



Investigations on tree species suitable for the recultivation of degraded land areas in Central Amazonia

(SHIFT project BMBF 0339638A / CNPq ENV 42-2)

From May 1, 1998 to April 30, 2001

Institute of Wood Biology, Hamburg University and Institute of Wood Biology and Wood Preservation, Federal Research Centre for Forestry and Forest Products, Hamburg: Prof. Dr. J. Bauch, Dr. O. Dünisch
Centro de Pesquisa Agroflorestal da Amazonia Ocidental/ Empresa Brasileira da Pesquisa Agropecuária (CPAA/ EMBRAPA), Manaus: Dr. L. Gasparotto, C. de Azevedo, R. de Lima, R. de Moraes

Cooperation: University of Paraná, Curitiba: Prof. Dr. Reissmann, E. Neves

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1. Introduction and approach to the second phase of the project

During the past decade, a distinct trend of population growth was observed in the Manaus region, Central Amazonia. Traditional systems for land use and monocultures around the city cannot guarantee a sustainable production and cannot sufficiently supply the population with food and wood. The consequence is the increasing demand for new land, which leads to extensions into the tropical forests.

Particularly the increasing demand for wood is exclusively available from primary forests, which frequently leads to exploitation of high quality species. The negative development, as a rule, is associated with serious negative effects on the ecosystem „tropical forest“. To counteract this tendency, CPAA/EMBRAPA in Manaus develops sustainable land use systems, since 1992 accompanied by a Brazilian-German cooperation (SHIFT). One of the main aspects is the recultivation of degraded areas. The main aim are polycultures with agroforestry tendencies, which means that agriculturally oriented systems should to some extent include native tree species for high valuable wood production.

The knowledge about the growth and the site demand of important commercial native tree species of the Central Amazon is still restricted. Therefore, since January 1, 1995, the dynamics of growth of eight native tree species in combination with the site conditions of plantation systems are studied within the Brazilian-German research project ENV 42 at the CPAA/EMBRAPA in Manaus.

During the first phase of the project (January 1995 until April 1998), most emphasis was laid on the characterization of the water and mineral element supply of the trees in different plantation systems (comp. chapter 5). In these studies, it was of main interest in how far the water and mineral element supply of plantation systems is mainly influenced by the selected tree species and the plantation management.

The data obtained during the first phase of the project were analyzed in 1998, and the results are summarized in nine publications within the series „Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft“, Hamburg (comp. chapter 5). These data are the basis for the second phase of the project, which lasts from May 1, 1998 until April 2001.

As to get stronger correlations between the site conditions and the growth of the plantation-grown trees, during the second phase of the project (May 1998 until April 2001) more emphasis is given to the subsequent aspects:

- (1) The significance of exogenous factors for the plant metabolism and with that on wood formation and wood quality is of major interest. For this purpose, the **water, element, carbohydrate and phytohormone** supply of the cambium is studied in more detail. In order to prove the results obtained in the field, supplementary experiments will be carried out under controlled conditions in the greenhouse and in growth chambers with simulated climatic conditions (comp. 2.1., 2.3., and chapter 5).
- (2) Besides exogenous factors, genetic (endogenous) factors influence tree growth, wood formation, and with that **wood quality**. Therefore, in the second phase of the project comparative studies are carried out at different forest sites and with different provenances as to study the variability in wood formation and wood quality of the investigated tree species caused by genetic input.

The concept of the project ENV 42 is part of the interdisciplinary research program SHIFT (Studies on human impact on forests and floodplains in the tropics) at the CPAA/EMBRAPA in Manaus. There are tight links to ENV 23 (comp. Schmidt et al., 1999; Preisinger et al., 1999), ENV 45 (comp. Dünisch et al., 1999) and ENV 52 (comp. chapter 5).

2. Investigations carried out in 1998 and the scientific results

During the first phase of the project (January 1, 1995 until April 30, 1998), the influence of the water and element supply of three different plantation systems on the growth and wood formation of eight native tree species (*Swietenia macrophylla*, *Carapa guianensis*, *Cedrela odorata*, *Dipteryx odorata*, *Hymenaea courbaril*, *Ceiba pentandra*, *Virola surinamensis*, *Tabebuia heptaphylla*) was investigated. In 1998, the data were analyzed. The results subsequently served as a basis for the second phase of the project (comp. chapter 5), which should give deeper insight into the relationship between exogenous and endogenous input, the plant metabolism, and the wood formation and wood quality of plantation-grown trees. Due to the results obtained in these studies in the second phase of the project, special attention is given to the subsequent species: *Swietenia macrophylla*, *Carapa guianensis*, *Cedrela odorata*, *Dipteryx odorata*, and *Hymenaea courbaril*.

Corresponding investigations are carried out in the plantation system I (monoculture system) in comparison to system III (enrichment system). Supplementary studies on the environment-tree growth relationship of *Swietenia macrophylla* and *Carapa guianensis* are carried out in a mixed culture system (system II, comp. Schmidt et al. 1999, chapter 5). For the study on wood quality and the significance of endogenous factors for wood formation experimental areas of the Instituto Nacional de Pesquisa da Amazonia (INPA, Manaus) 45 km north of Manaus, and some trees from primary forests of the region were included in this study.

System I (established January 1992):

- Former monoculture of *Hevea brasiliensis* (H.B.K.) Muell. Arg., clear cut in 1991
- Monoculture systems of 20 selected tree species with four repeats and 25 plants per plot
- Spacing 3 x 3m
- Fertilization 1992: 150g superphosphate per tree
- Spontaneous vegetation is suppressed by cover crops *Pueraria phaseolides* (Rosed.) Benth and *Homolepis aturensis* (H.B.K.) Chase and cutting by field workers.

System III (established January 1992):

- Former monoculture of *Hevea brasiliensis*
- Enrichment of a 25-year-old secondary vegetation with 10 species.
10 plants per species, four repeats
- Spacing 3 x 6m
- Fertilization 1992: 150g superphosphate per tree
- Spontaneous vegetation was not cut or suppressed for 25 years; dense vegetation with 76 genera out of 39 families.

2.1. Water supply of the selected tree species under field and controlled conditions

Field studies (Manaus): Besides the quantification of water fluxes in the plantations (comp. Dünisch et al., 1999a), studies on the relationship between the water potential of the soil, the stem and leaf of the trees and the atmosphere are of main interest to study in how far the investigated tree species are adapted to drier periods. For this purpose, in 1998 further tensiometers were installed in a soil depth of 120 cm in all three plantation systems to study the water content of the soil in deeper root zones, as well.

In order to quantify the water uptake and the water transport within the stem of *Swietenia macrophylla*, *Carapa guianensis* and *Cedrela odorata* xylem flux sensors (according to Granier, comp. chapter 5 Dünisch et al., 1999a) are installed in all three plantation systems (two trees per species; stem basis and below the canopy each, comp. Fig. 1a/b, Fig. 2a/b). Continuous measurements started in December 1998 (mean values for 10 minutes intervals).

In 1999, pressure bomb measurements will be carried out to study the plant water potential of the stem and the leaves. These investigations could not be started in 1998, due to severe problems related to the export of the scientific equipment to Brazil.



Fig. 1a/b: Installation of xylem flux sensors at the experimental plots in Manaus.

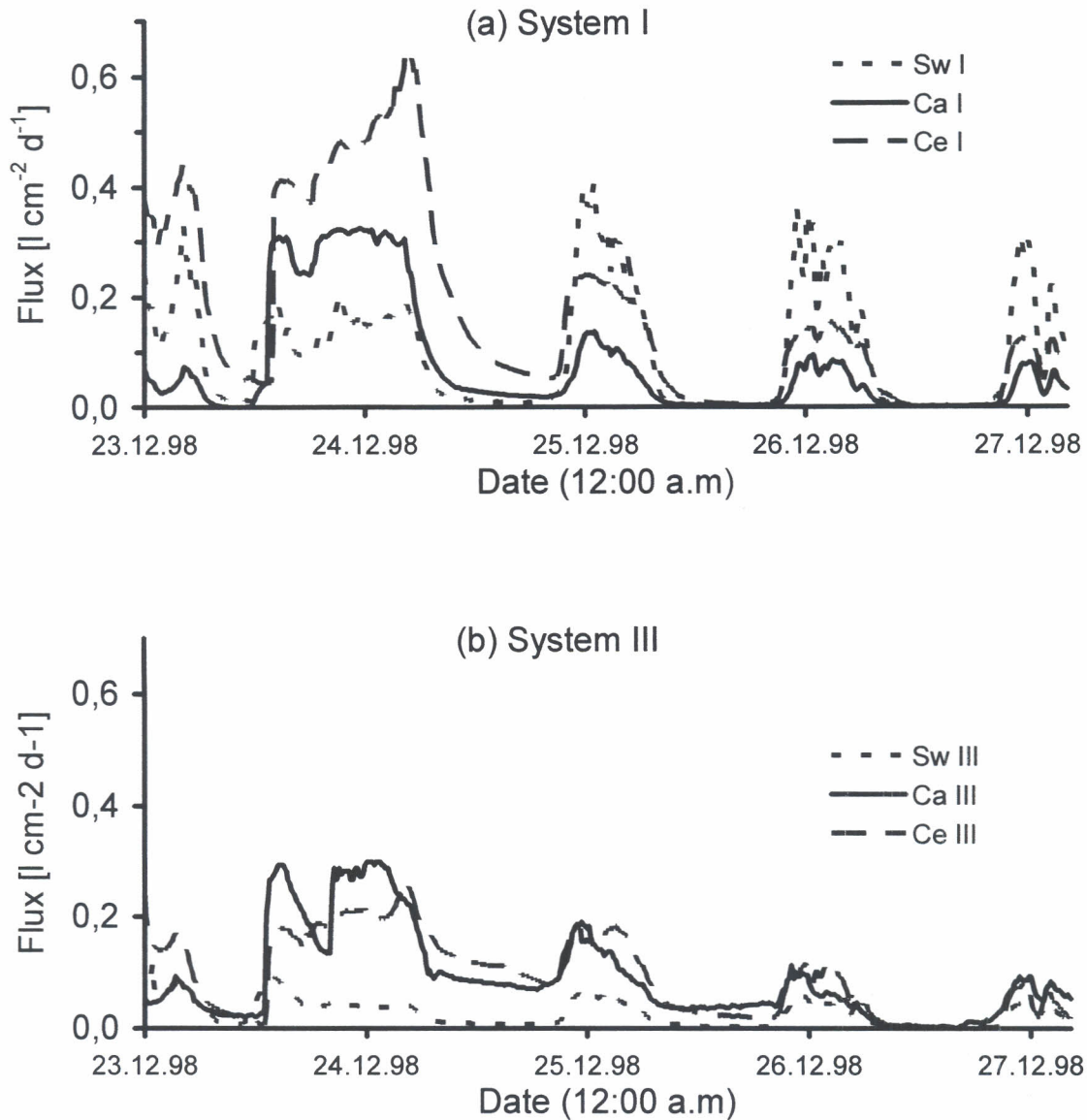


Fig. 2a/b: Xylem water flux [$\text{l cm}^{-2} \text{d}^{-1}$] of *Swietenia* (Sw), *Carapa* (Ca), *Cedrela* (C); from December 23, 1998 until December 27, 1998

Controlled conditions (Hamburg): Field studies carried out at the experimental plots in Manaus revealed a strong impact of drier periods to the growth dynamics of *Swietenia* trees (Dünisch et al., 1999c). In order to prove these results and to understand the reduced adaptation of *Swietenia* to the site conditions in the Manaus region, in 1998 (during the 3-month-research stay of Ronaldo Ribeiro de Moraes at Hamburg University), an experiment was carried out under controlled conditions in the greenhouse of the Federal Research Centre for Forestry and Forest Products in Hamburg.

Summarizing the main aspects of this experiment, it can be stated (comp. chapter 5, Ronaldo R. de Moraes):

- The suction force of the soil, the leaf water potential, the water potential of the air and the water uptake of the 4-year-old *Swietenia* plants were investigated during a wet period (soil water potential <100 hPa), a period of desiccation (100-250 hPa), a dry period (250 - 400 hPa), a period of rehydration (100-400 hPa) and a rehydrated period (<100 hPa). Duration of each period: 3 weeks.
- Changes of the stem diameter caused by water uptake and transport, as well as by cambial growth were registered continuously by highly sensitive laser measurements. The structure of the cambium was investigated by light anatomical studies.
- The water uptake of *Swietenia* was strongly reduced during the dry period (18% of the water uptake of the plant during the wet period). Even after a 3-week-period of rehydration (suction force of the soil <100 hPa), the water uptake of the plants was significantly reduced compared to the water uptake before the drought period. Preliminary results obtained from experiments with labelled water indicated a remarkable water uptake of *Swietenia* leaves caused by guttation (experiments are not finished yet). Due to the drought, strong litterfall was observed. These findings indicate a strong impact of drought periods on the water uptake of *Swietenia* trees.
- In contrast to that, the leaf water potential of the plants was strongly correlated with the suction force of the soil, which indicated that the maintenance of a sufficient water content of the leaves is of main importance for *Swietenia* trees. As to understand the mechanism of regulation of the leaf water potential, the osmotic potential of the leaf sap, the carbohydrate content, and the element content of the leaves were analyzed (data not available yet).

In general, a higher leaf water potential was found in younger leaves compared to older leaves, indicating a strong sink of younger leaves for water. The leaf water potential increased during daytime and decreased during the night, which might be explained by the higher vapor saturation deficit of the atmosphere during the night or an intrinsic day/ night cycle of the plants related to photosynthesis (comp. 2.3).

- High sensitivity laser measurements also indicated a strong diurnal variation of the stem radius of the plants, with a significant increase during the night and a decrease during the day, which is correlated with the plant water potential. Furthermore, shorttime cycles of changes of the stem radius with a wavelength of 1 to 3 hours were observed, which might be correlated with stomata activity (investigations not finished yet).
- Light microscopical studies of the cambial zone of the plants are not finished yet. In these studies, special attention is given to a cambial dormancy of the plants caused by drought (comp. chapter 5, Dünisch et al., 1999c).

These investigations under controlled conditions confirmed studies carried out in the field indicating a high sensitivity of *Swietenia* to drought periods (comp. chapter 5 Dünisch et al. 1999a, 1999c), which is of main importance for the cultivation of *Swietenia* in plantation systems near Manaus due to the specific climatic conditions in this region (drought periods even during the rainy season). For the selection of suitable tree species for the recultivation of degraded areas, comparative studies will be carried out in 1999 in the greenhouse with *Carapa guianensis* (comp. also chapter 5, Noldt et al., 1999).

2.2. Element supply of the plantation-grown trees

For the evaluation of the sustainability of longliving tree plantations, longtime studies on the element supply of the plantations are an urgent demand. During the first phase of the project, data analysis could be carried out for a two years period (comp. chapter 5, Dünisch et al. 1999b, Neves et al. 1999, Schmidt et al. 1999). The study on the element input and element output of the plantations will be extended to the years 1998 until 2000 to get data for 3- to 9-year-old plantations, which allow a trend analysis for the relationship between the age, the tree growth (yield) and the element supply of the plantation.

According to the studies already carried out from 1995 to 1997, the N, P, S, K, Ca, Mg, content of the soil solution is quantified in one-week-intervals. For this purpose, further suction caps were installed in a soil depth of 120 cm in 1998. The element content of the soil (total element content and Ake) is quantified annually. In order to study the variability within and between the experimental plots, the soil sample collection was extended to 30 samples per plot and four repeats per species (data are not available yet). The element input via litterfall, throughfall and stem flow is still determined in monthly intervals, as it was already done from 1995 until 1997.

In order to study the decomposition of litterfall with increasing age of the plantations, decomposition rates are calculated from litter bag experiments again, as it was already done in 1995/ 1996 (comp. chapter 5, Dünisch et al., 1999 b). The litter bag experiment started in November 1998.

The element content of selected plant tissues of all trees ($n > 70$ per specie) of the experimental plots is studied as to get insight into the variability between individuals and plots and as to calculate the Gauss' error of element flux and element stock calculations (sample collection for *Carapa guianensis*, *Dipteryx odorata*, and *Hymenaea courbaril* was carried out during the research stay of Mr. D. Harm at the EMBRAPA in 1998. Sample collection for *Swietenia macrophylla* and *Cedrela odorata* will be carried out in January 1999).

2.3. Carbohydrate supply of the selected tree species under field and controlled conditions

Field studies (Manaus): As to quantification, the seasonal variation of the reserve carbohydrate content of the trees, the soluble sugar content (glucose, fructose, saccharose, raffinose, stachyose) and the starch content of the leaves, the phloem of the stem, the xylem of the stem and of the roots were analysed. For this purpose, a sample collection is carried out in monthly intervals since July 1998. Sample preparation and carbohydrate analyses are carried out in cooperation with the Institute of Wood Chemistry, Federal Research Centre for Forestry and Forest Products, Hamburg (this study *will be continued until the year 2000*).

The relationship between the light intensity and the net photosynthesis of selected species is studied under growth chamber conditions in cooperation with the Institute of Forestry in Hamburg (see below). As to get some information on the photosynthetic activity of the trees under field conditions, besides the water and element supply of the trees, the light intensity is registered in the plantation systems since December 1998 (Fig. 3, Fig. 4 a/b). For this purpose, light sensors were installed in *Swietenia*, *Carapa*, and *Cedrela* plots of the plantation system I and in the secondary vegetation of the plantation system III.



Fig. 3: Installation of light sensors at the experimental plots in Manaus

Controlled conditions (Hamburg): In cooperation with the Institute of Forestry, Federal Research Centre for Forestry and Forest Products, Hamburg, the photosynthesis of 4-year-old *Swietenia* and *Carapa* is studied in relation to the light intensity and the soil water supply in a growth chamber. Furthermore, the content of chlorophylla a and b, the content of carotinoids, the reserve carbohydrate content, as well as the element content of the leaves are analyzed. From this study, information on the adaptation to different site conditions in different plantation systems is expected with special regard to the primary production of these two important tree species.

Preliminary results already indicated a higher light demand for photosynthesis of *Swietenia* compared to *Carapa*, which is in accordance with the reduced cambial growth of *Swietenia* in the enrichment system (System III) compared to *Carapa* due to the reduced light intensity in system III, compared to the monoculture system (system I, comp. Fig. 4a/b).

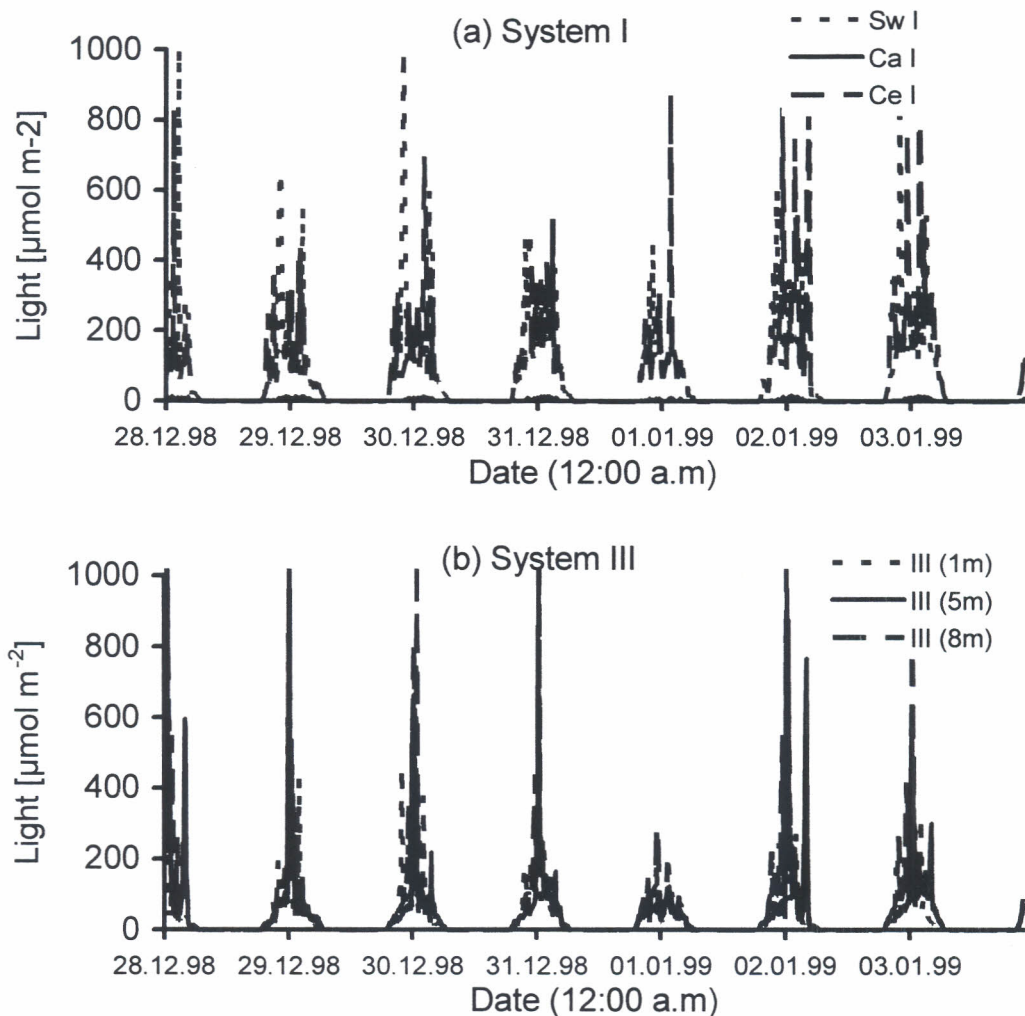


Fig. 4a/b: Diurnal variation of the light intensity [$\mu\text{mol m}^{-2}$] in (a) plantation system I (crown, 5m above ground) and (b) system III (1m, 5m, 8m above ground)

2.4. Phytohormone supply of the selected tree species under field and controlled conditions

Field studies (Manaus): In order to study the significance of the investigated site conditions for the phytohormone content of the trees, the content of auxin, gibberelin, cytokinin and abscisic acid of selected tree species will be analysed in 1999 in cooperation with the Institute of Botany, Hamburg University. In 1998, some studies were carried out in the laboratory as to select the suitable methodical approach for phytohormone analyses of these species.

Controlled conditions (Hamburg): Leaf sap and leaves of drought stressed *Swietenia* plants (comp. 2.1) were sampled to investigate the content of abscisic acid. Abscisic acid is a good stress indicator and is related to litterfall. From this study informations on the relationship between the soil water supply and stress situations for *Swietenia* are expected. Comparative studies will be carried out in 1999 with 4-year-old *Carapa*.

2.5. Biomass production, wood formation, and wood quality of the plantation-grown trees

The biomass production of the trees is determined annually. For this purpose, four trees of each species were cut and the biomass of different tree fractions was determined (sample collection was already carried out for *Carapa*, *Dipteryx*, and *Hymenaea*). Due to the reduced leaf biomass of *Swietenia* and *Cedrela*, corresponding samples of these species will be collected in January 1999.

In order to study the variation between individuals of one species and as to calculate the Gauss' error of biomass calculations on area scale, the subsequent parameters were investigated for all of the trees of the experimental plots (n/species >70):

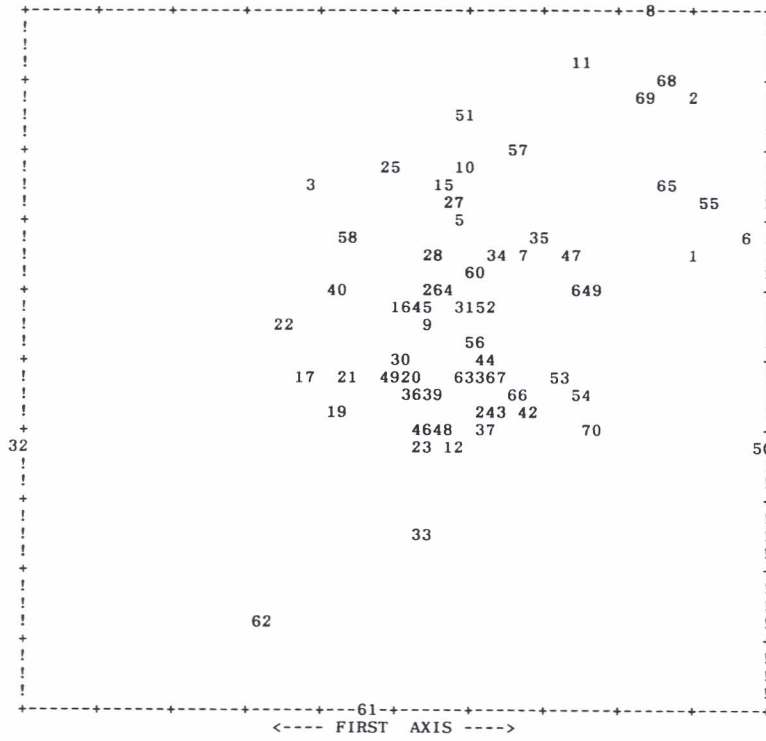
- Diameter (DBH 1,3 m)
- Tree Height
- Base of crown
- Crown projection area
- Canopy density

From these data, the most important parameters with regard to variability between individuals were investigated by principal component analyses (Fig. 5 a - c, Table 1). This study serves as a basis for error calculations for the biomass determination of plantation systems, which will be carried out in 1999 (comp. research stay of Mr. D. Harm).

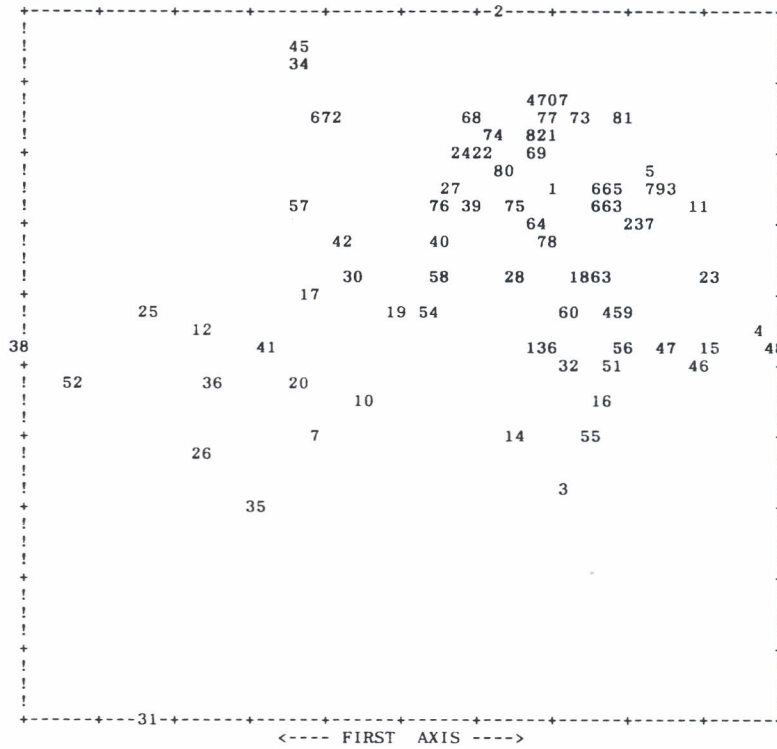
Table 1: Correlation coefficient between the first axis of the principal component analysis and the breast height diameter, the tree height, the height of the crown, and the crown projection of *Carapa guianensis*, *Dipteryx odorata*, and *Hymenaea courbaril*.

Species	Diameter	Height	Base of crown	Crown projection
<i>Carapa guianensis</i>	0,984	0,415	0,069	0,673
<i>Dipteryx odorata</i>	-0,968	-0,155	0,038	-0,952
<i>Hymenaea courbaril</i>	0,917	0,128	-0,014	0,870

Ordination forstliche Parameter Andiroba
SECOND
AXIS



Ordination forstliche Parameter Cumaru
SECOND
AXIS



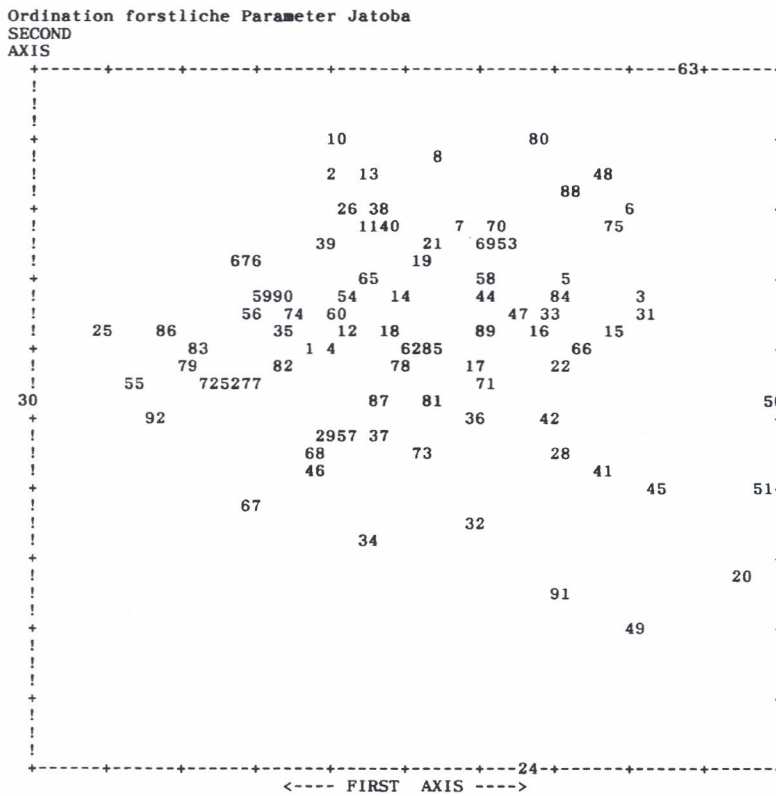


Fig. 5a - c: Principal component analysis of the breast height diameter, the tree height, the height of the crown, and the crown projection of (a) *Carapa guianensis* (n=70), (b) *Dipteryx odorata* (n=82), and (c) *Hymenaea courbaril* (n=92).

Studies on wood formation of selected species carried out from 1995 until 1998 are summarized by Dünisch et al. (1999 c, comp. chapter 6). Based on these results the cambial growth dynamics of *Swietenia*, *Carapa*, and *Cedrela* is studied by means of the pinning method, monthly sample collection by small borers, and dendrometer measurements (comp. Fig. 6 a - c). Dendrometers were installed at 64 trees with four measured points each in June 1998 (Fig. 7). Continuous measurements started in December 1998. Preliminary results indicate that cambial cell divisions of the fusiform initials of different points of a tree are not synchronous, even so, if the measurements are carried out at the same tree height. This indicates that the initiation of cambial cell divisions depends on the supply of the individual cell with water, element, carbohydrate, and phytohormones. Studies on a cellular level are necessary.

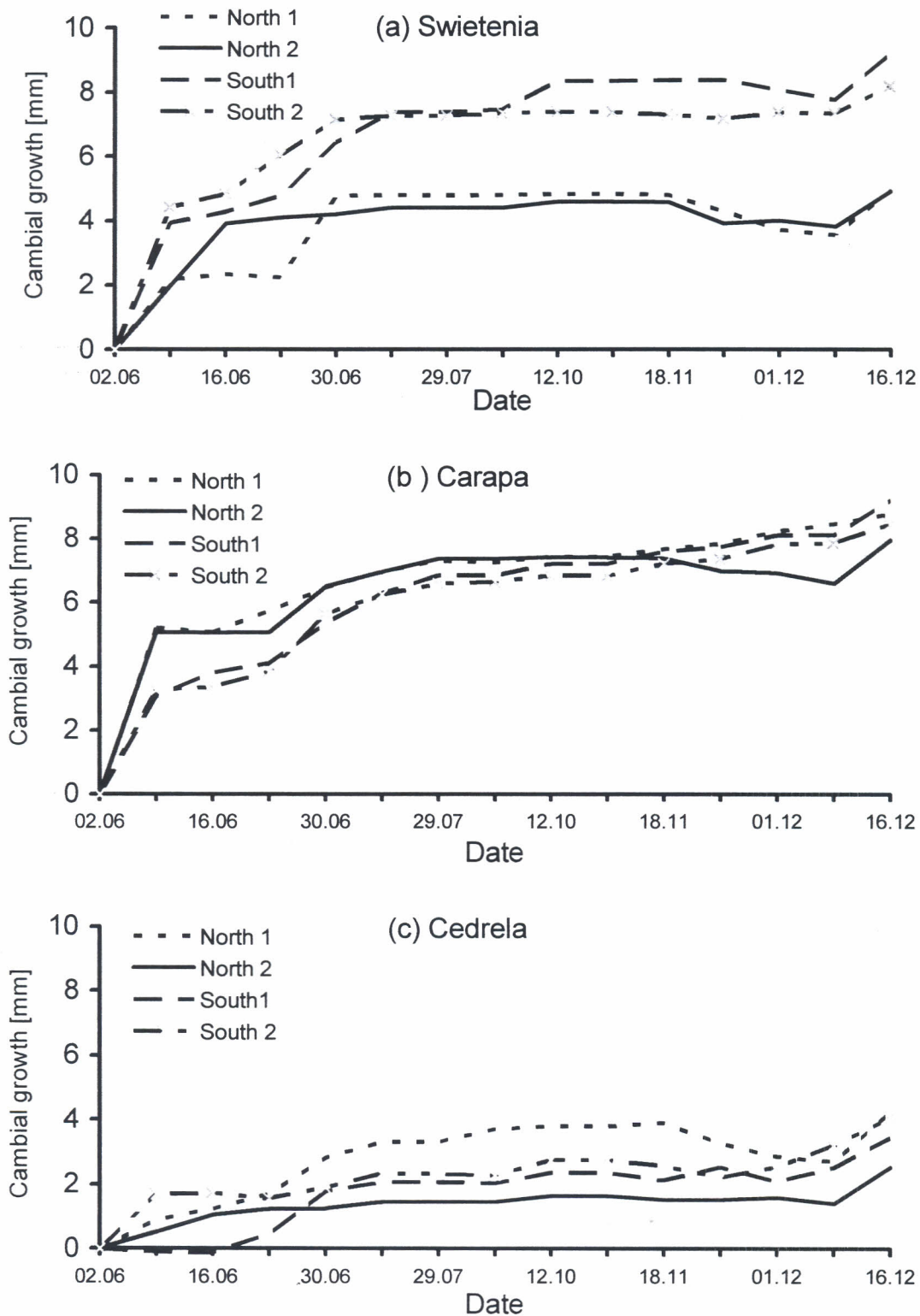


Fig. 6a-c: Cambial growth [mm] of *Swietenia macrophylla*, (b) *Carapa guianensis*, and (c) *Cedrela odorata* during the period June 6, 1998 until December 9, 1998. Four measured points of one tree each (1.3 m height).



Fig. 7: Dendrometer measurements carried out at the experimental plots in Manaus.

The wood quality of plantation-grown *Carapa guianensis* and *Hymenaea courbaril* was investigated from 1996 until 1998 with special regard to the anatomical characteristics of the trees (comp. Wohler 1998, Bauch et al. 1999, chapter 5). Studies on the technological characteristics of *Hymenaea courbaril* started in 1998 and are carried out by Mrs. Claudene Atayade (CNPq grant Master thesis, August 1998 until July 2000). Sample collection was carried out at the experimental plots of the EMBRAPA in November 1998. Comparative studies will be carried out with 20-year-old plantation-grown trees (cooperation INPA, Manaus) and with trees from primary forests.

2.6 Provenance studies on the genetic variability of the selected tree species

In order to study the influence of genetic factors on wood formation and wood quality of selected species, seeds from different forest sites were sampled in 1998 by the Brazilian group (C. de Azevedo). Germination is planned for March 1999, but it has to be taken into account that some seeds did not reach Manaus in good condition.

Therefore, supplementary investigations are planned on other plantations and natural sites representing different provenances of the investigated species. There seems to be a good chance to carry out comparative studies with different provenances of the subsequent species:

<i>Swietenia macrophylla</i> :	2 plantations EMBRAPA, plantations Aripuana, Mato Grosso
<i>Carapa guianensis</i> :	2 plantations EMBRAPA, plantation INPA, Manaus
<i>Dipteryx odorata</i> :	Provenance study established at the experimental site of the INPA, Manaus (CNPq grant Master thesis)
<i>Ceiba pentandra</i> :	2 plantations EMBRAPA, 1 plantation INPA, plantations Itacoatiara, 250 km east of Manaus)

3. Cooperation with other institutions

Cooperation with SHIFT-project ENV 23:

Autecological investigations of *Miconia* sp. and *Bellucia* sp. are carried out in cooperation with the SHIFT-project ENV 23 (Prof. Dr. R. Lieberei, Dr. H. Preisinger) as to study the relationship between secondary tree species and the planted trees in the plantation systems (comp. chapter 5, Preisinger et al. 1999)

Cooperation with the SHIFT-projects ENV 23 and ENV 45:

Investigations on the water supply of plantation-grown trees are carried out in cooperation with the SHIFT-project ENV 23 and ENV 45 (Dr. G. Schroth, Prof. Dr. W. Zech, comp. chapter 5, Dünisch et al. 1999a).

Cooperation with SHIFT-project ENV 52:

Investigations on the litter decomposition in the plantation system II are carried out by the SHIFT-project ENV 52 (Prof. Dr. Beck, Dr. C. Martius, Dr. Höfer). Data on the water and mineral element supply of this plantation system are studied within the project ENV 42 and will be evaluated in cooperation with project ENV 52.

Cooperation with the University of Paraná, Curitiba:

Chemical soil analyses and studies on the mineral nutrition of plantation-grown *Ceiba pentandra* and *Virola surinamensis* are carried out in cooperation with Prof. Dr. B. Reissmann and Mr. E. Neves, University of Paraná (comp. chapter 5, Neves et al. 1999). The PhD.-thesis of Mr. E. Neves is in its content integrated in ENV 42. It is also supervised by Prof. Dr. J. Bauch and Dr. O. Dünisch (ENV 42). The thesis will be finished in 1999.

Cooperation with the Institute of Wood Chemistry, Federal Research Center for Forestry and Forest Products, Hamburg:

Studies on the seasonal variation of the content of reserve carbohydrates of plantation-grown trees are carried out in cooperation with Dr. J. Puls, Institute of Wood Chemistry, Federal Research Center for Forestry and Forest Products, Hamburg (comp. 2.3.).

Cooperation with the Institute of Wood Technology, Federal Research Center for Forestry and Forest Products, Hamburg:

Technological investigations and high sensitivity growth measurements are carried out in cooperation with Dr. E. Schwab and Dr. K. Kruse, Institute of Wood Technology, Federal Research Center for Forestry and Forest Products, Hamburg (comp. 2.1.).

Cooperation with the Institute of Forestry, Federal Research Center for Forestry and Forest Products, Hamburg:

Studies on the photosynthesis of *Swietenia macrophylla* and *Carapa guianensis* are carried out under controlled conditions in cooperation with Dr. W.-K. Kriebitzsch, Institute of Forestry, Federal Research Center for Forestry and Forest Products, Hamburg (comp. 2.3.).

Cooperation with the Institute of Botany, Hamburg University:

Phytohormone analyses of different plant fractions are carried out in cooperation with Prof. Dr. K. Dörffling, Institute of Botany, Hamburg University (comp. 2.4).

4. Exchange of scientists:

Research stay from July 30, 1998 until October 24, 1998 of
Mr. R. de Moraes (CPAA-EMBRAPA, Manaus)
at the Institute of Wood Biology, Hamburg University (comp. 2.1, chapter 6 and Appendix).

Research stay from July 11, 1998 until October 30, 1998 of
Mr. D. Harm (Master thesis)
at the CPAA/EMRAPA, Manaus (see Appendix).

Research stay from August 29 to September 26, 1998 of
Mrs. G. Noldt
at the CPAA/EMBRAPA, Manaus (see Appendix).

5. Comparison of the investigations with the initial plan of the project

In 1998, the investigations concerning the **water supply** of the trees were intensified. For this reason, 20 new xylem flux sensors were installed in the field, and continuous sap flow measurements were carried out since December 1998. Unfortunately, due to great problems related to the export of the equipment to Manaus, leaf water potential measurements under field conditions only could start in 1999. Leaf water potential measurements were carried out under controlled conditions during the 3-month-research stay of Mr. R. de Morais in Hamburg. During this time, Mr. R. de Morais was well-prepared for studies at the experimental plots in Manaus related to the water supply of the trees. It was planned to integrate these studies in a PhD.-thesis of Mr. R. de Morais at Hamburg University, but unfortunately, the CNPq grant of Mr. R. de Morais was not renewed. Therefore, the presence of German scientists in Manaus had to be extended in 1999 to secure continuous measurements related to the water supply of the trees (xylem water flux measurements, leaf water potential measurements).

The **mineral element supply** of the trees was quantified in 1998, according to the initial plan of the project. Further subcellular element analyses will be carried out in 1999, in order to get more information on the uptake and the cellular distribution of mineral elements in the trees.

The study on the **carbohydrate supply** of the trees started in July 1998 according to the actual plan of the project. Supplementary investigations were carried out under controlled conditions (growth chamber, greenhouse) in Hamburg (comp. 2.3).

The content of **phytohormones** of different plant fractions will be studied in 1999 under field conditions. In 1998, some analyses were carried out with plants grown under controlled conditions, in order to select a suitable methodical approach for phytohormone analyses of the tropical tree species (no literature available).

In order to study the **biomass production, the wood formation, and the wood quality** of the plantation-grown trees, sample collection and analyses were carried out according to the actual plan of the project. Special attention was given to the pinning-method, the sample collection of small cambium samples (comp. Dünisch et al. 1999 c), and the dendrometer measurements (comp. 2.5).

Seed collection and germination of small plants for **provenance studies** were very time-consuming, and there are still some technical difficulties to establish the provenance study at the experimental site of the CPAA/EMBRAPA in Manaus. Therefore, for 1999, it is planned to include some plantations and natural sites of different provenances into the project to get more information on the genetic variability in wood formation and wood quality of the investigated tree species. This was not foreseen in the proposal of the project.

6. Relevant project publications and supplementary individual contributions

In 1998/1999, the main results of the first phase of the project were summarized and published in the series „Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft, Hamburg“, 193 (138 p., 1999). As a supplement to this annual report (May 1, 1998 until December 31, 1998), the report of the research stay of Mr. R. de Moraes and the summary of the master thesis of Mrs. Karin Wohler and Mr. M. Sack are enclosed:

6.1 Relevant project publications

- (1) Development of tree height and diameter of eight selected tree species under plantation conditions.
C. P. de Azevedo, L. Gasparotto, R. de Lima, E. Neves, and O. Dünisch
- (2) Water supply of *Swietenia macrophylla* King and *Carapa guianensis* Aubl. in three plantation systems.
O. Dünisch, G. Schroth, R. de Moraes, and M. Erbreich
- (3) Supply of *Swietenia macrophylla* King and *Carapa guianensis* Aubl. with K, Ca, and Mg in three different plantation systems.
O. Dünisch, J. Bauch, and Th. Schwarz
- (4) Biomass production and mineral element content of *Swietenia macrophylla* King in the juvenile phase.
P. Schmidt, R. Lieberei, J. Bauch, and L. Gasparotto
- (5) Nutritional status of *Ceiba pentandra* (L.) Gaertn. and *Virola surinamensis* (Rol.) Warb. under plantation conditions.
E. J. M. Neves, C. B. Reissmann, C. A. Ferreira, A. F. J. Bellote, and O. Dünisch
- (6) Growth dynamics in wood formation of plantation-grown *Swietenia macrophylla* King and *Carapa guianensis* Aubl.
O. Dünisch, J. Bauch, M. Sack, and M. Müller
- (7) Comparative study on wood characteristics of *Carapa guianensis* Aubl. from two plantations and a natural site in Central Amazonia.
J. Bauch, O. Dünisch, F. Schuster, L. Gasparotto, and C. P. de Azevedo
- (8) Structure of primary roots of *Swietenia macrophylla* King under controlled conditions.
G. Noldt, J. Bauch, U. Schmitt, and V. G. Balodis
- (9) Comparative studies on morpho-physiological traits of six Amazonian species of *Bellucia* and *Miconia* (*Melastomataceae*) and implications for their ecological behaviour.
H. Preisinger, O. Dünisch, R. R. de Moraes, K. Richter, and R. de C. Araújo

6.2 Supplementary individual contributions (see Appendix)

- (1) Ronaldo Ribeiro de Morais:
Estudo de espécies arbóreas com potencial para reflorestamento de áreas abandonadas e degradadas da Amazonia Ocidental (Research stay at the Institute of Wood Biology, Hamburg University, July 30 until October 24, 1998).

Cooperation: O. Dünisch (ENV 42), K. Kruse (Institute of Wood Technology, Hamburg University),
- (2) Karin Wohler:
Holzstruktur und Holzwachstum von *Hymenaea courbaril* L. unter Plantagenbedingungen in Zentralamazonien.
Diplomarbeit Fachbereich Biologie, Universität Hamburg, 1998, 56 S.

Supervised by J. Bauch and O. Dünisch (ENV 42).
- (3) Marco Sack:
Charakterisierung der Holzbildung und des Zuwachses von *Swietenia macrophylla* King und *Carapa guianensis* Aubl. aus der Familie der Meliaceae unter Plantagenbedingungen in Zentralamazonien,
Diplomarbeit Fachbereich Biologie, Universität Hamburg, 1998. 124 S.

Supervised by J. Bauch and O. Dünisch (ENV 42).

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(Univ.-Prof. Dr. J. Bauch)

(Dr. O. Dünisch)

Diploma-paper to obtain the title of the Diplom-Holzwirt at the University of Hamburg

**"Characterization of wood formation and growth increment of
Swietenia macrophylla King and *Carapa guianensis* Aubl. of the
family *Meliaceae* under plantation conditions in Central Amazonia"**

Marco Sack

Hamburg, June 1998

Summary

Since 1992, within a long-term Brazilian-German cooperation ("Studies on Human Impact on Forests and Floodplains in the Tropics", acronym: SHIFT) research work is done on the foundation of mixed culture systems in Central Amazonia.

Research on wood formation and growth dynamics in comparison to the site conditions is of great importance to be able to predict the adequacy of the very valuable and, therefore, economically attractive wood species *Swietenia macrophylla* King and *Carapa guianensis* Aubl. of the family of *Meliaceae* for mixed cultures. Qualitative data concerning intra-annual structural dynamics in wood formation, as well as quantitative data concerning growth are necessary to predict wood production under plantation conditions.

In the present paper, therefore, wood formation and growth of both species, *Swietenia macrophylla* King and *Carapa guianensis* Aubl. of the family of *Meliaceae*, under plantation conditions in Central Amazonia is characterized, and the relation between growth and exogenous influences is described. Additionally, in the area of wood anatomy, the compartmental reactions after wounding by pin-markers were described qualitatively and quantitatively to enable an estimate of the exactitude of the pin-marker method to determine intraannual growth.

Research measurements were done for *Swietenia macrophylla* King on four experimental trees of a monoculture system, an experimental tree of an extensively used mixed culture system and two experimental trees of an enrichment culture. Research on the species *Carapa guianensis* Aubl. was executed with four trees of a monoculture system, one in a mixed culture system, one of an enrichment system and three primary forest trees. At the time of the research, the experimental trees of the three plantation systems were six years old. The age of the primary forest trees is unknown. Moreover, air-dry sections of the trunk of five-year-old experimental trees of the three plantation systems referred to were available as material for research purposes.

At the beginning, the growth increment zones of the stem sections taken from the plantation systems were structurally characterized. They showed a certain trend according to the anatomical structure of the growth increments: The juvenile wood showed clustered vessels, while the adult wood was characterized by tangential bands of the axial parenchyma. With the species *Swietenia macrophylla* King, the ten distinctly indicated increment zones at the stem basis of the six-year-old experimental tree could easily be synchronized. Within the wood of a tree of the species *Carapa* of the same age, the number of increment zones varied across the four radii between ten and thirteen zones. Furthermore, the increment zones were less distinctly visible as in *Swietenia* and could not be synchronized definitely.

As to the characterization of the structural dynamics of wood formation, cambial samples were taken from in total 16 experimental trees of the four investigated sites. For *Swietenia*, the date of the formation of parenchyma bands could be defined. At the beginning of the drought period, the experimental trees of the three different plantation systems formed marginal parenchyma bands limiting the growth increment zones. It could only be proved that the experimental trees of the three plantation systems indicated tended to an increase in the formation of parenchyma bands in November 1997, i. e. at the beginning of the humid period.

The research executed as to the influence of tree height on cambial activity and its structure showed that the marginal parenchyma bands observed in the tree species of *Swietenia macrophylla* King, were present in all of the branch-, stem- and root-samples examined. The experimental tree of the species *Carapa guianensis* Aubl., during the entire period of research (October 27th to November 7th, 1997), did not show parenchyma bands near the cambium in any of the areas indicated. Differences in cambial activity obviously were not related to tree height.

By research on the influence of certain site conditions on cambial activity, a strong dependency between precipitation, and with it an amelioration in soil water supply of the experimental fields and cell division activity of the cambium of the experimental trees could be proved.

For both tree species, there were considerable differences between the three plantation systems as concerns the cell division activity in the cambium. While on November 27, 1997, the cambium of the experimental trees under monocultural conditions was very active in cell division, the experimental

trees of the enrichment system, due to drought, were still in a cambial dormancy. Between both tree species, under similar plantation conditions, there were distinct differences as concerns the point of reactivation of cell division after the cambial dormancy. In the cambium of *Carapa guianensis* Aubl., there was great cell dividing activity already at the end of November 1997, with the beginning of the humid period, while cell division of the experimental tree of *Swietenia* was only at its starting point.

Furthermore, it could be shown that compartmentalization after cambium wounding is very dependent on cambial activity. During the humid period, pin-markers done in monthly intervals were followed by quicker and stronger reactions of the experimental trees, as pin-markers done in the drought period. The pin-markers were wounds of a length of approximately 20 mm, effected by a scalpel.

In the following, five different reactions of blockage were observed. Moreover, the process of compartmentalization could be characterized. Three of the reactions of compartmentalization were caused by secondary differences in the tissue already present at the time of wounding. (1) An axial barrier was obtained by plugging with phenolic contents of the vessels in question, which could be detected six hours after wounding already. (2) Still differentiating fibres in the area near the wound inflicted reacted with a more rapid secondary wall formation, thus limiting the wound by tangential security walls. (3) Radial rays established radial walls by the synthesis of presumably toxic cell contents, thus barring the wound.

The barrier-zone tissue formed after wounding was characterized by two structural changes. (4) Firstly, parenchymatic wound tissue was established. The formation started at the upper and lower cutting edges of the cambial wounding and continued in the direction of the wound's centre. Secondly, the callus formation of the wound was finished after three to four weeks. In addition to the parenchymatic wound tissue, the wounding induced the formation of a tangentially running parenchyma band. Embedded in this parenchyma band, after two to three weeks intracellular cavities were formed. These cavities presumably are formed lysigenously. Immediately after formation, they are enriched by resin-like substances. (5) In this way, tangentially, traumatic resin channel bands were formed, which originated in the parenchymatic wound tissue. Special epithelic cells could not be detected.

By to the spatial description of the compartmental reactions, it could be proven that the formation of traumatic resin bands and that the plugs of the vessels were more convenient and of the largest spatial expansion of the compartmental reactions described above in the peripheral tissue of the wound. Furthermore, it was found out that the direction of the pin-markers had a strong influence on the extension of the formation of wound calluses.

With the aid of microscopic preparations taken vertically from twelve sections, essential parameters influencing the exactitude in measuring the intraannual growth by the pin-marker method could be described. A substantial one is the depth of the cut in the wound area. The influence of the depth of the wound on the exactitude when analyzing intraannual growth was quantified by measuring the distance of the wound to the cambium. The maximal deviation of 0.88 mm was measured with a pin-marker wound inflicted in May on an experimental tree of the species *Swietenia macrophylla* King.

From these experiments, it could be concluded that both of the tree species referred to, generally reacted in the same way on wounds inflicted to the cambium. However, due to the different dependency of the wood formation of *Swietenia macrophylla* King and *Carapa guianensis* Aubl. on precipitation, the extension of the wounds in the cambium is different according to the season. When using the pin-marker method for measuring the intraannual growth, exact knowledge about the structural dynamics in wood formation is necessary. For ameliorating the exactitude of pin-marker measurements of growth dynamics, another method than the wounding of the cambium with a scalpel should be chosen, as the irregular cuts strongly influence the results.

Diploma-paper to obtain the title of the Diplom-Holzwirt at the University of Hamburg

**"Wood structure and growth of wood of *Hymenaea courbaril* L.
under plantation conditions in Central Amazonia"**

Karin C. Wohler
Hamburg, November 1998

Summary

Within the framework of the Brazilian-German cooperation program SHIFT (Studies on Human Impact on Forests and Floodplains in the Tropics), concepts for sustainable land use systems in Central Amazonia have been developed at the research institution CPAA/ EMBRAPA run by the state of Brazil. In the focus of the present study was the reforestation of degraded areas through the plantation of native tree species suitable for forestry and wood production. By this, on the one hand the distinct trend to overuse primary forest due to a growing demand for wood in this region should be counteracted and on the other hand, subsistence farmers should be supplied with a secure economic basis. From the ten species grown under monocultural conditions, the species *Hymenaea courbaril* L. was chosen, because of its promising growth rate. Besides the growth rate, high-quality wood which is in demand at the market, is an essential factor for the success of a plantation. For this reason, the expected wood quality was determined by structural parameters and the density along the cross section profile of the stem. Research was done on four plantation trees of an age between four to five-and-a-half years. For comparison purposes, increment cores were taken from trees of the primary forest at a comparable site and wood sampled in Surinam from a collection.

The characterization of the growth dynamics showed that there were two types of limitations to growth zones. In all of the plantation trees, three to five, sometimes even seven, ringlike orientated fibre bands with intermediary paratracheal parenchyma could be detected near the pith. In the older trees, the parenchyma was followed by several broad zones of symmetrically structured vessels with paratracheal-aliform parenchyma. Less often, a single narrow parenchyma band established a limitation. Vessel density decreased from pith to cambium, while their size increased. Frequently, vessel bundles were found in the plantation trees. The samples from the external xylem area of primary forest trees, as well as the samples of a second site, taken for comparison generally showed narrow growth zones which respectively were limited by a distinctly visible parenchyma band. Within the growth zones, the mostly solitary vessels were distributed irregularly.

The cambium activity of *Hymenaea courbaril* L. is different throughout the year. The intraannual growth rate was determined according to the analysis of dated pin-marker series at two trees. The monthly growth in radial direction was between 0.2 mm and 2.2 mm, with the lower rates usually belonging to the drought period and the higher figures to the period of high precipitation. By the pin-marker method, the date of the formation of growth-determining parenchyma bands with vessel enrichment could be defined.

As concerns the percentages of the cell types, the plantation trees showed similar trends. The percentage of vessels decreased in all trees from pith to cambium. This average decreases with tree-age and is very near to the percentage of the adult heartwood with 7.8% and 6.25% respectively. Although fibres have the largest percentage in wood tissue, their average percentage of 44 - 49% is far lower than the 57% of the adult wood. Correspondingly, the percentage of the longitudinal and the ray parenchyma is higher. For plantation trees, it oscillates between 17 - 25% approximately.

The tangential vessel diameter increased across the cross-section from pith to cambium. Especially vessel groups of two and tree vessels contributed to the increase of the average figures. In many cases, in areas structured by a parenchyma band a lower average vessel diameter was detected.

The trend in the age of the fibres, which is to be seen in the increase of length measured diametrically from pith to cambium, could be proven in each of the experimental trees. In the area of the outer xylem, the average fibre lengths mostly reached their heights between 1,000µm and 1,200µm (primary forest: approximately 1,370µm). The average fibre wall thicknesses were almost constant at 1.6µm, while the diameter of the lumen decreased, so that the older fibres had a higher density.

The average density across the diameter of the plantation trees examined generally was very high: the rates were increasing with the tree age from 0.70g/cm³ (45 months of age) to 0.74g/cm³ (52 months), 0.79g/cm³ (64 months) and to 0.82g/cm³ (65 months). By this, the oldest tree of the study reached values of adult wood of between 0.80, 0.95 and 1.02 g/cm³, indicated in literature.

Taking the parameters of density and fibre dimension into account, the plantation trees of an age of nearly 5½ years did not yet reach the average level of the trees of primary forests or the level of adult wood, as indicated in literature.

The growth increment zones of primary forest trees are limited by parenchyma bands. Such parenchyma bands are rudimentarily visible in the older plantation trees in the outer xylem. Probably, this is a trace of the transition from the juvenile to the adult phase. It would be necessary to verify this assumption by quantitative examinations of the fibres and by determination of density in the outer xylem of the plantation trees, which at present (November 1998) have reached an age of nearly seven years.

Relatório de Atividades desenvolvidas no Instituto de Biologia da madeira
(Hamburg-Alemanha)

Universidade de Hamburg
Projeto SHIFT BMBF 0339638/CNPq ENV-42

Ronaldo Ribeiro de Moraes

(Período: 02.08-23.10)

(Cooperação Universidade de Hamburg/CPAA-Embrapa, Manaus)

Relatório de Atividades

(Período de Execução: 02/08/98 a 23/10/98)

Título: Influência da disponibilidade de água sobre a dinâmica de crescimento cambial de plantas de *Swietenia macrophylla* King. (Mogno).

Introdução

Este trabalho faz parte do projeto ENV-42 „Estudos de espécies arbóreas com potencial para reflorestamento de áreas abandonadas e/ou degradadas na Amazônia Ocidental“, o qual tem como objetivo avaliar a influência e o manejo de áreas degradadas sobre o crescimento e formação de madeiras de espécies nativas, em diferentes sistemas de plantios, e analisados os aspectos fisiológicos, ecológicos e econômicos.

A espécie *Swietenia macrophylla*, é nativa a região Amazônica, apresentando uma altura de 25-30 m, com tronco de 50-80 cm de diâmetro. Folhas compostas de 8-10 folíolos de 7-15 cm de comprimento. Planta semidecídua ou decídua, heliófita, característica da floresta clímax de terra firme, sobretudo argilosa. Possui a madeira moderadamente pesada (densidade 0,63 g/cm³), dura, de resistência moderada ao apodrecimento e alta ao ataque de cupins de madeira seca. A madeira é indicada para mobiliário de luxo, objetos de adornos, painéis, lambris, régua de cálculo, esquadrias, etc.

Para o estudo em questão foram selecionadas plantas de *Swietenia macrophylla* localizadas na Casa de vegetação do Intituto BFH (Hamburg-Alemanha). As plantas possuem aproximadamente 4 anos de idade, e encontram-se plantadas em vasos com 30 cm de diâmetro, e 25 cm de altura, e substrato composto por 1 parte de areia, mais 3 partes de solo fértil (Fig.1A). Foram realizados estudos principalmente com o limbo foliar devido este ser o órgão mais plástico do vegetal, tendo como função principal a fotossíntese. Sua posição e atividade fisiológica, o coloca em contacto com a atmosfera, onde se relaciona com fatores como luz, temperatura, umidade, concentrações de gases, etc, e indiretamente com o solo e outros órgãos. Devido a esses fatores, a maioria das mudanças adaptativas ou não do vegetal, são „registradas“ pelas folhas.

Atividades Desenvolvidas:

Potencial Hídrico das Folhas

O potencial hídrico das folhas, foi obtido através de medições com a Bomba de Scholander (Skye) (Fig.1B). Para efeito comparativo este estudo foi realizado com folhas novas e folhas velhas da mesma planta e entre plantas diferentes. Foram seccionados cada par de folíolos apicais de cada folha. Estas folhas foram posteriormente pesadas, e obtido a área foliar através de uma mesa digital (HIPAD PLUS, Hoston Instruments) (Tab.1). Foram efetuadas medições em cinco períodos distintos de disponibilidade de água: Período úmido (17.08-24.08), período de desidratação (31.08-03.09), período seco (07.09-09.09), período de hidratação (17.09-21.09) e período úmido (24.09-01.10).

Para efeito comparativo entre os períodos distintos (Úmido e Seco), foi realizado um acompanhamento diário, com medições de 3 em 3 horas (9:00, 12:00, 15:00, 18:00, 21:00, 00:00, 03:00 e 06:00).

As folhas novas apresentaram um potencial hídrico maior em relação as folhas velhas. Com relação aos períodos de disponibilidade de água para as plantas, percebe-se uma tendência a este potencial ser mais elevado em períodos secos, e com taxas mais baixas em períodos de grande disponibilidade de água (úmido) (Gráfico. 1).

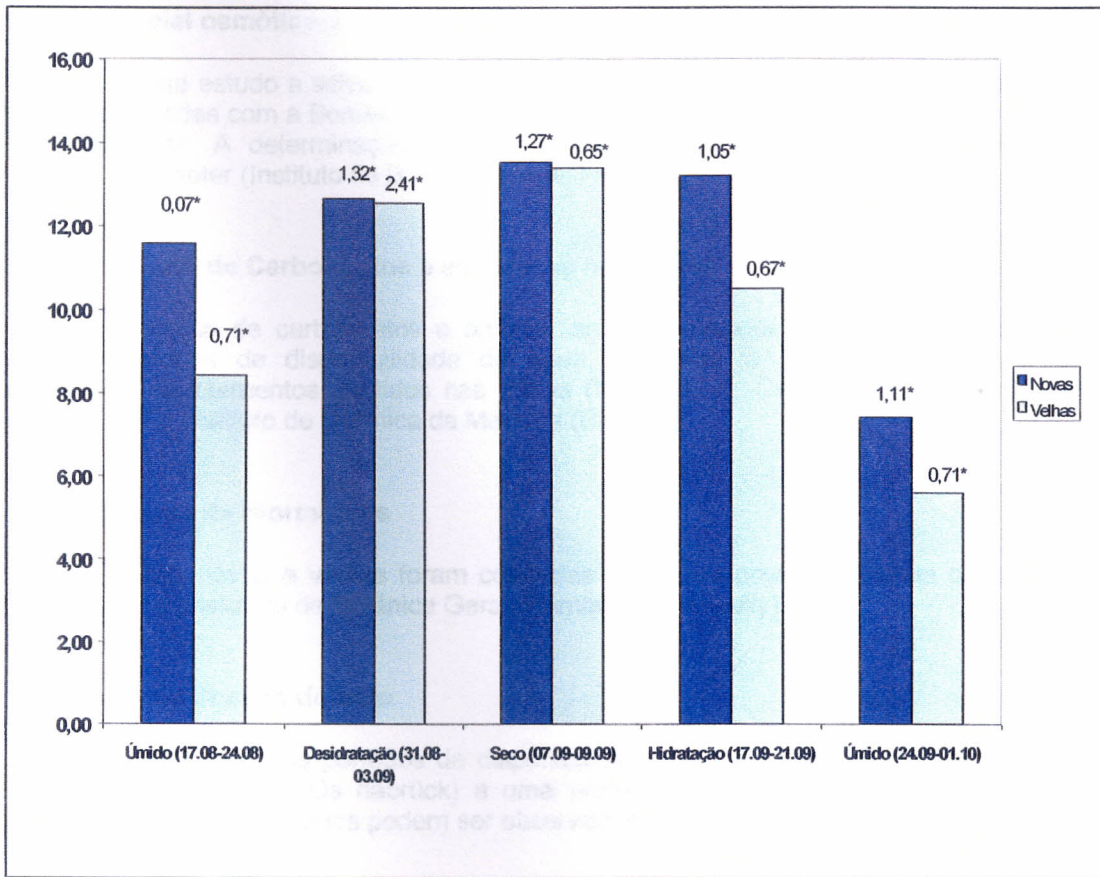
	Peso Fresco* (g)		Área foliar* (mm ²)	
	Média	Desvio padrão	Média	Desvio padrão
Novas	2,60	0,90	18974,93	5945,15
Velhas	3,31	1,23	24786,59	8207,69

*Correspondente ao par de folíolos apicais.

TABELA 1- Média e desvio padrão, do Peso e Área foliar, das folhas de *Swietenia macrophylla*.



FIG. 1- A. Plantas de *Swietenia macrophylla* na casa de vegetação; B. Bomba de Scholander; C. Tensiômetro; D. Spectrofotometria com UFV.



* Desvio padrão

GRÁFICO. 1- Potencial hídrico de folhas novas e velhas, em diferentes períodos de disponibilidade de água.

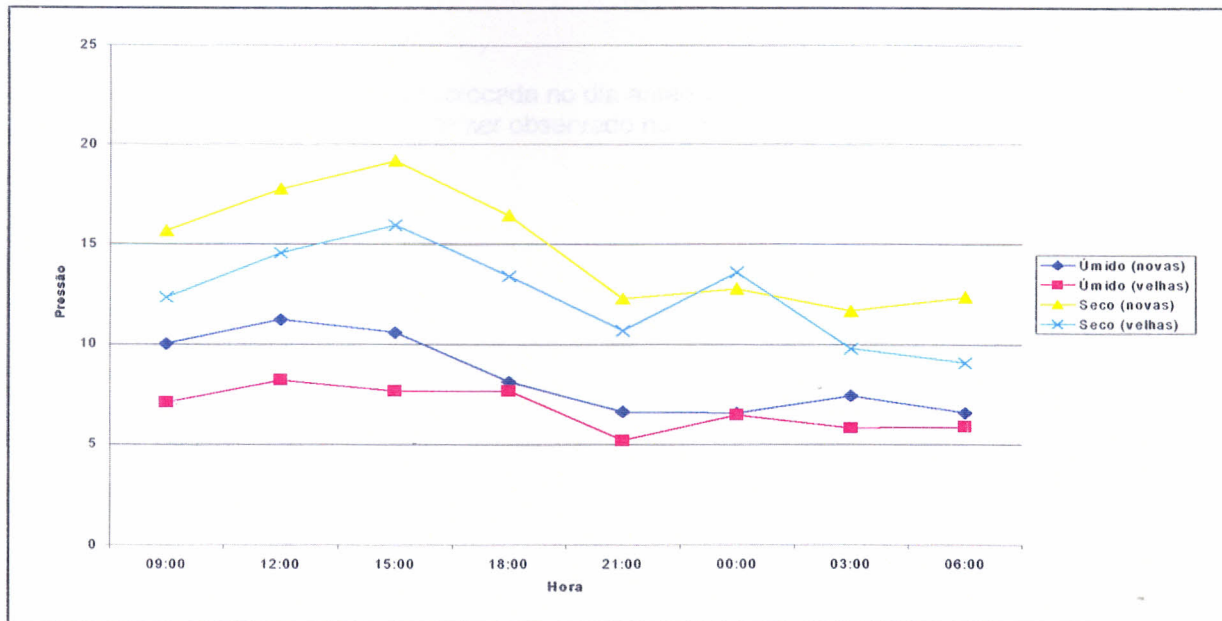


GRÁFICO 2- Ciclo diário do potencial hídrico, nas folhas novas e velhas de *Swietenia macrophylla*, em duas condições de disponibilidade hídrica.

Potencial osmótico das Folhas

Para este estudo a seiva foliar foi retirada da folha, através de pressão juntamente com as medições efetuadas com a Bomba de Scholander, e coletada através de um pequeno tubo acoplado ao pecíolo foliar, A determinação deste potencial osmótico será efetuada posteriormente por Roebing Osmometer (Instituto de Botânica Geral, Hamburg University).

Conteúdo de Carboidratos e elementos nas folhas

O conteúdo de carboidratos e amidos, serão analisados nas folhas novas e velhas, em diferentes períodos de disponibilidade de água, descritos já acima, assim como também, a concentração de elementos contidos nas folhas (N, P, S, K, Ca, Mg, Al, Fe). Este estudo será desenvolvido no Instituto de Química da Madeira (BFH).

Medições de fitormônios

As folhas novas e velhas foram coletadas para uma posterior análise da concentração de Ácido Abscísico (Instituto de Botânica Geral, Hamburg, University).

Força de Sucção do solo

Para avaliação dos períodos de disponibilidade de água para as plantas, foram instalados Tênsiômetros (UP GmbH Os nabrück) a uma profundidade de 20 cm (Fig. 1C), e efetuadas 3 medições diárias. Os resultados podem ser observados no Gráfico 3.

Consumo de água

As plantas foram pesadas diariamente, assim como também, efetuado o controle na quantidade de água para cada planta. O consumo de água pelas plantas, foi obtido através da seguinte fórmula:

$$C = P2 - P1 - A2$$

Onde: C= Consumo de água

P2 = Peso do dia anterior

P1 = Peso do dia

A2 = Quantidade de água colocada no dia anterior

Este consumo de água pode ser observado no Gráfico 3.

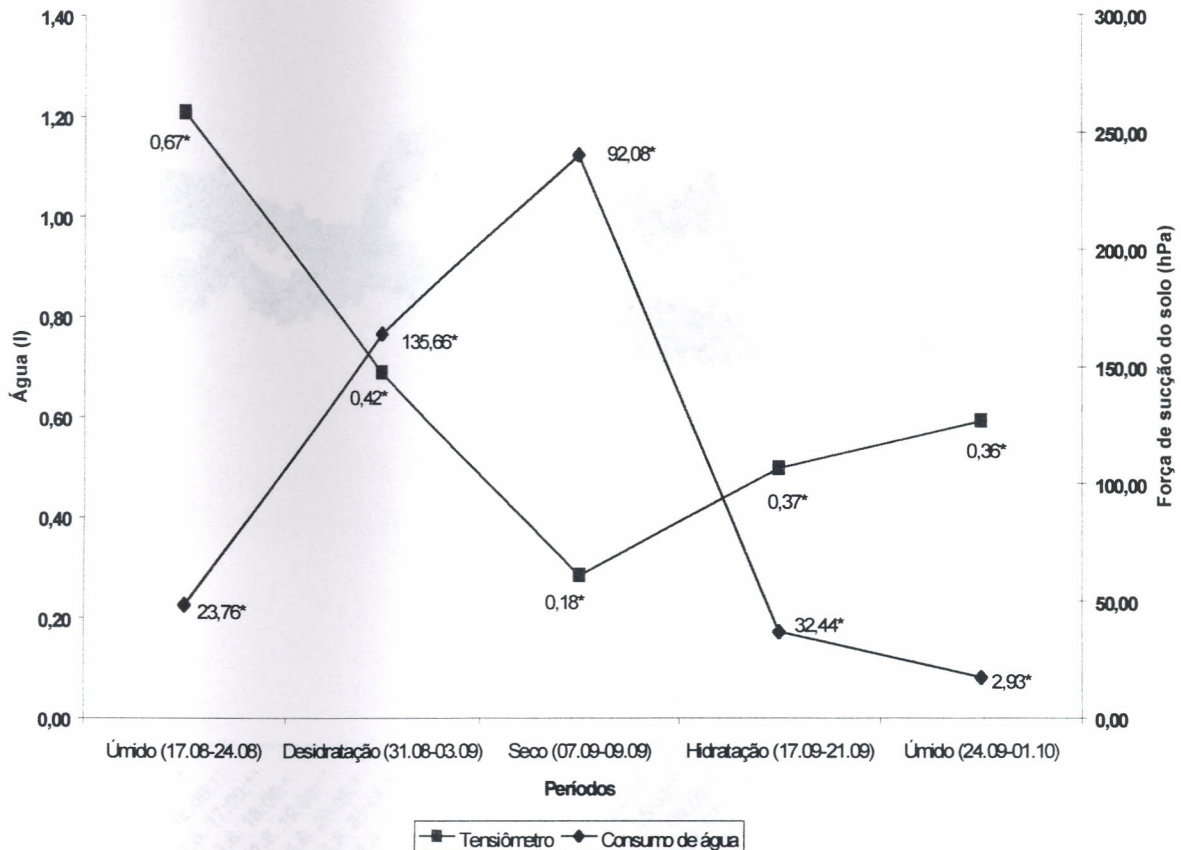


GRÁFICO 3- Força de sucção do solo e consumo hídrico de plantas de *Swietenia macrophylla*, observados nos cinco períodos distintos de disponibilidade hídrica.

Cicatrizes no lenho

Foram efetuadas em todas as plantas, pequenas incisões no lenho, com o auxílio de um alfinete, nos períodos seco e úmido, respectivamente. Estas „feridas“ tem como objetivo avaliar a intensidade de zonas de crescimento nas duas condições de disponibilidade hídrica, assim como, quantificar a divisão de células do câmbio. O caule desta planta foi posteriormente seccionado para a confecção de lâminas do tecido xilemático, a fim de serem efetuadas mensurações das diversas estruturas que compoem este tecido.

Espectrofotometria com UFV

Através do laser foi verificado o crescimento do caule em diâmetro (Fig 1D). Uma planta de *Swietenia macrophylla*, foi colocada em uma posição estável onde este comprimento de onda do laser, teve uma mensuração definida, assim como também, sua posição no caule da planta. Esta planta foi sujeita à cinco condições de disponibilidade hídrica, já descritas anteriormente, assim como, recebeu uma radiação luminosa artificial, por um período de aproximadamente 7 horas por dia.

Esta variação no comprimento de onda do laser, foi captado e registrado por um data logger, o qual também registrou a temperatura ambiente.

Os resultados parciais mostram uma pequena tendência para que o crescimento em diâmetro do caule desta planta, ocorra em maior intensidade em períodos noturnos, talvez devido a uma alta intensidade da atividade estomática.

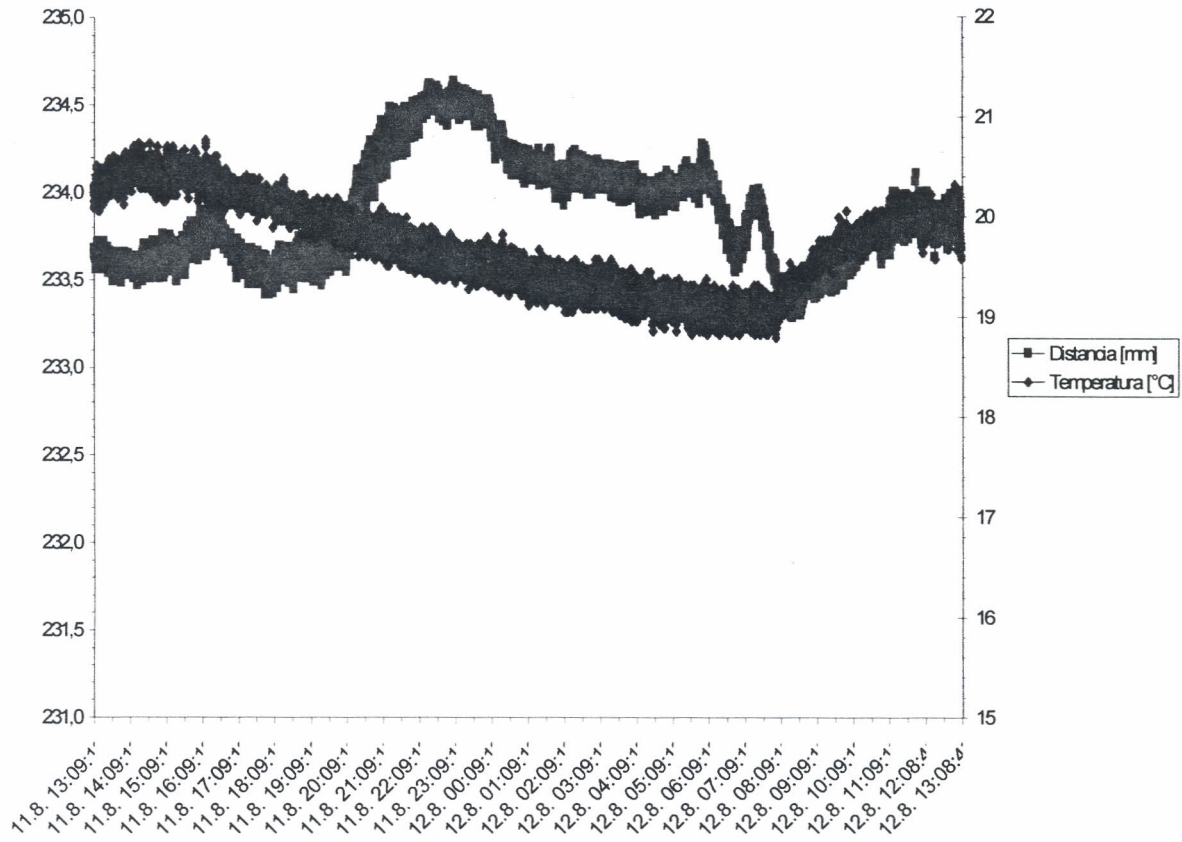


GRÁFICO 4- Acompanhamento diário do crescimento em diâmetro do caule, e temperatura.

Outras atividades Desenvolvidas:

Apresentação do respectivo trabalho no dia público do BFH, dia 29.09.98.
Excursão para o conhecimento do Manejo Sivicultural em florestas da Alemanha.

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