High quality timber production in mixed plantations of the Amazon

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Within the scientific coopertaion between the Embrapa Amazonia Ocidental in Manaus and the Institute of Wood Biology, University of Hamburg the relationship of exogenous input and the growth dynamics of eight native tree species was investigated from 1995 until 2000. In this study special attend was given to the important timber species for high quality timber production Swietenia macrophylla King, *Carapa* guianensis Aubl., and Cedrela odorata L (Meliaceaea). The aim of this study was to optimise the wood production of these species under plantation conditions with special regard to sustainable timber production in mixed plantations.

The study was carried out on the research station of the Embrapa Amazônia Ocidental, 24 km out of the city of Manaus, 3°8' S, 59°52'W. The area is located at approximately 50 m above sea level with an annual precipitation of about 2,500 mm , a mean air temperature of 26.4° C, and a mean humidity of the air of 87 %. According to categorisation, the soil is a poor xanthic Ferralsol. The experiments were carried out in monoculture and enrichment plantations installed in January 1992 (study of 3 to 8-year-old plants and in January 1998 (study of 1 and 2-year-old plants). Corresponsding studies were carried out on natural sites of *Swietenia macrophylla* King and *Cedrela odorata* L. in the north of Mato Grosso (close to the city of Aripuana) and on natural sites of *Carapa guianensis* Aubl. in the states of Amazonas (close to the cities of Manaus and Itacoatiara) and Para (close to the city of Santarem).

The light demand of the trees was studied by means of light saturation curves of the photosynthesis of 5 to 8-year-old trees obtained from light measurements and gas exchange measurments carried out on 5 trees of each species (250 measurements each).The water uptake of trees with diameters more than 2.5 cm was calculated from xylem sapflow measurements. The N, P, S, K, Ca, and Mg demand of the species was calculated from the nutrient content of different plant tissues (9 to 40 fractions per tree) and the biomass of the trees. The light supply of plantation and natural grown trees was studied by means of PAR sensors installed on the surface and in the crown of the trees (8 sensors per tree). The water fluxes within the plantations were calculated for one-month-intervals. The nutrient stocks of the soil were quantified by the element analyses of annually collected soil samples and the density of the soil fractions quantified gravimetrically. As to study the relationship of exogenous input and the biomass production of the trees the biomass of the trees was annually quantified in the field (4 trees per species harvested, 13 to 93 trees measured dendrometrically (height, stem diameters, height of the crown, projection area of the crown)). These data were compared with the biomass production calculated by multiple regression analyses (polynomial functions) from the data on the light, water, and nutrient demand of the species and the light, water, and nutrient supply of the study sites.

Based on 6 years of measurements the light demand for biomass production of the species was calculated. It turned out that *Swietenia* and *Cedrela* has a higher light demand for biomass production compared to *Carapa*. Studying the relationship of photoactive radiation and the net photosynthesis per leaf area and time it became obvious that the higher light demand of *Swietenia* and *Cedrela* is predominately due to the lower photosyn-

thesis capacity of these species compared to *Carapa*. The maximum rate of photosynhesis at light saturation of *Carapa* is approximately 3 times higher than the maximum photosynthetic capacity of *Swietenia* and also significantly higher than corresponding data of Cedrela. In addition under shading the net photosynthesis of *Carapa* is higher than the net photosynthesis of Swietenia and *Cedrela*. At an photoactive radiation of 50 uE per m^2 s the net photosynthesis of *Carapa* is 3.7 µmol/m^2s compared to 2.4 of *Cedrela* and 1.3 of Swietenia. Interpreting the results it has to be mentioned that the differences in wood production of the species are not equivalent the differences found in primary production due to the higher photosynthesis use efficiency and major portion of wood production of Swietenia and *Cedrela* compared to *Carapa* (comp. Dünisch and Schwarz 2000). No significant difference was found between the water uptake per kg biomass production of Swietenia and *Carapa*, whereas *Cedrela* showed a higher demand of water for biomass production. Based on more than 3000 data collected on the experimental sites in 1998 and 1999 the relationship of the suction force of the soil and the water uptake in ml per cm^2 sapwood and s of Swietenia, *Carapa*, and *Cedrela* was calculated. Comparing the relationship obtained for Swietenia, *Carapa*, and *Cedrela* it turned out that the relationship obtained for Swietenia followed a similar pattern compared to *Cedrela* whereas the pattern obtained for *Carapa* was different. This is especially caused by structural and physiological differences of the roots between Swietenia and *Cedrela* on the one hand and *Carapa* on the other hand. Maximum water uptake of Swietenia and *Cedrela* was found in wet soils with low soil water potentials. In contrast maximum water uptake of *Carapa* was found in soils with a soil water potential of approximately 250 hPa. The specific water uptake of *Carapa* already exceeds the water uptake of Swietenia and *Cedrela* in soils with a suction force higher than 70 and 100 hPa respectively indicating a better adaptation of this species to drier site conditions. Comparing the mean K content per kg dry mass of Swietenia, *Carapa*, and *Cedrela*, it became obvious that the K demand for biomass production of Swietenia and *Cedrela* is significantly higher than the K demand of *Carapa*, which is only 4940 mg K/kg dry mass compared to 6967 mg/kg and 8604 mg/kg, respectively. As to study, whether Swietenia and *Cedrela*, which showed a high demand of K for biomass production also show a high absorbance capacity for K the relationship of the K content of the soil and the K uptake per kg dry mass and year was investigated. Consequently to the high K demand of *Cedrela*, in more fertile soils the K uptake of this species exceeds the K uptake of Swietenia and *Carapa*. Although Swietenia has a higher K demand for biomass production than *Carapa*, even in fertile soils the K uptake of Swietenia is lower than the K uptake of *Carapa*, which is predominately caused by anatomical and physiological differences in the root zone of these species. In soils with extremely low K contents, the K uptake of *Carapa* was significantly higher than the K uptake of Swietenia and *Cedrela* indicating a good adaptation of this species to poorer sites.

During the initial phase of the monoculture maximum light intensities are available for plant growth. After 8 years of growth 80% of the maximum light intensities are available in the Swietenia and *Cedrela* plots, whereas the light intensity of the *Carapa* plots was strongly reduced, which indicates that thinning is an urgent need. At the start of the enrichment plantation only 40% of the maximum light is available for the planted trees. With increasing age more light is available for the planted trees and after 8 years *Carapa* already reached the upper crown layer of the plantation. Natural growth of Swietenia and *Cedrela* was found at open sites with high light intensities. In contrast to that juvenile plants of *Carapa* were often found in the understory of primary forests. Light intensities measured on these sites varied between 35 and 55% of the maximum light intensity. Studying the water supply of plantations and natural sites it became obvious that the water supply of plantations can differ significantly from natural site conditions. The central Amazon is characterised by a season with high precipitation from December

until June and a season of lower precipitation from July until November. Due to this reduced precipitation an increase of the water potential of the soil was found on all sites. With regard to the growth dynamics of planted trees short-term periods of higher soil water potentials, which were found in the monoculture also during the rainy season are of special interest.

For most of the tree species on terra firme sites the rainy season is the main growth season. Therefore these shortterm changes of the soil water content during this period observed in the monoculture plots might have a strong impact on the growth and wood formation of the planted trees. In contrast to the monoculture the water budget of the enrichment plantation was more balanced. Short-term periods of reduced precipitation during the rainy season did not have a significant influence on the mean monthly soil water potential of the soil indicating a better water availability during that period. No significant difference was found between the maximum soil water potential of the monoculture and the enrichment plantation during the dry season. On natural sites of *Swietenia* and *Cedrela* low and well balanced soil water potentials were found during the wet season from December until June, whereas *Carapa* was often found on sites with a high ground water level with water logged soils from May until June and lower suction force values from July to November compared to native sites of *Swietenia* and *Cedrela*.

The nutrient balance of all macronutrients of the monoculture, the enrichment plantation, and natural sites was calculated from nutrient input and output data collected from 1995 until 1999. Based on these measurements the K stocks of the soil (kg/ha) up to 60 cm depths of the monoculture, the enrichment plantation and of natural sites were quantified. A strong decrease of the K stocks of the soil was found in the 1 to 8 year-old monoculture plots. Beside the uptake of K by the vegetation this decrease was predominately caused by high leaching of K out of the soil and low litter decomposition during the initial phase of the monoculture plantation. After approximately 5 years the K stocks of the soil of the monoculture were stabilised at a level of 30 to 63% of the K stocks found before planting indicating a strong need for appropriate tools for the improvement of the nutrient supply of plantations especially during the initial phase of growth. In contrast to that the K input into the soil and the K output out of the soil of the enrichment this plantation system on the nutrient supply of disturbed sites. According to the findings in the enrichment plantation a balanced nutrient input and output was found on natural sites of *Swietenia*, *Carapa*, and *Cedrela*. Natural growth of *Swietenia* and *Cedrela* was only found in more fertile soils compared to the soil conditions in the monoculture and in the enrichment plantation considered in this study. In contrast to that the K content of the soil of natural growth of *Carapa* varied in the range of the K content of the soil of the 2 plantation systems.

The biomass of the trees was annually quantified in the field. These data were compared with the biomass production calculated by multiple regression analyses from the data on the light, water, and nutrient demand of the species and the light, water, and nutrient supply of the study sites presented before.

The growth dynamics of the three Meliaceae species was strongly correlated with the light, water, and nutrient supply, which offers the chnace to select suitable sites and management practices by means of geographical information systems as to improve the timber production of these species in plantations like agroforestry systems.