SHIFT Project ENV 45

BMBF No. 0339641 5

Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus

Annual Report 1995

by
Institute of Soil Science and Soil Geography
University of Bayreuth (UBT)

and

Empresa Brasileira de Pesquisa Agropecuaria - Centro de Pesquisa
Agroflorestal da Amazônia Ocidental (EMBRAPA-CPAA)

Manaus and Bayreuth

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Abstract

The project started in March 1995. Its objective is the quantification of water and nutrient fluxes in an experimental plantation, which is composed of different monoculture and polyculture systems with mainly perennial crops, as well as in primary and secondary forest at EMBRAPA-CPAA, Manaus/Brazil. The flux measurements are expected to provide information about the efficiency with which the different land use systems exploit the available resources (water, nutrients) on the infertile soils of the area and minimize unproductive losses, e.g. through leaching. Efficient resource utilization is seen as a precondition of sustainable land use on this site.

The time until August 1995 was used for purchasing and assembling the field and laboratory equipment; field work in Manaus was taken up in September 1995. As a precondition for the flux measurements, the mass and distribution of the root systems of the four mainly investigated species, pupunha (*Bactris gasipaes*), cupuacu (*Theobroma grandiflorum*), urucum (*Bixa orellana*) and castanha-do-brazil (*Bertholletia excelsa*) were analyzed in an excavation/soil coring study, which took place in a polyculture plot. A cover crop (*Pueraria phaseoloides*) and spontaneous *Vismia* fallow were also included in the study. Aboveground biomass and nutrient accumulation in the plants are currently investigated by means of allometric relationships. The field equipment for the flux measurements, consisting of rainfall and stemflow collectors, ceramic suction cups, tensiometers and time domain reflectrometry (TDR) probes, was installed in polyculture plots with two fertilization levels, three different monocultures as well as spontaneous fallow. Each treatment is replicated threefold. With the help of a visiting scientist, transpiration measurement devices were installed and tested on the four aforementioned tree species. An analytic system (Segmented Flow Analyzer) was installed in the EMBRAPA laboratory and will be used for the nutrient analyses of rainwater and soil solution as well as soil and plant samples.

Contents

1. Introduction

The research project "Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus" started in March 1995. The present report is the first annual report and refers to the project activities between March and December 1995 (see Table 1, p. 22).

The project is part of the activities of the German-Brazilian SHIFT program in Manaus. The research site is the experimental 17 ha plantation that was installed by the SHIFT project ENV 23 during 1992/93 on the EMBRAPA-CPAA research station at km 29 on the road Manaus-Itacoatiara. Additionally, water and element fluxes will be measured at some points in the surrounding forest for better understanding of the processes in these contrasting ecosystems.

Due to the early stage in the development of this project, the present report will inform mainly about activities of the project group, and will present only few and preliminary results. The results which have already been produced by the project can be found in the annexes. The main part of the report will give an introduction into the concept and the applied methodology of the project as it was presented on the 2nd SHIFT workshop at Cuiabá in July 1995 and will show the progress in the implementation of the research goals.

The research group which is directly involved in the project activities would like to acknowledge the continuous support from various persons and institutions that it recieved during the past months: The CNPq provided funds for the invitation of visiting scientists, and the EMBRAPA administration helped to solve many technical and administrative problems. Of particular importance was the logistic support by Dr. Luadir Gasparotto, Dr. Helmut Preisinger and Dr. Oliver Dünisch. Close contacts between the Brazilian project group (Dr. Gasparotto, Wenceslau Geraldes), Prof. Dr. R. Lieberei (University of Hamburg), Prof. Dr. J. Bauch (Federal Institute of Forest and Wood Sciences, Hamburg), H. Bianchi (GKSS, Geesthacht), Dr. Stüttgen (KFA Jülich) and Prof. Dr. W. Zech (University of Bayreuth) proved to be very valuable for the successful realization of the 1995-activities.

2. The ENV 45 research group

The following staff of the University of Bayreuth (UBT) and the EMBRAPA participated in the project activities during 1995/96:

Name and affiliation	Function
Prof. Dr. Wolfgang Zech (UBT)	head of the project
Dr. Luadir Gasparotto (EMBRAPA)	administrative coordination of the project on the EMBRAPA side; this function was taken over in March 1996 by Dr. Manoel Cravo
Dr. Götz Schroth (UBT)	until August 1995 purchasing and preparation of project material at Bayreuth, since September 1995 coordination of project activities at Manaus and installation of field and laboratory equipment
Wenceslau Geraldes Teixeira (EMBRAPA)	coordination and soil physics
Ecila Merces de Albuquerque Villani (CNPq fellow)	soil chemistry, laboratory analyses, root studies
Olivio Pedro Faccin (CNPq fellow)	soilwater, soil physics
Daniel Haag (UBT student)	root studies
Marc-Andree Wolf (Univ. Braunschweig student)	above-ground biomass and allometrics

3. Concept and methodological approach of the project

Since the presentation and approval of the project proposal by BMBF and CNPq, the concept of the project has gone through numerous discussions with members of other SHIFT projects and of EMBRAPA and also through several months of field experience with the implementation of the concept. This has led to specifications and modifications of the concept and the working plan, and it seems thus appropriate to outline here the project concept in its current version. The following part follows closely the presentation of the project at the SHIFT workshop at Cuiabá (Zech and Schroth, 1995).

Background and working hypotheses

Land use systems that are adapted to sites with low nutrient supply like the Terra firme should be characterized by

- a minimum of unproductive nutrient losses (nutrient leaching with infiltrating water beyond the crop rooting zone);
- an efficient absorption and retention of available nutrients (from rain water, fertilizer, litter decomposition etc.); and
- the efficient transformation of limiting nutrients into biomass and harvest products.

These characteristics should increase both the economic return and the ecological sustainability of a land use system, especially under low-input conditions. Presently, we know very little about the way how a heterogeneous, mixed plantation system should be composed, designed and managed to fulfill the aforementioned requirements. To contribute to this question is the main intention of the present research project.

When we want to establish such site adapted, nutrient efficient land use systems with a number of economically and/or ecologically interesting plant species, we need to know which "role" each of these species will play within the context of the land use system. "Role" means here the total effect of the species on water and nutrient fluxes within the system, or in other words, its "ecological function" with respect to water and nutrient cycling. Examples for possible "roles" of tree or crop species would be:

- increase of the nitrate concentration in the soil solution through N-fixation and/or low N uptake, leading to a better N-supply for associated plants, but also to a higher leaching risk;

- high water consumption, leading to rapid drying of the soil after rainfall events, thereby reducing nutrient leaching;
- creation of vertical, continuous macropores in the soil through root activity and the attraction of soil fauna (like earthworms), leading to more rapid water infiltration;
- production of recalcitrant litter, forming a continuous litter layer and protecting the soil surface against drying and rain splash.

In a monoculture system, the "role" of the planted species is determined only by its specific properties, such as growth, root distribution, water and nutrient consumption etc., and the management of the stand (fertilization, weeding, harvest, pruning etc.). In a mixed cropping system, the interactions between associated species modify their influence on water and nutrient cycles, for example through root competition and mutual shading.

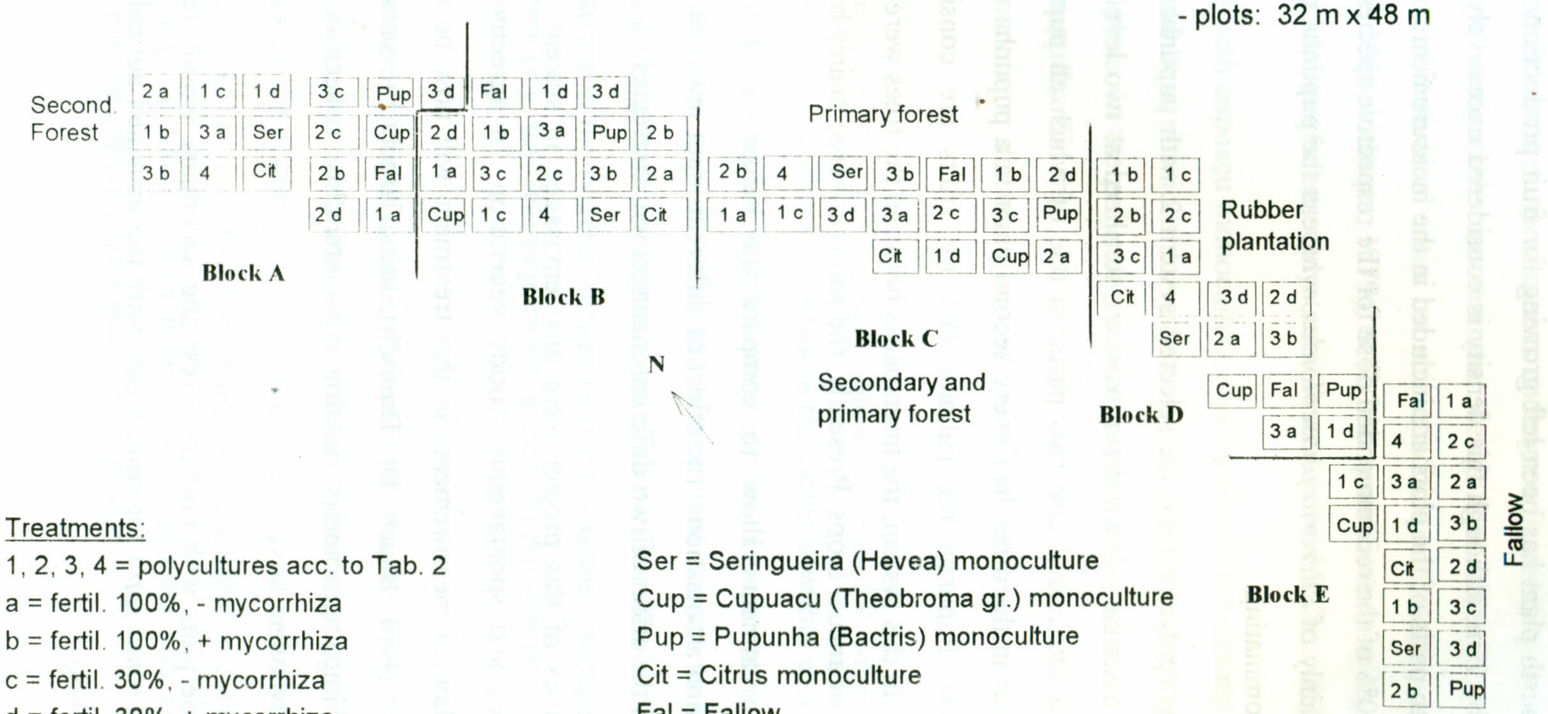
The fundamental hypothesis of this research is: *When we know the effects of a number of economically interesting tree and crop species on soil conditions, water and nutrient fluxes* (i.e. their "roles" in a land use system), *we can use this information for designing sustainable, site adapted and productive land use systems according to the requirements of a given site and the priorities of the land users.*

Treatments to be studied

The research will be carried out within the existing field experiment on "Recultivation of abandoned monoculture areas on the Terra firme" at the EMBRAPA-CPAA research station near Manaus. The experiment has been installed in 1992/93 on an area of about 17 ha and comprises 18 treatments in 5 replicate blocks (see Layout of the field experiment, next page). The treatments are different plantation systems, consisting of combinations of the factors tree species (for monocultures) or species mixtures (for polycultures), fertilization level (30% or 100% of the dose recommended by EMBRAPA) and inoculation of the tree seedlings with VA mycorrhiza. In our study, only a selection of the currently most interesting factor combinations can be included. Also, only three of the five blocks of replicate plots are sufficiently level and pedologically homogeneous to permit hydrological investigations with the selected methodology; these are the blocks A, B and C.

Within this experiment, the effect of several tree species on soil properties and water and nutrient fluxes will be investigated in different monoculture and polyculture systems.

Layout of the field experiment



<u>Experimental design</u>

- area total: 189.997 sqm
- area of plots: 138.240 sqm
- plots: 32 m x 48 m

<u>Treatments:</u>

1, 2, 3, 4 = polycultures acc. to Tab. 2
a = fertil. 100%, - mycorrhiza
b = fertil. 100%, + mycorrhiza
c = fertil. 30%, - mycorrhiza
d = fertil. 30%, + mycorrhiza

Ser = Seringueira (Hevea) monoculture
Cup = Cupuacu (Theobroma gr.) monoculture
Pup = Pupunha (Bactris) monoculture
Cit = Citrus monoculture
Fal = Fallow

As monocultures, we selected pupunha (*Bactris gasipaes*) and cupuaçu (*Theobroma grandiflorum*), two highly relevant local tree crops with contrasting properties. Pupunha is a fast-growing palm species which rapidly dominates other species in associations; and cupuaçu is a slowly growing undergrowth species. The pupunha plots are subdivided into a part where all plants (spaced 2 by 2 m) are managed for palmheart (palmito) production, and a part in which every fourth plant has been left growing for fruit production. In this part the trees are also spaced 2 by 2 m, although this density is considered excessively high for a pupunha fruit plantation. Both parts of the plots are included in the measurements. All monoculture plots are fertilized at 100% of the recommended dose for the respective species. The cupuaçu plots have a soil cover mainly of *Pueraria phaseoloides*, whereas the pupunha plots have little soil cover with grasses dominating.

As associations (polycultures), we selected system 2 with pupunha, cupuaçu, urucum (*Bixa orellana*) and castanha (*Bertholletia excelsa*), fertilized at two levels (100% or 30%). These plots were also subdivided into two parts, in one of which all pupunhas were managed for palmito, whereas in the other half every second plant in a pupunha row was left growing for fruit production. Pupunha for palmito and for fruits are considered separately in the measurements. In this system, the interspaces between the trees were limed in the first year for the cultivation of annual crops. Presently, the soil is covered mainly by *Pueraria*.

The selected treatments allow to compare the behaviour of pupunha and cupuaçu in monocultures and associations, the effect of different input levels on four highly relevant local tree crops, and the effect of two different management strategies on pupunha.

Initially, activities of this project were also envisaged in system 4, which is composed of forestry species and spontaneous woody vegetation. In agreement between both project groups, the planned measurements in this treatment will now be conducted by the project group ENV 42 (Prof. Bauch, Dr. Dünisch), using largely the same methods as our project (biomass sampling, tensiometry, suction cups, stemflow collectors, raingauges, transpiration measurement by xylem flux).

We also include plots with primary forest and secondary woody regrowth (capoeira, mainly composed of *Vismia spp.)* for comparison with the managed agricultural treatments using the same methodology.

Principles of the experimental design

The analysis of the effect of a certain tree species within a complex land use system requires that measurements of soil properties and water and nutrient fluxes are carried out close to individual plants of this species where its influence is likely to be the most pronounced - and thus the most easily detectable. For comparison, measurements are also taken at positions mainly influenced by cover crops or spontaneous undergrowth, with minimum influence of the planted tree species. A comparable measurement design has often been employed in the analysis of the effects of individual trees on soil conditions in savannas (Dunham, 1991; García-Miragaya et al., 1994; Kellman, 1979), or for the quantification of the so-called "single-tree influence" (Zinke, 1962) in forest ecosystems (Boettcher and Kalisz, 1990).

For example, in a plot with cupuaçu monoculture, two positions are distinguished, 1) close to cupuaçu individuals, and 2) at positions dominated by pueraria, at maximum distance from the cupuaçu plants in the plots. In the polyculture system 2, six positions are distinguished, close to individuals of 1) pupunha for fruit, 2) pupunha for palmito, 3) cupuaçu, 4) urucum, 5) castanha, and 6) at maximum distance from the trees at positions dominated by pueraria undergrowth.

So, we do not primarily try to obtain average values of, e.g. soil water dynamics, nitrate leaching etc. for a whole plot, but rather to measure the extrema within each plot and to relate them to specific properties of the investigated plant species. This should allow to define the specific "role" of the different species within the system with respect to water and nutrient cycling. Also, modelling of the systems on the basis of these data should then allow to check the effects of modifications in the systems' design (species, spacing, management) on "target" properties of the systems (e.g. low leaching losses, maximum nutrient and water consumption etc.).

In fact, it would be extremely difficult to obtain "average" values for a whole plot or plantation system without possessing information about the within-plot heterogeneity. The measurements in extreme positions within the systems do not exclude the analysis of gradients between trees and open areas, for example in root distribution and soil chemical and physical properties, which will ultimately allow to translate spot measurements into per-area estimates. For this, geostatistical methods may be used in a later stage of the project.

Parameters measured

The following parameters will be measured:

- physico-chemical soil properties as influenced by different tree species and fertilization levels, such as macroporosity, hydraulic conductivity, sorption characteristics for cations and anions as influenced by texture, pH, organic matter etc.
- biomass and nutrient accumulation in the vegetative biomass by destructive harvesting in combination with allometric estimation techniques
- water and nutrient input through rainfall and their redistribution within the canopy of different tree species with rainfall and stemflow collectors and analysis of the collected solutions
- soil water contents and soil water tensions with time domain reflectrometry and tensiometry for calculating both water availability for transpiration and water infiltration into the subsoil
- the chemical composition of the soil solution as obtained with ceramic suction cups for estimating nutrient leaching below the main rooting zone and nutrient availability in different soil layers
- water consumption of different tree species by xylem flow measurements
- root distribution and root mass of different tree species with excavations combined with soil coring.

4. Project activities during 1995

Field installation of equipment for water and nutrient flux measurements

The water and nutrient flux measurements comprise the following types of measurement devices:

- tensiometers (installation depths 10, 30, 90, 150 and 250 cm)
- time domain reflectrometry probes (30, 90 and 150 cm plus mobile probes for 10 cm)
- suction cups (10, 60 and 200 cm)
- rainfall collectors
- stemflow collectors.

In agreement with the project proposal, the equipment was assembled from raw materials such as PVC tubing, ceramic cups, PE bottles etc. in Bayreuth between April and July/August 1995 and was then sent to Manaus. By early November, most of the material was released by the Brazilian customs, so that the field installations could begin. This was also at the onset of the rainy season, which considerably slowed down the work. In addition, the sticky soil of the experimental area made the installation of the probes, especially those below 1 m depth, very laborious.

By end of December, we had installed all suction cups within the 17 ha experiment including spontaneous secondary vegetation (but not primary forest), a total number of 180 cups (meanwhile about 200; with 6 series of 3 depths in each of 6 polyculture plots, 4 series in each of 3 pupunha monoculture plots, 3 series in each of 3 cupuaçu monoculture plots, and 1 series in each of 3 capoeira plots). Suction is since applied to all cups once a week for equilibration with the soil solution, the obtained solution is discarded. For unknown reasons, some cups do not produce solution and have to be changed or complemented by other cups, so that installations still continue. Installation of tensiometers (5 per series, total number 300) and TDR probes (3 per series, total number 180) was completed by early March 1996. The series composed of 3 suction cups, 5 tensiometers and 3 TDR probes were installed in the measurement plots in the proximity of well-developed, but not exceptional individuals of every tree species (pupunha for fruit, pupunha for palmito, castanha, urucum, cupuaçu plus open area for comparison) at a distance of 40 cm from the tree. Probes of more than 1 m depth were installed in upright position, other probes were installed inclined at 30° from the vertical. This set of instruments may later be completed by automatically registrating tensiometers and TDR which have already been purchased by project ENV 23 for detailed model studies on short-term infiltration processes, but this has not yet been possible.

Rainfall collectors (total 184) were installed in January at two distances from individuals of every tree species (40 and 150 cm) and in the open. One tree was selected in every measurement plot in a way that all trees from one species together represented more or less the size range of this species. Stemflow collectors (total 60) were installed on the same trees. This design will presumably increase the variability of the data, but will allow to determine the dependence of crown interception and stemflow on tree size. For the soil water measurements, we decided not to use a series of trees of differing size for every species because of the risk of inacceptable increase in the variability of the measured data.

Regulary data collection (rainfall, interception, stemflow, soil water dynamics) will begin in March 1996.

Transpiration measurements

Transpiration is not only an important component of the water balance of a vegetated plot, it is also a physiological process through which a plant can show reactions to its physical and biological environment, such as modified microclimate in polyculture vs. monoculture systems, competition from associated plant species etc. We thus considered it worthwhile to try to obtain an independent estimate of tree transpiration by measurements directly on the plants, apart from the transpiration estimate that can be obtained by difference from the input-output balance of the soil water economy and from meteorological estimations of potential evapotranspiration.

The transpiration of the trees is measured with the xylem flux technique after Granier (1985; 1987). The principle of the method is the continuous measurement of the temperature difference of two sensors which are installed in the xylem of the trunk at a vertical distance of approximately 15 cm. The upper sensor is heated with a constant power of 130 mA. Transpiration is calculated by empirical relationships from the fluctuations in temperature difference between night (no transpiration, maximum temperature difference) and day (when the upper sensor is cooled by xylem water). The Granier method differes from alternative methods based on xylem flux by its lower price, which enabled us to measure continuously on more tree species and individuals than would have been possible with more expensive methods with a better physical foundation.

The method was established in the research group by Dr. Barbara Köstner from the Bayreuth Institute of Terrestrial Ecosystems Research (BITÖK) during her stay in Manaus in December 1995. Our initial intention had been to use this stay for the optimization of the method with the tree species in the experiment, including the monocotyledoneous species pupunha (the method has so far only been calibrated with various dicotyledoneous tree species). This was not possible, because some necessary equipment for calibrating the method under local conditions and with local species did not arrive in Manaus at time. The calibration will thus be done later during the year 1996.

The transpiration equipment was installed in three plots close to the fixed meteorological station (B7, B8 and B13). The neighboring plots B8 and B13 are both from system 2, 100% fertilization. They thus offer better conditions for the development of a typical microclimate for this association than single plots of the same system and are thus particularly suitable for transpiration studies. Plot B7 is a pupunha monoculture. Transpiration sensors were installed in four trees of each of the species pupunha (for fruit), castanha, urucum and cupuaçu. Simultaneous measurements were conducted in different depths in the trunk of the trees of all species (3 depths in pupunha, 2 in the dicotyledoneous species) as a check on conductivity gradients over the wood of different age. This design already showed that all tree species conduct water over the whole diameter of the trunk, although apparently not at equal rates. More details on the method and the obtained data can be found in the annexe (report by B. Köstner and G. Schroth).

For comparison with the transpiration data, a mobile meteorological station has now been installed in the polyculture plot which was supplied by SHIFT project ENV 23. In the future, the transpiration and micrometeorological conditions in the plots will be continuously and simultaneously monitored.

Estimation of aboveground biomass and nutrient accumulation in the systems

The determination of the *status quo* in biomass and nutrient accumulation in the investigated systems has two principal functions in the context of this project: Firstly, repeated estimates of the nutrient content of the systems provide an independent check on the results of the flux measurements; e.g. it can be checked if a less positive nutrient input-output balance of one system compared to another as measured with the "flux equipment" does in fact correspond to a difference in nutrient accumulation within the systems after a certain time interval. Secondly, the measured fluxes can be interpreted in relation to what is actually present, e.g. percent gain or loss of a nutrient per time interval relative to the total amount of this nutrient in the plant-soil system.

Biomass estimations in long-term experiments with perennial plants are characterized by a trade-off between maximizing the precision of the estimate and limiting the severity of the disturbance of the systems. An initial idea had been to destructively sample one out of the five replicate plots of every investigated treatment progressively during the study period and to determine biomass and nutrient content directly from the sampled plot. This idea had to be abandoned when the decision was taken to conduct the flux measurements only in the blocks A, B and C because of the irregular topography of the remaining two blocks. The less fertile blocks D and E could not be considered representative for the measurement plots, and from the only three replications in the blocks A to C none could be sacrificed for destructive harvesting.

We thus decided to use the alternative strategy of harvesting a limited number of individuals (approximately 6-7) of every species from the measurement plots, to develop relationships between size parameters and biomass (allometric relationships) on these individuals and to apply these relationships on all remaining trees through a corresponding inventory. The harvested trees were to be taken from the outer tree rows of all plots, thereby reducing the level of disturbance of the plots to an acceptable limit. This strategy was agreed upon between members of the different projects during the Cuiabá workshop.

Until now, allometric relationships have been developed for castanha, and a corresponding inventory of all castanha trees in the measurement plots has been made in December 1995/January 1996. Measured parameters include tree height, stem diameter at several heights, and number and diameter of all first-order branches. Estimated parameters include stem biomass and volume, total wood biomass, leaf biomass and leaf area. Further details can be seen from the preliminary work report by Marc-Andree Wolf in the annexe.

Within the following months, similar relationships are to be developed for cupuaçu, urucum and fruit-pupunha. Allometric relationships for palmito-pupunha have recently been established by INPA researchers (C. Clement, pers. comm., Jan. 1996) and can hopefully be used for the project without the need for major modifications.

For estimating the nutrient content of the aboveground biomass, wood and leaf samples will be analyzed from all species. We also intend to conduct a study on biomass and nutrient dynamics in the pueraria soil cover.

Biomass and distribution of root systems

An essential precondition for the interpretation of soil water and nutrient flux data is the knowledge of the rooting density and root distribution of the investigated species. Also, the belowground biomass and its nutrient content has to be known for estimating the total carbon and nutrient stocks in the systems. In coordination with the project ENV 23 (Prof. Lieberei), we designed a root study which also faced the difficulty of having to provide the necessary information about the root systems of the species within the context of the cropping systems without being too distructive.

In heterogeneous perennial systems like polyculture 2 it is very difficult to obtain biomass estimates of the whole root systems by soil coring, because coarse roots are not adequately represented in the comparatively small volume of soil extracted. On the other hand, soil coring is the most (if not the only) appropriate method for obtaining reliable data on live fine root length per volume of soil (live root length density), which is one of the most important root characteristics for water and nutrient acquisition. We thus used a combination of root excavation and soil coring. Root excavation is very distructive, especially as the root systems of boundary trees are not representative for those of trees surrounded by neighboring trees of the same and other species, so that the excavations had to be done in the central part of the plots. We thus decided to conduct all root studies in one plot which was not used for other measurements and chose the plot D12 (polyculture 2 with 100% fertilization, without mycorrhiza inoculation). This plot is exceptional for block D in so far as the plants in the plot are comparable in size to those in the blocks A to C which we are using for the other measurements (in most of block D plant growth is much less than in blocks A to C).

Within this plot, 2 to 3 individuals of every tree species were chosen for excavation. In addition, we excavated pueraria areas at maximum distance from the trees. The excavated areas were normally 2 by 2 m for the trees with the tree in the center, and 1 by 2 m for pueraria. Excavation was done in depth increments of 0-10 cm, 10-30 cm, 30-60 cm and 60-100 cm. All roots > 1 mm diameter were collected, separated into diameter classes of 1-2 mm, 2-5 mm and > 5 mm as well as into species, washed, dried (70°C), weighed and retained for later analysis. From every layer and also from 100-150 cm, 2 to 4 soil cores were drawn at 35 and 80 cm distance from the trunk and were processed according to Schroth and Kolbe (1994). Dry mass was determined for live and dead roots and length for live roots (Tennant, 1975). This work is still in progress. Subsamples of the soil were retained for chemical analysis which have recently been taken up. Between the "extreme" points in the plots (trees, open areas), we also excavated transects, e.g. from a pupunha tree through a pueraria area to a neighboring urucum tree. These data will allow to draw an idealized root map of a whole study plot. We also excavated root systems under near-by *Vismia* (capoeira) vegetation for comparison.

The root excavations have been completed by end of February 1996. The collected data are still in an early state of analysis. More details on the methodology and preliminary results can be found in the work report by Daniel Haag in the annexe.

Laboratory

This project will produce large numbers of soil, plant and especially solution samples (rainwater and soil) for analysis. It is our aim to bring the EMBRAPA soils and plant laboratory into a condition that at least the vast majority of these analyses can be done at Manaus, with only some specialized analyses to be carried out in Germany (e.g. digestions of very small fine root samples).

An important step in accomplishing this aim was to purchase a Segmented Flow Analyzer (SFA), with modules for automated analysis of total N in solution (with on-line UV digestion), ammonium, nitrate/nitrite, aluminium (water-soluble and hydrolizable) and phosphorus. Sample and data transfer with AAS and flame photometer is in principle also possible. The SFA has already successfully been tested for P analysis in plant digests in February 1996 and will be prepared for routine measurements of rainwater and soil solutions during March and April 1996 with the help of a technician from the University of Bayreuth.

It is evident that running this apparatus requires a reliable, uninterrupted and stable supply of energy in the laboratory, and this was not given at the beginning of this project. We thus purchased and installed an electrical power system composed of a 10 kVA diesel generator and a no-break/stabilizer with automatic switch to the generator in case of failure of the mains energy supply. This should enable the laboratory to function at least in its main parts during power failures independently from their duration. Until now, the system seems to function satisfactorily, but there is as yet only limited experience.

Another major investment into the laboratory was a new digestion block which allows to carry out some 100 or more plant digestions per day, depending on the employed method. This was necessary in view of the temperature regulation problems of the existing digestion blocks and the continuously high demand for plant analyses by both this project and other EMBRAPA units.

Laboratory work for this project is only just beginning. Due to extensive reform works in the whole laboratory, neither analyses nor even the installation and test of new equipment were possible until January 1996. Important laboratory activities during the next months will include analyses of root samples from the excavations and aboveground biomass from all species in the investigated treatments, including litter and ground vegetation, soil analyses from the excavation experiment, and analyses of the solution samples from rainwater and stemflow collectors as well as suction cups.

Soil physics

Soil physics play an important part in this project because of their central role in the analysis of water and nutrient fluxes in the plant-soil system. So it is fortunate that the head of the soil physics laboratory at EMBRAPA, Wenceslau Geraldes Teixeira, participates in the coordination of this project as the direct counterpart of Götz Schroth at Manaus. With the support and supervision of Prof. Dr. Bernd Huwe from the Soil Physics Department of the University of Bayreuth, Wenceslau Teixeira will prepare his Ph.D. thesis on soil physical questions within the frame of this project.

An important step in the calculation and modelling of soil water fluxes is the parametrization of soil water models with soil hydraulic properties and their variability in space and time. Also, soil physical properties such as the capacity to retain plant available water (porosity), aggregate stability, infiltration and aeration are important components of overall soil fertility, and the influence of the tested land use systems on these parameters is of major importance for their sustainability.

In this project, field methods will primarily be used for measuring soil physical properties, although these will be checked against laboratory methods wherever possible. The comparison of TDR (water content) with tensiometer (water suction) data will already give information about porosity. The calibration of the TDR will first have to be checked and adjusted, if necessary. For measuring saturated and unsaturated hydraulic conductivity of the soils, we intend to use two different field methods: The established method of tension infiltrometry (Elrick and Reynolds, 1992; Reynolds et al., 1995) and the recently developed piezometer-permeameter probe after Punzel (Punzel et al., 1994). The latter method allows the determination of hydraulic properties in the subsoil with almost negligible disturbance of the system. However, the method has not yet been tested with the clayey soils of the region. Our current activities in the area of soil physics concentrate on the comparison and test of the two methods with the local soil types including that of the experiment itself. Subsequently, the methods will be used for specific investigations within the experimental area. No definite results are available at this stage.

5. Comparison with the work and time plan of the project

This section compares the activities of the project with the project proposal. We mainly discuss differences between the proposal and the real project activities here. Many of the points in this part have already been mentioned and explained in the preceding two sections.

Work plan

A major change was in the treatments and number of replications under investigation: Instead of one monoculture only, we work in three monocultures, the two subtreatments of the pupunha monoculture (palmito only and fruit/palmito) and in the cupuaçu monoculture. We will thus obtain a clearer picture of what are the principal differences between monoculture and polyculture treatments. As polycultures, we study system 2 instead of systems 1 and 3, but the former is studied on two fertilization levels (30 and 100%). System 2 contains more interesting but less well-known tree species than the other two systems and less species with currently unsatisfactory growth (e.g. seringueira, cocos) or better-known species (citrus, cocos). Polyculture system 4 is no longer included in our measurements, but is studied by project ENV 42 with essentially the same methods. Primary as well as secondary forest (spontaneous *Vismia* regrowth) are or will be included in the measurement.

Instead of 5 replications, measurements are only carried out in 3 blocks (A to C) because of the unregulary terrain and heterogeneous plant growth in the blocks D and E. The latter two blocks are used for special studies, e.g. on root systems and gradients in soil properties.

The root study in plot D12 was not planned in the proposal, but was agreed upon on the Cuiabá conference. Much of the study was accomplished when the principal project activities could not start because the imported equipment was still in the customs.

Time plan

The project is about 6 months late with regard to the time plan of the project proposal. Purchasing and assembling the equipment for the water and nutrient flux measurements (tensiometers, suction cups, rainfall collectors etc.) took about 4 months (April to July 1995), but their transport to Manaus and customs clearance took until early November. The principal field installations were carried out within about 3 1/2 months (proposal: 3 months), despite the holydays in December and in early January (traditional vacations in Brazil). Due to the reform works, the laboratory could not be used before January 1996. Monitoring of water movements in the field and solution analyses for nutrients will start in March 1996, 1 year after the beginning of the project (6 months according to the proposal).

Table 1: Overview of project activities in 1995

Month	Activity	Persons involved
Mar-Aug	Purchasing project equipment, assembling tensiometers, suction cups, rainfall collectors etc., organizing transport to Manaus	Götz Schroth
Sept-Dec	Root excavation, soil core sampling, washing and processing of root samples	Daniel Haag, Ecila Villani, Götz Schroth
Oct-Dec	Development of allometric relationships on Castanha	Marc Wolf
Oct	Test of sensors for invisible leaf wetness	Jürgen Burkhardt*
Nov-Dec	Assembling, field installation and testing of soil water flux equipment	Götz Schroth, Wenceslau Teixeira
Nov-Dec	Testing of soil physics equipment	Wenceslau Teixeira
Dec	Installation and test of transpiration measurement devices (xylem flow)	Barbara Köstner*, Götz Schroth

* visiting scientists

6. Cooperation with EMBRAPA, University of Hamburg (Prof. Lieberei, Prof. Bauch) and University of Göttingen (Prof. Fölster)

EMBRAPA-CPAA

The cooperation with the EMBRAPA is necessarily very close. All important activities of the project have been coordinated with EMBRAPA responsibles, especially with Dr. Gasparotto (since March 1996, the coordinator of the project on the EMBRAPA side is Dr. Cravo). This is particularly so in the case of destructive measures, like the root excavations in plot D12 or the harvesting of selected tree individuals for the development of allometric relationships. We also inform potentially interested EMBRAPA researchers about planned activities in their research area and invite them to participate in these activities in cases of potential overlap. For example, the responsible persons for the different tree species are informed about the trees to be harvested (every individual tree is shown to them before harvesting if desired), and they are asked if they are interested in any parameters that could be measured for them in the course of allometric relationship development. In special cases we cooperate with EMBRAPA researchers in work outside the SHIFT program, e.g. in the development of a root sampling scheme for pupunha plantations of differing management in the area of Rio Preto da Eva. There are numerous cases in which we use EMBRAPA equipment in the project, and in some cases EMBRAPA uses project equipment, e.g. in the laboratory.

University of Hamburg (Prof. Lieberei, Prof. Bauch)

The final details of the project as outlined in this report have been repeatedly coordinated with the projects ENV 23 and ENV 42, for example during the Cuiabá conference in July 1995 as well as during meetings in Bayreuth and Hamburg in 1995. Particular areas of cooperation with these two projects include the following:

We agreed with Dr. Helmut Preisinger from project ENV 23 on a procedure to study the assumed fertility gradient between the blocks A and E of the field experiment, which has so far been characterized through differences in the spontaneous vegetation and in the productivity of the crops (decreasing from A to E) as well as some soil analyses (see 1994 work report of project ENV 23). The pedological basis of this gradient is however not well understood so far.

Its analysis has to take the history of the sites into account: Part of the area has in the past been prepared for planting with heavy machinery, other parts have not. We agreed to concentrate on one plot of every block in the first instance and to study the series of these five plots in detail. The concentration on few representative plots will allow us to conduct measurements not only on standard parameters such as C, N, CEC and acidity, but also on P fractions and soil physical properties which would not be possible with all plots of the experiment. Ecila Villani and Wenceslau Teixeira will participate in this study, among other project participants. The selection of the actual plots is still under discussion.

A further area of cooperation with project ENV 23 is the selection of suitable measurement points in the primary forest. This problem is complicated by the heterogeneity of this vegetation system which practically excludes measurements that can be considered representative for the whole system with the available staff and equipment. In cooperation with Dr. Preisinger and using the forest inventories made by ENV 23 at the EMBRAPA area as well as INPA inventories at nearby sites, we are trying to identify tree species which are relatively frequent in the forest of the region and eventually represent contrasting strategies within the forest ecosystem.

ENV 23 has also placed at our disposal some equipment which had already been purchased by this project before the beginning of ENV 45 (e.g. a solar station and an automatic tensiometry station).

ENV 42 uses a very similar experimental approach to the study of nutrient cycles and availability in systems with forest trees that we use in agricultural systems. This enables us to cooperate in methodological aspects and jointly use project equipment. For example, ENV 42 will use constant energy sources for transpiration measurements which have been supplied by our project, whereas we will use a special balance owned by ENV 42 for calibrations of the xylem flux data. Also, ENV 42 works on the characterization of xylem structure of trees where we are measuring conductivity gradients along the stem radius in the field.

University of Göttingen (Prof. Fölster)

The practical experiences that the University of Göttingen obtained during earlier work within the SHIFT program at Belem was of great practical value for us during the preparation of the project, and we would especially like to thank Prof. Fölster and Dr. Manfred Denich for methodological discussions with Prof. Zech as well as Rudolf Klinge for explaining details of the field measurement devices and also for some nutrient concentration values of rainwater and soil solution which helped in selecting and designing laboratory equipment (Segmented Flow Analyzer).

7. Conclusions

During 1995 and early 1996, the equipment for an extensive field and laboratory measurement program was purchased, transported to Manaus, installed and, in parts, successfully tested. The major challenge of the months to come will be to conduct the routine measurements in the field on hundreds of individual samplers and measurement devices as well as the laboratory analyses of the collected solution, soil and plant samples. At the same time, the project should remain flexible enough to address specific questions related to soil fertility and plant nutrition, such as the above-mentioned analysis of the fertility gradient and new questions of interest which arise from the analysis of the collected data.

One new aspect already appears clearly from the described measurement program: the topic of describing and analyzing the investigated systems with the help of an integrative computer model, which not only comprises soil water and nutrient fluxes, but also above- and below-ground development of the plant stands, their mutual interference, microclimatic processes with their various consequences for gas exchange of the plants, development of diseases and so on. The development of such models (including the adaptation of existing models for the specific systems and pedoclimatic conditions) is a very complex task. On the other hand, the presented project will produce data which are ideal for modelling: Not the fixed systems are the topic of the measurements, but the system components (plant species, soil in its small-scale heterogeneity etc.), their interactions (root extension, microclimate etc.) and their development in time (continuous measurements during several years, measurements on indiviual plants of differing size). The actual measurement will provide information on characteristics of the components and their interactions in the systems as they are. However, models adapted to the data and suitably calibrated would provide a tool for optimizing the systems, addressing questions such as the effect of removing or adding species; altering spacing, fertilization or other management measures; characterizing the growth conditions of an annual crop within the different systems and so forth. Model development could be based on work of British research groups which allow the integration of existing submodels into complex systems models with the help of a "modelling environment" (Muetzelfeldt, 1995). This work should start soon and should accompany the field and laboratory measurements, rather than follow them. None of the SHIFT projects in Manaus would presently be able to close this gap, and the extension of one of the projects, or the creation of a separate modelling project, is highly recommended

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Annexe 1: List of visiting scientists during 1995

1) Dr. Jürgen Burkhardt

University of Bayreuth, Department of Agro-ecology, D-95440 Bayreuth, Germany

9.-13.10.1995

2) Dr. Barbara Köstner

Bayreuth Institute of Terrestrial Ecosystem Research, Department of Plant Ecology, D-95440 Bayreuth, Germany

28.11.-17.12.1995

Annexe 2: Training activities during 1995

A) Persons preparing Ph.D. theses within the project

1) Wenceslau Geraldes Teixeira (EMBRAPA-CPAA)

Subject: Soil physical parameters with relevance for transport processes as influenced by different land use systems on the terra firme near Manaus, Amazonia

Supervision: Prof. Dr. Bernd Huwe, University of Bayreuth, Institute of Soil Science, Department of Soil Physics, D-95440 Bayreuth, Germany

B) Persons preparing Diplom theses within the project

1) Daniel Haag (University of Bayreuth)

Subject: Root characteristics with relevance for agroforestry of four tree crops in a mixed cropping system on the terra firme near Manaus, Amazonia

Supervision: Prof. Dr. Wolfgang Zech, University of Bayreuth, Institute of Soil Science, D-95440 Bayreuth, Germany

2) Marc-Andree Wolf (University of Braunschweig)

Subject: Biomass and nutrient accumulation of mono- and polycultures with four tree crops as influenced by their management on the terra firme near Manaus, Amazonia

Supervision: Prof. Dr. Wolfgang Zech, University of Bayreuth, Institute of Soil Science, D-95440 Bayreuth, Germany

Annexe 3: Publications

Wolfgang Zech and Götz Schroth, 1995: Water and element fluxes as indicators for the stabilitys of different land use systems on the terra firme near Manaus - background, hypotheses and methodological approach. 2nd SHIFT Workshop, July 1995, Cuiabá

Annexe 4: Work report by Daniel Haag, Institute of Soil Science and Soil Geography, University of Bayreuth, D-95440 Bayreuth, Germany (UBT)
with Ecila Villani (EMBRAPA-CPAA, Manaus) and Götz Schroth (UBT)

Biomass and distribution of roots in a polyculture system with four local fruit tree species

Introduction

It is a prerequisite for the interpretation of soil water and nutrient flux data to know the root distribution of the investigated plant species. We therefore assessed root distribution of the species that compose the polyculture system 2 of the SHIFT experiment, namely Castanha (*Bertholletia excelsa*), Cupuaçu (*Theobroma grandiflorum*), Urucum (*Bixa orellana*), Pupunha (*Bactris gasipaes*) for fruit and for palmito production, and of *Pueraria phaseoloides* which is used as a cover crop.

The principal focuses of this study were the following:

(1) Coarse Roots: Belowground carbon and nutrient stock

For evaluating the nutrient fluxes within the system, which is the main objective of the ENV 45 project, it is important to know the point of departure, i.e. the total stock of nutrients and carbon in the aboveground and belowground biomass and in the soil. The present study enables us to estimate the total belowground nutrient and carbon accumulation in the biomass of polyculture system 2. This complements the aboveground biomass estimations carried out by Marc Wolf (see Annexe 5).

(2) Fine Roots: Root turnover and nutrient and water aquisition

While the coarse roots play an important role for carbon and nutrient accumulation in the system, the fine roots with their shorter life time and their much greater length and surface area are largely responsible for carbon and nutrient turnover in the soil as well as for the aquisition of nutrients and water by the plants. Root sampling for fine roots was done to obtain information on live fine root length per volume of soil ("root length density") as a function of soil depth and horizontal distance from the trees.

(3) Present root arquitecture as indicator for present and future root interactions between species

When trees grow bigger, competitive interactions in the systems may gain importance, and the root arquitecture and distribution found at the moment may already give hints on such future developments. We therefore assessed the different rooting habits under the conditions of our plantation system with the objective of getting an idea of different root strategies of the species, of root/shoot ratios (which are helpful for estimating the belowground nutrient and carbon stocks from the aboveground biomass in other plots), of possible root interactions and potential root competition and of the suitability of the species in polycultural systems from the point of view of their root arquitecture.

(4) Relationship between chemical properties of the soil and root distribution

Soil conditions influence root growth, and roots influence soil conditions (Schroth et al., in press (a); Schroth et al., in press (b)). During the root excavations, we sampled soil from every horizon for later carbon and nutrient analysis. Subsamples from the same sample were used for both fine root extraction and chemical analysis of the soil (Schroth and Kolbe, 1994). We expect that this increases the probability of obtaining relationships between chemical soil properties and root characteristics which can give information about interactions between root growth and soil conditions (e.g. Al toxicity, pH, nutrient distribution, carbon). The chemical analyses are not part of this study, but will be carried out by Ecila Villani.

Materials and methods

For assessing the biomass and distribution of both fine (< 1 mm) and coarse (> 1 mm) roots, we combinded two different sampling methods: Coarse roots are not adequately sampled by soil coring, so these were obtained by excavating the root systems of individual trees in depth increments of 0-10 cm, 10-30 cm, 30-60 cm and 60-100 cm. All roots with a diameter > 1 mm were collected, separated into diameter classes of 1-2 mm, 2-5 mm and > 5 mm and according to species, hand-washed with tapwater, dried (70° for 3 days), weighed and stored for later analysis. The central roots of the excavated trees were measured, dried and weighed apart.

For the fine roots (< 1 mm) we took soil samples with a soil corer of either 8 cm or 5 cm diameter from the different layers (0-10, 10-30, 30-60, 60-100 and 100-150 cm) at a distance of 35 cm and of 80 cm from the respective tree, usually 4 cores per distance. In the *Vismia* plots, the position of the soil samples were chosen randomly, at positions without trees (*Pueraria* positions), they were taken on the diagonals through the excavated hole, and in the transects they were taken at the end of the respective transect plot. For a more detailed description of the position and of the numbers of samples taken see Table 1.

From the samples, representative subsamples were taken (Schroth and Kolbe, 1994), the samples were stored in a freezer and then washed. Fine roots were not separated for species, but for live and dead roots. Live root length (Tennant, 1975) and dry mass of live and dead roots were determined. Subsamples of the soil were taken for the determination of the water content and for later chemical analysis.

For the extremely destructive root excavations we chose the plot D12 (polyculture system 2 with 100% fertilization and without mycorrhiza inoculation), because the plants of this plot were comparable in growth to the plants of the blocks A, B and C (in contrast to many other plots in block D). These latter blocks are used for the flux measurements, and excavations were thus not possible here.

Within this plot, 2 pupunha trees for palmito, 2 pupunha trees for fruit, and 3 trees of castanha, cupuaçu and urucum were chosen for excavation. All the chosen trees were well developed, but varied in size. By excavating a small and a large tree from each species, we tried to obtain an idea about the variability of the root systems of the same species as well as about root development in time. Additionally, we excavated 2 pueraria parcels at maximum distance from the neighbouring trees in order to assess potential minima of root biomass in the system (potential sites for maximum nutrient leaching?), and we excavated two neighbouring plots with spontaneous vegetation (*Vismia*).

The size and the position of the excavated plots varied: For all trees except pupunha the respective tree was situated either in the centre of a 2m*2m plot or in the corner of a 1m*1m plot which represented a fourth of the bigger 2m*2m plots. Because of the narrow spacing in the pupunha rows, we chose a different excavation design for this species: The width of the excavation corresponded to half the distance between the excavated and the neighbouring tree, and the length was either 2 m (including 1 m on both sides of the pupunha row) or 1 m with the tree being situated in the corner. For a detailed layout see attached plan of the excavated plots (Fig. 1) and Tables 1 and 2.

For assessing the maximum lateral root extension and gradients of root biomass with increasing distance from the trees, we also excavated transects departing from one individual of each tree species. The starting point was always a 1m*1m excavation with the respective tree in the corner. The transects continued then in a 90° angle from the tree line into the pueraria interspaces (with the exception of transect IV which connects two urucums). Transects are composed of successive 0,5*0,5 m plots in which the root mass was quantified separately. Transect length varied according to the maximum root length of the respective tree species (see Table 2). In contrast to the tree excavations, soil cores were only taken to a depth of 100 cm in the transects.

For avoiding border effects, the excavations were restricted to the central 32 m*32 m of the plot D12. From this, we excavated approximately 40 m² down to a depth of 100 cm. For fine roots, we took 176 core samples from D12 and 10 core samples from neighbouring secondary vegetation.

Preliminary results and discussion

Only a part of the results of this root study has already been analyzed. The fine root data as well as nutrient contents of coarse roots and soil chemical properties are only partly available yet. Only for the coarse roots (> 1 mm), some preliminary results can be presented in this 1995 report.

(1) Coarse root mass and aboveground biomass of excavated trees

Table 3 gives an overview of the root concentration (in g/m² for 1 m soil depth) within the excavated plots and of the aboveground biomass of excavated trees.

Table 1: Excavations in plots D12 and neighboring plots in the SHIFT experiment: area of excavation, position of the tree within the excavation, and position and number of core samples taken at the respective distances from the tree. "P" stands for palmito, "F" for fruit

Excavation	Area in m	Position of tree	Number of corings per sample	Position of samples [cm from tree]	Number of samples
Castanha 1	2*2	Centre	4	35/80	10
Castanha 2	2*2	Centre	4	35/80	10
Castanha 3	1*1	Corner	2	35/80	10
Cupuaçu 1	2*2	Centre	4	35/80	10
Cupuaçu 2	2*2	Centre	4	35/80	10
Cupuaçu 3	1*1	Corner	0	---	0
Urucum 1	2*2	Centre	4	35/80	10
Urucum 2	2*2	Centre	4	35/80	10
Urucum 3	1*1	Corner	1	35/80	10
Pupunha 1P	2*1,2	Lateral	2	35/80	10
Pupunha 2F	2*1,2	Lateral	2	35/80	10
Pupunha 3P	1*1	Corner	1-2	35/80	10
Pupunha 4F	1*0,8	Corner	1	35/80	10
Pueraria 1	1*2	--	4	Diagonals	10
Pueraria 2	1*2	--	4	Diagonals	10
Vismia 1	1*1	Several	2-4	Randomly	5
Vismia 2	1*1	Several	2-3	Randomly	5

Table 2: Transects: Direction of the transects (into the pueraria interspaces or towards neighboring trees), plot size within the transects, length of the transects and position of core samples (distance from respective tree)

No	Transect	Direction	Plot size in m	Length in m	Distance of core samples from tree in m	Number of samples
I	Pupunha 3P	Pueraria	0,5*0,5	3,5	1,5 / 2,5	8
II	Pupunha 4F	Pueraria	0,5*0,5	4,0	1,5/2,0/2,5/3,0/3,5	20
III	Urucum 3	Pueraria	0,5*0,5	4,0	1,5/2,0/2,5/3,5	14
IV	Urucum 3	Urucum	0,5*0,5	2,0	1,5	4
V	Castanha 3	Pueraria	0,5*0,5	1,5	--	0
VI	Cupuaçu 3	Pueraria	0,5*0,5	1,5	--	0

Considering only roots > 1 mm, pupunha for fruit production had the highest dry mass from all species in the plot, followed more or less closely by pupunha for palmito. Urucum had considerably less roots > 1 mm, and castanha and even more so cupuaçu follow in great distance. The ratio between belowground and aboveground biomass has to interpreted with the following restrictions:

- Roots extending laterally beyond the limits of the excavated pit are not included. This is of particular importance for pupunha (not given for this reason; see below), still considerable for urucum and negligible in the cases of castanha and cupuaçu.

- Roots below 100 cm depth are not included. Again, this could be significant in the case of pupunha.

- Fine roots have not been evaluated yet.

Keeping these restrictions in mind, we may nevertheless conclude that the root/shoot ratio is within the same order of magnitude for all dicotyledoneous trees. As the aboveground biomass of the excavated trees covers a fairly broad range, while root/shoot ratios seem to be relatively constant, the aboveground biomass data of other plots of the plantation might be used to estimate belowground biomass in these plots.

Table 3: Total root dry matter and root dry matter of the excavated tree per unit area (g/m²) in the upper 100 cm of soil (without the tap root), percentage of the roots of the respective tree from the total root mass of the excavation, weight of the main (tap) root, aboveground biomass of the excavated trees, and root/shoot ratios

Excavated tree	Total root mass [g/m²]	Root mass of excavated tree [g/m²]	Root mass of excavated tree % of total	Weight of central root [g]	Above-ground biomass [g]	Root/ shoot ratio
Castanha 1	151,8	123,0	81,2	2649	12058	0,26
Castanha 2	120,5	69,7	57,8	1843	7868	0,27
Cupuaçu 1	99,8	99,8	78,2	295	2252	0,31
Cupuaçu 2	48,8	25,6	52,5	200	942	0,32
Pupunha 2F	975,8	969,0	99,5	--	15984	--
Pupunha 4F	1144	1144	100	--	33521	--
Pupunha 1P	823,1	820,6	99,7	--	3566	--
Pupunha 3P	801,4	795,9	99,3	--	8555	--
Urucum 1	307,4	295,0	96,0	930	5960	0,35
Urucum 2	525,0	511,4	97,4	1117	13496	0,23
Urucum 3	460,9	452,4	98,2	1131	12848	0,23
Vismia 1	1160,1	156,4	97,7	189	5473	--
Puer 1 (Uruc)	20,9	19,6	93,9	--	150	--
Puer 1 (Pup)	17,6	11,8	67,1	--	273	--
Puer 2 (Uruc)	3,61	3,35	92,8	--	161	--
Puer 2 (Pup)	33,7	10,2	30,3	--	156	--

(2) Distribution of roots with depth

The Figures 2 and 3 show the distribution of the different root diameter classes with depth (note the different scales for pupunha and urucum on the one hand and castanha and cupuaçu on the other). Only roots > 1mm and no central roots are taken into consideration in the Figures. Depicted are the individuals with the highest biomass for each species. The maximum of root concentration in the A horizon with a strong decrease of root mass in lower horizons is evident for all species except castanha. Rooting depth is not restricted to the excavated 100 cm, but the contribution of roots from the 60-100 cm layer indicates that below 60 cm root biomass is comparatively low for all species.

The amount of roots from species other than the excavated tree is negligible in the case of pupunha and urucum but is considerable for cupuaçu and castanha. This shows the high competitiveness of the former two species with respect to ground vegetation.

(4) Maximal root length of the excavated trees

The following tables give an idea of the maximal length attained by the roots of the excavated trees at this stage of root system development. The data are based on the transects and on the urucum and pupunha roots found in the castanha, cupuaçu and pueraria plots.

Table 4: Maximal root length (in m) of the excavated species for the different depths (in cm) within the transects

Nr.	Species	Lateral root extension in soil layers (cm)				
		Litter	0-10	10-30	30-60	60-100
I.	Pupunha (Palmito)	3,5 m	3,0 m	3,0 m	2,0 m	1,0 m
II.	Pupunha (Fruit)	4,0 m	4,0 m	4,0 m	3,0 m	3,0 m
III.	Urucum	2,5 m	2,5 m	2,0 m	1,0 m	1,0 m
IV.	Urucum	>1,5 m	>1,5 m	>1,5 m	>1,5 m	1,0 m

Table 5: Additional information on maximum root length (in m) from excavated plots other than the transects

Species		Lateral root extension in soil layers (cm)				
	Plot	Litter	0-10	10-30	30-60	60-100
Urucum	Cast 2	>3,0 m	>3,0 m	>3,0 m	<3,0 m	<3,0 m
	Cast 1	<3,0 m	<3,0 m	<3,0 m	<3,0 m	<3,0 m
	Puer 1	<3,0 m	3,0-4,0 m	<3,0 m	<3,0 m	<3,0 m
	Puer 2	<3,0 m	<3,0 m	<3,0 m	<3,0 m	<3,0 m
Pupunha (Fruit)	Cast 1	>3,0 m	>3,0 m	>3,0 m	<3,0 m	<3,0 m
	Cast 2	>3,0 m	>3,0 m	>3,0 m	<3,0 m	<3,0 m
	Puer 2	3,0-4,0 m	3,0-4,0 m	>4,0 m	<3,0 m	<3,0 m
	Cup 2	>3,0 m	>3,0 m	>3,5 m	<3,0 m	<3,0 m
Pupunha (Palmito)	Cup 1	<3,0 m	<3,0 m	<3,0 m	<3,0 m	<3,0 m
	Puer 1	3,0-4,0 m	3,0-4,0 m	3,0-4,0 m	<3,0 m	<3,0 m

These data enable us to make predictions concerning actual or future root interactions and competition between the species of the system and concerning "root gaps" within the system that could be important e.g. for nutrient leaching.

(4) Root Strategies

4.1 Pupunha

As a palm, pupunha does not possses a central root, roots originate directly from the base of the trunk and are mainly oriented in a horizontal direction. Pupunha does not have root hairs, its roots are fairly coarse: the roots of 2-5 mm diameter are the dominant root fraction and contribute between 61 and 66% to the total roots >1 mm, while roots of 1-2 mm diameter only contribute 19-22% as is shown by Table 6.

Table 6: Percentage of roots >1mm in the different diameter classes

Plot	Roots 1-2mm in %	Roots 2-5mm in %	Roots >5mm in %
Pup 1F	18,6	64,8	16,6
Pup 2P	22,0	65,8	12,2
Pup 3P	19,4	60,5	20,1
Pup 4F	22,1	63,1	14,8

A large part of roots >1 mm is found in the upper 30 cm of the soil with a pronounced concentration of roots in the 0-10 cm layer (between 41 and 61% of all roots >1 mm were found in 0-10 cm depth, and 69-89% in 0-30 cm depth), where pupunha roots form a very dense net. Thus root length density of roots > 1 mm (not yet including roots < 1 mm) in the upper 0-10 cm varies from 0,47 cm/cm³ (Pup 3P) and 0,48 cm/cm³ (Pup 1F and 4F) to 0,58cm/cm³ (Pup 4G), the main contribution coming from roots 2-5 mm (0,23-0,36 cm/cm³). Root length density of roots > 1 mm declined to values ranging from 0,06 to 0,14 cm/cm³ in the 10-30cm layer.

In the vertical direction coarse roots surpass the 100 cm depth line; to what extent was not evaluated by excavation, but the core data will give some indication.

In the horizontal direction roots surpass the limits of the excavations considerably, in the case of pupunha for fruit they reach maximum lengths of 4 m in the upper 30 cm and of 3 m in the 30-100 cm layer. Lateral root extension is minor for the palmito trees which reach maximum lengths of 3-4 m in the upper 30 cm of the soil, 2 m in the 30-60 cm layer and only 1 m in 60-100 cm (see Tables 4 and 5). A preliminary evaluation of the transect data seems to indicate that approximately one quarter of all coarse roots surpasses the area of excavation in the case of the palmito tree and approximately one third in the case of the fruit tree.

A comparison of pupunha for fruit production and for palmito gives the following indications:

- Total root mass and root concentration are smaller for the palmito trees (807,1 g/m and 795,9 g/m for palmito compared to 969,0 g/m and 1144,0 g/m for the fruit tree).

- Lateral root extension is greater for the fruit tree (see above).

- It seems as if the root system of the palmito trees was more superficial with a higher concentration of roots in the upper 0-10 and 10-30 cm of the soil and smaller percentages in deeper soil layers; Table 7 shows this trend, which is in line with other work on the effects of regulary shoot pruning (van Noordwijk et al., 1991).

Table 7: Dry matter of roots > 1 mm for the different excavation depths and percentage from the total roots > 1 mm in 0-100 cm

	Pupunha 1 F		Pupunha 4 F		Pupunha 2 P		Pupunha 3 P	
Depth in cm	g/m²	% of total	g/m²	% of total	g/m²	% of total	g/m²	% of total
0-10	568,8	58,7	471,1	41,1	602,8	74,5	484,8	60,9
10-30	216,8	22,3	325,5	28,4	114,8	14,0	153,3	19,3
30-60	136,5	14,2	219,5	19,2	75,8	9,3	115,2	14,5
60-100	42,5	4,4	123,8	10,8	13,7	1,7	31,5	4,0
total	969,0	99,6	1144,0	99,5	807,1	99,6	795,9	98,7

4.2 Urucum

The central root of Urucum has no cylindrical shape (as in the case of castanha and cupuaçu), but starts out with the prolongation of the trunk down to 10 -15 cm and then opens up into several still very coarse (> 10 mm) roots which penetrate the soil at some angle from the vertical.

Root concentration is highest in the upper 10 cm of the soil where most nutrients are found. Nevertheless, the greatest part of root dry matter in the topsoil consists of structural roots with a diameter between 5 and 25 mm. There is a pronounced decline of root density with depth and only few roots pass below 60 cm. Coarse roots beyond 100 cm seem to be negligible. Thus, the root system of urucum is rather superficial.

For the maximum lateral root extension, the transect excavation shows maximum lengths of 2,5 m in the upper 10 cm, of 2,0 m in the 10-30 cm layer and of 1 m in greater depths, while the urucum roots found in other excavations indicate that at least in some cases urucum roots can be more distant from the tree than 3 m in the 0-10 cm layer. Already by the end of 1993, urucum was one of the few non-palm trees that had considerably surpassed the limits of the planting hole (K. Voß: Internal work report of the SHIFT project, Manaus 1.11.93-20.1.94). Lateral root extension of Urucum is rather limited in depths greater than 30 cm, hardly ever surpassing the limits of the excavations. This again shows the superficiality of the root system.

Within the limits of the excavated plots, urucum coarse roots > 1 mm are highly dominant (96-98%), with no roots of other trees being found (see Table 3); only pueraria roots contribute to a very limited extent to total root mass.

4.3 Castanha

The Castanha root system consists of a rather massive (1843 and 2649 g dry mass, respectively) root cylinder that bifurcates at about 40 cm and continues to grow downward to depths greater than 100 cm while becoming continously smaller in diameter. From this taproot, lateral roots depart, most of them rather fine, but ocasionally larger structural roots (> 10 mm diameter) can be found. One such root reached more than 2 m in length, growing horizontally in approximately 15 cm depth.

In the upper 10 cm, castanha roots do not dominate other root systems, but make up for only 11% (Cast 1) and 3,0% (Cast 2) of all coarse roots found. The roots of other species are dominant here, mostly of pueraria (42-43%), pupunha (23 and 43%) and to a limited extent urucum (11% for Cast 2).

The highest concentration of castanha roots > 1 mm is found in 10-60 cm, where castanha becomes dominant. Roots of 1-2 mm have their maximum in 10-30 cm depth (see Figure 3).

4.4 Cupuaçu

The root system of cupuaçu is similar to that of castanha, with a central taproot from which lateral roots of limited extension depart.

Cupuaçu is the tree with the lowest aboveground and belowground biomass in system 2. Therefore cupuaçu is not capable of dominating the surrounding soil in terms of coarse root biomass: cupuaçu roots make up for 53 and 78% of all roots > 1 mm found within the 2m*2m excavation plot, with the lower value being the one of the smaller tree. Still its root mass in the upper 10 cm is much higher than the one of the much bigger castanha (see Figure 3). There is a strong decline of root mass with depth, and in 60-100 cm only very few cupuaçu roots can be found, most of them close to the central root, while in a distance of more than 50 cm from the tree hardly any roots < 1 mm occur.

(5) Influence of the planting hole

Root morphology of the investigated species seems to be related to the width and especially the depth (approx. 40 cm) of the planting hole. This confirms observations made by Voß (loc. cit.) in an earlier stage of plant establishment, i.e. about two years ago:

- The central root of castanha becomes suddenly thinner and bifurcates at a depth of about 40cm.

- The taproot of cupuaçu also becomes rapidly thinner and bifurcates at that depth.

- Roots >10 mm diameter departing from the central root of urucum are mostly oriented in a vertical direction in the upper 30-40 cm while few roots with a vertical orientation are found below 40 cm.

- The concentration of pupunha roots is particularly high within the limits of the planting hole.

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Figure legends:

Figure 1: Layout of polycultural system 2 and position of the excavations in plot D12. T1-T5: transects; Pp: pupunha for palmito; Pf: Pupunha for fruit

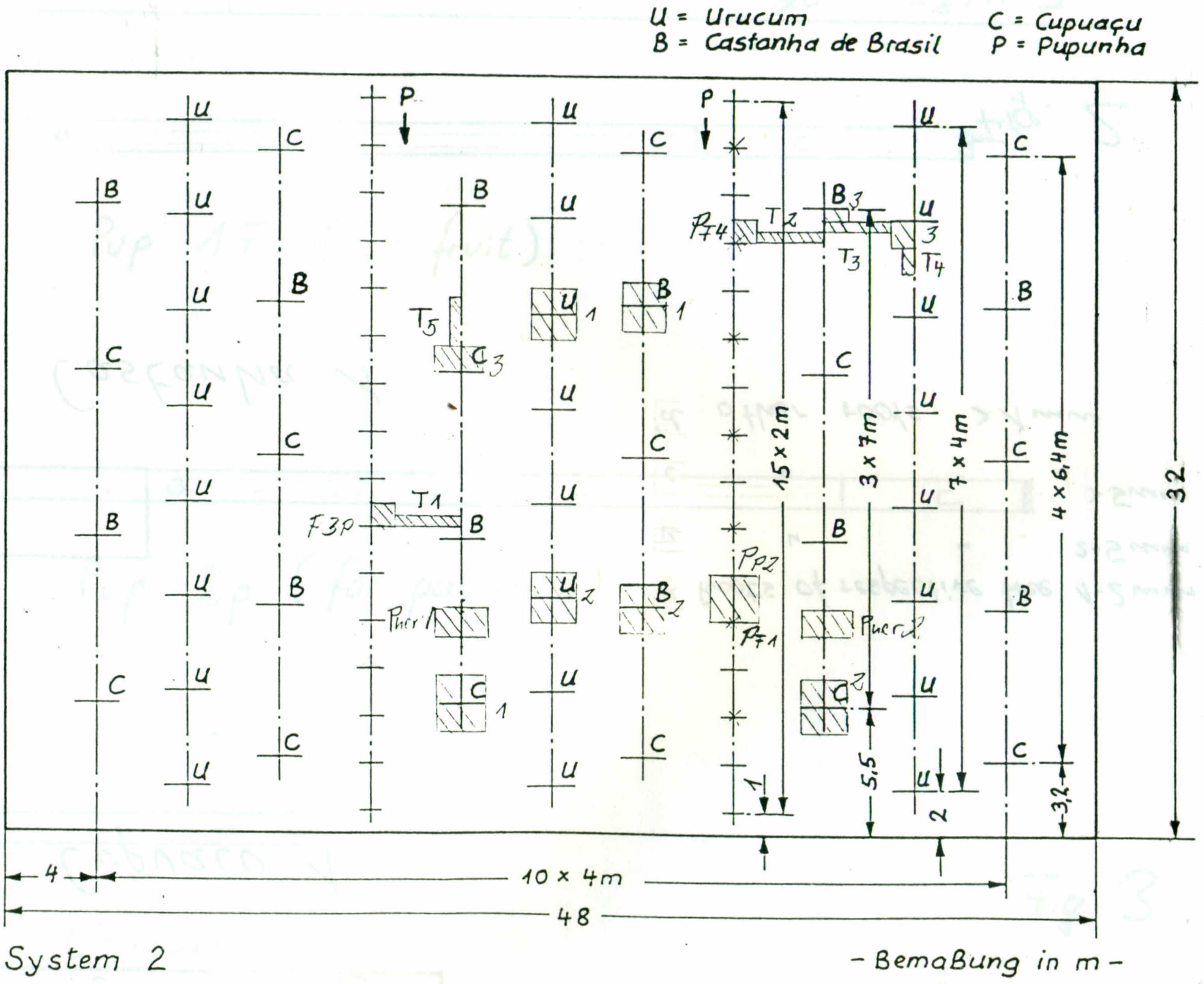
Figures 2,3: Dry matter of roots > 1 mm of the largest of the excavated trees for each species. The taproot and the the fine roots < 1 mm are not depicted. The roots of the excavated trees are cross-hatched (1-2 mm), horizontally hatched (2-5 mm) or in blank (> 5 mm), the roots of other species (all size classes > 1 mm combined) are shaded. The values (in g/m²) refer to the excavated area (see Table 1). Note the different axis scales of Figures 2 and 3.

Fig. 1: LAYOUT OF POLYCULTURAL SYSTEM 2 and POSITION of the EXCAVATIONS in the PLOT

$T_1 - T_5$: Transects

P_P: Pupunha for Palmito

P_F: Pupunha for Fruit (×)



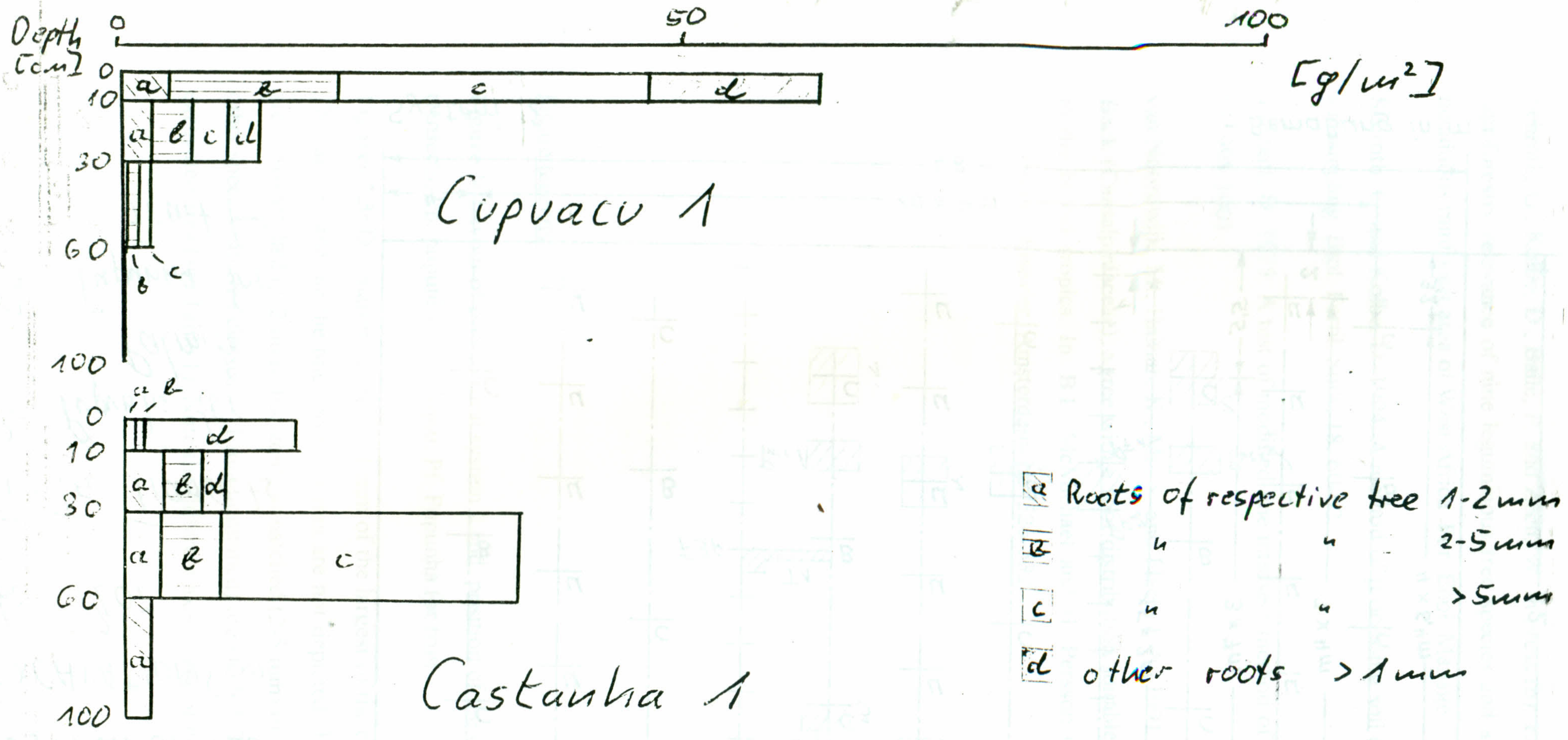

Depth [cm]
0
50
100
[g/m²]
0
10
30
60
100
a
b
c
d
Cupuacu 1
Castanha 1
a Roots of respective tree 1-2mm
b " " 2-5mm
c " " >5mm
d other roots >1mm

Fig. 2

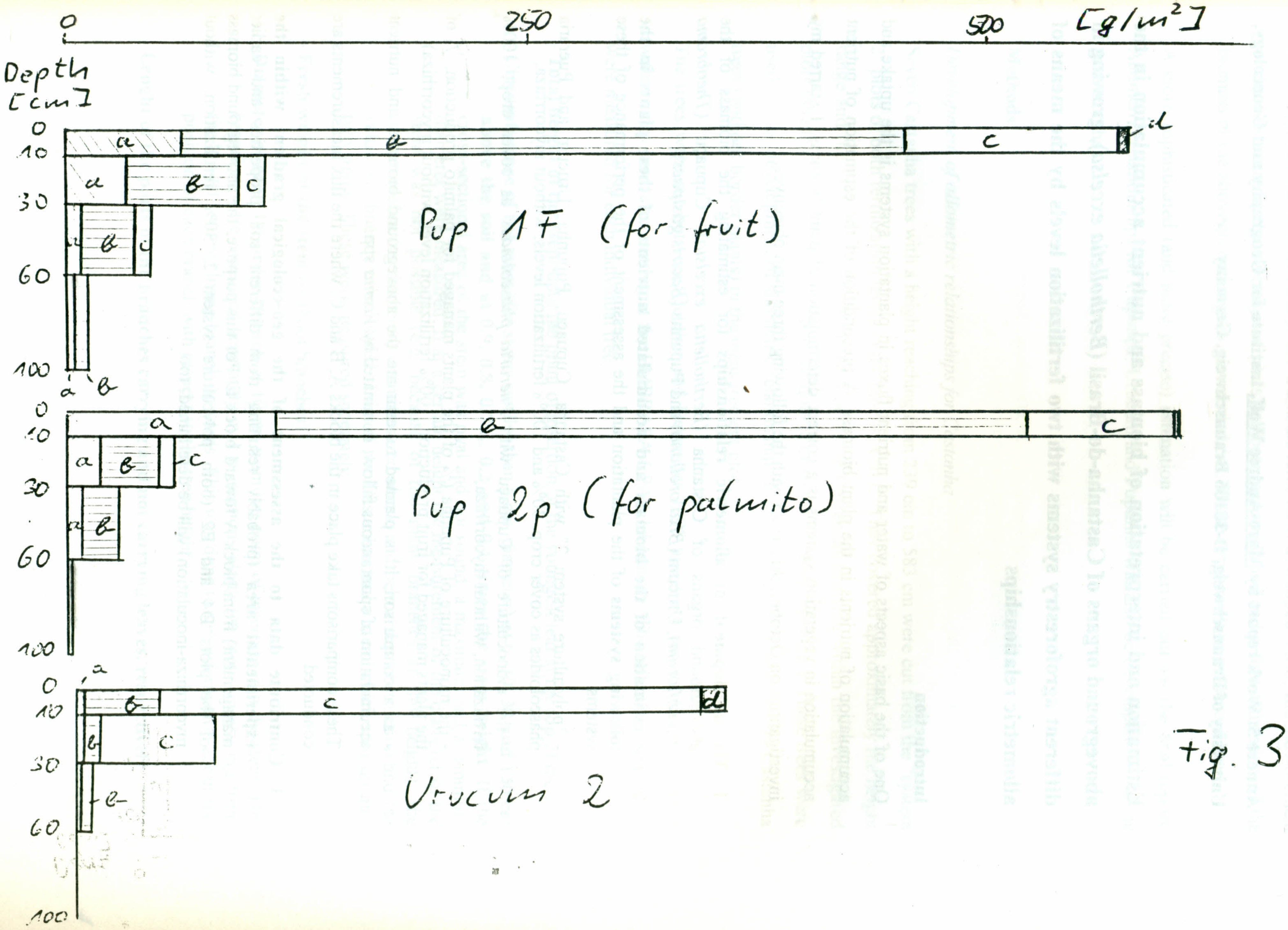

0
250
500
[g/m²]
Depth
[cm]
0
10
30
60
100
a
b
c
d
a
b
c
a
b
c
a
b
Pup 1F (for fruit)
0
10
30
60
100
a
b
c
a
b
c
a
b
Pup 2p (for palmito)
0
10
30
60
100
a
b
c
d
b
c
e
Urucum 2

Fig. 3

Annexe 5: Work report by Marc-Andree Wolf, Institute for Geography and Geoecology, University of Braunschweig, D-38106 Braunschweig, Germany

Estimation and interpretation of biomass and nutrient accumulation in the aboveground organs of Castanha-do-Brasil (*Bertholletia excelsa*), growing in different agroforestry systems with two fertilization levels by the means of allometric relationships

Introduction

One of the basic aspects of water and nutrient fluxes in plantation systems is the uptake and accumulation of nutrients in the plant biomass. A precondition of the estimation of nutrient accumulation in vegetation systems is a correct determination of plant biomass. I started my investigations on October, 9th, 1995 with the following three main objectives:

1. The **development of allometric relationships** for estimating the biomass of the aboveground organs of Castanha (*Bertholletia excelsia*), Cupuaçu (*Theobroma grandiflorum*), Urucum (*Bixa orellana*) and Pupunha (*Bactris gasipaes*)
2. The **estimation of the biomass and accumulated nutrients of these plants in the following systems** of the plantation and the assessment of the performance of these systems:

   - "polyculture system 2" with Castanha, Cupuaçu, Pupunha, Urucum and Pueraria phaseoloides as cover crop, 30% and 100% fertilization levels; without mycorrhiza;

   - the monoculture of Cupuaçu with *Pueraria phaseoloides* as cover crop, 100% fertilization; without mycorrhiza;

   - the monoculture of Pupunha (¾ of the plants managed for palmito production, ¼ of the plants managed for fruit production, 100% fertilization level; without mycorrhiza)

   - as a comparison, it is planned to estimate the aboveground biomass and nutrient accumulation of spontaneous fallow, dominated by *Vismia* spp.

   These comparisons take place in the blocks A, B and C, where the flux measurements are conducted.
3. **Contribute data to the assessment of the geo-ecological gradient within the experimental area** (probably resulting from different soil properties and earlier management) from block A toward block E. For this purpose, the aboveground biomass of the plots D4 and E2 (both polyculture system 2, 30% fertilization, without mycorrhiza-inoculation) will be determined, too.

So far, the allometric relationships for Castanha have been developed. Also, the measurement of the Castanhas in the investigated plots has been accomplished and a first estimation of the biomass of the aboveground organs was carried out. These results will be presented here.

A more sophisticated (and more precise) estimation will be carried out for the final report. Allometric relationships for Cupuaçu, Urucum and Pupunha will also be developed within the next months.

Methods

Development of allometric relationships for Castanha

Seven Castanha trees with a height reaching from 239 cm to 583 cm were cut from the "system 2" plots of both fertilization levels in the blocks A to C. They covered approximately the height range and the range of other characteristics of the Castanhas growing within the investigated plots (shape of the crown, occurrance of double or triple stemmed trees etc.). These trees were used for the development of allometric relationships for the biomass estimation of 64 Castanha trees (without border plants) in the measurement plots.

The trees were cut between October and December 1995 and were measured and weighed within a few days after cutting at the EMBRAPA-CPAA laboratory. The following parameters were measured for each individual tree:

- **Total height of the stem** until the point of insertion of the youngest leaf at the top of the tree

- **Circumference of the stem** (for stems smaller than 5 cm: diameter) **at 0, 10, 30 and 130 cm above the soil and at 0.9, 0.8, 0.7 ... 0.2 and 0.1 times the stem height**. If the cross-sectional area of the stem was oval and not round, a maximum and a minimum diameter were measured. If at a certain height the measurement of the diameter of the stem was not possible (e.g. because of too many branches at this height), the circumference (or diameter) was measured above and below this obstruction and the value was linearly interpolated. Two of the Castanhas had a stem which split up into two stems. These were measured seperately.

- **Fresh weight of the stem** (without branches)

- **Diameter of each 1st-order branch** at 10 cm from the point of insertion into the stem. The branches were measured separately in 1 m sections along the stem, measuring from the lowest (oldest) living branch upwards. This was done to get information about the position of each branch with respect to the tree height.

- **Lenght of the parts of the branches carrying and not carrying leaves, respectively**

- **Number of secondary twigs** of more than 10 cm length **for each branch** and the number of twigs of less than 10 cm length

- **Fresh weight of each branch** (including twigs, without leaves)

- **Fresh weight of the "older" and "younger" leaves of each branch**. "Younger" leaves means the outermost group of leaves which were seperated from the "older" leaves by a short gap at the branch without leaves which was probably due to water deficiency during the dry season. The younger leaves were lighter green or reddish in color and softer than the "older" leaves. For practical reasons, the leaves were cut from the twigs with about two thirds of the petiole remaining on the leaf.

- **Additional observations** were made, e.g. on wounds at the stem basis caused by a machete, nests of tree-defending ants in the crown etc.

To determine the heterogenity within different samples of the plant organs with respect to water content and the concentrations of macro- and micronutrients, several representative samples of leaves, branches and stems were taken from each individual. The chemical analysis of these samples will allow to determine the necessary sample size for the determination of the nutrient content in the trees. The water content of the plant tissue was determined by drying leaf samples at 70°C for about 3 days and branches and stems at 105°C for 3 to 4 days. The necessary duration of drying was determined by repeated weighing of samples during the drying process and took occasional power failure into account. The nutrient analyses have not yet started. The quotient of leaf dry matter/leaf area was determined on representative leaf samples with a LI-3100 leaf area meter of LI-COR (Lincoln, Nebraska, USA; available at EMBRAPA) after calibration for different Castanha leaf sizes.

The development of allometric relationships from the measured data was carried out with the program STATISTICA for Windows. Optimization criterion for all models was the minimization of the squared difference between observed and predicted values.

Field measurement of the Castanha trees and estimation of their biomass

Because of the heterogenity of growth form of the Castanhas (presumably caused by both the heterogenity of planting material and soil properties within the plots), a relatively comprehensive and time-consuming measurement of the Castanhas was necessary to obtain information about the biomass and accumulated nutrients with the desired precision. The inventory started on December, 1st 1995 and was finished by mid January 1996. For each of the 64 Castanhas, the following measurements were carried out (see above for details):

- stem height

- stem circumference at the above-mentioned heights

- diameter and position of all 1st order branches in 0.5 m sections of the stem

- number of secondary twigs longer than 10 cm for each branch

- additional observations.

If a Castanha had more than one stem, all of them were measured in the same way as for single-stemmed trees, their cross-sectional areas were summed up and a "equivalent diameter" was calculated from the total stem cross-sectional area.

Because of the growth of the trees within the 6-week-period of measurement, the measurements of some of the earliest trees were repeated at the end of the period for determining the growth and, if necessary, correcting the collected data of the trees.

Preliminary results

Allometric relationships in Castanha

Different equations consisting of different combinations of parameters can be used to estimate the biomass of the trees:

- **One or several stem diameters** can be used to estimate the dry matter of the stem. The frequently used estimation of branch and leaf biomass from stem diameters (Uhl and Jordan, 1984) was not possible because the relationships of stem biomass/branch biomass or stem biomass/leaf biomass were not sufficiently constant (data not shown).
- The **sum of the cross-sectional areas of all branches** of a tree can be used to estimate the dry matter of all branches and leaves of this tree.
- The **cross-sectional area of each single branch** can be used to estimate its dry matter and the dry matter of its leaves; these can then be summed up for all branches of a single tree to obtain the dry matter for the whole tree. This estimation should be more precise than the one above but is also more time-consuming and has not yet been tested.
- The **cross-sectional area of each single branch combined with the distance of the point of insertion of this branch from the top of the tree** allows to include the relative age of a branch and the degree of shading by higher branches in the estimation.

Castanha leaves

A first approach to the estimation of leaf dry matter is the following equation (model 1). It **estimates the sum of the dry matter of all leaves of a single tree using the sum of the**

cross-sectional areas of all branches of this tree (measured at 10 cm distance from the stem):

$$DMLeaves = 60{,}82899 * SecAreaBranch^{1{,}014934} \qquad R = 0.992, \quad n = 7$$

DMLeaves = sum of the dry matter of all leaves of the tree in [g]
SecAreaBranch = sum of cross-sectional areas of all branches of the tree in [cm^2]

Castanha branches

A fitting for the **dry matter of the branches of a tree using the sum of the cross-sectional areas of all branches of this tree** gives the following equation (model 2):

$$DMBranch = 5{,}679641 * SecAreaBranch^{1{,}532029} \qquad R = 0.995, \quad n = 7$$

DMBranch = sum of the dry matter of all branches (including secondary and lower-order twigs) of the tree in [g]
SecAreaBranch = sum of cross-sectional areas of all first-order branches of the tree in [cm^2]

Castanha stems

To estimate the dry matter of the stem itself, **first the volume of the stem is calculated as the sum of truncated cones** using the diameters at 10 cm above ground and 10 diameters equally spaced along the stem (see above) in combination with the length of the corresponding stem cross-sections:

StemVolu = Height / 10 * ((SecArea10cm / 2) + SecArea0,9 + SecArea0,8 + SecArea0,7 + SecArea0,6 + SecArea0,5 + SecArea0,4 + SecArea0,3 + SecArea0,2 + SecArea0,1 + (0,1256 / 2))

StemVolu = calculated volume of the stem in [cm^3]

Height = total height of the stem till point of insertion of the youngest leaf in [cm]

SecArea10cm = cross-sectional area of the stem at 10 cm above the ground [cm^2]

SecArea0,9 = cross-sectional area of the stem at 90% of the total height of the stem a relative height of 0,9 of the stem [cm^2]

For the lower end of the first stem segment, the cross-sectional area at 10 cm height was used. As upper diameter for the heighest stem section, 0.4 cm was used as a typical value giving a cross-sectional area of the 0,1256 cm^2 which appears in the equation.

This calculated stem volume was used to calculate the dry matter of the stem obtaining the following approximation (model 3):

DMStem = 0,517934*StemVolu^{0,995749} R = 0.9996, n = 7

DMStem = dry matter of the stem in (g)

Figure 1 shows observed versus predicted values.

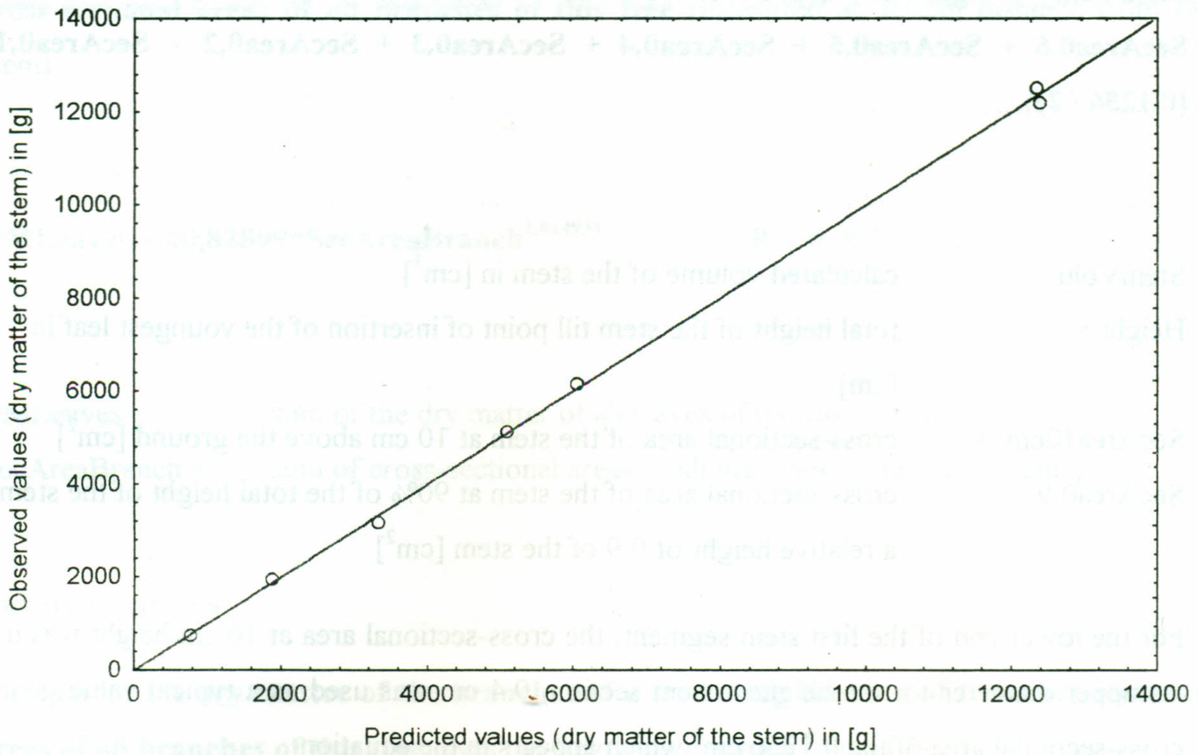


Fig. 1: Estimation of the dry matter of the stems of seven destructively harvested Castanha trees (model 3). Observed versus predicted values.

Whole Castanhas

Fig. 2 shows the results of the presented fittings for the seven destructively harvested Castanha trees comparing the measured and the estimated dry matter of the aboveground organs as paired columns.

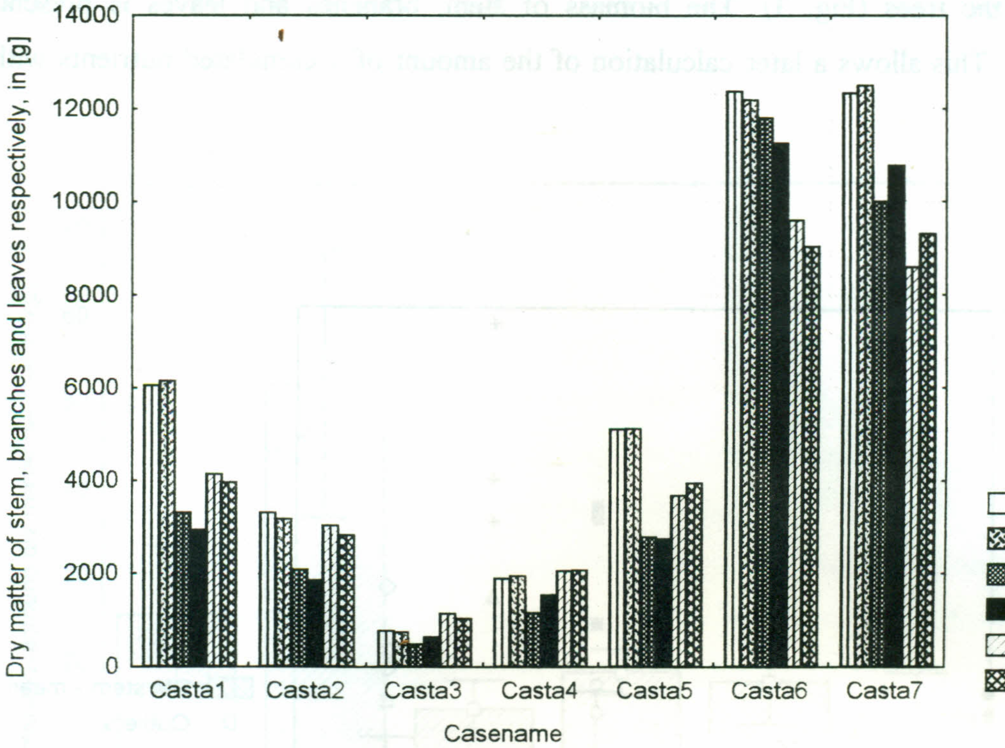


Fig. 2: Comparison of observed and predicted values of the dry matter of the stem, branches and leaves, respectively, of the 7 cut Castanhas. DMSTEM = Estimated dry matter of the stem; DMSTEMME = Measured dry matter of the stem; DMBRANCH = Estimated sum of dry matter of all branches; DMBRANME = Measured sum of dry matter of all branches; DMLEATOT = Estimated sum of dry matter of all "older" and "younger" leaves; DMLEATME = Measured sum of dry matter of all "older" and "younger" leaves. The models 1, 2 and 3 were used for the predictions.

It is to be expected that the aforementioned more complex model will obtain even more precise results especially for the dry matter of the leaves.

Biomass estimation of the living Castanhas

Comparison of the different fertilization levels in "system 2"

From December, 1st until January, 6th the above-mentioned parameters were measured on the remaining Castanhas in the investigated plots ("system 2", 30% and 100% fertilization, without mycorrhiza inocculation). The allometric relationships were used to calculate the aboveground dry matter of the trees (Fig. 3). The biomass of stem, branches and leaves is presented separately here. This allows a later calculation of the amount of accumulated nutrients within the plants.

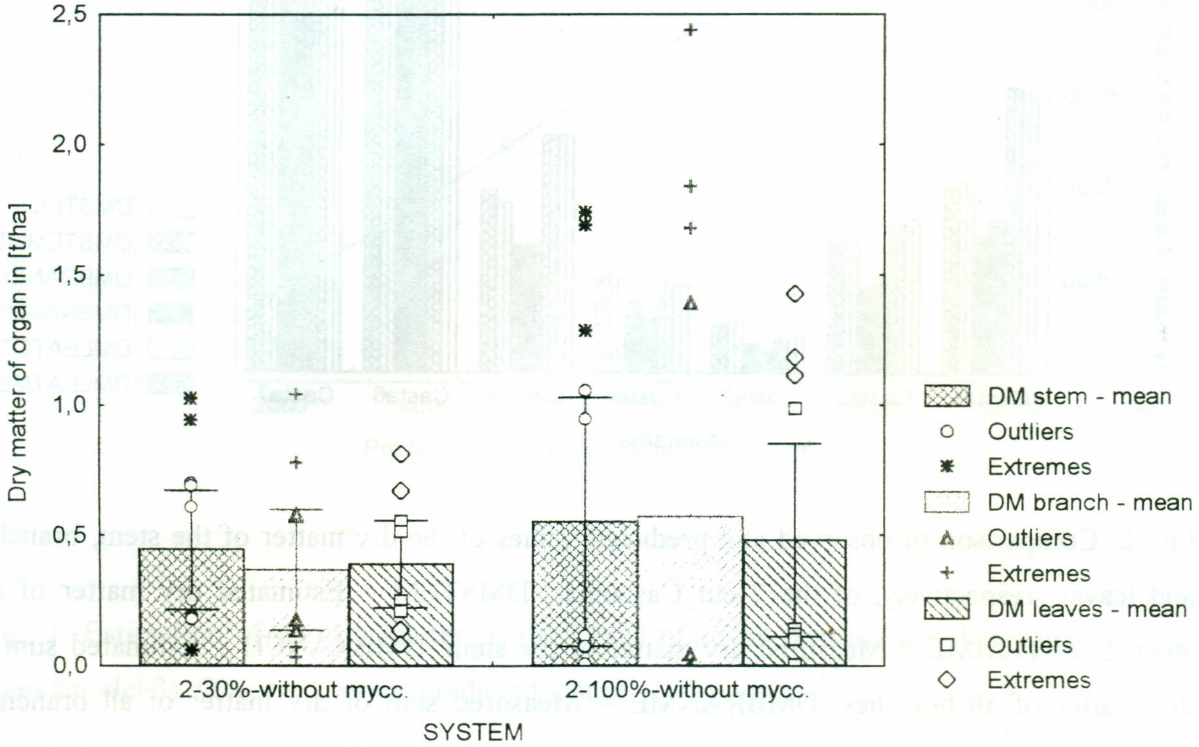


Fig. 3: Biomass of the Castanhas in "system 2" with 30% and 100% fertilization, respectively, calculated from the eight "inner" Castanhas (without border plants) of the 6 investigated plots of blocks A, B and C according to the December 1995/January 1996 inventory. Tree biomass is related to the plot area here. When related to the 7 by 4 m area corresponding to each tree, the biomass values are about 4.5 times higher.

As can be seen from Fig. 3, there was a great heterogenity regarding the biomass of the Castanhas. As an attempt to reduce the plant-related (genetic) component of this variability, the mean biomass of the 5 biggest Castanha trees only was used to characterize the soil conditions in the different plots (Fig. 4). The Figure illustrates well the exceptional growth of the trees in plot A1. The reasons for this will have to be investigated in future studies.

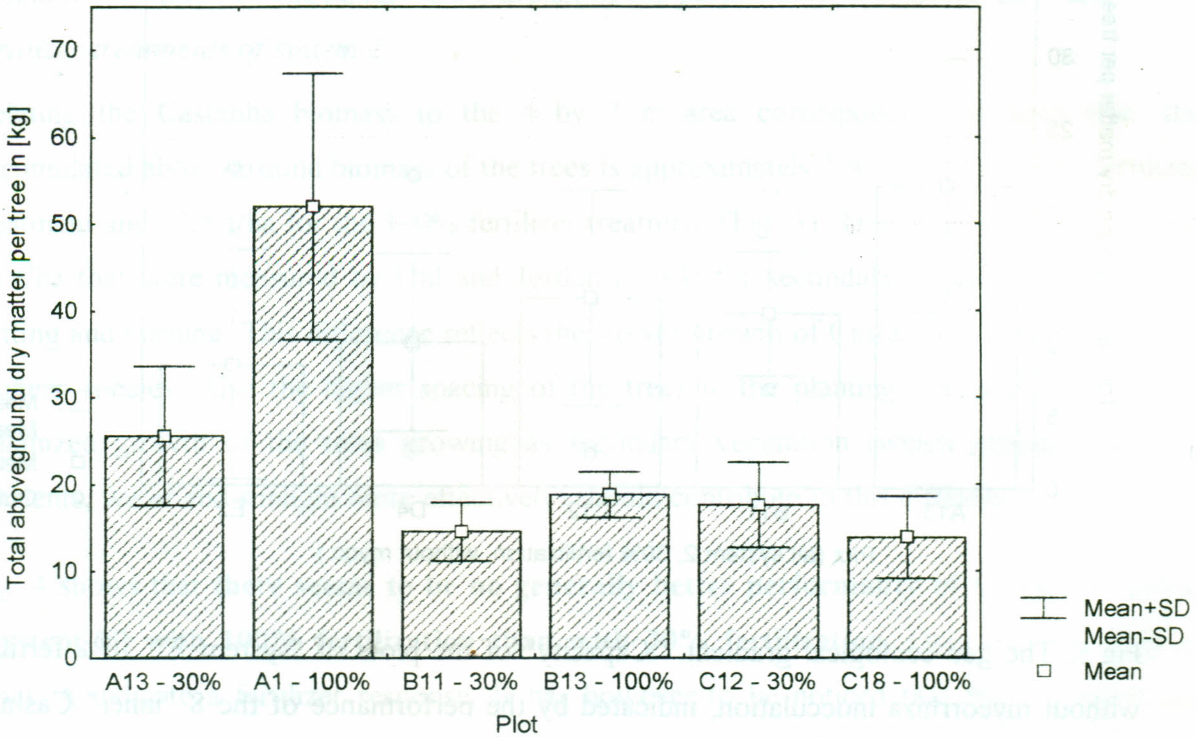


Fig.4: Biomass of the five biggest Castanha trees in each of the six investigated plots according to the December 1995/January 1996 inventory

The geo-ecological gradient

Another main aspect of this work is to contribute to the analysis of the geo-ecological gradient on the experimental site between blocks A and E. Therefore, the "inner" Castanhas in the plots D4 and E2 (system 2, 30% fertilization, no mycorrhiza) were included in the inventory. Fig. 5 shows the total aboveground dry matter, calculated for all 8 "inner" trees of each plot. The geo-ecological gradient is indicated, but strongly overlaid by the heterogenity of plant growth within each plot.

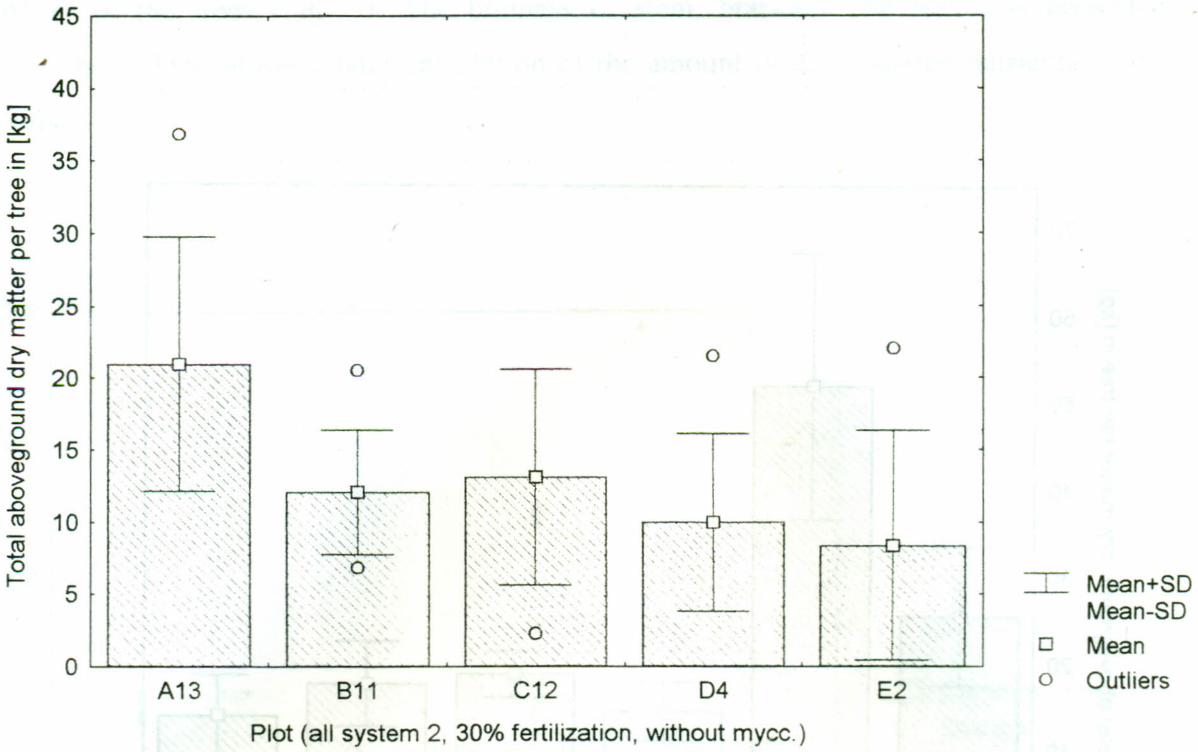


Fig.5: The geo-ecological gradient: "Capacity" of the plots of "system 2", 30% fertilization, without mycorrhiza inocculation, indicated by the performance of the 8 "inner" Castanhas in the plots

Discussion

Allometric relationships in Castanha

The **allometric relationships turned out to be reasonably precise despite a considerable heterogenity of the measured individuals** regarding height, shape, secondary stems etc., even with the presented simple models (Fig.2). The fitting for the biomass of the stem is the most precise (Fig.1). The estimation of the branch dry matter will possibly be improved by the use of a more advanced model. The estimation of the leaf biomass in contrast will probably remain less precise even when a more advanced model is used because of the more dynamic quotient leaf biomass/branch biomass and leaf biomass/stem biomass. The additional measurement of the lenght of the parts of branches carrying leaves would allow a substantially more precise estimation of the leaf biomass, but this would be excessively time-consuming for larger numbers of trees. This parameter may however be used to determine the biomass on small tree numbers where high precision is required.

Biomass estimation of Castanha - comparison of the performance within the 30% and 100% fertilizer treatments of system 2

Relating the Castanha biomass to the 4 by 7 m area corresponding to each tree, the accumulated above-ground biomass of the trees is approximately 5,4 t/ha for the 30% fertilizer treatment and 13,5 t/ha for the 100% fertilizer treatment (Fig. 3). This is lower than the about 16 t/ha that were measured by Uhl and Jordan (1984) for secondary vegetation after forest cutting and burning. This difference reflects the slower growth of Castanha in comparison with pioneer species. Also the higher spacing of the trees in the planting compared to the self-organized growth of the trees growing as secondary vegetation (which probably use soil nutrients, water and sunlight more effectively) should contribute to this difference.

Fig. 4 shows that **there seems to be no generally better performance of Castanha within "system 2" with 100% fertilization than with 30% fertilization.** Only the two plots in block A indicate a fertilizer response. It has however to be noticed that the correction for growth during the 6 weeks measurement period has not yet been included in the presented data.

Fig. 4 also shows **a great variability of growth within each plot** even if only the 5 largest trees are compared. This heterogenity probably has at least two main reasons: Firstly, the genetical heterogenity of the planting material (see lit.1), and secondly the already detected heterogenity regarding soil properties (see lit.1) which will have to be investigated by further studies, e.g. on the modification of topsoil depth during earlier mechanized site preparation. The additional estimation of the biomass of the other 3 tree-species, which I am planning to carry out during the next two months, should reveal a more precise picture of the performance of "system 2" under the two different fertilizer-treatments and along the fertility gradient.

Outlook - future tasks

Information about leaf-area, shading and especially about the amount of accumulated nutrients (N, K, P, Mg, Ca) within the aboveground organs of Castanha and about the performance of the other useful plants of "system 2" will be presented in the final report (diploma thesis).

Additionally, representative samples of leaves and branches of the 4 species in all investigated plots have to be collected and analyzed to determine the amount of accumulated nutrients in the systems. As a comparison, an estimation of the aboveground biomass and accumulated nutrients of the fallow-treatment with *Vismia* spec. as main species is planned.

In addition to the presented models, more precise models will be developed later for each tissue type, using more parameters than the simple equations presented above. This will allow to select the models and parameters according to the objective and required precision of the biomass estimation, and according to the available time for the measurements on the trees. The models will then be progressively extended to larger trees when the Castanhas in the experiment exceed the size range for which the equations are valid.

A still unresolved statistical problem is the choice of the apropriate optimization criterion to fit the models, since the commonly used "(Observed-Predicted)^2" criterion in non-linear estimation, as used here, yields a systematically distorted fitting (Lit.3). Moreover, an approach has to be found to get similarly precise estimations of the biomass independently from the absolute value of the biomass of the estimated tree; the optimization criterion "(Observed-Predicted)^2" yields less precise estimates for smaller than for bigger trees.

Acknowledgements

This work has been carried out within the project ENV 45, a component of the German-Brazilian SHIFT program. Financial support of the CNPq is gratefully acknowledged.

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Annexe 6: Work report by Jürgen Burkhardt, University of Bayreuth, Dept. of Agroecology, D-95440 Bayreuth, Germany

Measurements of invisible leaf wetness on pupunha, cupuaçu, pueraria and seringueira leaves at EMBRAPA-CPAA, Manaus, Brazil; 9.-13.10.1995

Introduction

Leaf wetness is an important parameter for nutrient fluxes in ecosystems as well as for the development and maintenance of the phyllosphere, e.g. fungi and lichens. The wetness of leaves is usually produced by rain, fog, or dew. Many plants have hydrophobic surfaces resulting in large contact angles of droplets. Wetting times are reduced by hydrophobicity, and it is known that leaves usually loose their hydrophobic character and become more wettable with time. Leaf wetness promotes transport processes across the leaf surface, called foliar leaching (= loss) and uptake of substances. These processes are of importance for the transport of nutrients as well as for the leaching of allelopathic substances. Foliar fertilisation is an established technique which takes advantage of this transport across the leave surface.

Fungi on leave surfaces require wetting times above a certain threshold value, but prediction models are still very uncertain. Apart from visible leaf wetness by precipitation or dew, an invisible wetness on leaf surfaces has been detected by continuous measurements of the electric conductance along the surface of leaves. It was first detected during a five months measurement in the crown of a Norway spruce (Picea abies (L.) Karst.) in Northeastern Bavaria, and the wetting time by this kind of wetness amounted up to more than 30% of the total time, i.e. more than the time of visible wetness (Burkhardt and Eiden, 1994). In detailed laboratory studies, this invisible form of wetness could be attributed to an interaction between salts on the leaf surface and the transpirational water vapour coming out of the stomata. Thus, invisible water films of less than 1 mm thickness are formed due to the reduced saturation vapour pressure resulting from the salts, and the generally higher humidity in the laminar boundary layer of the leaf.

The present study was a pre-investigation concerning the occurrence of invisible wetness on the leaf surface of four tropical species at the EMBRAPA research station near Manaus.

Methods

Leaf wetness was measured on two days (11 and 12 Oct 1995) during the dry season in a plantation containing the species castanha, pupunha, cupuaçu, urucum and seringueira. The weather was cloudy, but rainless on the first day (pupunha measurements) and sunny and hot on the second day (remaining species). The electrical conductance along the leaf surfaces was measured using wetness sensors which were directly clipped on the leaves. An AC voltage of 6 V is applied and the electrical conductance is measured. The output signal is in mVolt, and is a direct measure for the electrical conductance (see Burkhardt and Gerchau, 1994). A one-day course of the electrical conductance was measured on a pupunha leaf. The relative humidity (rh) was measured using a psychrometer. Values were recorded every minute between 7 am and 5 pm. On leaves of cupuaçu and on pueraria leaves, conductance measurements were made for about 90 minutes each, parallel to rh measurements with the psychrometer.

Results

On all five investigated species, a high correlation between relative humidity and conductance on the leaf surface could be detected. The conductance during the daily record on the pupunha leaf was at full scale (ca. 1800 nSiemens) in the beginning, due to the presence of dew droplets. When the dew droplets had disappeared at 8.10 am, the conductance signal of about 800 nSiemens indicated continuing invisible wetness (Figure 1). The conductance signal decreased further until about 10.30 am, but from then on showed a close correlation with rh (Figure 2). The same tendency was observed during the measurements on cupuaçu (Figure 3) and pueraria (Figure 4), and during short time monitoring on seringueira leaves.

Discussion and conclusions

The high correlation between the conductance signals and relative humidity indicate a continuous liquid water connection between the two electrodes which are about 5 mm apart. The conductance increase on pupunha leaves at rh > 70 % indicates the presence of a liquid water connection of variable thickness. This liquid water may be present inside of cuticle pores or on the leaf surface. In the case of Norway spruce where the same phenomenon has been observed, there is strong evidence for a thin water layer on the leaf surface, which was found in laboratory experiments under controlled conditions (Burkhardt and Eiden, 1994).

~~Liquid water on the leaves, even if it is present in minute, invisible amounts, is important in~~ different aspects. It provides a medium for the transport of dissolved substances into and out of the leaf. Concentrations of substances coming from the atmosphere will usually be higher than in rain water, thus establishing a stronger gradient and subsequently higher fluxes on an areal basis, compared to wetting by rain. On the other hand, leaching of substances is only possible as long as there is water on the outer surface. These transport processes will happen across the cuticle, but potentially also via the stomata in case the thin water films extend continuously into the stomatal opening. The substances leached by invisible wetness may subsequently be washed down by rain. Apart from facilitating transport processes, invisible wetness may provide a source of water for the germination of fungal spores on the leave surfaces.

These preliminary results show the presence of invisible micro-wetness on the investigated tropical plant species under field conditions. More detailed investigations concerning the occurence of these wetness films as well as their ecological implications (e.g. nutrient transport across the leaf surface) are in preparation.

Reference

Burkhardt J., Eiden R. (1994): Thin water films on coniferous needles. Atmospheric Environment, 28 A, 2001-2017 (including an appendix by Burkhardt and Gerchau).

Fig. 1

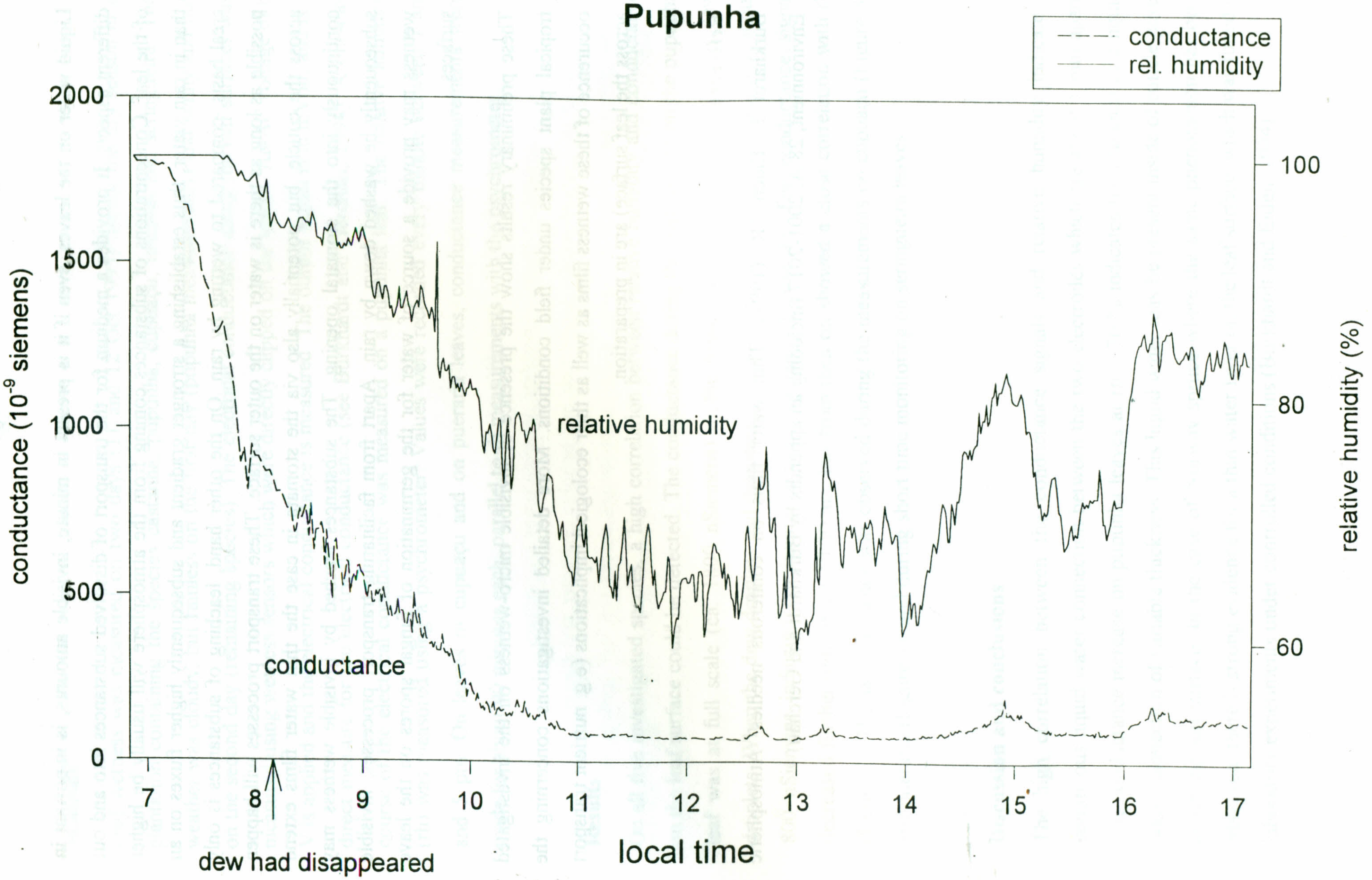
Pupunha
conductance
rel. humidity
conductance (10^-9 siemens)
2000
1500
1000
500
0
relative humidity (%)
100
80
60
relative humidity
conductance
7
8
9
10
11
12
13
14
15
16
17
local time
dew had disappeared

Fig. 2

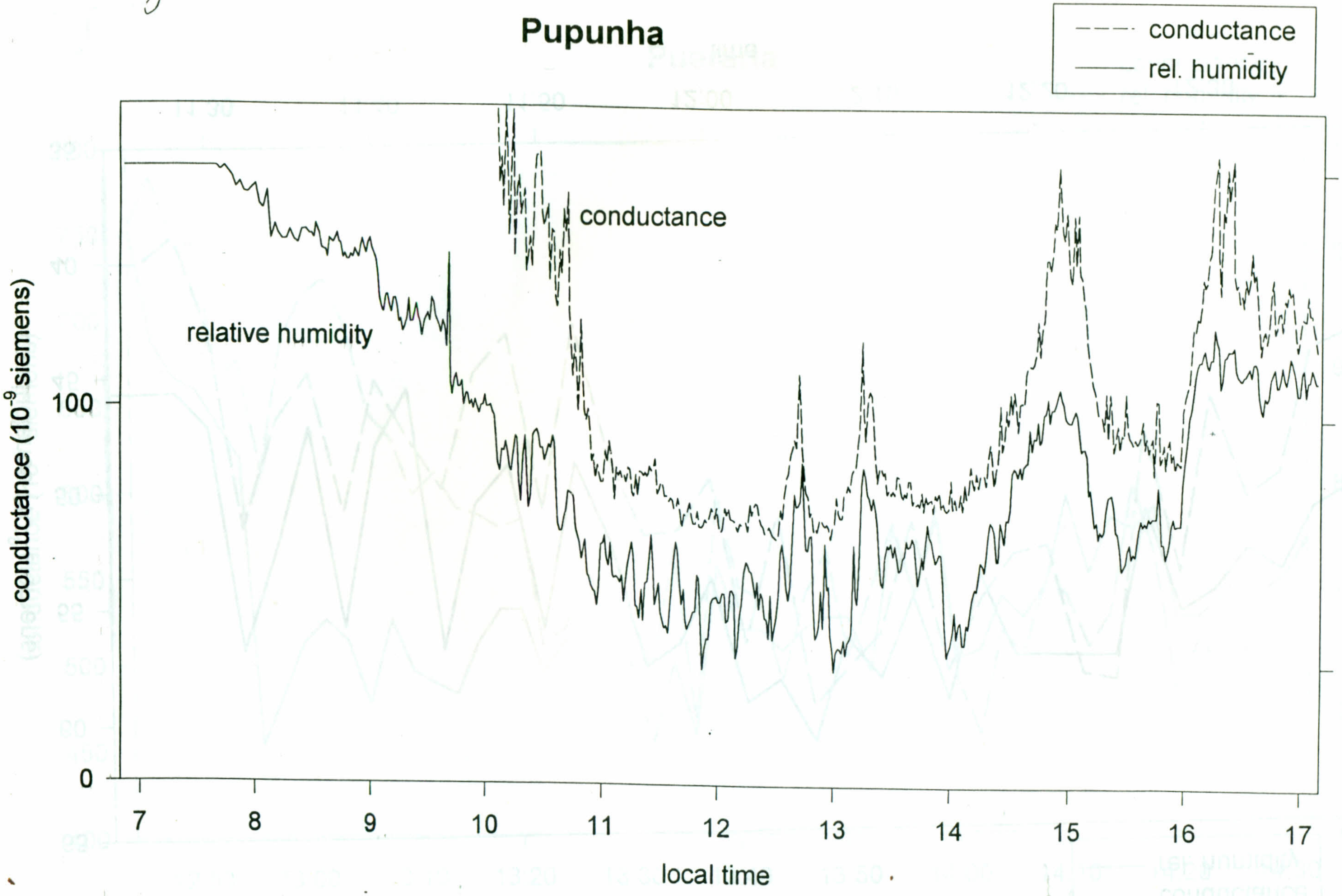
Pupunha
conductance
rel. humidity
conductance
relative humidity
conductance (10^{-9} siemens)
0
100
relative humidity (%)
60
80
100
7
8
9
10
11
12
13
14
15
16
17
local time

Fig. 1

Fig 5

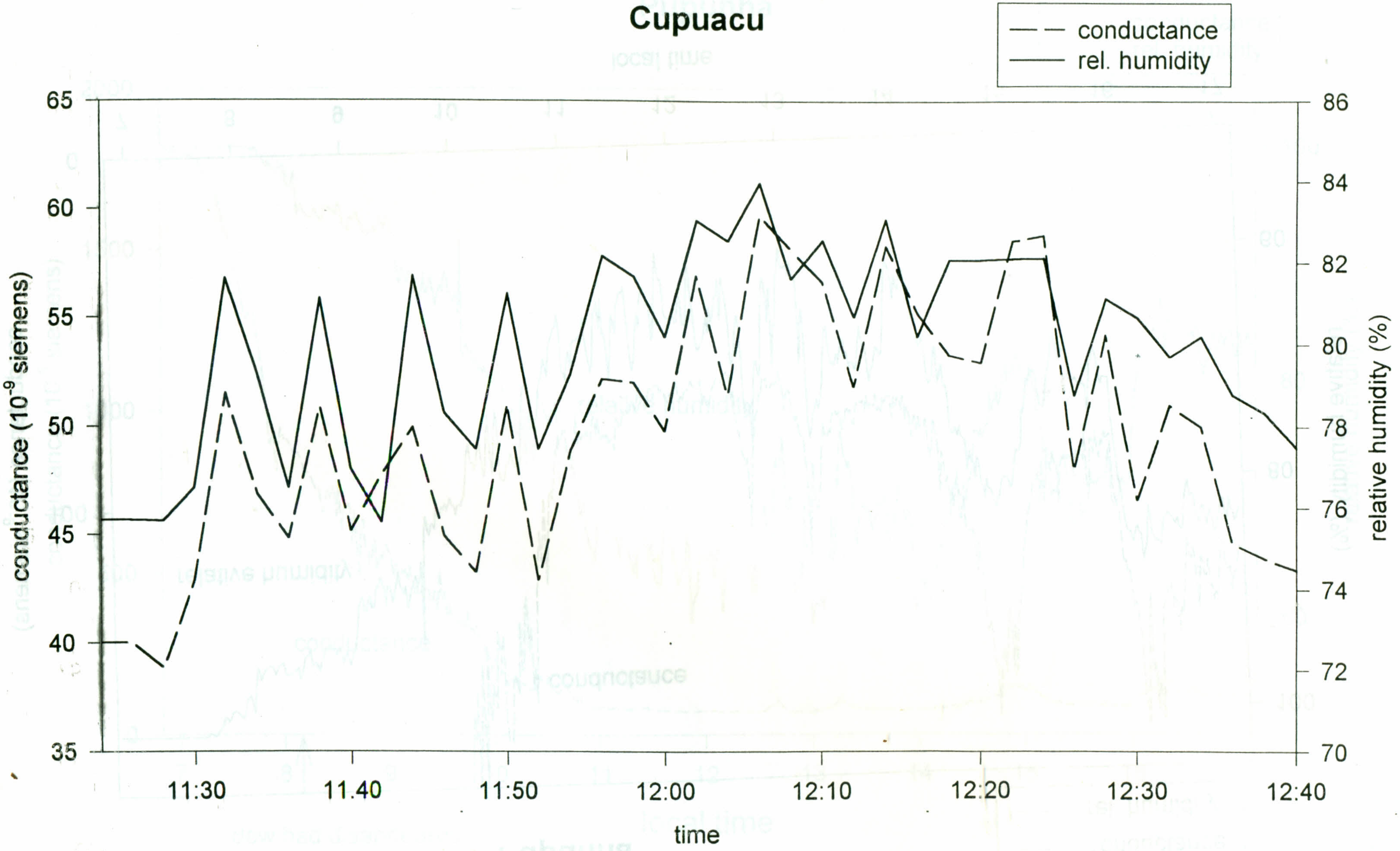
Cupuacu
conductance
rel. humidity
65
60
55
50
45
40
35
conductance (10^-9 siemens)
86
84
82
80
78
76
74
72
70
relative humidity (%)
11:30
11.40
11:50
12:00
12:10
12:20
12:30
12:40
time

Fig 4

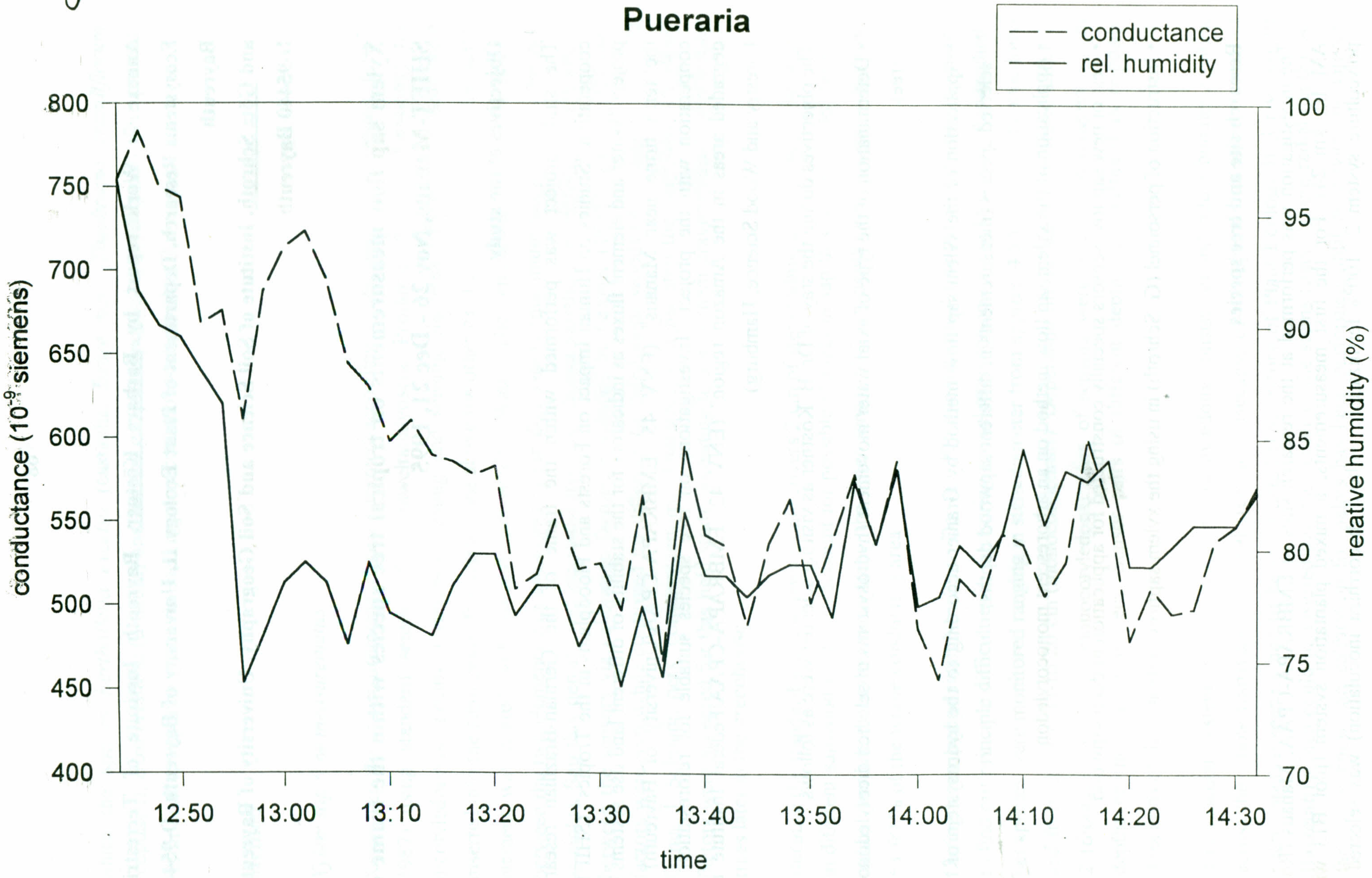
Pueraria
conductance
rel. humidity
conductance (10⁻⁹ siemens)
800
750
700
650
600
550
500
450
400
relative humidity (%)
100
95
90
85
80
75
70
12:50
13:00
13:10
13:20
13:30
13:40
13:50
14:00
14:10
14:20
14:30
time

Fig 3

Annexe 7: Work report by Barbara Köstner, Bayreuth Institute of Terrestrial Ecosystems Research, Department of Plant Ecology II, University of Bayreuth, D-95440 Bayreuth
and Götz Schroth, Institute of Soil Science and Soil Geography, University of Bayreuth, D-95440 Bayreuth

Xylem sap flow measurements on tropical tree species within the frame of SHIFT-Manaus, Nov 26 - Dec 21, 1995

Objectives of the study

The study project was performed within the frame of the German-Brazilian research cooperation "Studies on Human Impact on Forests and Floodplains in the Tropics" (SHIFT), project "Water and element fluxes as indicators for the stability of different land use systems on the terra firme near Manaus" (ENV 45, EMBRAPA-CPAA/University of Bayreuth) in cooperation with the project "Investigations on tree species suitable for reforestation of degraded areas in the Amazon region" (ENV 42, EMBRAPA-CPAA/Federal Institute for Forestry and Wood Science, Hamburg).

The objectives during the stay of Dr. B. Köstner as visiting scientist were as follows:

- Determination of the type of axial water movement (hydrosystem) in selected dicotyledonous trees
- Application of the xylem sap flow method by Granier according to the hydrosystem of the selected species (measurements in different sapwood depths)
- Application of the xylem sap flow method on an arborescent monocotyledon
- Test of new sapflow sensors specially constructed for application in deep sapwood
- Instruction of personnel (G. Schroth) in using the xylem sapflow system

Research site and tree species

The investigation was performed at the research sites of EMBRAPA-CPAA, Manaus (Road AM 10, km 24). For the first measurements, a mixed plantation system (plot B13 with polyculture system 2, 100% fertilization, without mycorrhiza inoculation) was selected in which the species *Bertholletia excelsa* (castanha, Brazil nut), *Theobroma grandiflorum* (cupuaçu), *Bixa orellana* (urucum) and *Bactris gasipaes* (pupunha, peach palm) were present. Additionally, pupunha was examined in an ajacent monoculture (**Fig. 1**).

Method

Xylem sap flow measurements

Xylem sap flow measurements were performed according to the method by Granier (1985; 1987) using standard sensors (UP Umweltanalytische Produkte, Munich, Germany) for dicotyledonous species. Cylindrical heating and sensing elements (diameter: 2 mm) were inserted into the stem below live crown, one above the other ca. 12-15 cm apart, and the upper element was heated with constant power (0.2 Watt). The temperature difference sensed between the two elements was influenced by sap flux density (maximum temperature difference at night). Sap flux density was estimated from the diurnal variations in temperature difference between the sensors via calibration factors established by Granier (1985). These calibration factors were meanwhile confirmed for different dicotyledonous woods (A. Granier, I. Ferreira Gama, J. Schmidt, pers. communications). Therefore, in a fist step the published calibration factors were accepted for this field study, intending to verify them gravimetrically with potted trees later in the greenhouse.

Because the standard sapflow sensor only covers 2 cm of stem radius, sensors had to be placed in different sapwood depths to account for possible changes in sap flux density along the stem radius. For the dicotyledonous trees, the outer sensor (0-2 cm depth) was sufficient to cover 63-99 % of the whole conducting area.

During a test period from Nov 29 to Dec 6, 1995 one individual tree per species was measured to find out principle difficulties in measuring the selected species. From Dec 6 on, 4 individuals per species were monitored ranging in stem diameter from approx. 4.5 to 10 cm (dicotyledons) and from approx. 11 to 20 cm (monocotyledons). Depending on the size of the trees, either 1, 2 (dicotyledons) or 3 (monocotyledons) pairs of sensors were inserted in different xylem depths of the individual trees. Sensor pairs of different depth were installed in opposite directions of the stem.

The vascular system of arborescent monocotyledons consists of individual bundles existing across the whole transverse-sectional stem area. Because of this specific transport system of palms, special sensors had to be constructed (Laboratory of Plant Ecology II, University of Bayreuth) which could be inserted into the center of the stems (max. 10 cm radial depth). As far as we know, no calibration for palms has been performed until now with the Granier *method. Because of the high water content of palms and therefore high thermal conductivity of* the tissue, it was expected that mutual disturbances between sensors of different depth should be most pronounced. The sensors were installed in every palm in three different radial depths (up to 10 cm). The angle between sensor pairs was 120°.

Examination of axial water movement by dye ascent

To visualize the hydroactive area of the selected dicotyledons, the sapwood was stained by dye ascent (methylene blue) of freshly cut trees which grew on a plot where biomass harvests took place. After a few hours, the stems were cut in different heights and the active sapwood was macroscopically determined. Stained stem disks were frozen for further microscopical investigations (Dr. O. Dünisch, EMBRAPA/Hamburg). The dye ascent indicated that all selected dicotyledons belonged to the diffuse-porous conduction type showing active vessels across the whole cross-sectional area of the xylem.

In arborescent monocotyledons, the vascular bundles are normally spread over the whole cross-sectional area of the stem. It was known from the selected species that the inner tissue consisted mainly of parenchymatic cells, while larger bundles occurred in the outer stem area (O. Dünisch, pers. comm.).

Results and discussion

Xylem sap flow measurements

In Fig. 2, three selected daily courses of sap flux per sapwood area (flux density) are shown for one individual per species during the initial test period. On Dec 2, only the outer sensor (0-2 cm sapwood depth) of the dicotyldeonous species (**Fig. 2A-C**) was monitored. Sap flow increased between 7 and 8 h local time, decreased almost up to zero in the afternoon during a rain event, recovered after the rain and dereased again between 16 and 17 h. On Dec 3, both the outer sensor and the inner sensor (2-4 cm depth) were working. Both for castanha (**Fig. 2E**) and urucum (**Fig. 2G**) flux density measured in the inner sapwood was only ca. 50 % of flux density in the outer xylem. In contrast, flux density in the inner xylem of cupuaçu (**Fig. 2F**) was increased compared to the outer xylem. On Dec 3, flux density in the inner xylem remained similar to the day before for cupuaçu and urucum, but slightly decreased for castanha.

The palm pupunha was measured in 3 different stem depths. A decrease of flux density from the outer to the inner stem area was observed (**Fig. 2D, H**). Although the vascular system of palms consisting of individual bundles seems simple and vulnerable, their transport system is obviously efficient and connections of axial bundles allow lateral transport of water (cf. Zimmermann 1983). While relative water content of the dicotyledonous species typically ranged between 60 and 40 % from outer to inner xylem, relative water content of the palms amounted to approximately 80 % in the outer 0-2 cm depth of the stem and to approximately 90 % between 2 cm depth and the center of the stem.

On Dec 5, only the inner sensor was heated while ambient temperature difference between sensors was monitored with the outer sensor pair. Compared to Dec 3, this resulted in an increase of flux density of the inner sensor for castanha (**Fig. 2i**), a decrease for cupuaçu (**Fig. 2J**), and an unstable situation for urucum (**Fig. 2K**). The reason for the different relative change in flux densities of Dec 5 compared to Dec 3 remains unclear and deserves future investigations. In comparison to relatively high temperature differences between heated and reference sensor during active measurement (10-15 K for the dicotyledonous species, >20 K for pupunha!), ambient temperature difference between the non-heated outer sensor pair remained low (± 0.5 K) and changed with flux density according to the daily course exhibiting relatively small offsets for castanha, urucum, pupunha (0.5 K) and cupuaçu (1 K). A four-fold increase in flux density was observed for pupunha when only the inner sensor was working (Fig. 2L). This unrealistically high increase may be due to higher thermal conduction of the outer, non-heated palm tissue cooling the inner sensor. Obviously, the temperature field in the stem was better stabilized when using 2 or 3 sensor pairs than only one. Up to now it remains unclear why temperature differences in palms were higher than in dicotyledonous trees. To reduce high sensor temperature differences during active measurement in pupunha, the constant heating supply was set to approx. 75 % of standard heating power (0.2 Watt). This requires new calibration of the method for the palm.

In **Fig. 3**, a series of 5 consecutive days is presented showing sap flux measurements on the dicotyledonous species selected for continuous monitoring in plot B13. Only in the thicker stems, measurements were performed in 2 different depths (0-2 cm and 2-4 cm). Flux densities in the inner xylem were either lower, higher or similar to those in the outer xylem. Thus, the variation in flux density seems to be more stochastical than reflecting a consistent gradient in these young trees. As far as the calibration factors of Granier can be accepted for the 3 diffuse-porous species, maximum sap flux densities ranged from 1-3 kg dm^{-2} sapwood area h^{-1} which is in the typical range of other tropical trees (Granier et al. 1992) and various European tree species. Because of the small differences in flux densities between species, differences in absolute water flux rates will be more closely related to tree size (e.g. stem cross-sectional area) than to principle differences in the normalized hydroactivity of the species.

In **Fig. 4**, calibration factors of Granier (1985) were used to compare the relative daily courses of 3 individuals of pupunha. In the smallest palm (pu2, 13 cm diameter), flux densities from different stem depths were not different while in the other palms (16-20 cm diameter), flux density was lowest in the inner area and highest in the middle of the stem. Reliable absolute sap flux rates of the palms can only be presented when calibration factors have been tested versus gravimetrical determinations of water flux in potted trees under controlled conditions.

Conclusions

- The xylem sap flow method by Granier can be principally applied to the examined species
- Variation within trees seems to reflect stochastic variation rather than consistent radial gradients of xylem sap flow density in these relatively small trees
- The newly constructed long sensors for measuring in deep areas of stems have stood the technical test
- The gravimetrical check of quantitative results on potted plants in the greenhouse is desirable for the dicotyledonous species, but necessary for the monocotyledonous palm
- In general, the study provided new information about the applicability of the method on diffuse-porous tree species and arborescent monocotyledons, especially in consideration of mutual thermal influences of sapflow systems installed together in the same stem area.

Acknowledgements

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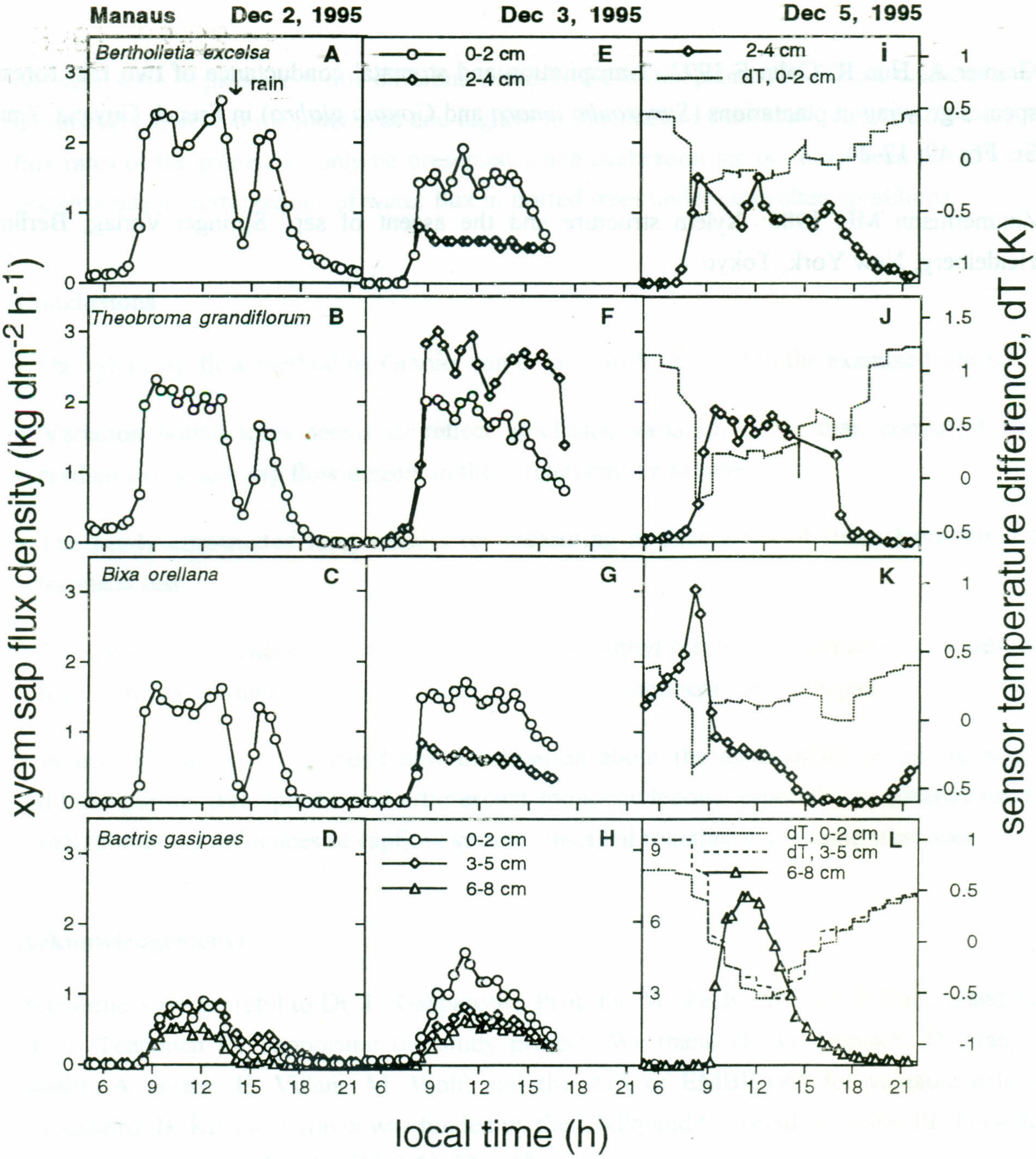

Fig. 2

Half-hourly courses of xylem sap flux density (left axis) and ambient temperature difference dT (right axis) between sensors without heating for 4 investigated species and 3 selected days. Symbols indicate different sapwood depth measured. Please, note different scale for sap flux density of plot L, left axis

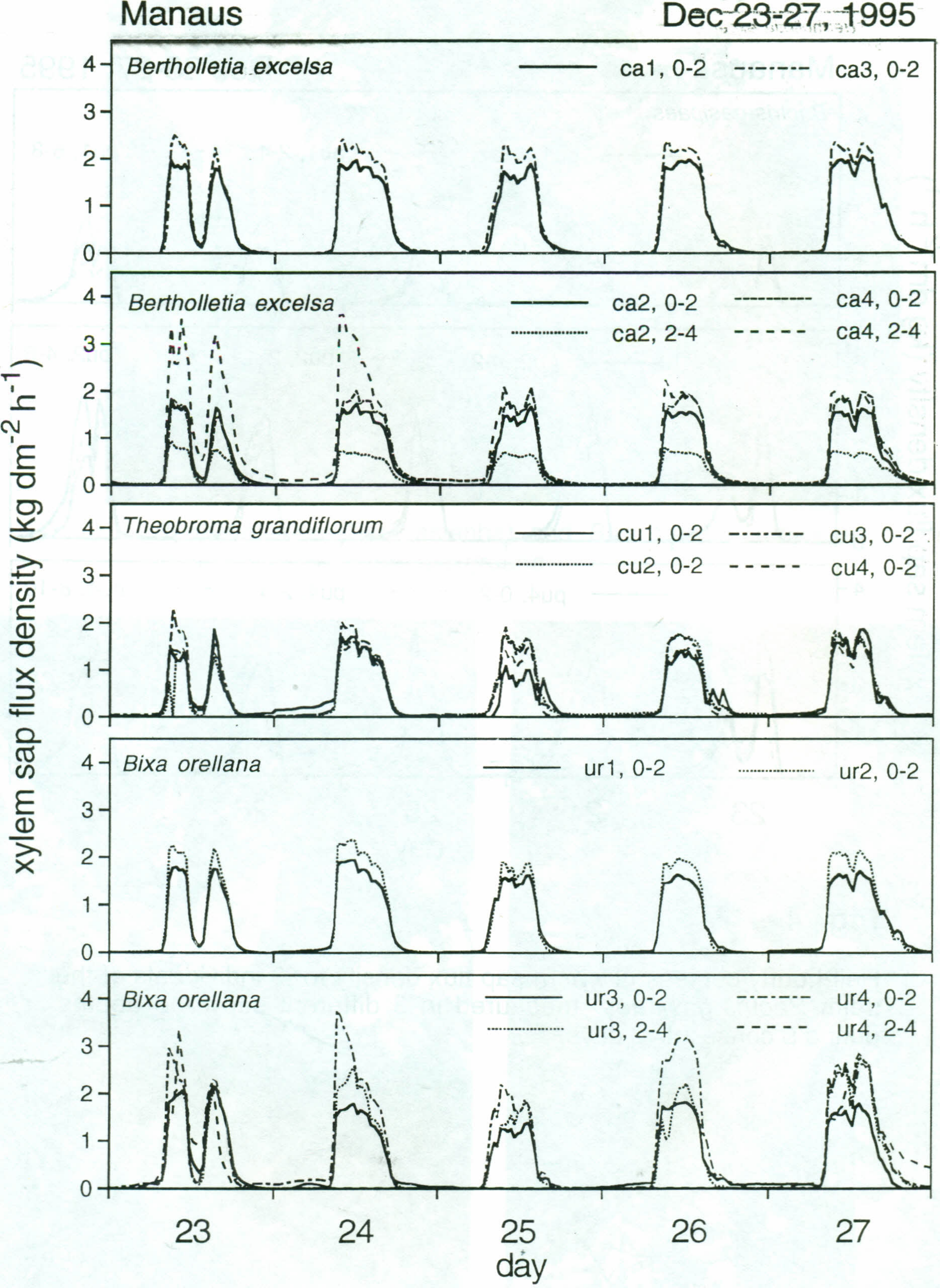

Fig. 3

Half-hourly courses of xylem sap flux density for 3 dicotyledonous species (4 individuals per species) measured in different sapwood depth (0-2, 2-4 cm) during 5 consecutive days

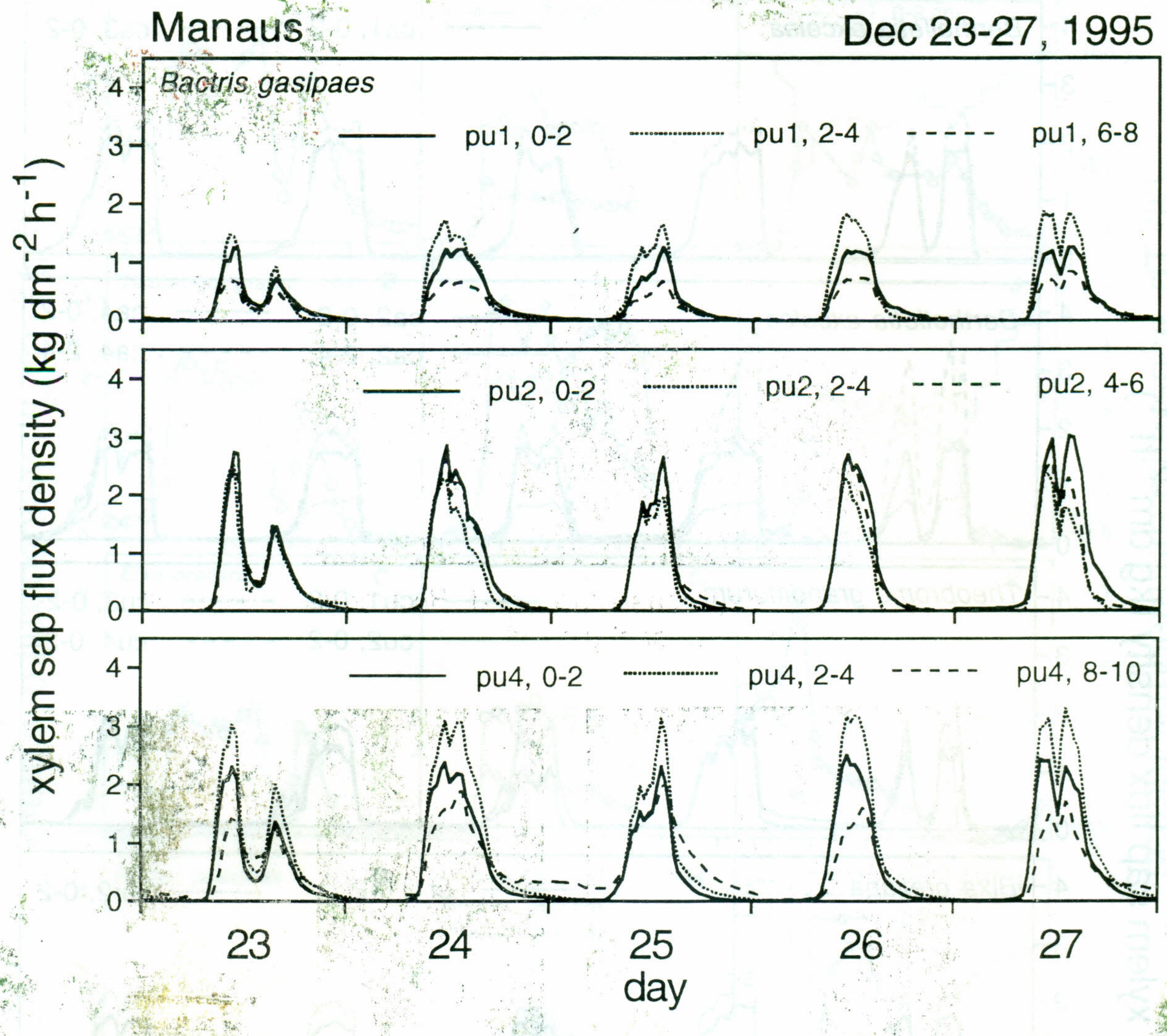

Fig. 4

Half-hourly courses of xylem sap flux density for 3 individuals of the palm *Bactris gasipaes* measured in 3 different sapwood depths during 5 consecutive days

Bertholletia excelsa (castanha) and *Bixa orellana* (urucum) at the right side in the background

Sap flow installation at *Theobroma grandiflorum* (cupuaçu)

Sap flow installation at *Bactris gasipaes* (pupunha)

Fig. 1