (1995) 12 – 19.

MÜLLER, F. B.: Untersuchungen zur Entwicklung der Holzeigenschaften während des juvenilen Wachstums bei tropischen Laubhölzern. Diss. TU Dresden,1987, 209 p.

OBAYASHI, H.; SHIOKURA, T.: Anatomical structure of fast-growing tropical tree species with differing growth rates. IAWA Bulletin, 10, 3 (1989) 342 – 343.

PANSHIN, A. J.; DE ZEEUW, C.: Textbook of Wood Technology. McGraw-Hill Book Company, New York, 1980, 722 p.

SACK, M.: Charakterisierung der Holzbildung und des Zuwachses von *Swietenia macrophylla* King und *Carapa guianensis* Aubl. aus der Familie der *Meliaceae* unter Plantagenbedingungen in Zentralamazonien. Dipl. Arbeit, Universität Hamburg (1998) 124 p.

VETTER, R. E.: Untersuchungen über Zuwachsrhythmen an tropischen Bäumen in Amazonien. Diss. Univ. Freiburg, 1995, 109 p.

WIEMANN, M. C.; WILLIAMSON, G. B.: Extreme radial changes in wood specific gravity in some tropical pioneers. Wood and Fiber Science, 20, 3 (1988) 344 – 349.

ZOBEL, B. J.: Juvenile wood in tropical forest plantations: its characteristics and effect on the final product. CAMCORE Bulletin on Tropical Forestry, 2 (1985) 1 – 19.

ZOBEL, B. J.; BUIJTENEN VAN, S. P.: Wood variation – its causes and control. Springer Verlag Berlin, Heidelberg, New York, 1989, 336 p.

ZOBEL, B. J.; JETT, J. B.: Genetics of wood production. Springer Verlag, Berlin, 1995, 337 p.