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Institute of Soil Science and Soil Geography, University of Bayreuth

and

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

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

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Annual Report 1996

Author: G. Schroth

Abstract

This second annual report of the project summarizes the activities between Januar and Dezember 1996. During this year, the project left the preparatory stage of purchasing, importing and installing equipment and entered into the stage of routine data collection and analysis.

The report is divided into two parts. In the main part, the project team is presented and its acitivities during the year 1996 are briefly summarized. The annexes give detailed accounts of selected research acitivities of the project.

Despite numerous technical problems, all project activities were in principle successful, and there were no major changes to the time plan of the project. The root distribution studies were completed. Significant progress was made in soil physical studies, soil solution and rainwater analyses and stand hydrology (stemflow, throughfall). The laboratory analyses at Manaus faced no major problems. Two visiting scientists carried out supplementary studies (role of invisible leaf wetness films in nutrient uptake) and gave technical and scientific assistance in the equipment of the soil physics laboratory, software installation and use and in the development of the soil physical field measurement program.

Embrapa

Contents

. Introduction

This is the second annual report of the research project "Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus" which started in March 1995. The report summarizes the project activities between Januar and Dezember 1996. During this year, the project left the preparatory stage of purchasing, importing and installing equipment and entered into the stage of routine data collection and analysis.

The report is divided into two parts, the main part and the annexes. In the main part, the project team is presented and its acitivities during the year 1996 are briefly summarized, giving only the most important results. The annexes are written by different members of the project team and the two visiting scientists which the project received during this year. They give more detailed accounts of the different research acitivities, the applied methodology and the obtained results.

The ENV 45 team would like to acknowledge the assistance and cooperation of numerous persons and institutions which proved to be invaluable again during this year. The CNPq and the GKSS-IB provided funds for visiting scientists. The EMBRAPA administration helped to resolve many technical and administrative problems and provided a pleasant environment for our research work. For this, we would like to thank particularly Dr. E.A.V. Morales, the director of the EMBRAPA-CPAA. Of particular importance was also the cooperation of the other SHIFT projects at Manaus and particularly of Dr. Luadir Gasparotto, Dr. Helmut Preisinger and Dr. Oliver Dünisch. Encouragement and helpful comments from Prof. Dr. R. Lieberei are also acknowledged.

2. The ENV 45 research group

The following persons participated in the project activities during 1996:

Name and affiliation	Function
Prof. Dr. Wolfgang Zech (UBT)	German project leader
Dr. Manoel Cravo (EMBRAPA)	administrative coordination
Dr. Götz Schroth (UBT)	German project coordinator in Manaus; supervision of all project activities, soil solution studies, laboratory analyses, project administration (since 16. Jan. 1997: Univ. Hamburg)
Wenceslau Geraldes Teixeira (EMBRAPA)	coordination; soil physics, soil fertility analyses and fertilizer recommendations
Ecila Villani (CNPq fellow)	soil chemistry, laboratory analyses
Olivio Pedro Faccin (CNPq fellow)	soil water measurements, soil physics
Francis Wagner (CNPq fellow)	microclimatology, meteorological stations
Daniel Haag (UBT student)	root distribution studies
Marc-Andree Wolf (Univ. Braunschweig student)	above-ground biomass and allometrics
Luciana Ferreira da Silva	field technician
Rosangela Maria Auzier Seixas	laboratory technician
Luiz Gonzaga Seabra	field worker
Francisco Arragao	field worker

New in the project group is Francis Wagner, who conducts microclimatological studies in the experiment and collects the data from the two meteorological stations in the SHIFT area. He joined the project in August 1996. Ecila Villani left the project group at the end of the year 1996 to take up a Ph.D. course at the University of Vicosa. She plans to conduct her Ph.D. work in the SHIFT experiment. Daniel Haag and Marc-Andree Wolf left Manaus in the first half of 1996 to complete their data analysis in Germany. Daniel Haag has completed his diplom thesis in March 1997.

3. Project activities during 1996

Water and nutrient flux measurements

The installation of the field equipment for the water and nutrient flux measurements was more or less completed until March 1996. The treatments, in which equipment was installed are the following: polyculture system 2 with pupunha (Bactris gasipaes), cupuacu (Theobroma grandiflorum), castanha (Bertholletia excelsa) and urucum (Bixa orellana) in two fertilization levels, cupuacu monoculture, pupunha monoculture, young Vismia fallow and mature rain forest. In the latter, the installations were made at two relatively frequent tree species in this forest, Eschweilera sp. (Matamata) and the palm Oenocarpus bacaba (Bacaba). Eschweilera is a genus with numerous very similar species which cannot be distinguished from the ground.

Every treatment and position within the plots is replicated threefold (see Annual Report 1995 for details of the experimental design). The field installation presently consists of 196 rainfall collectors, 60 stemflow collectors, 330 tensiometers (in 66 positions and 5 depths: 10, 30, 90, 150, 250 cm), 198 TDR-sensors (3 depths: 30, 90 and 150 cm; 10 cm is still measured with mobile sensors, but fixed sensors for this depth have already been ordered and will be installed as soon as they arrive) and 198 suction cups (3 depths: 10, 60 and 200 cm). In the following, problems encountered and preliminary results achieved will be summarized briefly for each of the activities involved in the water and nutrient flux measurements. More definite conclusions and an integrated analysis of the data are only possible after completing at least an annual cycle for each type of measurement.

Rainfall, stemflow

Since March, rainfall and stemflow collector readings have been made after every rainfall (with the exception of the weekends and some holydays). This was necessary because the stemflow of some tree species is very high and requires an installed collection volume of more than 100 l per tree even if the collectors are emptied daily. Rainfall collection usually takes about 3 hours for two persons. In addition, the installed equipment needs frequent replacement and reparation works, so that the total requirements in manpower for these measurement are considerable. At present, the responsibility for these activities is assumed by the field technician of the project, Luciana Ferreira da Silva. From April 1997, when one annual cycle of data collection has been completed, the rainfall and stemflow measurements will be reduced to one event per week.

The most significant results from the rainfall and stemflow measurements are the following:

- The stemflow of some species is very high; especially fruit-pupunhas may produce 100-150 l or more of stemflow from an individual tree during a strong rainfall event (e.g. 70 mm). Some big castanha individuals produce similar stemflow quantities, but the stemflow of most individuals is much lower. This may have consequences for nutrient distribution within the plots: as fertilizer is distributed around the individual plants and not covered with soil, nutrients may be washed away from the stem by surface runoff if stemflow exeeds the infiltration capacity of the soil near the tree. This will be tested in future work.

- The stemflow differs drastically between the species within a polyculture system: when a pupunha tree produces 100 l of stemflow, an urucum individual may produce less then 5 l. The other trees (castanha, cupuacu) are intermediate between these extremes.

- The two tree species from the primary forest which are included in the monitoring produce much lower stemflow than morphologically relatively similar trees in the agricultural experiment (e.g. bacaba vs. pupunha).

- The analysis of the rainfall and stemflow data will concentrate on the minimum measurement requirements which allow the prediction of throughfall and stemflow under a particular tree individual and/or species from rainfall data as collected by automatical meteorological stations.

Soil water measurements

Tensiometer and TDR readings were made since spring 1996 once or twice a week. For two persons, it proved difficult to complete the readings for the whole installation on one day. In case of rainfall during the afternoon (rather the rule than the exception during the rainy season), two days are necessary for a single reading of all sensors.

At the beginning of the data collection with the TDR technique, the calibration of the equipment was tested by gravimetric determination of water contents and was found unsatisfactory. For this reason, a large number of TDR measurements was taken from soil samples from different depths and different positions in the experiment and in the adjacent primary forest, and the gravimetric water content and the bulk density of the soil was determined simultaneously with 100 cm^3 metal rings. Data of this kind were collected during the rainy and the dry season, and positions with different bulk density, vegetation cover etc. were included. From the obtained data, a site-specific field-calibration for the TDR devices was obtained (see work report by Teixeira et al. in the annexe

). This work was only recently completed (April 1997). With the obtained calibration formula, the TDR readings of the past year have to be corrected before the analysis of the soil water data. For this reason, no soil water data are presented in this report.

Chemical analysis of rainfall and stemflow

Rainwater and stemflow samples were analyzed repeatedly since July 1996. The samples were always collected early on the day following the rainfall event, so problems of sample conservation in the field were avoided. This enabled us to fractionate nitrogen and phosphorus into their organic and inorganic components (ammonium/nitrate/organic nitrogen; orthophosphate/organic P forms). Further analyses conducted on these samples were: pH, conductivity, concentrations of K, Mg and Ca.

It is to early to draw conclusions on nutrient imports via rainfall etc. because the number of rainfall events analyzed so far is too small and the yearly cycle has not yet been completed. Preliminary conclusions are the following:

- Nutrient concentrations in the throughfall do not show major differences between species, but stemflow does: stemflow from urucum has significantly higher nutrient (especially P) concentrations than stemflow from all other species. This is partly an effect of the lower amount of stemflow (see above); nevertheless, high nutrient concentrations in a small amount of stemflow may be much more favourable for plants, soil fauna, soil microorganisms etc. near or under urucum than low nutrient concentrations in a huge quantity of water as the stemflow of pupunha.

- About 50% of the N and 90% of the P in rain and stemflow are in organic forms, so that measurements which do not take these into account would be grossly in error. Reasons and effects of the high contribution of organic constituents to total P deserve further study.

Analyses of soil solution

Soil solution samples have been collected for analysis about once per month since May 1996, with the exception of the dry months September to November, when no soil solution could be extracted. The collection of the solution samples takes always about two weeks during which suction has to be applied repeatedly to the ceramic cups. Analyses of samples which had been conserved during the collection time with sulfuric acid showed that almost all the nitrogen in the samples was present as nitrate, even very shortly after the application of urea fertilizer. Organic nitrogen was a proportion of only a few percent of the total nitrogen in the sample. As sample preservation with acid caused severe problems in the laboratory analyses and preservation with chloroform seemed too problematic because of the large number of samples, we decided to collect the solution samples without preservation and analyse only total nitrogen instead of a fractionation into the different nitrogen forms. Additional studies concerning transformations of different N forms in the soil are planned. Other measurements which were made in the solution samples were pH, conductivity, and concentrations of K, Mg, Ca, hydrolyzable Al (i.e. Al in solution including forms associated with complexing agents such as polyphosphates) and Cl (as a tracer for potassium fertilizer movements in the soil). The Cl measurements had to be discontinued in early 1997 because of instrument failure.

Phosphorus cannot be analyzed in samples from ceramic cups because this element is strongly retained by the ceramic material. In late 1996, we installed suction cups from an inert plastic/quartz material (PTFE) in the topsoil (5-10 cm depth) in different positions in the experiment. Because of the high cost of these cups, only a selection of positions could be equipped in this way. After the equilibration time, some soil solutions extracted with these cups have already been analysed for total (including organic) P. First measurements indicate that total P can be detected in the soil solution, whereas orthophosphate cannot be detected with our equipment (detection limit: about 2 ppb).

Nutrient concentrations in the soil solution have to be analysed together with water flux data, or more precisely: with an integrated water-nutrient-transport model. This has not yet been done. However, some preliminary conclusions can already be drawn:

- The nutrient concentration in the topsoil shows strong increases and a very high variability after fertilizer applications. Because of the increased nutrient concentration in the soil solution, aluminium is released into the soil solution following fertilization. The consequences of the increased Al concentrations for root growth, nutrient absorption etc. merit study.

- The nitrogen concentration in the soil solution under the trees increases from 60 to 200 cm soil depth. This is contrary to expectation: subsoils of tropical oxisols are generally assumed to be very nutrient-poor. This is not the case here; the subsoils contain significant amounts of mineral nitrogen, even when the nitrogen in the topsoil has already been depleted. The comparison with the unfertilized Vismia plots and with the primary forest shows clearly that the subsoil nitrogen is leached fertilizer nitrogen. Leaching of fertilizer nutrients may explain why several of the investigated tree species do not (yet) show a response to fertilizer treatments (see SHIFT ENV 23, Final report, 1997).

- There is always a relatively high concentration of mineral nitrogen in the soil solution under the Pueraria between the tree crops, even when the nitrogen under the trees has already been depleted (the sampling point under Pueraria is at only 3-4 m distance from the next trees!). This means that nitrogen is still available in the system, but despite the considerable lateral extent of the root systems of some trees (see report by D. Haag in the annexe) the transfer of this nitrogen to the trees is insufficient. This raises two questions: Why do the trees not use this nitrogen? How can the nutrient transfer from the Pueraria to the trees be improved?

These observations had several consequences for research and management activities in the experiment:

- As a first step to improve the nutrient transfer between the cover crop and the trees, Pueraria will now be left growing under the trees and will not be drawn away by the workers as they used to do until now (this decision had already been taken before, but had not been enforced). An exception to this rule is Citrus where the soil around the stem must be kept free for phytosanitary reasons.

- We proposed a modification in the fertilizer treatments which has now been adopted by the other project participants and has first been applied in the experiment in Dezember 1996: In polyculture systems 1 and 2, the 30% treatment without mycorrhizal inoculation will not receive nitrogen fertilizer any more. We hypothesize that the trees will develop a stronger ability to compete with the Pueraria for nitrogen when they are not supplied with this nutrient at the stem base. The same treatment will also not receive any lime and will gradually be developed into a system which receives only the minimum inputs which are necessary to sustain the system.

- We collected soil samples in more than 60 positions in the experiment and the adjacent primary forest until a depth of 2 m to investigate the potential role of the subsoil in plant nutrition on this site. The analysis of these samples is currently in progress.

- In cooperation with EMBRAPA researchers from other SHIFT projects and researchers which have not yet participated in SHIFT, we prepared a proposal for the SHIFT program about integrated plant nutrition for important tree crops of the region. This proposal is an attempt to protect the Amazonian environment from the danger of nitrate leaching, substitute N-fertilizer by biological N-fixation and provide basic knowledge about the nutrient management of some of its major agricultural crops.

Above- and belowground biomass and nutrient accumulation

The belowground biomass in a polyculture system and, for comparison, spontaneous Vismia fallow had been determined by excavating one plot (D12) during 1995 (see work report by Daniel Haag et al. in Annual Report 1995). Fine root washing and sorting extended into 1996. The analysis of the data has recently been completed and the results have been presented in the form of a Diplom thesis at the University of Bayreuth. The summary of this work can be found in annexe.

In addition to this work, during which we quantified the amount and distribution of root mass and root length in the plots, a study of three-dimensional, small-scale distribution of soil fertility has been carried out by Ecila Villani. She analyzed subsamples from the same soil cylinders from which the fine roots had been extracted for C, N, Mehlich III-extractable P, K, Mg and Ca, KCl-extractable acidity (Al and H) and pH. The samples include soil from below different tree species, different distances from individual trees (gradients) and soil depths down to 150 cm. There have been some analytical problems, so that the analysis of these data is still in progress and the results will be presented in a later report. However, some conclusions can already be drawn:

- There is a very pronounced decrease in soil fertility between 35 cm and 80 cm from the trunk of the trees. As all samples were taken outside the former planting hole, the nutrient enrichment at 35 cm distance is therefore a result of fertilization in the proximity of the trunk, eventually in combination with some nutrient transport (through mass flow and diffusion) out of the planting hole. This sharp decrease in soil fertility already at a small distance from the trees can explain pronounced decreases of tree root mass with increasing distance from the trunk already within the first meter (D. Haag, annexe). Restricted lateral root development may thus be a consequence of fertilizer application too close to the plant.
- Although soil fertility is clearly concentrated in the topsoils, the subsoils show a certain potential to contribute to plant nutrition; e.g. plant-available P in low concentrations could be extracted from all soil samples even at 100-150 cm depth. This point will be considered in more detail in the aforementioned subsoil fertility study.

A more complex analysis will attempt to establish relationships between the distribution of fine roots and soil fertility. These are expected to influence each other, as roots proliferate typically in fertile microsites, where they may later enrich the soil organic matter with their decomposition products.

Aboveground biomass and nutrient accumulation in the plots of polyculture system 2 and the pupunha and cupuacu monocultures is currently quantified by Marc-Andree Wolf (see his work report in the Annual Report 1995). After establishing allometric relationships for the biomass estimation of castanha, cupuacu and pupunha, extensive inventories were carried out in the experimental area with the aim of quantifying both standing biomass and its dynamics with time. Samples of the different tissue types of each of the plant species were taken in May 1996 and were analyzed for main and micronutrients in the EMBRAPA laboratory in Manaus. The final analysis of the data is still in progress, but the final results will be available during 1997.

Soil physics

Both conceptually and in practical terms, the soil physical component of the project has made a major step forward during the stay of Prof. Dr. Bernd Huwe at Manaus in April/May 1996 (see his work report in the annexe). Prof. Huwe is principal advisor of Wenceslau Teixeira's doctoral thesis at the University of Bayreuth. His travel to Manaus was made possible by financial support from CNPq and GKSS-IB.

As has been pointed out in the Annual Report 1995, the role of soil physics in the project is on the one hand to quantify soil parameters involved in the water fluxes (especially macroporosity and near-saturated hydraulic conductivity of the soils as influenced by experimental treatments and plant species) and on the other hand to relate physical soil fertility to characteristics of the plant species under study. This project component depends thus heavily on field measurements, which however need to be complemented by measurements under more controlled conditions in the laboratory.

During Prof. Huwe's stay, the soil physical field equipment purchased by the project (infiltrometers etc.) was tested, several new measurement devices were installed in the laboratory, soil physical and simulation software was installed and demonstrated, and a work plan for the soil physical studies was developed. As the whole concept of the project depends on the quantification of "deterministic" heterogeneity of soil properties (i.e. soil properties as influenced by certain tree species or management measures), it was necessary first to obtain an idea of the "stochastic" heterogeneity present, i.e. heterogeneity which cannot be explained with the currently available information. This was done by measuring some soil physical properties on transects within different treatments of the experiment and calculating semi-variograms (see Prof. Huwe's work report).

Based on this information, a measurement design was developed for the quantification of some important soil physical properties in the experiment at different levels of presicion: in the whole area; on the plot level and around individual plants. The following data collection by Wenceslau Teixeira concentrated on near-saturated infiltration measurements (quantification of macroporosity) with the tension-infiltrometer near different tree species in the treatments under study. In the same positions, cylinder samples were collected for the measurement of bulk density, saturated conductivity, water retention curves and root mass/length density. This information is particularly important for transport processes in the soil (water infiltration, nutrient leaching) and the capacity of different tree species for regenerating physically degraded (compacted) sites.

From 25 August to 23 September 1996, Wenceslau Teixeira visited Bayreuth and Bonn, where he presented a poster about the SHIFT project on the "9th International Conference on Soil Conservation", 26-30 August, in Bonn. In Bayreuth, he received training in the utilization of software packages for soil physical and geostatistical data analysis and further developed the measurement plan for Manaus based on an initial analysis of the field data so far obtained.

An important activity of the soil physics group (W. Teixeira, Olivio Faccin) was the calibration of the TDR sensors for the soils of the experiment. Preliminary tests showed that neither the internal calibration curve of the used TDR devices (from Easy Test, Poland) nor the factory-supplied adjustment function for soils of low bulk density (as those under study) gave satisfactory matching with the gravimetric/volumetric determination of soil water content. As mentioned before, a large amount of combined TDR and gravimetric/volumetric soil water measurements were made in the field during 1996 at different water contents, at different positions (species, treatments) and in different depths. As a result, an adjustment function has been developed which allows the transformation of the TDR readings into volumetric soil water content (see report by Wenceslau Teixeira et al. in the annexe).

Existence and ecological function of invisible wetness films on plant leaves

The cooperation of the project with Dr. Jürgen Burkhardt from the Insitute of Agro-ecology of the University of Bayreuth which had started in 1995 (see his work report in the Annual Report 1995) continued also in 1996 (see his work report in the annexe). This cooperation was made possible by financial support for travel from CNPq.

With the help of a specially designed "leaf-surface conductivity meter", Dr. Burkhardt has discovered invisible wetness films which cover the surface of plant leaves at high atmospheric humidity. These wetness films are strongly influenced by the presence of hygroscopic substances on the leaves, e.g. some aerosols. There is evidence that the wetness films extend during the daytime into the open stomata of the plant leaves and form a bridge for the exchange of nutrients and other dissolved substances between the leaf surface and the interior parts of the leaf. This is in contrast to the earlier perception that liquid water cannot pass the stomata. Such a bridge would facilitate the uptake of nutrients dissolved in rainwater into the leaves, e.g. of forest trees, but would also make them more vulnerable to atmospheric polutants and to nutrient leaching out of the leaf. Wetness films may also play a role in the uptake of foliar applied fertilizer nutrients.

During his second stay at Manaus in April 1996, Dr. Burkhardt produced further evidence for the existence of such wetness films also on tropical tree leaves. A difference to the results from October 1995 was that the wetness films developed only at higher atmospheric humidities, presumably because there were less hygroscopic substances on the leaf surfaces during the rainy season (April) than during the dry season (October). Foliar fertilization reduced the atmospheric humidity necessary for the formation of the wetness films, thereby effectively extending the wetting time of the leaves.

^{15}N which was applied to urucum leaves either during the day (open stomata) or during the night (closed stomata) was more rapidly taken up at daytime, giving support to the aforementioned hypothesis. However, Citrus leaves showed contrasting behaviour, for still unclear reasons. From these results it was concluded that foliar fertilizers would be taken up by the plants most rapidly during the early morning hours.

Interestingly, no wetness films could be measured on old castanha leaves. Possibly, these leaves are very inefficient in the uptake of nutrients from rainwater, but are also better protected against nutrient leaching and leaf pathogens than leaves which form invisible wetness films.

Laboratory

One of the major strategic decisions taken during the preparation of this project was that all analyses should be made at EMBRAPA, Manaus, with exceptions only in very special cases. Until now, the project has achieved this goal; the exceptions were ^{15}N-analyses and CN-measurements in some very small fine root samples which were made at Bayreuth. The soils and plant laboratory of EMBRAPA was equipped with an uninterrupted energy supply (UPS plus diesel generator) as a basis for all further developments. A segmented flow analyser (SFA) was installed with the capacity to measure ammonium, nitrate, total nitrogen (on-line UV-digestion), phosphate and hydrolyzable aluminium. With temporary help of Kai Möller, a technical assistant from Bayreuth University, the SFA was prepared for routine nutrient analyses in March/April 1996 and worked without major problems since this time. In June 1996, the module for total N analysis was transformed into a dual application module for the analysis of both total N and total P. This allowed the total P measurements in the rainfall and stemflow samples (see above). Since March 1997, a separate module for organic P measurements is available. The presence of the analytical laboratory in Manaus avoids problems of sample conservation for the analyses of organic and inorganic N and P in solution samples.

A further major improvement of the soils and plant laboratory of EMBRAPA to which the project contributed was the installation of several measurement devices in the soils physics laboratory during Prof. Huwe's visit in Manaus. As mentioned before, these include devices for the determination of saturated and unsaturated hydraulic conductivity of soil samples, and water retention curves with special emphasis on the near-saturated range.

At present, it can be said that the laboratory provides a good basis for present and future research activities at EMBRAPA.

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

As pointed out in the Annual Report 1995, the beginning of the field measurements had been delayed until approximately one year after the start of the project (March 1995). During 1996, there were no major discrepancies between the time plan of the project and the progress of the work. However, technical problems with the soil water measurement devices (tensiometers, TDR sensors) and especially the difficulties of reimporting the TDR devices after they had been repaired by the supplier caused periodical interuptions of the soil water measurements.

There were no changes in the work plan since the Annual Report 1995 in which some differences in the experimental design from the original proposal had been outlined.

5. Cooperation with EMBRAPA, University of Hamburg and University of Göttingen

EMBRAPA-CPAA

The cooperation between the project and EMBRAPA is necessarily very close, especially in the laboratory. There is also frequent exchange of information and opinions of project staff mainly with

Wenceslau Teixeira (who prepares a doctoral thesis within the project and participated in its coordination since the beginning) as well as Dr. Cravo, Dr. Gasparotto and many other EMBRAPA researchers.

Information about the SHIFT project is regularly offered to interested EMBRAPA researchers via the internal communication periodical of the project, "SHIFT-Info", which has appeared in four numbers during 1996. The SHIFT-Info is jointly edited by a German and an EMBRAPA member of the SHIFT team (G. Schroth from ENV 45/23 and Marcos Garcia from ENV 52). The periodical is also sent to the working groups in Germany which participating in SHIFT Manaus.

Since March 1997, there are regular SHIFT seminars at EMBRAPA to which interested researchers are always wellcome.

University of Hamburg

The coordination between ENV 45 (Bayreuth) and ENV 23 (Hamburg, Institute of Applied Botany) was very close during 1996 because after the departure of the former coordinator of ENV 23, Dr. Helmut Preisinger, in March 1996, the coordination activities were assumed by G. Schroth from ENV 45. During this time, a joint project proposal on integrated plant nutrition was developed by researchers from both projects which has been submitted to the SHIFT program.

Cooperation with ENV 42 (BFH Hamburg) occured commonly on the technical level (e.g. the technician of ENV 42 was trained by a technician from ENV 45 in the fabrication of stemflow collectors). On the scientific level, information and data were exchanged between the projects for the analysis of biomass and nutrient accumulation in castanha by the student Marc-Andree Wolf from ENV 45. Joint activities were also envisaged concerning biomass and nutrient accumulation in paricá trees (Schizolobium amazonicum). Paricá is currently being taken out of polyculture system 3 because of the threat to other tree crops from falling tree tops. Paricá breaks frequently during rainstorms.

University of Göttingen

There were no coordinated activities between the projects during 1996. In November 1996, the SHIFT project in Belem was visited by G. Schroth together with other EMBRAPA researchers from Manaus (Dr. Cravo, Wenceslau Teixeira, Elisa Vandelli) to obtain some information about ongoing and planned activities and for a first contact with the project participants.

6. Conclusions

During 1996, the project has entered into the phase of routine data collection and analysis. Although every single measurement technique had its problems and delays, the main components of the project were in principle successful. During 1997, some measurements will be continued or even intensified (e.g. chemical analyses of rainwater and soil solution, soil water dynamics), whereas others may already be reduced in their intensity (rainfall and stemflow collection), thereby leaving more flexibility for other activities.

Although all of the project's activities are still in progress and no definite conclusions have yet been reached, several interesting lines of evidence have been produced during the past year which deserve further investigation:

- There is evidence for nutrient leaching even in the low-fertilizer treatments which may explain unexpectedly low fertilizer response of some crops.

- Sharp soil fertility gradients around individual trees as a result of earlier fertilizer placement may discourage tree roots from exploring effectively the available space.

In addition to the already demanding routine measurement program (water and nutrient fluxes), a considerable amount of work has accumulated in front of the project team: For example, several hundreds of soil samples have been collected for the analysis of subsoil fertility and its relationships to the different plant species and treatments. Also, the data from the different parts of the project await an integrated analysis. Moreover, new and interesting questions appear continuously: What exactly is the relationship between cover crop and tree crops in terms of nutrient and water availability - does the cover crop always facilitate tree growth or is there also competition? What is the fate of P fertilizer in the soil and what are the consequences for P-fertilizer forms, their timing of application and distribution in the plot? When, where and in which form should mobile fertilizer nutrients (N, K) be applied in the systems to minimize unproductive losses? What are the rapid processes that occur in the soil during heavy rainfall, in addition to the slower processes which can be measured with the equipment currently in use in the project? What is the long-term effect of the strongly differing litter quantity and quality under the different tree species on soil organic matter and soil fauna? These and many other questions are highly relevant to the development of sustainable land use systems.

Annexe 1: List of visiting scientists during 1996

1) Dr. Jürgen Burkhardt

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

7 April - 28 April 1996

2) Prof. Dr. Bernd Huwe

University of Bayreuth, Department of Soil Physics, D-95440 Bayreuth, Germany

15 April - 3 May 1996

Annexe 2: Publications

W.G. Teixeira, G. Schroth, E. de Albuquerque Villani, O.P. Faccin, F.W. Silva Correia, M. da Silva Cravo, B. Huwe, W. Zech, 1996: Fluxos de água e de nutrientes como indicadores da estabilidade de diferentes sistemas de uso da terra na Amazônia. B. Inf. da SBCS 21 (3): 105-107

W.G. Teixera, G. Schroth, W. Zech, B.Huwe, 1996: Land use systems in degraded areas in the western amazon region of Brasil. 9th Conference of the International Soil Conservation Organisation (ISCO), 26-30 August 1996, Bonn (Abstract)

W.G. Teixeira, E.M.A Villani, 1996: Variabilidade espacial de características químicas do solo em um latossolo amarelo, com utilizacao agricola anterior. 22 th Reuniao Brasileira de Fertilidade do Solo e Nutricao de plantas, 21-26 July, 1996, Manaus. (Abstract)

W.G. Teixeira, G. Schroth, O.P. Faccin, B. Huwe, W. Zech, 1997: Avaliacao de parâmetros físico-quimicos e hídricos do solo como indicadores da recuperacao de areas degradadas na Amazônia ocidental. III Simpósio Nacional sobre Recuperacao de Áreas Degradadas, 18-24 May 1997, Ouro Preto, Brazil (Abstract)

W.G. Teixeira, O.P. Faccin, G. Schroth, C.P. de Azevedo, B. Huwe, 1997: Calibracao da tecnica de TDR para avaliacao da umidade do solo em um latossolo amarelo textura muito argilosa - avaliacao no campo. XXVI Congresso Brasileiro de Ciencia do Solo, 20-26 June 1997, Rio de Janeiro, Brazil (Abstract)

Annexe 3: Summary of the Diplom thesis of Daniel Haag, Institute of Soil Science and Soil Geography, University of Bayreuth:

Root distribution patterns in a polycultural system with local tree crops on an acid upland soil in central Amazonia

Part A: Belowground biomass

Root biomass and its distribution in space and among pools of different turnover rates are keys to the understanding of the biomass allocation patterns and the root architecture of different species and of the stock and distribution of biomass and the nutrients within a system. Moreover, the root biomass of competing land use systems is of outstanding importance in the context of global warming. The distribution of root dry matter (DM) was studied in a polycultural system on a Xanthic Ferralsol in central Amazonia. The system consisted of Bixa orellana (Urucum), Bertholletia excelsa (Castanha), Theobroma grandiflorum (Cupuaçu), Bactris gasipaes (Pupunha; a palm, used for the production of both palmito and fruits) and Pueraria phaseoloides as a cover crop. Additionally root mass of adjacent spontaneous vegetation (Vismia japurensis and V. cayennensis) was examined.

Characteristic differences in the ***distribution of coarse roots*** (CR) were detected under the different trees: Castanha (Cas) and Cupuaçu (Cup) both possess massive tap roots, that exceeded a vertical length of 1 m. However, lateral root extension was fairly limited (within 2 m from the tree 88 % of Cup and 95 % of Cas CR were found). Root DM of the trees ranged between 50-120 g/m² under Castanha and 25-80 g/m² under Cupuaçu. Under Cas and Cup other species (Pueraria, Pupunha, Urucum) contributed considerably to total root mass.

The central root of Urucum (Ur) split up in a depth of 30 cm, giving way to a number of coarse laterals. Urucum roots dominated CR mass in the proximity of the tree. Coarse roots were essentially restricted to the upper 60 cm of the soil, but the lateral extension exceeded 3 m in places. Hence within a radius of 2 m from the tree only 75 % of total CR were found. Urucum coarse root DM ranged between 300-500 g/m² within 2 m from the tree.

Pupunha coarse roots started out from the base of the trunk. They continued on the one hand along a *horizontal* plane, in which Pupunha CR were largely restricted to the topsoil, where they dominated root matter and where they attained a maximum length of 4 m. Due to their lateral extension, a high percentage (23 %) of Pupunha CR was found beyond a distance of 2 m from the tree. On the other hand, Pupunha roots grew along a *vertical* axis, i.e. close to the projection of the stem, where they attained sizeable root mass concentrations to a depth > 1 m. DM of CR was in the range of 800-900 g/m² under the Palmito-Pupunha and 1000-1200 g/m² under the Fruit-Pupunha.

The trees had in common that the bulk of coarse and fine roots was concentrated in the topsoil (except for the coarse roots of Castanha, which attain a maximum concentration in 10-30 cm or 30-60 cm). Abrupt changes in the morphology of the dicot central roots were linked to the lower boundary of the planting hole. In the interspaces between the trees, i.e. under Pueraria, generally very low values of CR mass were attained.

Live ***fine root*** (LFR) concentrations were in the order of 140-160 g/m² under the dicot trees, of 50-85 g/m² under Pueraria, of 220-290 g/m² under Palmito-Pupunha and of 330-430 g/m² under Fruit-Pupunha. Dead fine root (DFR) mass under the dicot trees was 50-65 g/m², whilst under Pueraria half this value was achieved and under Pupunha twice as much. On the pit level, one third of fine roots (FR) classified as dead.

The distribution of FR generally follows CR distribution, the bulk being concentrated in the upper 30 cm of the soil. Generally more than 65 % of total FR mass to a depth of 150 cm were localised there. This value is relatively low, if compared to tropical primary forest. LFR contributed approximately 5% to total below-ground matter in Castanha, 6% in Urucum, 14% in Cupuaçu, 36% in Pupunha and 98% in Pueraria.

Root-shoot ratios (RSR) of the dicot trees were similar (0,27-0,43) and thus higher than the average of primary forests in Amazonia (0,19), but comparable to agroforestry species of similar age and to temperate tree species. For Cas, Cup and Ur very good regressions between the biomass of corresponding above- and below-ground plant organs could be established, i.e. between trunk and tap-root biomass and between the DM of branches + twigs and CR. The dry matter of central root plus coarse roots was 0,41 times the DM of trunk + branches + twigs ($R^2 = 0,94$). The RSR of Pupunha varied widely, for Fruit Pupunha it was 0,29 and 0,49, for Palmito-Pupunha it was 0,86 and 1,88, hinting at a disequilibrium between above- and below-ground biomass in the latter.

Average below-ground DM of the plot was 369 g/m², with DFR contributing 15 %, LFR 31 %, CR 43 % and central roots 10 %. Total DM values for Vismia japurensis were slightly higher (500 g/m²), and for V. cayennensis they were considerably higher (2111 g/m²). The below-ground biomass of the polycultural system had a similar order of magnitude as tropical pastures and as tropical succession and plantations of similar age, but it was 16 times lower than in Amazonian primary forest.

Part B: Absorptive Surfaces

Root length distribution governs nutrient and water uptake and thus has important implications for the functional role of a species within a ecosystem, for root competition and for the loss of resources from the system. The distribution of root length densities (RLD) was studied in a polycultural system consisting of Bactris gasipaes, Bixa orellana, Bertholletia excelsa, Theobroma grandiflorum and Pueraria phaseoloides (as a cover crop) on a Xanthic Ferralsol in central Amazonia. Additionally, adjacent spontaneous vegetation dominated by Vismia japurensis and Vismia cayennensis was examined.

Specific root length was similar under the dicot trees of the system (range: 26-30 m/g dry matter), while it was considerably lower under Pupunha (11 m/g). This indicates that to obtain an equivalent root length Pupunha has to allocate 2,4-2,8 times more biomass to its fine roots than the other trees.

The pattern of ***vertical root length distribution*** was very similar under Bixa, Bertholletia and Theobroma, despite substantial differences in coarse root distribution. Under the trees in the upper 10 cm of the soil on the average 81 % of the root length index (RLI, i.e. the sum of root lengths found to a depth of 150 cm in cm/cm^2) were concentrated. RLD distribution patterns under Pueraria were similar to the trees, except for the intimate association which Pueraria (fine) roots formed with the litter.

Pupunha roots grew both along a horizontal plane, where they were largely restricted to the topsoil, and along a vertical axis, where they remained confined to the area of the projection of the stem. Accordingly, in 35 cm distance from the tree more than 80 % of RLI was localised below a depth of 10 cm (70 % in 80 cm distance). On the other hand, in the horizontal direction Pupunha roots dominated the upper 10 cm up to a distance of 3 meters from the tree, while they attained very low root lengths below 30 cm.

In the ***upper 10 cm of the soil*** RLD was rather similar under the trees: Mean RLD was 1,98 cm/cm^2, which can be regarded as sufficient for the rapid uptake of mobile nutrients and water, but not of less mobile nutrients. Under Pueraria mean RLD in 0-10 cm was 0,82 cm/cm^2. In ***10-30 cm*** a sharp drop of RLD was observed, with most values remaining below 0,4 cm/cm^3. In ***100-150 cm*** RLD values tended to be higher under Pueraria and Pupunha (in 80 cm distance) than under the dicot trees, but RLD was generally very low ($\ll$ 0,1 cm/cm^3).

RLI ranged between 30 and 60 cm/cm² under the trees. The wide discrepancy in above-ground biomass among the trees is thus not reflected in overall root length. The contribution of coarse roots to overall root length was negligible under the dicots, but considerable under Pupunha (16-22 %). RLI under Pueraria ranged between 20 and 30 cm/cm², indicating potential gaps of absorptive capacity in the Pueraria interspaces between the trees.

Root length distribution under ***Vismia*** was more superficial than under the other trees (below 30 cm only 4-8 % of RLI were found), but RLD in 0-10 cm and RLI were in the range of the trees of the polycultural system.

Annexe 4: Work report about the travel of Jürgen Burkhardt to EMBRAPA/CPAA, Manaus, Brazil, 7.-28.4.1996:

Experiments on microscopic leaf wetness and foliar uptake of nutrients with two useful tree species in central Amazonia

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Abstract

Electrical conductance measurements were carried out on the surface of leaves of six tree species at EMBRAPA-CPAA near Manaus, Brazil. These measurements are indicate for three phenomena: The existence of invisible wetting produced by hygroscopic substances on the leaves; stomatal transpiration leading to recondensation of transpired water vapour on the leaves; cuticular water content. In most cases, these three phenomena can be separeated due to different time scales of the relevant processes.

Invisible wetness was detected starting from about 85% relative humidity (rh) which was considerably higher than in October, 1995, when water films had started to form at 70% rh. This difference was possibly due to the frequent rains during April, which removed hygroscopic substances from the leaf surfaces. Overall, the visible wetting time was 73% (approximately 17% by rain and 56% by dew), invisible wetting occurred during 20% of the time, and during 7% of the total time no wetting was detected. No invisible wetting could be detected on old castanha (Bertholletia excelsa) leaves. The duration of invisible wetting was extended by foliar fertilization. Electrical conductance data of urucum leaves were compared with xylem sap flow and photosynthesis measurements of the same tree.

The contribution of the stomata to nutrient uptake through the leaf was investigated by applying a solution containing ^{15}N-labelled nitrate and phosphate to the leaves of urucum (Bixa orellana) and citrus (Citrus sinensis) either during the day (open stomata) or during the night (closed stomata). The highest nutrient values for citrus were found in the untreated control, indicating a dilution

effect, possibly caused by incomplete drying. For the more delicate urucum leaves, a twofold increase in nutrient uptake at daytime compared to the night gave evidence of the potential role of open stomata as a path of nutrient uptake.

Introduction

The surface of leaves, the phyllospere, is the plant's interface with its atmospheric environment. The prevailing conditions in this zone influence the gas exchange of the leaf, the uptake and release of dissolved substances by the leaf, and the living conditions of organisms on the leaf surface. Water vapour and the presence of liquid water on the leaf surface are the most important factors for the description of these conditions. The vapour pressure deficit of the atmosphere is the driving force for the transpiration of the leaf. Liquid water on the leaf surface, on the other hand, provides the medium through which nutrients can be taken up by the leaf or lost from the leaf, and it is often essential for organisms living on the leaf surface (epiphyllic organisms).

Usually, plant surface wetness is considered to be visible wetness (e.g. raindrops, dew). However, it has recently been found that there is a form of invisible leaf wetness which may persist even on hydrophobic leaf surfaces during extended periods of time (Burkhardt and Eiden, 1994). Plants on which such invisible wetness occurs may thus have "wet leaves" even when the leaves look dry for the naked eye.

Conductance measurements which have been carried out on pupunha (*Bactris gasipaes*) leaves at EMBRAPA-CPAA, Manaus, in October 1995, provided for the first time clear evidence for the existence of such invisible water films on this tropical plant species (see Annual Report 1995 of SHIFT project ENV45, work report by Jürgen Burkhardt). Based on these observations, an extended study was conducted in April 1996 which had the following aims:

- analyse the effect of invisible water films on foliar nutrient uptake and

- test the possibility of using leaf wetness sensors for transpiration monitoring under field conditions.

The effect of water films on foliar nutrient uptake was tested by applying a nutrient solution to the surface of citrus (Citrus sinensis) and urucum (Bixa orellana) leaves during the daytime and during the night and measuring the uptake of the applied nutrients by the leaves. In case of the presence of water films which extend into the stomata, nutrient uptake through the leaf surface would be expected to be higher during the day (open stomata) than during the night (stomata closed). The possibility of using wetness sensors as an instrument to measure transpiration of leaves was investigated by parallel measurements of stemflow (transpiration) and photosynthesis (stomatal conductance). We also tested the possibility of a self-accelerating effect of fungal infections of plant leaves through increased presence of leaf wetness on infected as compared to healthy *Hevea* leaves.

Materials and Methods

a) Leaf wetness measurements:

The leaf wetness measurement system has been described by Burkhardt and Gerchau (1994). Shortly, a pair of electrodes is clamped on the leaf where wetness films are to be measured, and an AC voltage of about 6 V with a frequency of 2 KHz is applied. The electrical conductance determined by this method depends on the presence of liquid water on the leaf surface. The method does not give an absolute quantitative information about the thickness of the wetness films, due to variations in the pressure applied to the leaves by the electrodes. But under normal conditions (no heavy gales) the electzrodes stay stable on the leaves and the signal can be interpreted in a semi-quantitative way.

The sensors were applied to seringueira (*Hevea* spp.), cupuacu (*Theobroma grandiflorum*), pupunha (*Bactris gasipaes*), castanha (*Berthollecia excelsia*), urucum (*Bixa orellana*) and citrus (*Citrus sinensis*) leaves. The sensors were applied to leaves of different age (castanha), to sun and shade leaves (urucum), and to leaves differently affected by fungal diseases (seringueira). One sensor was attached to an urucum leaf which had been dipped into a 0.1 M K_2HPO_4 solution (this type of solution was also used in the foliar nutrition experiment). The sensors were attached to leaves in heights between 2 m and 2.5 m, which represented the middle part of the crown in most cases, except for the castanha trees which were about 10 to 12 m high. Air temperature and relative humidity (rh) were determined by using ventilated psychrometers (3 m and 6 m height) with Pt 100 sensors. Psychrometer as well as conductance data were stored every minute in a datalogger (Delta T).

In order to investigate the relationship between stomatal opening and leaf conductance signal, this method was applied to an urucum tree simultaneously with sapflow measurements and determination of stomatal conductance by an ADC LCA2 IRGA (infrared gas analyser) device (we thank Pia Parolin from INPA-MPI, Manaus, for help with the IRGA measurements).

b) Foliar nutrition experiments:

The uptake of nutrients by the leaves was measured by applying a nutrient solution to the leaves of citrus and urucum. The leaves were dipped into a solution containing 100 mM K_2HPO_4, and 250 µM $Na^{15}NO_3$ in distilled water. The solution was held in position for a moment to recollect dripping water, thereby avoiding contamination of other leaves. Either five or ten leaves of each tree were dipped into the solution. The solution was weighed before and immediately after this procedure in order to determine the amount of solution retained on the leaves. After 3.5 hours, the leaves were cut from the trees and immediately washed first in deionised water for 15 seconds and subsequently in chloroform for another 15 seconds in order to remove remaining solution, contaminants, epiphytes, and waxes. Fresh weight of the leaves was determined in some cases, and the leaf area was measured by a Licor 3100 leaf area meter. Then, the leaves were dried for 4 days at 70°C, weighed for determination of dry weight and ground for analysis. The samples were digested under pressure in HNO_3 conc.. Then, phosphate was determined by the molybdene blue method (Frevert, 1983), and C and N were determined by an elemental analyzer (NA 1500, Carlo Erba, Milano, Italy). $\delta^{15}N$ was detemined by introducing about 1% of N_2 by a 'split interface' (Finnigan MAT, Bremen) into a mass spectrometer (Delta-E, Finnigan MAT, Bremen) where the different isotopes were analysed according to their mass. Ca was measured by atomic absorption spectrometry.

This procedure was carried out with the two species citrus and urucum, including ten trees of both species. Untreated leaves of both species were washed and analysed in the same way as the treated leaves for comparison. The experiment was carried out twice, once at daytime (starting around 9 am), and once after sunset. We hypothesized that a higher nutrient influx into the leaves at daytime would indicate nutrient uptake through the opened stomata via waterfilms extending from the leaf surface into the stomatal opening.

Twigs of some trees were sampled and analysed in the same manner as the leaves to investigate if a relocation of substances (especially ^{15}N) had taken place subsequently to the nutrient uptake into the leaves.

Dew samples were taken directly from leaves of castanha, urucum, and cupuacu in the mornings, by stripping them down from the leaves into plastic vials. Subsequently they were analysed for pH. Analysis for organic acids was done in Germany using HPLC.

Timetable:

date	sensors attached to	other experiments	weather
8.4.	urucum, pupunha,		
	castanha (2), cupuacu		
9.4.	" "		strong wind, rain 9 pm
10.4.	" "	dew samples	rain all day after 11.30 am
11.4.	" "		rain (morning)
12.4.	" "		no rain
	& urucum leaf with K_2HPO_4		
13.4.	" "		hot, no rain all day
14.4.	" "		rain 3 pm
15.4.	" "	dew samples	rain 8 am, 5 pm, 7 pm
16.4.	" "		rain 9 am, 12 am,
17.4.	urucum	prep. foliar nutrition	rain 12 am to 5 pm
18.4.	" "	" "	heavy rain all day
19.4.	" "	IRGA	
		dew samples	rain 11.30 am
20.4.	" "		rain all day

21.4.	" "		no rain
22.4.	" "	foliar nutrition	rain 1 pm
23.4.	" "	foliar nutrition	rain 1 pm, 5 pm
24.4.	" "	IRGA	rain 4 pm
25.4.	urucum, castanha	IRGA	no rain
26.4.	seringueira		
27.4.	" "	foliar nutrition	rain 12.30 pm
28.4.	" "		

Relative humidity was between 75% and 100% throughout the study.

Results

a) Leaf wetness measurements:

The leaf wetness measurements confirmed the existence of invisible water films on most of the investigated species. Invisible wetting is indicated by a non-stochastic relationship between electrical conductance and environmental parameters, principally relative humidity.

A positive correlation between rh and conductance was observed above 85% rh on pupunha and cupuaçu (fig. 1) as well as on urucum and seringueira leaves. This was in contrast to observations which had been made in October 1995, when a positive correlation to humidity had started already at about 70% rh (fig. 2).

Visible wetting time was 73% of the total observation period (approximately 17% by rain and 56% by dew), invisible wetting happened during 20% of the time and during 7% of total time no wetting was detected. All the leaves were very easily wettable, water droplets forming small contact angles. The electrical conductance on old castanha leaves was virtually zero below 95% rh and the signal did not show any humidity related dependence before the formation of visible dew (fig. 3b). On young castanha leaves, in contrast, there was a positive correlation between conductance and humidity (fig. 3e). Old castanha leaves are the only leaves observed so far which do not form invisible wetness films.

Below 85% rh the electrical conductance was either uncorrelated (pupunha, fig. 3a) or negatively correlated to relative humidity (cupuaçu, fig. 3d). The negative correlation of the conductance signal can be interpreted as positively related with temperature or vapour pressure deficit ('vpd'- fig. 4 between 11 and 14 hours). ('vpd' indicates the pressure deficit which is calculated from air temperature as leaf temperatures were not measured.)

A switch was observed between negative and positive correlation of the conductance signal with relative humidity for an urucum leaf (fig. 5 - same day as fig. 4). Another urucum leaf of the same tree which had been dipped into K_2HPO_4 solution the day before showed a closely positive correlation between conductance and relative humidity over the entire time (fig. 5).

The signals observed on 21/04 and 22/04 for several urucum leaves showed a positive correlation with relative humidity during the day but in the evening the signal decreased contrary to relative humidity and again increased contrary to humidity in the morning (fig. 6). The noisy signal of one of the leaves fig. 6 was possibly because of wind moving the leaf.

The sap flux of this urucum tree was measured at the same time and was positively related to 'vpd' and one of the (noisy) leaf wetness sensors (fig. 7). The positive correlation between sap flux and 'vpd' can also be seen in fig. 8. Minima and maxima of the 2 curves coincided during the day, but the ratio sap flux/'vpd' became smaller towards the evening.

Measurements with the IRGA on 19th, 24th and 25th indicated a cessation of photosynthesis of the urucum leaves on two days around noon (19th, 24th) whereas on the 25th this did not occur.

A strong correlation between conductance and rh was found on seringueira leaves but no difference could be detected between leaves with and without fungal infection during a 2 day measurement.

b) Dew samples

pH in the dew samples of urucum and pupunha (only 1 sample) was below 4, whereas it was higher in dew from cupuacu leaves and castanha (table 1). No organic acids could be detected in the dew samples, which was probably due to unsatisfactory conservation during the transport to Germany.

Table 1 pH values in dew samples:

	Urucum	castanha	cupuacu	pupunha
10.4.	3.5	4.4	4.7	
15.4.	3.7	5.2	4.6	
19.4.	3.5	4.8		3.6

c) Foliar nutrition experiment

Water retention:

The mean projected leaf surface of one leaf was 42.5 ± 1.4 cm^2 (citrus) and 83.6 ± 2.4 cm^2 (urucum). The amount of solution retained by the leaf (calculated as a homogeneous film wetting both sides of the leaf) was 44.4 ± 2.0 μm on citrus and 31.4 ± 0.7 μm on urucum leaves.

The results for nutrient uptake by the leaves differed between citrus and urucum (table 2 and 3, fig. 9). In the case of citrus, ^{15}N, N, and P were different for the different groups. ^{15}N, total N and P concentrations were highest in the control leaves. The dry weight/fresh weight ratio of the control leaves (37.7%) was significantly higher than that of the treated ones (35%). In urucum there was a significant difference for ^{15}N with highest concentration for the day treatment, and lowest for the control. There were no significant differences for the other elements. The fresh weight of urucum leaves had not been determined. For both trees the twigs did not show significant differences between day and night nutrient applications.

Table 2: Foliar concentrations (means) of citrus leaves. Different letters indicate statistically different groups (5% level).

	control	treatment day	treatment night
N (%)	2.39 *a*	2.27 *a*	1.93 *b*
^{15}N (at-%)	0.3691 *a*	0.3686 *b*	0.3682 *c*
C (%)	46.12 *a*	46.54 *a*	47.39 *a*
P (%)	0.19 *a*	0.18 *ab*	0.16 *b*
Ca (%)	0.68 *a*	0.69 *a*	0.72 *a*

Table 3: Foliar concentrations (means) of urucum leaves. Different letters indicate statistically different groups (5% level).

	Control	treatment day	treatment night
N (%)	2.70 a	2.63 a	2.66 a
^{15}N (at-%)	0.3665 a	0.3675 b	0.3670 c
C (%)	48.32 a	48.19 a	47.96 a
P (%)	0.32 a	0.33 a	0.31 a
Ca (%)	0.29 a	0.32 a	0.34 a

Uptake rates for $^{15}NO_3$ on urucum can be calculated using our results and different assumptions:

- A difference of 0.001 at% ^{15}N between control and treated samples (day) had been detected, and a total N-content of 2.65%, resulting in 26,5 mg/g= 1893 μmol/g.

- The mean dry weight of one urucum leaf was 0.44 g.

- The average projected area of one urucum leaf was 83.6 cm^2, leading to a ratio total area/dry weight of 380 cm^2/g dw.

The net uptake rate was therefore (Berger, 1996): NUR = (^{15}Nsample*Nsample*(100/^{15}N-NL/ET) =0.0001[at%] * 1893 μmol/g dw * (100/10 at%)/3.5h = 0.541 μmol/(g dw h) = 13 μmol/(g dw day)

with EF=enrichment factor (10%) and ET=exposure time

This leads to a total area based uptake rate of 13 μmol/(g dw day) *1g/380 cm^2 = 34.2 nmol/(cm^2 day).

Discussion

a) Leaf wetness:

The close correlation between electrical conductance and high relative humidity indicates a liquid water connection between the electrodes. There are different processes contributing to this liquid connection which may explain the different patterns of conductance measured on the leaves. According to the present state of knowlewdge three factors influence the formation and existence of thin water films on leaves:

- hygroscopic substances on the leaf surface

- stomatal transpiration

- cuticular structure and uptake of water, cuticular transpiration

There was evidence for each of these factors during the measurements:

At high rh, dew formation is initiated by hygroscopic substances (condensation nuclei) on the leaf surface. The source of these substances may be the plant (leaching), the atmosphere, rain residues, dry deposition or microorganisms. The more of these substances are present on the surface, the more increases the conductance signal with increasing relative humidity. The difference between the measurements in October 1995 when formation of invisible water films was detected to start around 70% rh, and April 1996 when formation started at around 85% rh is most likely due to the fact that there was much more rain in April, which presumably removed most of the hygroscopic substances from the leaf surfaces. Considerable differences of ion concentrations in rain have been found in the central Amazonia throghout the year (Williams et al., 1997). The components are biogenic and oceanic in approximately equal amounts, organic acids making considerable contributions to the biogenic part (Artaxo and Hansson, 1995; Williams et al., 1997).

The idea that hygroscopic substances increase wetting times is supported by the fact that the correlation between conductance on urucum leaves and rh was increased when salts (PO_4) were artificially applied to the leaves. Nevertheless there must still have been considerable amounts of substances on the leaves as indicated by the dew measurements. It remained unclear where the low pH values in dew from urucum leaves come from, but it seems important to note that these exceptional conditions exist on these leaves. The mean pH value of rain in this region has been reported to be 4.6 (Williams et al., 1997). Leaves from tropical plants are generally very easily wettable and most of the soluble substances on the leave surfaces will easily be washed down, and due to long wetting times (visible and invisible) an extensive exchange of substances across the leaf surface may take place. So, organic acids washed out of the leaves by wetness films may be an explanation for the observed low pH values.

The idea that the microroughness created by fungi leads to increased wetting times and water amounts, which would in turn facilitate further growth of the fungi, was tested comparing infected and uninfected seringueira leaves. No clear indication for this mechanism of a potential positive feedback was found but the analysis could not be done *in extenso* due to instrument failure.

A negative correlation between conductance signal and humidity (Figs. 3d, 4 and 5) indicates an atmospheric reason for the increase and decrease of water film thickness with decreasing and increasing humidity. One explanation would be a change due to temperature changes, as temperature and rh are usually inversely correlated and conductivity measurements are known to be temperature dependent. However, the general impression when viewing the complete data set under this aspect is that the variations in temperature are not strong enough to explain the conductance variations. Another explanation is more likely: The vpd increase leads to increasing transpiration as long as stomata do not close. This could increase the water film thickness directly at the leaf surface. It seems possible that in fig. 5 the untreated urucum leaf first (until 14 o'clock) responded in this way to humidity. Then (before 16 o'clock) the stomata closed and when humidity increased above 85% rh, the conductance signal switched to positive correlation with humidity.

The influence of stomatal closure could probably be seen in fig.6 when conductance decreased in the evening and increased in the morning contrary to the long term humidity changes, although it was positively correlated to humidity fluctuation before the sunset. The puzzling thing in this explanation is that there was no conductance increase during the night when humidity raised to

100% and normally visible dew would have formed. It might be that dew did not form because there were wind velocities higher than 3 m/s. This point will still have to be checked with weather station data from the stationary weather station on the SHIFT area. The noisy signal of several of the sensors in this night supports this possibility.

Apart from hygroscopic substances and stomatal opening, the cuticle is another factor which influences conductances. This may be due to an uptake of water from the atmosphere or stomatal transpiration, or due to cuticular transpiration (i.e. water coming out of the cuticle and evaporizing on the leaf surface). The latter could be the reason for the response of castanha leaves. The old leaves which are very stiff did not respond to humidity changes at all and showed an extremely low absolute conductance signal. The absolute value of conductance depends always on the pressure of the sensor and the leaf area touched by the electrodes but some tests variating these influences showed that the old castanha leaves had the highest ohmic resistance (lowest conductance) of all the leaves so far measured (around 30 species). The young castanha leaves, however, responded differently with a relatively high absolute conductance value which was positively correlated with relative humidity (fig. 5 e). Young castanha leaves are much softer than the old ones and this supports the view that a part of the conductance which is measured on leaf surfaces comes from intrinsic water in the cuticle.

The similar course of xylem sap flux and the conductance signal of one of the wetness sensors on the 21st of april (fig. 7) can again be interpreted as a changing water film thickness driven by the vpd with constant stomatal opening. It can be seen from this plot and from fig. 8, how xylem sap flux is driven by the water vapour pressure deficit of the air. Apart from the relative course with similar minima and maxima, the ratio between sap flux and 'vpd' changes, i.e. a higher 'vpd' is required in the afternoon to produce the same amount of sap flux as in the morning. This is most likely the result of stomatal closure. The IRGA measurements which were conducted on the same tree and at the same date as fig. 8 indicated a complete cease of transpiration at noon which is not confirmed by the sap flux data. Assuming the IRGA worked correctly, the transpiration which is indicated by the sap flux must have happened by other leaves than the ones (around 10) measured with the IRGA cuvette system; cuticular transpiration certainly contributed but is unlikely to have been responsible for all of the registered sap flux. The vpd which is noted by the plant could be even higher than calculated by the air temperature because radiation will heat the leaf surface to higher temperatures.

b) Foliar nutrition experiment

The differences noted between citrus and urucum are mainly a result of the high control values observed for citrus. As it is the group with the highest concentrations of all the 6 groups it is unlikely that contamination during analysis was the reason for the contradictory result that the untreated group showed the highest enrichment for ^{15}N and P. It is unlikely that the citrus leaves chosen for the control were younger than the ones which were treated as the calcium values of all groups were the same. The lower dry weight/fresh weight ratio of the treated leaves suggests incomplete drying. Citrus cuticles have a high water sorption, the water being strongly bound (Kerstiens and Lendzian, 1989; Kerstiens, 1996). This would explain the differences found for citrus leaves by a dilution effect, and would indicate that the drying procedure (70°C for 4 days), is not enough under the prevailing conditions of high moisture in the surrounding air.

For urucum, there is an increasing ^{15}N concentration with the control group being the lowest and the day treatment being the highest level. As the remaining ^{15}N as well as epiphytes should have been removed by the washing procedures, the uptake of the $^{15}NO_3^-$ could have happened via cuticle or stomata. According to visible wetting, cuticular uptake should be more easily possible at night as leaves are wet and diffusion coefficients through the cuticle would increase with swelling of the cuticle but possibly be lowered in case of lower temperature. During times of visible wetting, no uptake by the stomata will take place (Schönherr and Bukovac, 1972). Our conductance measurements showed that invisible wetting was very persistent on urucum leaves which had been treated with this nutrient solution (fig. 4), so the uptake will increase. The nutrient concentrations in the solution on the leaf surface are expected to be higher during the day than at night when the films become more diluted by atmospheric humidity, and this should lead to increased cuticular uptake during the day. This could be the reason that twice the amount of ^{15}N was taken up during the day. However, the cuticle is negatively charged, and this reduces the possibility of the plant to take up nutrients through the cuticle.

The alternative (or additional) explanation for the higher nutrient uptake into the leaf during the day is nutrient uptake through the stomata which are closed at night. For this uptake, continuous, invisible water films extending from the leaf surface through the stomata opening into the interior of the leaf could provide an effective pathway.

The observed uptake rate of 34.2 nmol/(cm^2 day) is within the lower range reported from other foliar fertilization measurements (Marschner, 1995). Usually uptake is measured for longer times (days) which could help to establish continuous films into the stomata.

Conclusions:

Invisible leaf wetness existed on the investigated tree leaves. It wil certainly influence exchange rates of solutes over the leaf surface and supposedly influence the living conditions in the phyllosphere. The uptake of nutrients applied to the leaf surface is higher during the day than during the night, probably because of wetness films extending into the open stomata. Therefore, stomatal closure during transpirational depression around noon could decrease the uptake of nutrients applied to the leaf surface, either as fertilizer or naturally through rain.

Further development of the leaf wetness sensors may lead to a relatively simple device for the automated monitoring of plant transpiration.

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Fig. 1 Leaf wetness measurements

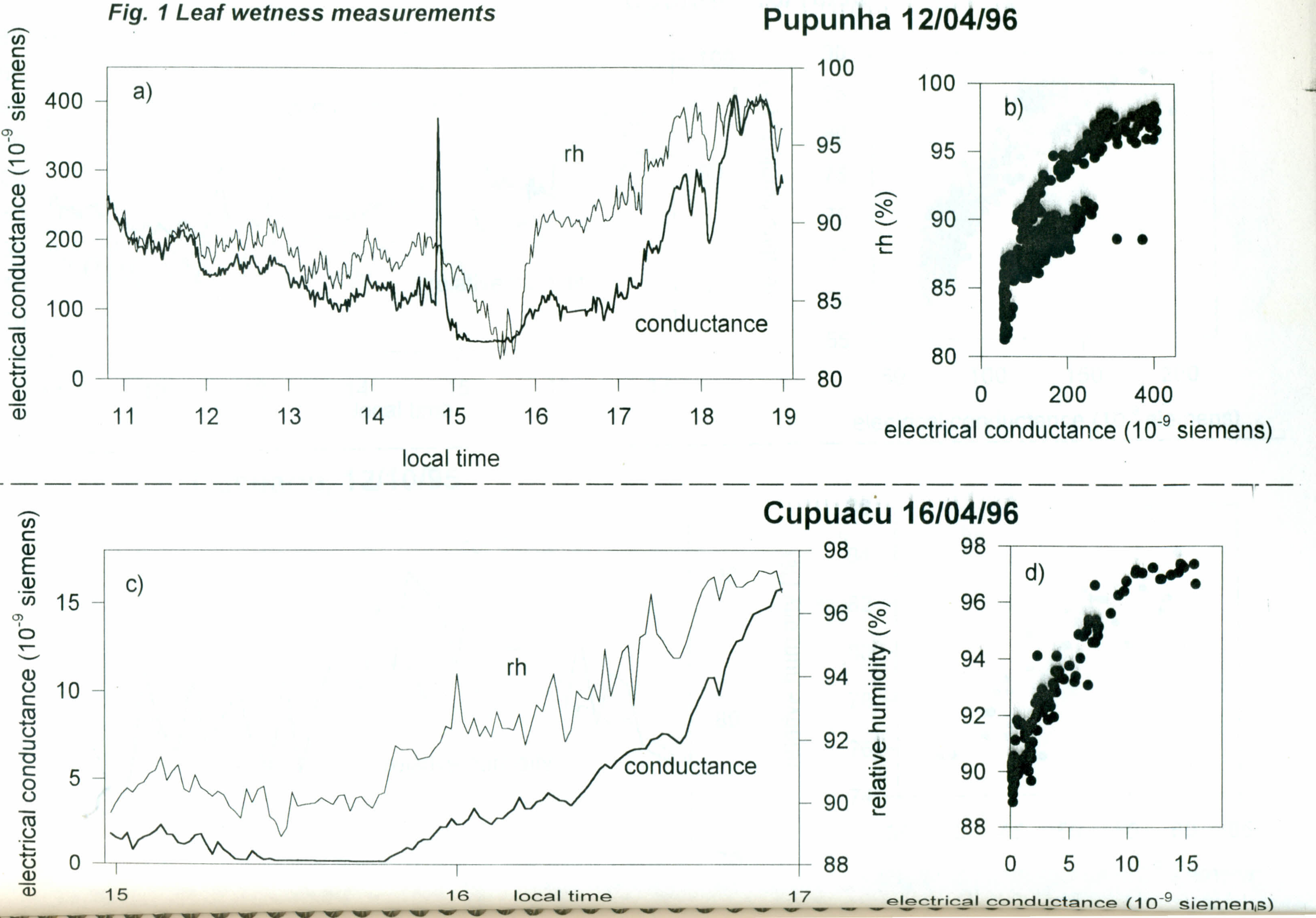


Fig. 2 Leaf wetness measurements

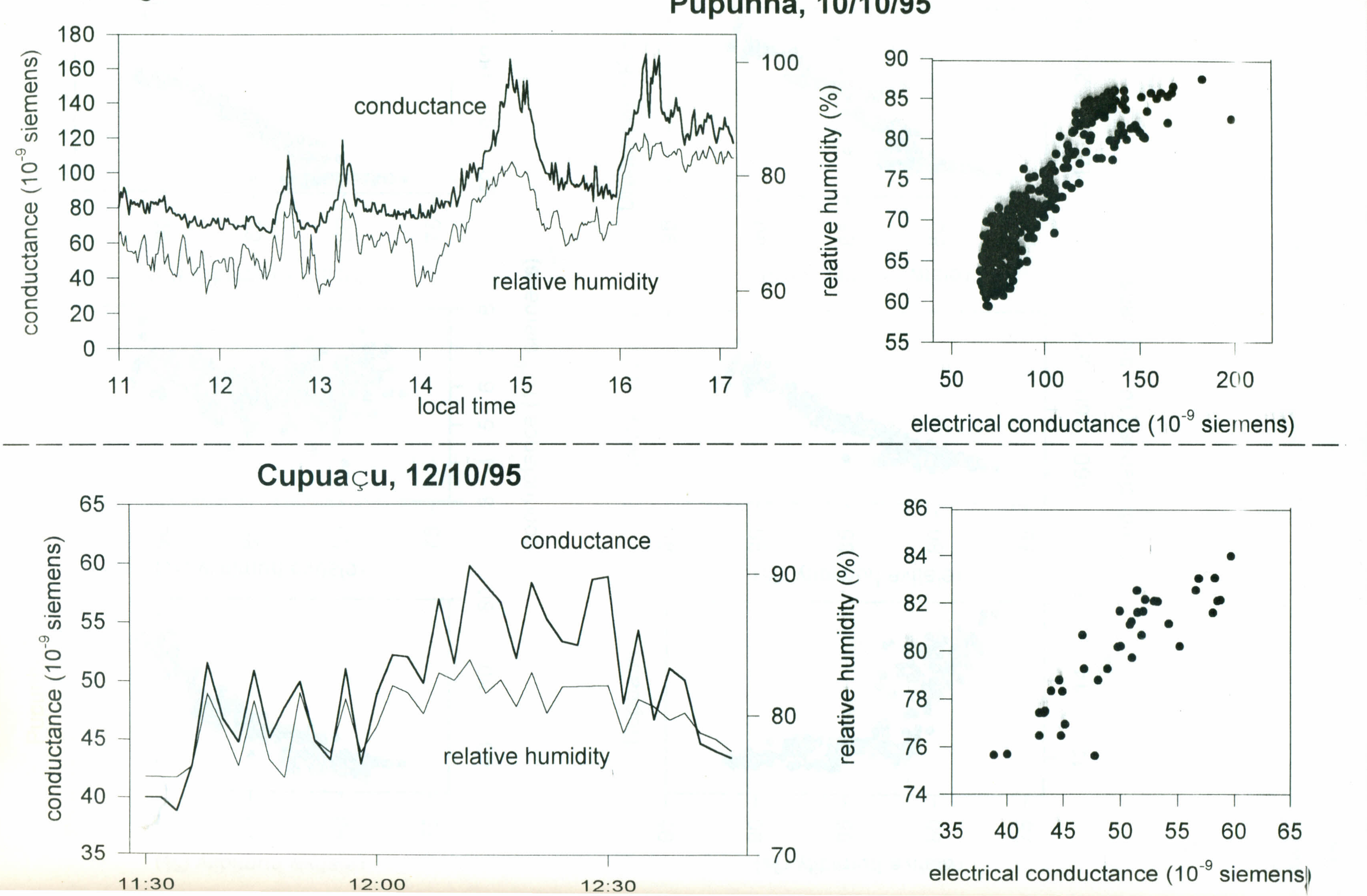


Fig. 3 Leaf wetness measurements 13/04/96, hours 9 - 13

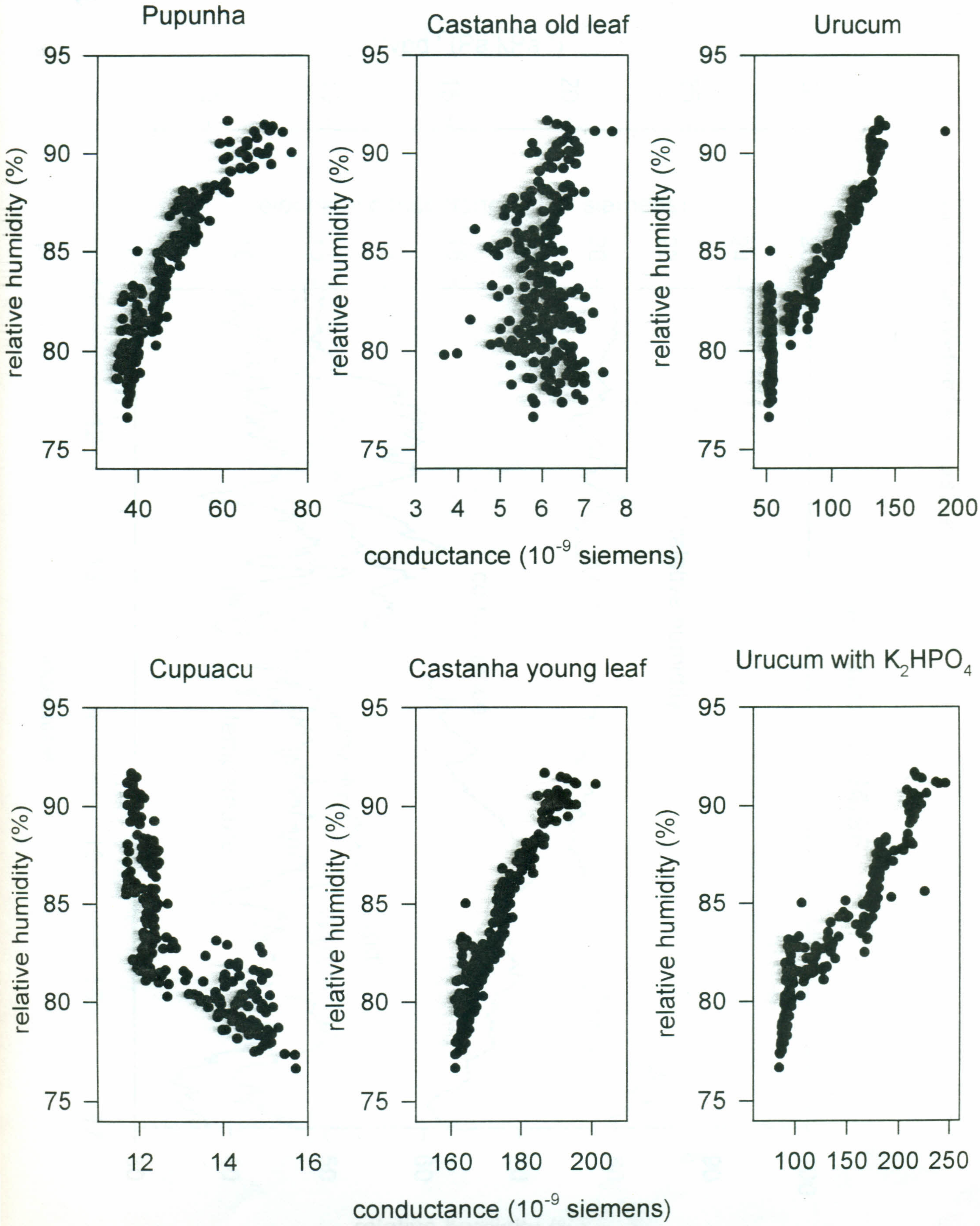


Fig. 4 Leaf wetness measurements

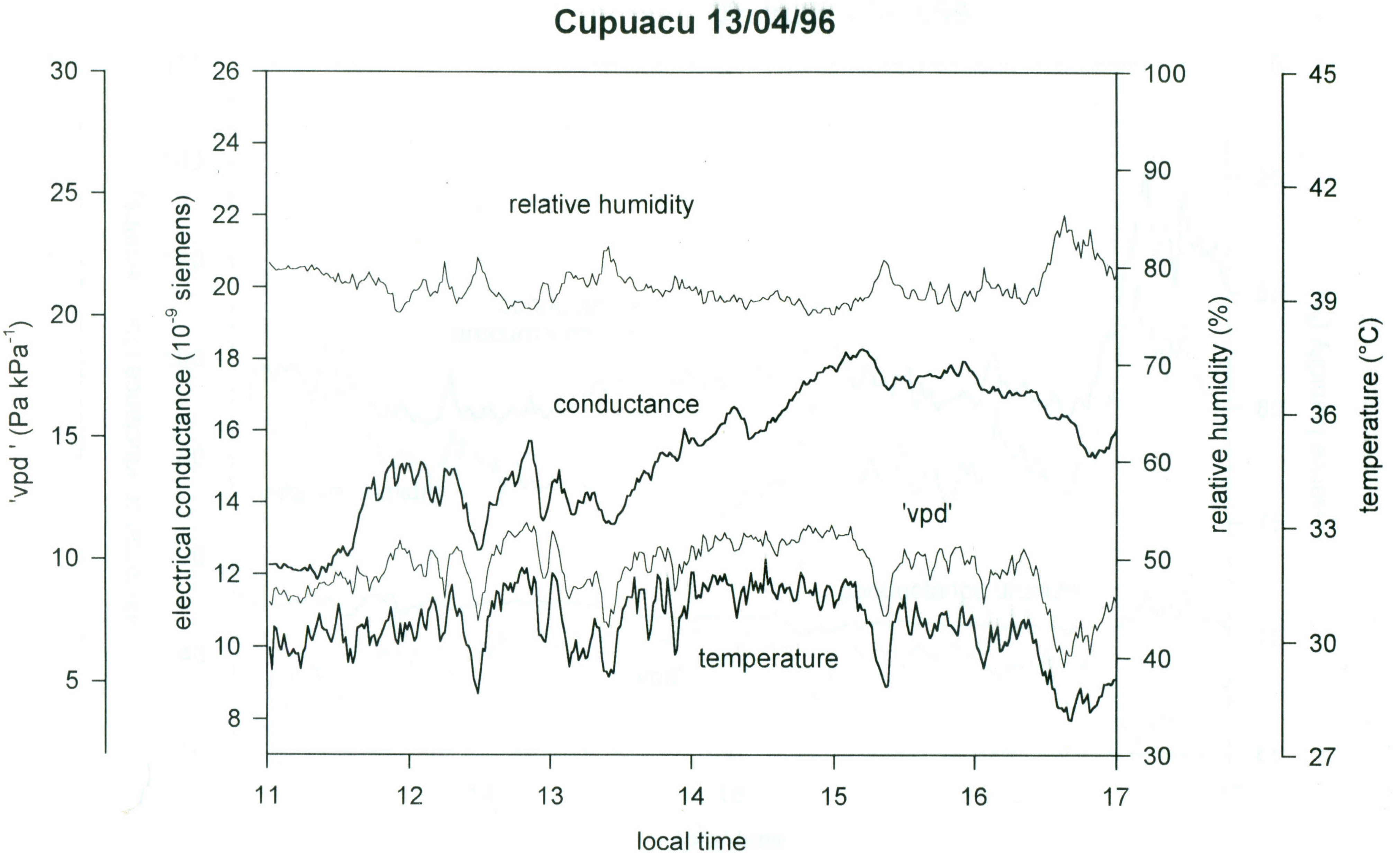


Fig. 5 Leaf wetness measurements

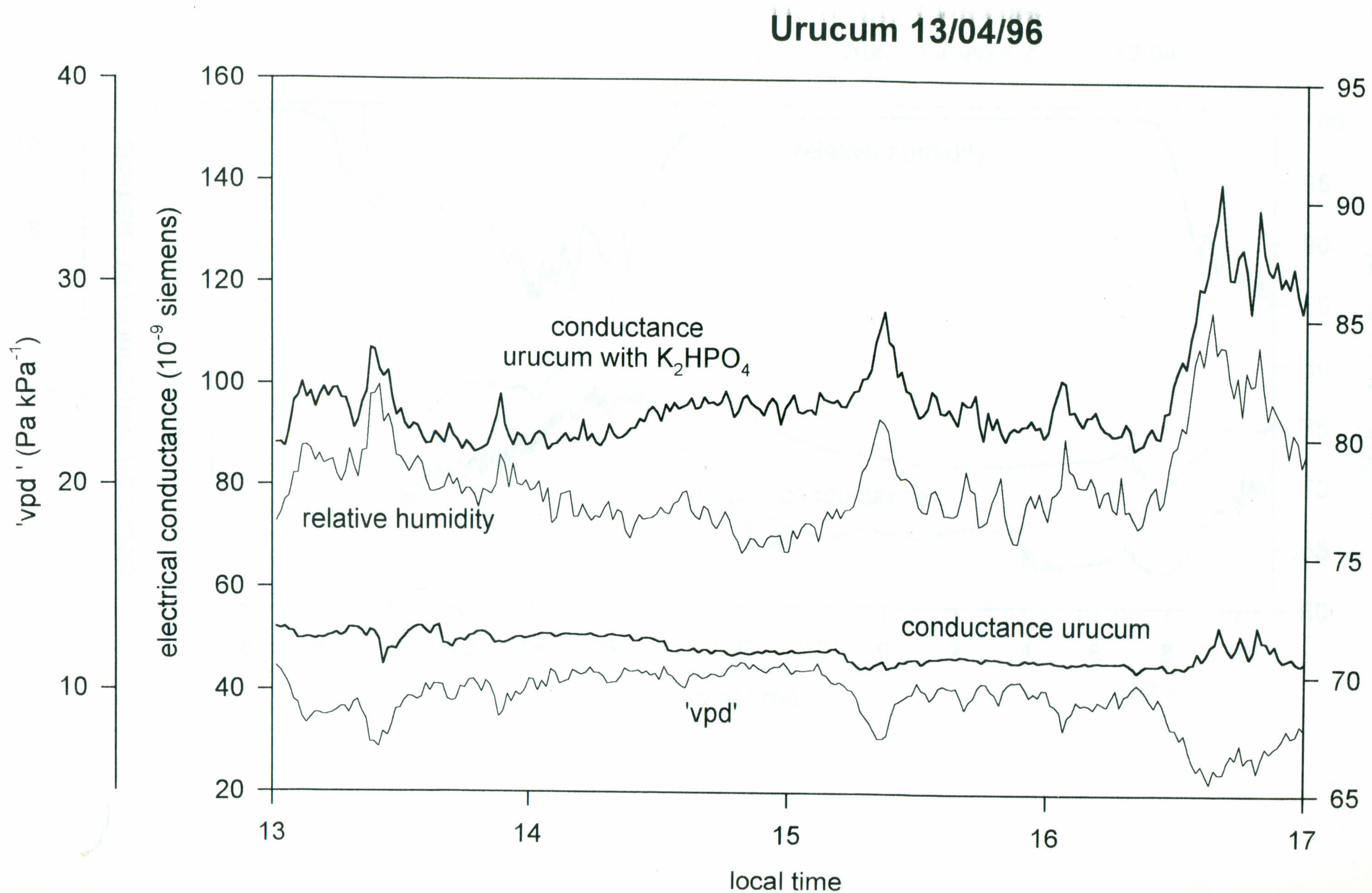


Fig. 6 Leaf wetness measurements

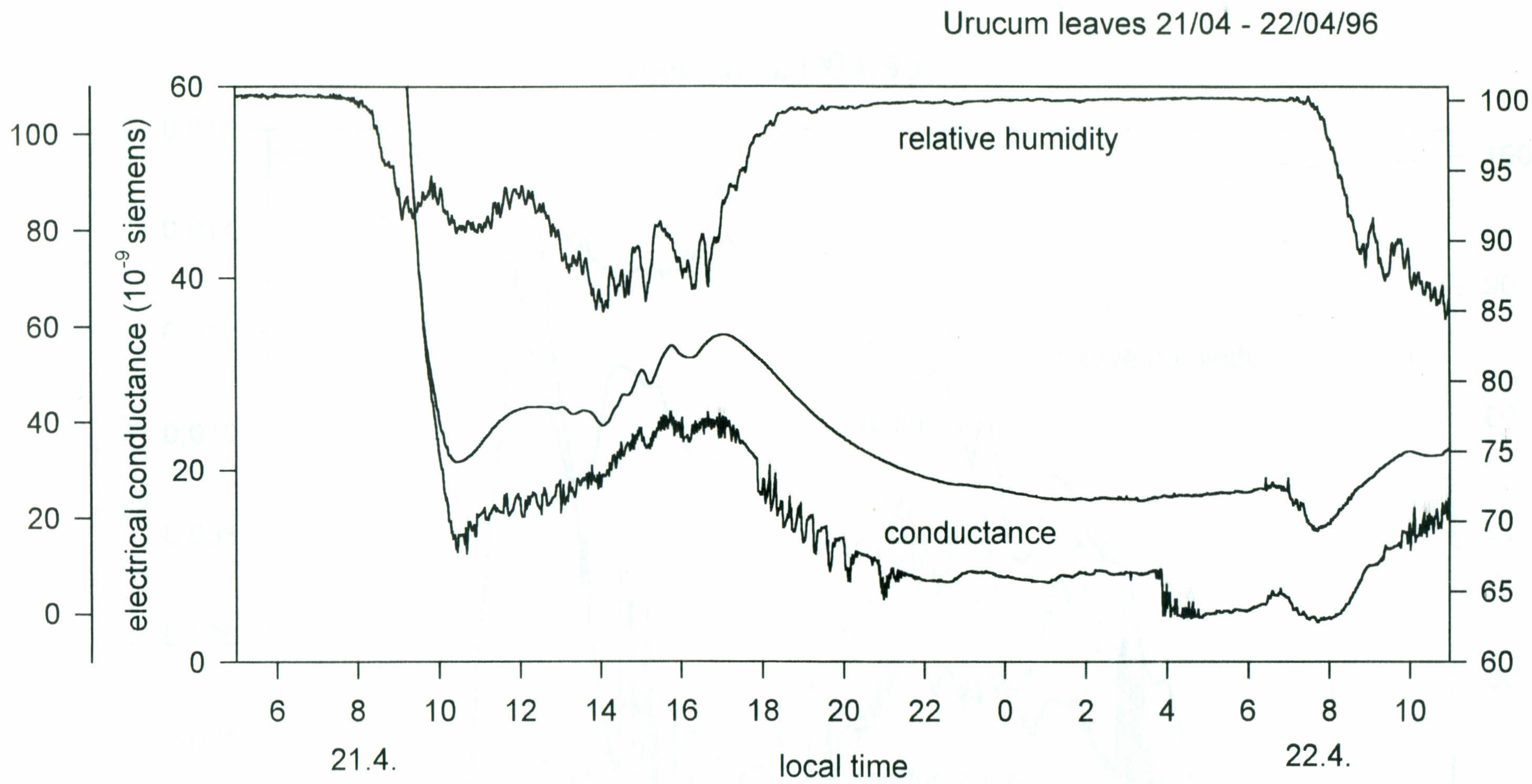


Fig. 7 Sap flux and leaf wetness measurements

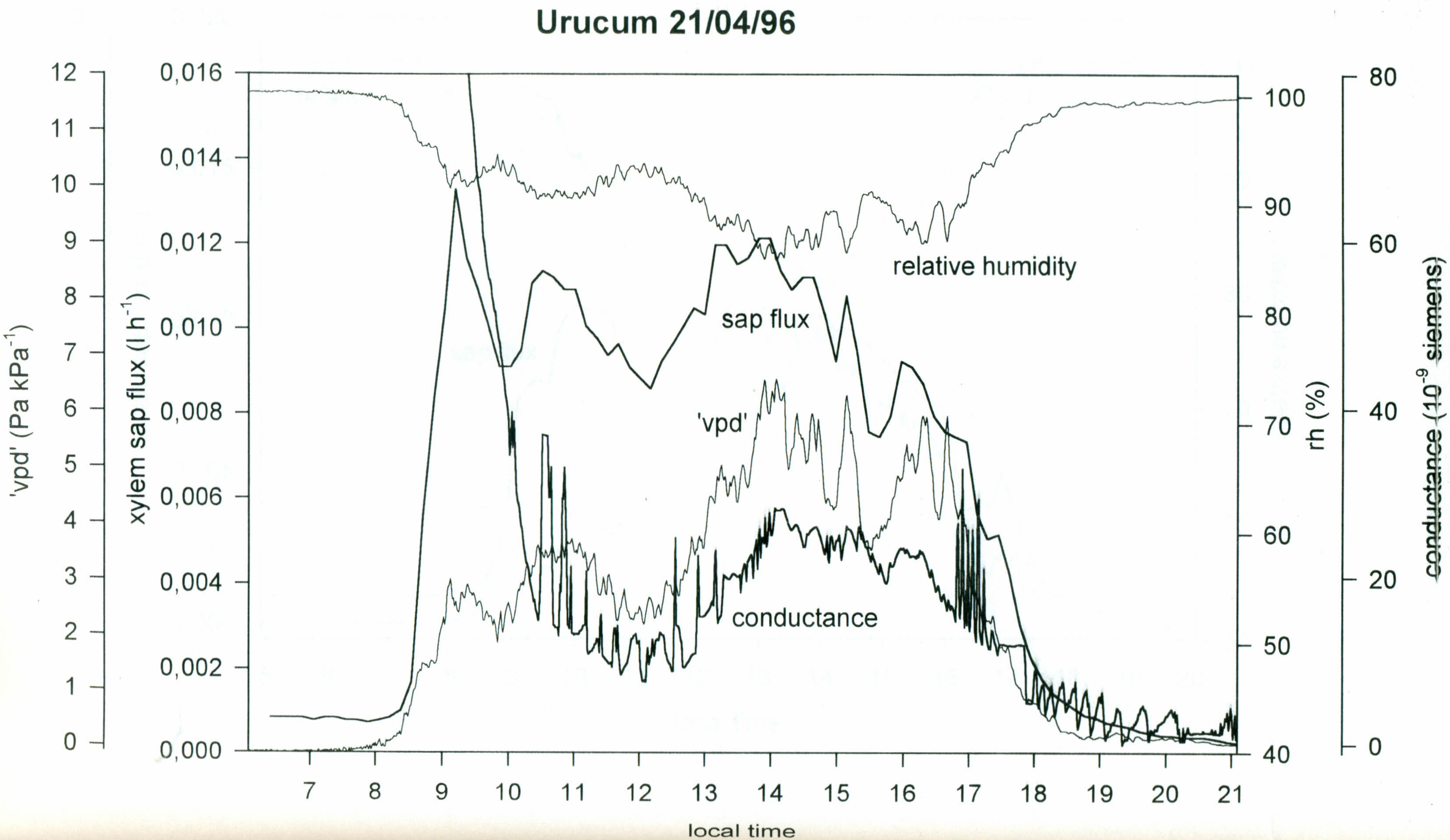
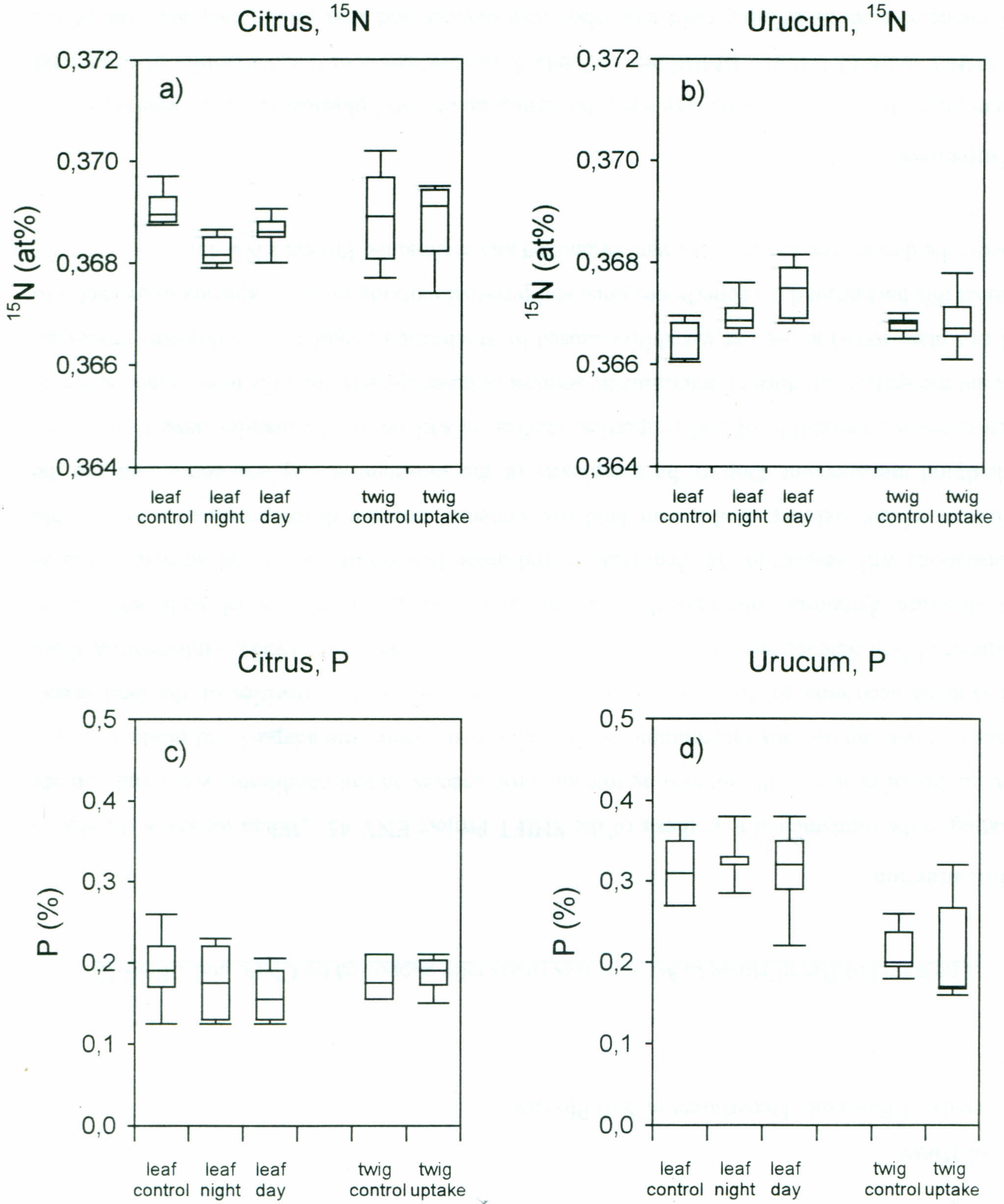


Fig. 9 Foliar nutrition experiment



Annexe 5: Work report about the travel to EMBRAPA-CPAA, 15 April to 3 May 1996

Impact of soil-plant-interactions on soil physical and soil hydraulic properties of abandoned field sites with different land use systems on the Terra firme near Manaus

Bernd Huwe
University of Bayreuth, Department of Soil Physics

The travel of Bernd Huwe to Manaus was financially supported by CNPq and GKSS-IB

1. Introduction

Relating to the fundamental hypothesis of the SHIFT Project ENV 45: „When we know the effects of a number of economically interesting tree and crop species on soil conditions, water and nutrient fluxes (...), 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" (Institute of Soil Science and Soil Geographie / University of Bayreuth, 1995), - information about soil structure dynamics, mechanical behaviour and hydraulic properties of soils are crucial informations with respect to the identification and quantification of „water and nutrient fluxes as indicators of the stability of different land use systems" and the development of a sustainable agricultural management. Due to the complexity of the soil-plant-atmosphere continuum and the often excessive variability of soil properties, studies on soil physical dynamics have to take into account the spatial structure of deterministic sources of heterogeneity (like the intense interaction of soil and plant-roots) as well as variability caused by stochastic (irregular and unknown) processes. Against this background, a properly designed soil physical working program appears to be useful to support the demanding aimes of the well organized and maintained Project ENV 45.

2. Objectives

The main goals of this scientific stay were the setting-up of a soil physical research program within the SHIFT project ENV 45 / BMBF No. 0339641 5, the evaluation of the availability of equipment and methods, tests of existing field and laboratory devices and first preliminary analyses of the spatial heterogeneity of physical and hydraulic soil properties. Thus the working program was divided into the following parts:

1. *Field program:* field excursions; identification of soil physical aspects of the experiment design; field measurements and sampling of soil cores at 1-dimensional transects for variography and methodological laboratory studies (pupunha and cupuaçu); tests of existing field devices (penetrometer, TDR, disc infiltrometer, point source infiltrometer)
2. *Laboratory program:* test of ceramic plates for the determination of water retention curves; construction of a combined constant head/falling head water permeameter
3. *Software installation and demonstration:* soil physical base software; simulation programs; geostatistical programs
4. *Seting-up of a soil physical research program* within SHIFT/ENV 45
5. *Discussion of possible modelling activities*

3. Results

3.1 Field program:

As a consequence of the demanding experiment design, several direct and indirect links with respect to soil physical problems could be identified. This concerns particularly the quantification of water and matter fluxes in the soil, which essentially involves soil physical methodology, interactions between hierarchic root-systems and transport characteristics of the soil as well as probems of spatial heterogeneity. At its present state the project is optimized for statistical analyses. Quantification of fluxes in the soil requires apart from the determination of transport parameters, initial and boundary conditions, the use of site-adapted simulation tools and, partly, an intensification of field measurements for calibration purposes.

In view of the setup of a soil-physical working plan, field measurements were carried out in order to get a first impression of the magnitude of easy to measure soil physical parameters and their spatial structure. For this, regular onedimensional transects in pupunha (25 cm mesh-size) and cupuaçu (50 cm mesh-size) monocultures were established and measurements of water content, penetration resistance in three depth intervals as well as bulk densities were determined. For penetration resistances and water contents empirical semivariograms were calculated according to

$$\gamma(h)=\frac{1}{N(h)}\sum_{i=1}^{N(h)}\left[Z(x_i)-Z(x_i+h)\right]^2$$

where

γ := semivariance vor lag h

h := lag (distance between gridpoints)

N := number of pairs $[Z(x_i), Z(x_i+h)]$, depends on h

Z := grid value at position z of the variable under study

x := spatial coordinate

i := index number of grid-points

First results are shown in fig. 1 to fig. 3. They indicate a pronounced spatial autocorrelation of the variables under study. At larger sampling distances, the semivariance again is decreasing due to deterministic regularities, breaks in the measuring periods and the decrease of the number of pairs in the above formula for larger lag values. The interpretation of possible deterministic components is not well understood so far and needs further investigation.

The tests of the field equipment (tension infiltrometer, point-source infiltrometer, penetrometer) was successful as far as the handling and the algorithms are concerned. Time requirements for the respective measurements were estimated and used in the design of the working plan.

3.2 Laboratory program:

Ceramic plates are used for the determination of the water retention curve of porous media and the calculation of the statistical distribution of equivalent pore sizes. We especially tested the 1 bar plate for suitability for lower suction values (≤ 250 cm). The saturated hydraulic conductivity of the plate was measured by means of a modified falling head method and compared with the data provided by the manufactoring firm to check for possible changes. The differences were negligible. The relatively low conductivity of the ceramic plates can be expected to be a limiting factor only when using soils with high conductivities. In any case, the attainment of equilibrium should be checked by repeated weighing. The dewatering times were estimated by a first determination of the water content at pF=2.1. Simultaneously we tested different materials to attain a close contact between soil samples and ceramic plates (fine sand, caolin, nylon nets, nylon nets treated with caolin). From this experiment we were able to conclude that the 1 bar plates are suitable provided that the equilibrium is controlled, and that at pF=2.1 the contact material is not a source of errors.

A second aspect of the laboratory program was the construction of a combined constant head / falling head water permeameter for measurements of the saturated hydraulic conductivity. A first draft of this permeameter could be completed and the principle of the measurements was demonstrated. Possible improvements of the device were outlined. We also discussed the construction of an easy-to-use permeameter for unsaturated conductivities with a one step method. The alogrithm for the evaluation was provided (Mua'zu et al., 1990)

3.3 Software installation and demonstration:

Soil physical base software (BAPS, SHYPFIT), simple and complex simulation programs (BLAU, WHNSIM) and geostatistical software (SEMI, GEOPACK, VARIOWIN) was installed on two PC's. The principal handling of the software was explained and manuals, mainly in English, were provided. First geostatistical calculations were carried out by the simple and easy to use SEMI which allows for the calculation of empirical semivariograms on regular one-dimensional grids.

3.4 Set up of a soil physical research program within SHIFT/ENV 45

Goals and Hypotheses

As mentioned above one of the main goals of the scientific visit was the setting-up of a soil physical research program within the SHIFT project ENV 45 / BMBF No. 0339641 5. Due to the needs of ENV 45 and based on preliminary estimates of labour requirements the main goals of the program can be summarized as follows:

- Methodological studies on unsaturated conductivity measurements under tropical conditions
- Evaluation and mapping of the the spatial distribution of important soil physical and soil hydrological properties of field soils at different agroforest sites near Manaus
- Identification of the main sources of spatial heterogeneity (deterministic, stochastic)
- Analysis of the deterministic and stochastic structure of heterogeneity and their respective contributions

The spatial variability of soil physical and soil hydrological properties of field soils at different agroforest sites will be studied on different scales, with different methods and different intensity. Regular one-dimensional and two-dimensional as well as irregular grids are to be established in order to identify deterministic and stochastic sources of heterogeneity. Special consideration is given to soil-root interactions. The analysis is carried out by means of classical statistics (analysis of variance) as well as spatial statistics (variogram analysis, kriging, local gradient analysis etc.; Ripley, D. B., 1981).

The main working hypotheses from a scientific point of view are:

- The piezometer permeameter is a suitable device for high resolution in-situ measurements and analyses of spatial heterogeneity of hydraulic conductivity in the near saturation range.
- Differences in root structure and biological activities like mesofauna are the main sources of spatial heterogeneity of soil structure and hydraulic properties on the experiment sites under study.
- The spatial distribution and patterns of soil mechanical and hydrological properties can sufficiently be explained only by a combination of deterministic and stochastic methods.

Sites and methods

The measurements will be carried out at the experimental fields (blocks and treatments) of the agroforestry experiment of EMPRABA (SHIFT) near Manaus. The measurements comprise the following variables and parameters:

a) *Characterization cf soil structure:* bulk densitiy, particle density, porosity, particle size distribution, aggregate distribution, pore size distribution

b) *Soil mechanical parameters:* penetration resistance, aggregate stability (wet sieving method)

c) *Soil hydraulic prcperties:* water content, matric potential, water retention curve, field capacity (pF 1.8) saturated conductivity (laboratory), unsaturated conductivity (tension infiltrometer, piezometer permeameter, laboratory permeameter, several estimations), infiltration capacity

d) *Soil chemical parameters:* Corg, Al, CEC, base saturation, ...

e) *Pedological parameters:* thickness of Ah horizon

f) *Biological parameters:* root density

Special methodological aspects of the program are

a) The comparison of different methods for the determination of unsaturated conductivity: different field methods, laboratory method, estimations by SOILPROP, BAP3/4, SHYPFIT

b) Calibration of penetrometers and TDR

c) Determination of normalization functions for penetration resistances (pF, θ)

Grid design

The design of the grids, the choice of variables for different grids and data management and documentation are essential points in the analysis or spatial heterogeneity. Grids are designed on different leves for different reasons. Whenever possible the dimensioning of the experiments (replications, spacing) should be based on existing data or a short prestudy.

Global scale:

Irregular grid for the analysis of the impact of different tree species resp. their root systems on the variables under study. The design is mainly suitable for variance analysis techniques and multivariate analysis.

- ***Variables:*** all
- ***Positions:*** tree and inter-tree areas; 3-5 trees per species and plot (dependent on type of measurements); 2-3 measurement depths;
- ***Replications*** (time): 1-2 for all, 4-8 for water content and matric potential

Local scale:

Irregular 2-D-, regular radial 2-D- and regular 1-D grids for main treatments. Only one block. Design is suitable mainly for descriptive analysis, multivariate analysis and spatial statistics (variogram analysis, kriging and advanced spatial analysis rsp. estimation methods). The design for the radial and one-dimensional grid may also be set up in a hierarchical way in order to get spatial information on different scales within one grid;

- ***Variables:*** bulk densitiy, porosity, aggregate distribution (top soil), pore size distribution (water retention curve), penetration resistance, aggregate stability (wet sieving method), water content, saturated conductivity (laboratory), estimations for unsaturated conductivity, field measurements of unsaturated conductivity with different methods (tension infiltrometer, piezometer permeameter) infiltration capacity, Corg, Al, CEC, base saturation, thickness of Ah horizon, root density

- ***Positions:*** tree and intertree areas (2-D, 30-40 points per plot); 1-D transects, parallel and perpendicular to rows, different stem distances; radial 2-D grids for main trees; 2-3 depths; high spatial resolution within the root-system for the piezometer permeameter.

- ***Replications*** (time): 1 for all plus 4-8 for water content

Remark: According to the progress of measurements this design may be simplified. Esp. the number of parameters and the intensity of measurements may vary due to available laboratory and labour capacity.

Data analysis:

The data analysis is mainly based on classical and spatial statistical methods and comprises

- Error analysis for measurement procedures (e.g. impact of root water uptake on conductivity measurements with the piezometer permeameter)
- Sensitivity studies in order to determine the required precision for measurements; error propagation;
- Descriptive data analysis and mapping
- Multivariate statistical methods
- Analysis of variance
- Spatial statistical methods: variogram analysis, BLUES (kriging), cross validation and others

Software needed or recommended

In addition to the existing software the following packages are necessary or recommended:

- Geostatistical Software: Variowin, GEO-EAS, Geopack
- Graphical Software: CoHort-Software (DOS), SIGMA-plot
- Mapping Software: e.g. Map-Viewer, Surfer for windows

Time table

	1996 1997 1998
Literature study	XXXXXXX
Preliminary studies, calibrations	XXXXXXX
Studies on the global scale	XXXXXXXXXX
Studies on the local and single tree scale	XXXXXXXXXXXXXXXXXX
Data analysis	XXXXXXXXXXXXXXX
Report	XXXXXXXXXXXXXX

The research will be carried out by Wenceslau Teixeira and coworkers, results will be used for the preparation of his Ph.D. thesis.

4. Discussion of possible modelling activities

From a practical point of view, site specific adapted simulation models can be regarded as useful tools for several reasons. They allow for the quantitative estimation of internal water and matter fluxes "as indicators of the stability of different land use systems" as well as boundary fluxes (surface runoff, leaching); secondly, they support system optimization and decision making strategies; and, thirdly, transfer of scientific results to other sites and regionalization is not possible without the use of simulation models. Against this background the need and possibilities of a new project which focusses on the modelling of essential processes in the soil-plant-atmosphere system was intensively discussed with Dr. Alvaro, Dr. Cravo and Dr. Schroth. The need of such a project was recognized by all participants of the discussion. A possible project could have integrating properties, it should include education and training activities to ensure knowledge transfer and it should closely cooperate with ENV 45 and other existing SHIFT projects.

5. Figures

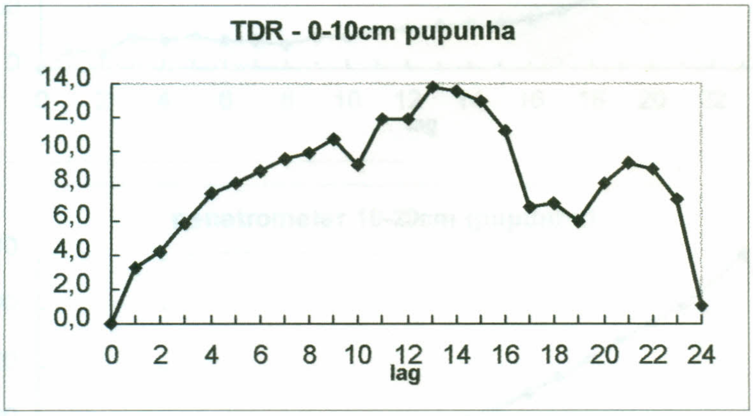


Fig. 1: Empirical Variogram ($\%^2$) of water content in a pupunha monoculture (mesh-size 0.25 m).

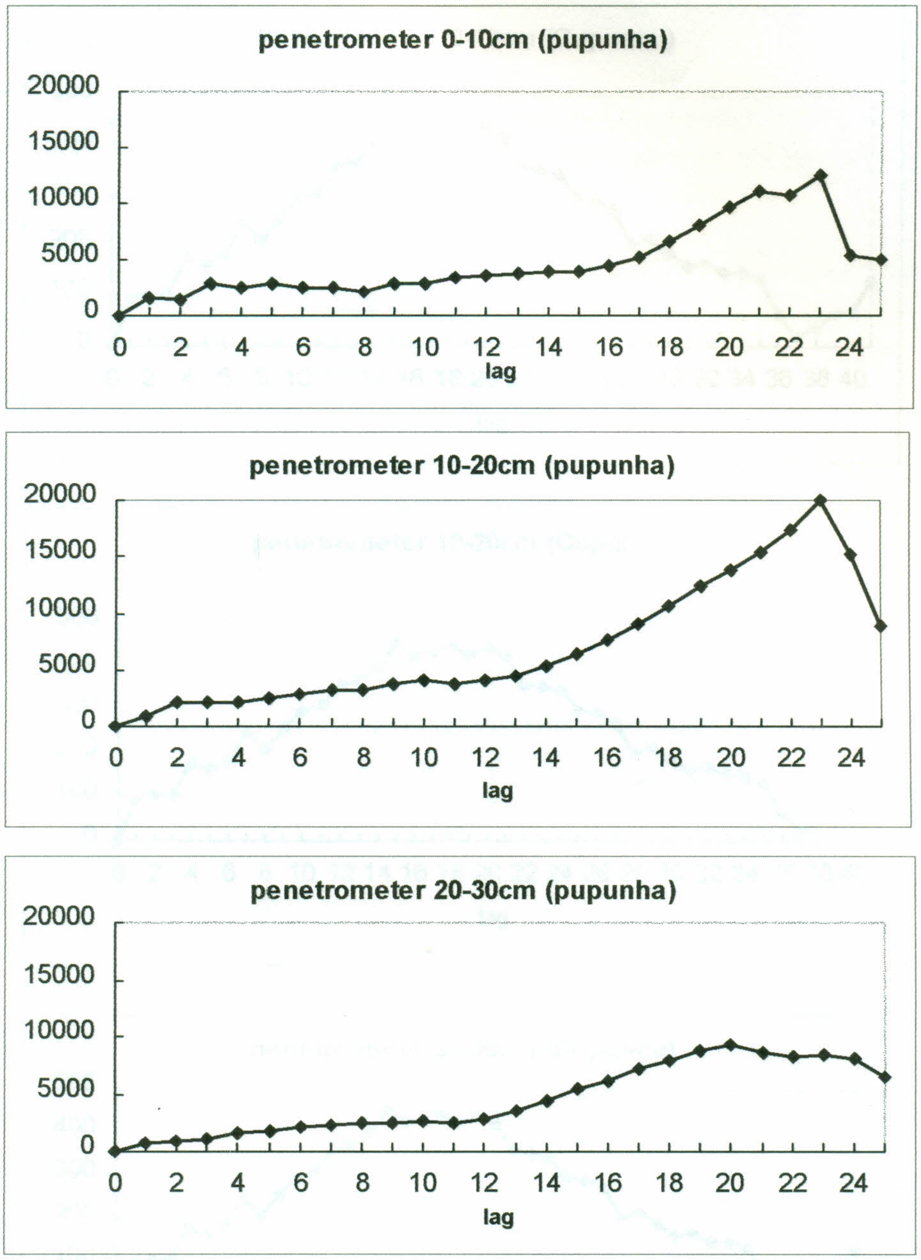
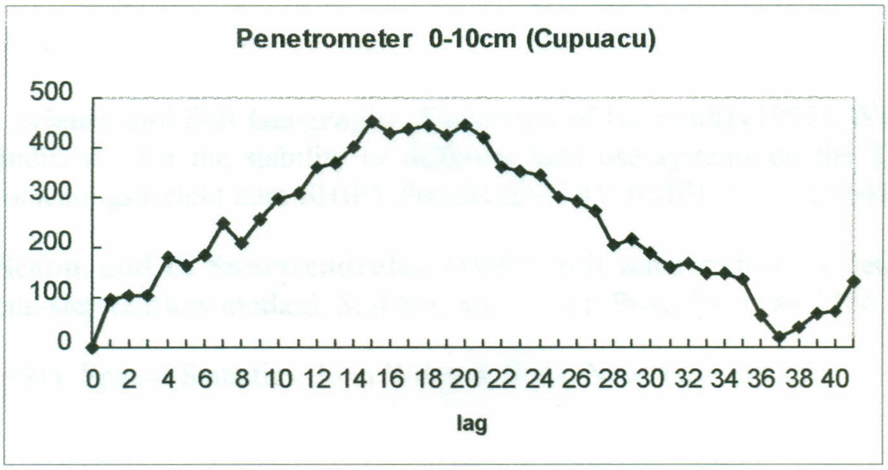
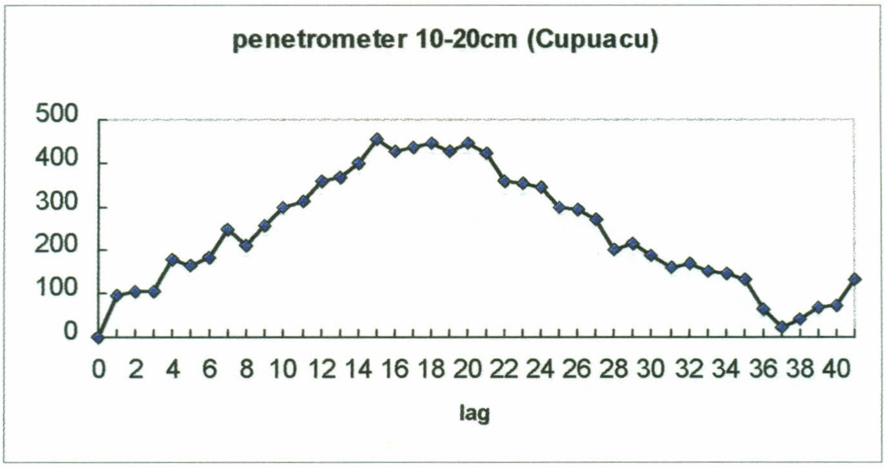


Fig. 2: Empirical Variogram (in kp^2cm^{-2}) of penetration resistances in a pupunha monoculture (mesh-size 0.25 m).





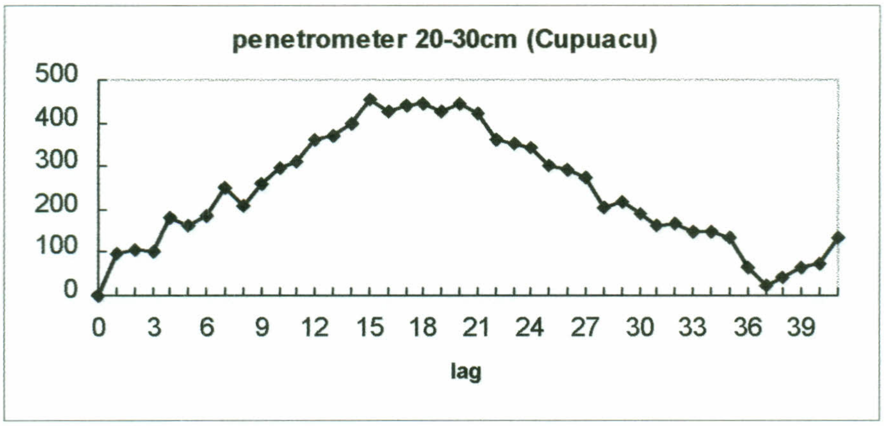


Fig. 3: Empirical Variogram (in kp^2cm^{-2}) of penetration resistances in a cupuaçu monoculture (mesh-size 0.5 m).

6. References

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Annexe 6:

CALIBRAÇÃO DA TÉCNICA DE Time Domain Reflectometry (TDR) PARA AVALIAÇÃO DA UMIDADE DO SOLO EM UM LATOSSOLO AMARELO, TEXTURA MUITO ARGILOSA, COM DIFERENTES VALORES DE DENSIDADE APARENTE DO SOLO - Avaliação no campo.

Wenceslau Geraldes Teixeira; Olivio Pedro Faccin; Celso Paulo de Azevedo; Bernd Huwe; Götz Schroth

INTRODUÇÃO :

A técnica de reflectometria no domínio do tempo (TDR), vem sendo cada vez mais utilizada para avaliação da umidade volumétrica do solo (θ).

Esta técnica se baseia determinação da constante dielétrica aparente (ε) do solo através de determinação da velocidade de propagação de ondas eletromagnéticas. É bastante útil quando se pretende fazer avaliações não destrutivas e repetidas num mesmo local, permitindo também leituras próximas à superfície, sem apresentar perigo de contaminação radioativa, como os métodos de atenuação de raios gama e moderação de neutrons.

Dada a grande magnitude das diferenças encontradas entre os valores da ε da água(81), ar (1) e principais constituintes sólidos do solo (3-5), todos estes valores, adimensionais, estão condicionados a uma dada frequência e temperatura (Biscegli et al.,1996), acreditava-se a princípio que poderia se utilizar uma calibração universal com uma função θ=f(ε) (Topp et al. 1980).

Trabalhos posteriores mostraram que diversos fatores podem causar influenciar as medições da ε havendo portanto a necessidade de calibrações específicas, quando se requer uma maior precisão das avaliações, principalmente em solos argilosos e/ou com baixos valores ρ .

Esses fatores podem ser divididos em dois grupos: a) características técnicas do equipamento, como: como comprimento das hastes guias, comprimento e resistividade do cabo, frequência do sinal e espaçamento entre as hastes guias (Hook & Livingston, 1995; Petersen, et al., 1994; Zegelin et al., 1992) e propriedades e característica do local avaliado como : a matriz do solo e consequentemente a sua densidade aparente (ρ) (Malicki et al., 1996; Bohl & Roth, 1994, Dirksen & Dasberg, 1993; Roth et al., 1992 Herkelrath, et al., 1991); textura (Bohl & Roth, 1994);

temperatura (Pepin et al., 1995); heterogeneidade da umidade na transecção vertical (Topp & Davis, 1985; Baker & Lascano, 1989) e presença de minerais magnéticos (Roth et al., 1992).

Muitos desses fatores, como a ρ e temperatura, podem variar não somente entre locais, mas também em áreas próximas, em função das espécies presentes e manejo empregado (preparo do solo, poda, colheita, mulching, etc.). Essas variações podem ser especialmente importante em sistemas de uso da terra, heterogêneos, como os sistemas agroflorestais, onde espécies com diferentes características (crescimento da copa, sombreamento, produção de liteira, distribuição do sistema radicular, etc.) e manejo utilizado, são associadas, também em comunidades naturais heterogêneas como as florestas e cerrados.

Quando se pretende avaliar fluxos de água no solo, através da técnica TDR, em situações heterogêneas, a consideração dessas potenciais fontes de interferência, nessa técnica e a sua quantificação é requerida.

Este trabalho, teve por objetivo a obtenção de uma equação de calibração para a avaliação da umidade volumétrica do solo pela técnica TDR (θ_{TDR}) para o latossolo amarelo (Xanthic ferralsol - FAO), textura muito argilosa, com diferentes valores de ρ.

MATERIAL E MÉTODOS :

As avaliações da ε e amostragens para determinação da θ_{Grav} e ρ, foram realizadas na Estação Experimental do Centro de Pesquisa Agroflorestal da Amazônia Ocidental - (EMBRAPA-CPAA), em Manaus - AM.

Foram realizadas na camada superficial de um latossolo amarelo, textura muito argilosa, em um experimento sobre diferentes sistemas de uso da terra, com plantios de cupuaçu (*Theobroma grandiflorum*); pupunha(*Bactris gasipaes)* para colheita de frutos e palmitos e sob uma planta de cobertura do solo, o kudzu tropical (*Pueraria phaseoloides*) sendo as amostras coletadas a aproximadamente 40cm do tronco, também foram avaliadas duas espécies frequêntes na floresta primária: a bacaba (*Bactris gasipaes*) e o matá-matá (*Eschweilera spp*). Também foi aberta uma trincheira e coletada amostras nas profundidades de 30cm, 90cm e 150cm. As espécies que haviam no local das avaliações e os resultados obtidos estão apresentados na Tabela 1.

Verde

As avaliações foram realizada ao longo do ano de 1996, abrangendo uma parte do período mais seco do ano, e posteriormente, o período chuvoso, para obtenção de uma maior amplitude de variação da umidade do solo.

Foi utilizado, nesta avaliação, um aparelho comercial da marca EASY TEST® - Polônia, com as seguintes características técnicas: pulso de 250ps, e sondas com duas linhas de transmissão de 100mm de comprimento com diâmetro de 2mm espaçadas entre si por 16mm.

Simultaneamente à avaliação da ε pela sonda TDR, inserida verticalmente na superfície do solo, foram coletadas amostras, com anel volumétrico de $100 cm^3$, com 5cm de altura, para avaliação termogravimétrica da umidade volumétrica do solo (θ_{Grav}) e ρ, realizada em estufa 105° C, até peso constante.

O aparelho da EASY TEST® apresenta uma equação de calibração programada para apresentar diretamente o resultado da θ_{TDR} em %, mas é possível resgatar os valores da ε. A equação programada no aparelho, segundo informações do fabricante, para solos minerais compreendidos na faixa de $1,4 g\ cm^{-3} < \rho < 1,8 g\ cm^{-3}$, é a seguinte : se $\varepsilon \leq 36 \Rightarrow \theta^* = 10,64 \sqrt{\varepsilon} - 15,82$ e para $\varepsilon > 36 \Rightarrow \theta^* = 17,54 \sqrt{\varepsilon} - 57,21$.

O fabricante sugere que seja utilizada a equação de Malicki et al.,1996, quando os valores de ρ apresentarem um desvio de $\pm$ 0,2g cm^{-3} em relação a faixa de ρ apresentada para solos minerais.

$$\theta^*(\varepsilon,\rho)=(\sqrt{\varepsilon}-0,819-0,168\rho-0,159\rho^2)/(7,17+1,18\rho).$$

Foi verificada também, a adequabilidade da equação apresentada por Topp et al.,(1980), para essas condições.

$$\theta^*=-0,0053 + 0,00292\varepsilon-0,000055\varepsilon^2+0,0000043\varepsilon^3 .$$

Após análise dos desvios (θ_{Grav} - θ_{TDR}), decidiu-se realizar ajustes de calibração entre os valores de θ_{Grav} e com os valores da ε. através de análise e regressão, testando-se os seguintes modelos : $\theta_{TDR} = \beta_0 + \beta_1\varepsilon$:, $\theta_{TDR} = \beta_0 + \beta_1\varepsilon + \beta_2\varepsilon$;

$\theta_{TDR} = \beta_0 + \beta_1\varepsilon + \beta_2\varepsilon + \beta_3\varepsilon$.

Para os dados da θ_{TDR} obtidos pela equação proposta por Malicki et al.(1996), equação proposta por Topp et al.(1980) e pela equação programada pelo fabricante do EASY TEST®, foram testados ajustes lineares e quadráticos, com e sem o coeficiente $\beta 0$.

Foram determinados: os coeficientes da regressão, sua significância, os coeficientes de determinação (R^2), de determinação ajustada (R^2) e o erro padrão da média (Tabela 3). Os valores de R^2 foram calculados por serem apropriados para comparações de modelos com diferentes números de variáveis (Jacobsen & Schojonning, 1993; Draper & Smith, 1981).

Foi realizado também um ajuste por regressão múltipla, para ρ e ε , selecionando-se as variáveis que contribuíam significativamente para o modelo por procedimento de seleção stepwise (Draper & Smith, 1981).

RESULTADOS E DISCUSSÃO

Na Figura 1 são apresentados os valores da ε em relação aos valores de θ_{Grav} , na Figura 2 observa-se os desvios entre os valores de θ_{TDR} estimados pelas equações de Topp et al., 1980 e Malicki et al., 1996 e aos valores apresentados diretamente no display do aparelho da EASY TEST® e os valores de $\theta_{Grav.}$ Verifica-se que estes ajustes não se adequaram bem a este conjunto de dados.

Baseado nesses resultados e dado que se pretendia obter uma maior acuracia do método, decidiu-se realizar novos ajustes para os dados, utilizando-se os modelos descritos acima. As equações obtidas, para os valores de ε apresentaram parâmetros estatísticos, pouco diferenciados (Tabela 2) entre as equações linear e quadrática, tendo a equação cúbica apresentado alguns coeficientes não significativos, sendo por este motivo descartada das análises posteriores.

Como os parâmetros, eram pouco diferenciados, optou-se por fazer analises gráficas dos desvios para as equações linear e quadrática para auxiliar na escolha da melhor ajuste (Figura 3).

A equação quadrática foi o selecionada como a que melhor ajustou os valores da ε, apresentando os coeficientes ligeiramente superiores (Tabela 2) aos do modelo linear e uma menor amplitude dos desvios (Figura 3 e 4). Resultados semelhantes de melhores ajustes para função quadrática, já foram encontrados para outras classes de solos brasileiros, em experimento de laboratório.(Tommaselli & Bacchi, 1996).

São apresentados também os ajustes lineares para as equações de Topp et al.,1980; Malicki et al., 1996 e para a equação programada no aparelho da EASY TEST , dado que alguns aparelhos comerciais, fazem o ajuste automático com estas equações, e determinadas finalidades da avaliação de θ , não necessita de elevada acuracia.

A diferença de modelos para o melhor ajuste, esta relacionada, entre outros fatores, a faixa de valores de umidade obtida para o ajuste dos dados . Em trabalho realizados no laboratório, como os de Topp et al., 1980, e Malicki et al., 1996, há a possibilidade de criar artificialmente valores de θ. Estes valores extremos da umidade do solo podem mudar o modelo de ajuste das equações.

No presente caso a faixa de variação de θ no solo foi de 22% a 53 %, que são os valores extremos encontrados no latossolo amarelo, textura muito argilosa, na região de Manaus, em condições naturais. Este faixa de valores é semelhante aos obtidos na avaliação realizada através da técnica de moderação de neutrons, realizada por Cabral, 1991 e por Hodnett, et al., 1996, respectivamente em um seringal e floresta primária e pastagens e floresta primária, em Manaus, sob latossolo amarelo. Esses valores se encontram também dentro da faixa determinada por Medina & Júnior, 1987, quando da avaliação da capacidade de campo para esta classe de solo.

A presença de materiais orgânicos, pode levar a uma subestimação da ε, como indicado previamente no trabalho de Topp et al. (1980) e no trabalho de Herkelrath et al. (1991), posteriormente os trabalhos de Malicki, et al., 1996; Roth et al., 1992; Roth et al., 1990; Dirksen & Dasberg, 1993, comprovaram um efeito acentuado da ρ do solo sobre a ε, por essa razão foi feito o ajuste por regressão múltipla, para θ_{TDR} em função de ρ e ε , que resultou na seguinte equação :

$$\theta_{TDR} = 0,156204 + 0,00087\varepsilon^{2**} - 0,000017\varepsilon^{3**} + 0.020799\rho^{2**}$$

($R^2 = 0,9212$, $R^2 = 0,9202$ e um erro padrão da média de 0,0222).

Este tipo de ajuste foi também realizado por, Tommaselli & Bacchi, 1996; Jacobsen & Schjonnig, 1993, que encontraram pequenas melhorias no ajuste como o verificado nesse estudo. Diferindo dos obtidos por Malicki et al., 1996 que com este modelo de ajuste conseguiu uma boa redução dos desvios.

Os desvios da equação múltipla estão apresentados na Figura 3, onde observa-se uma distribuição semelhantes aos das equações linear e quadrática.

Uma análise da distribuição gráfica dos resíduos (Figura 5) em relação aos valores de ρ evidenciou, um melhor ajuste dos dados, para valores de $\rho > 1,1$ g cm^{-3}, baseado nessa evidência foi realizado um novo ajuste dos dados reagrupando-os em duas faixas de ρ , amostras com $\rho < 1,1$ g cm^{-3} e amostras com $\rho \geq 1,1$ g cm^{-3}. Os modelos de equações ajustados foram os mesmos utilizados anteriormente.

Os coeficientes das equações ajustadas, e os parâmetros estatísticos, são apresentadas na Tabela 3 , os melhores ajustes foram novamente os modelos linear e quadrático.

Foi realizada também uma análise de variância para testar a identidade das equações ajustadas, para os diferentes valores de ρ em relação a equação geral para os dados analisados conjuntamente (Tabela 4), onde verificou-se que os modelos são significativamente diferentes, este resultado permite recomendar um ajuste diferenciado do dados, quando se dispõe de resultados da ρ ou sua estimativa.

Relaciona-se também os menores desvios apresentados para as dados de amostras com $\rho \geq 1,1$ g cm^{-3} , a esses dados apresentarem valores elevados de θ, isto é facilmente observado quando se compara as Figuras 6 e 7. Há uma indicação que os locais nesta, classe de solo, onde os valores de ρ são mais elevados, apresentam uma maior capacidade de retenção de água, que pode ser verificada pelos valores máximos de umidade observados no solo serem correlacionados os locais de maior ρ. Outro fato que deve estar contribuindo para a maior acuracia deste grupamento de dados refere-se a menor variância dos valores de ρ dessas amostras (Tabela 2).

Esse efeito da maior acuracia dessa técnica para valores elevados de θ, provavelmente está relacionado ao bom contato do solo com a haste guia e a inexistência de descontinuidades (como bolhas de ar, rachaduras e grandes poros no solo) que causam problemas na determinação de ε (Baker & Lascano, 1989), bem como de um efeito proporcional do maior conteúdo de água em relação aos outros constituintes que fazem parte do solo (fase gasosa e fase solida). Este fenômeno já foi verificado por outros autores (Roth et al, 1990).

A acuracia da avaliação da θ_{TDR} pode ser verificada pela análise do erro padrão da média, apresentado na Tabela 2. A magnitude dessa variação é semelhante a encontrada por outros autores como Herkelrath et al., 1991 que encontrou valores da ordem de 0,02cm^3 cm^{-3} ; Bohl & Roth, 1994 que encontraram valores entre 0,02 até 0,03cm^3 cm^{-3} para solos minerais e 0,03cm cm^{-3} e 0,07cm cm^{-3} para solos orgânicos, Topp et al., 1980 descreve valores de 0,013cm cm^{-3}

A grande maioria dos estudos de calibração da técnica do TDR, encontrados na literatura foram feitos em condições de laboratório com solos peneirados, e colocado em vasos. No presente caso a variabilidade esperada para os valores de θ_{TDR}, é previsivelmente maior dado que esta classe de solo, nas condições amazônicas e sob as formas de uso, onde foram coletadas as amostras favorecem uma intensa atividade na camada superficial, com mudanças em algumas características do solo de forma bastante acelerada, estas alterações ocorrem de forma bem menos acentuada nas camadas mais profunda onde há também uma menor variabilidade da ρ, como pode ser verificado comparando-se os valores do desvio padrão das amostras coletadas superficialmente com os valores coletados em profundidade (Tabela 1).

Um outro ponto a ser abordado quando se discute a acuracia do método refere-se diretamente a precisão do método gravimétrico, tomado como padrão para a calibração, que apresenta uma boa acuracia, no entanto, uma serie de cuidados devem serem tomados (aferição da balança, amostragem com o anel volumétrico cuidadosa para se evitar compactação, volume do anel volumétrico) para que não se tenha uma propagação elevada de erros (Gardner, 1965).

Os desvios apresentados provavelmente são devidos a um somatório de pequenas interferências que podem interferir na avaliação da ε. No entanto fatores isolados, ou erros sistemáticos podem ocorrer (sondas defeituosas, erros de pesagem, locais com grandes rachaduras no solo), esse problema que foi detectado em algumas avaliações e amostragens, foi parcialmente resolvido, pela análise de dados discrepantes e sua eliminação quando da constatação de um erro causado por um problema desta natureza.

As pequenas interferências que isoladamente são desprezíveis para alteração de resultados, quando ocorrem em conjuntos ou em casos específicos podem ser a explicação para estes desvios. É importante que neste tipo de avaliação se conheça as causas dessas interferências, como uma forma de se evitar, atenuar ou controlar as mesmas.

A área de influência da avaliação pela propagação das ondas pelas haste guias é descrita por Baker & Lascano, 1989, correlacionada com áreas ao redor da haste(s) guia(s), não havendo diferenças ao longo de seu comprimento. O volume de solo avaliado pela sonda da EASY TEST, segundo informações do manual, é basicamente um cilindro que circunda as hastes guias, tem uma área de influência de aproximadamente 5cm de diâmetro com 13 de comprimento, perfazendo um volume avaliado mais que duas vezes superior ao amostrado pelo anel volumétrico, no entanto pressupõe-se que as maiores possibilidade da área avaliada ter causados desvios, está relacionada a gradientes de umidade que ocorrem no sentido vertical no solo.

Se no momento da avaliação estiver ocorrendo o deslocamento de uma frente de molhamento na parte avaliada, isto dificulta a interpretação automática do sinal por algoritmos programados no aparelho (Dasberg & Hopmans, 1992), recomenda-se a interpretação gráfica do sinal manualmente, esse efeito não foi controlado nessas avaliações, pelo fato do aparelho utilizado não apresentar os gráficos do sinal. Deve ser melhor estudado, pois em grande parte do ano, ocorrem precipitações bastante frequêntes, na região amazônica, que podem causar desvios inaceitáveis, principalmente em medições automáticas, com intervalo de leituras rápidas, ou com haste guias de grande comprimento.

A instalação horizontal das hastes guias, pode atenuar o efeito da frente de molhamento, assim como reduzir o efeito da variabilidade na transecção vertical, entretanto nem sempre esta instalação é possível de ser realizada pela necessidade da escavação do local para a sua instalação.

As avaliações foram realizadas imediatamente após a inserção das hastes guias no solo, isso pode causar uma interferência pela compressão da água na região próxima as hastes quando da sua instalação (Jacobsen & Schjonning, 1993), este problema provavelmente teve um efeito reduzido nessas avaliações pelo pequeno diâmetro das hastes guias utilizadas nestas avaliações (2 mm).

Dado que a ε é uma propriedade que tem relação com a temperatura (Pepin et al.,1995), a avaliação da umidade em diferentes condições de temperatura pode alterar os valores, esses efeitos da temperatura é mais pronunciados quanto a θ do solo é mais elevada, isso está relacionado ao efeito da temperatura afetar de forma mais intensa a parte liquida do solo, em relação a fase gasosa e sólida, este fato provavelmente teve pequena interferência nestas avaliações dado que a grande maioria dos locais onde foram realizadas as avaliações, sofre baixa incidência direta da radiação solar, é a magnitude da variação da temperatura, nestes locais serem reduzidas (Cabral, 1996).Entretanto o efeito da temperatura, pode ser um fator importante, se ocorrerem mudanças de forma mais acentuada em outras condições, como é um parâmetro de fácil mensuração avaliação recomenda-se avaliá-lo em estudos que requerem grande precisão dos dados.

A variação dos valores de ρ está diretamente relacionados ao uso do solo (espécie presente e o manejo praticado), este pode ser um importante fator a ser considerado, pois as mudanças nesta característica do solo, podem ser alteradas de uma forma rápida, e consequêntemente podem alterar os processos físico-hídricos e químicos do solo, especialmente os relacionados ao movimento da água no solo.

Neste estudo diferenças importantes, entre a ρ foram observadas entre as áreas cultivadas e as áreas de floresta primária. Os valores reduzidos de ρ próximo as plantas de pupunha, em relação a outras espécies cultivadas como o cupuaçu e a kudzu, se deve uma elaborada trama com elevada massa de raízes na superfície do solo (D. Haag., annexo 1 deste relatório), e não há espaços porosos no solo, como poderia se imaginar.

É importante o conhecimento das diferentes propriedades do solo que podem interferir na avaliação da θ_{TDR}, através dos quais é possível evitar ou controlar estas interferências através de calibração no campo.

Para a decisão sobre o melhor modelo de ajuste de calibração deve se considerar a precisão desejada ou necessária, a qual está relacionada diretamente aos objetivos para o qual se esta determinando θ.

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Tabela 1- Valores da umidade volumétrica e densidade do solo avaliados próximo a diferentes espécies de plantas, e em três profundidades num latossolo amarelo, textura muito argilosa, Manaus.

Tratamento	θ(%) – umidade volumétrica					ρ - densidade do solo (g cm^{-3})			
	n	Média	Desvio padrão	Mínimo	Máximo	Média	Desvio padrão	Mínimo	Máximo
				Floresta primária					
Matá-matá (*Eschweilera spp*)	19	34,10	6,49	25,40	47,70	0,78	0,11	0,62	0,98
Bacaba (*Oenocarpus bacaba*)	18	41,44	5,81	30,20	48,70	0.81	0,10	0,63	1,00
				Áreas cultivadas					
Pupunha (*Bactris gasipaes*) -Fruto	20	26,71	3,15	22,20	33,00	0,94	0,13	0,73	1,22
Pupunha -Palmito	38	34,68	7,26	20,27	47,75	0,91	0,10	0,71	1,16
Cupuaçu (*Theobroma grandiflorum*)	33	41,81	2,61	34,67	46,68	1,10	0,21	0,91	1,54
Pueraria (*Pueraria phaseoloides*)	20	36,20	2,90	30,80	42,50	1,05	0,06	1,18	0,93
			Avaliação do perfil em três profundidades						
30cm	26	43,62	3,07	34,50	47,40	1,23	0,06	1,06	1,33
90cm	27	48,27	3,05	40,80	53,40	1,21	0,06	1,05	1,30
150cm	25	48,28	3,05	44,50	53,20	1,22	0,06	1,14	1,29

Tabela 2 - Coeficientes das equações de regressão para os modelos ajustados.

β_0	β_1	β_2	β_3	R^2	R^2ajustado	Erro padrão ($cm^3\ cm^{-3}$)
			θ (ε)			
0,108794**	0,013690**	-	-	0,9079	0,9075	0,0239
0,046367**	0,020444**	-0,000169**	-	0,9123	0,9115	0,0233
0,142527*	0,004207^{ns}	0,0000684^{ns}	-0,000014^{ns}	0,9133	0,9127	0,0233
			θ(ε,ρ)$^{+}$ –Equação de Malicki, et al., 1996.			
-0,03289*	1,0795**	-	-	0,7875	0,7866	0,0362
-	0,9994**	-	-	0,9920	0,9919	0,0365
			θ (ε)$^{++}$ -Equação de Topp et al., 1980.			
0,2082*	1,0766**	-	-	0,9082	0,9078	0,0238
-	0,9965**	-	-	0,9965	0,9965	0,0241
			θ (ε)$^{+++}$ - Easy Test®			
0,03065**	1,1259**	-	-	0, 9113	0,9109	0,0234
-	1,2159**	-	-	0,9964	0,9965	0,0241

** e *: significativo ao nível de 1% e 5% de probabilidade, respectivamente, pelo teste de F.; ns: não significativo; $^{+}$: fórmula proposta por Malicki et al.,1996; ++: fórmula proposta por Topp et al., 1980; formula embutida no aparelho EASY TEST®

Obs.: Nomes comerciais e industriais aqui incluídos são em benefício do leitor e não implica em preferência ou recomendação dos produtos pelos autores ou instituições.

Tabela 3 - Coeficientes das equações de regressão para os modelos ajustados para os dados analisados conjuntamente e separados pelos valores de densidade aparente do solo (ρ) em amostras com ρ menor que 1,1g cm^{-3} e ρ maiores ou iguais a 1,1 g cm^{-3}.

β_0	β_1	β_2	β_3	R^2	R^2ajustado	Erro padrão ($cm^3\ cm^{-3}$)
			θ (ε) – Todos os dados (n = 226)			
0,108794**	0,013690**	-	-	0,9079	0,9075	0,023869
0,046367**	0,020444**	-0,000169**	-	0,9123	0,9115	0,023339
0,142527**	0,0042070 ^{ns}	0,0000684 ^{ns}	-0,000014 ^{ns}	0,9133	0,9127	0,023260
			θ (ε) - Densidade menor 1,1 g cm^{-3} (n = 134)			
0,105602**.	0,013687**			0,8929	0,8921	0,02396
0,068213*	0,018129**	- 0,000122 ^{ns}		0,8944	0,8928	0,02388
0,143210 ^{ns}	0,004446 ^{ns}	0,000664 ^{ns}	-0,000014 ^{ns}	0,8950	0,8926	0,02390
			θ (ε) - Densidade maior ou igual 1,1 g cm^{-3} (n = 92)			
0,0178980**	0,011077**	-	-	0,7621	0,7595	0,02135
- 0,077161^{ns}	0,032686**	-	-	0,7833	0,7784	0,02049
-0,0312368^{ns}	0,06422^{ns}	-0,001825^{ns}	0,000020^{ns}	0,7844	0,7771	0,02055

** e *: significativo ao nível de 1% e 5% de probabilidade, respectivamente, pelo teste de F.; ns : não significativo .

Tabela 4: Resultados da análise de variância para testar a identidade dos modelos ajustados para a constante dielétrica em diferentes densidades aparentes do solo.

Fonte de variação	Graus de liberdade	Soma de Quadrados	Quadrado médio	Valor de F calculado
		Modelo Linear		
Parâmetro (c)	(4)	37,13576		
Parâmetro (r)	2	37,11459		
Redução(Ho)	2	0,02117	0,10585	8,64*
Resíduo	222	0,27199	0,0012251	
Total	226	37,40775		
		Modelo Quadrático		
Parâmetro (c)	(4)	37,2920		
Parâmetro (r)	2	37,28323		
Redução(Ho)	2	0,00877		
Resíduo	222	0,11575	0,004385	
Total	226	37,40775	0,0005213	8,41

Valores de F (2,226) $\alpha_5 = 3{,}00$; $\alpha_1 = 4{,}6$; ** significativo a 1% pelo teste de F.

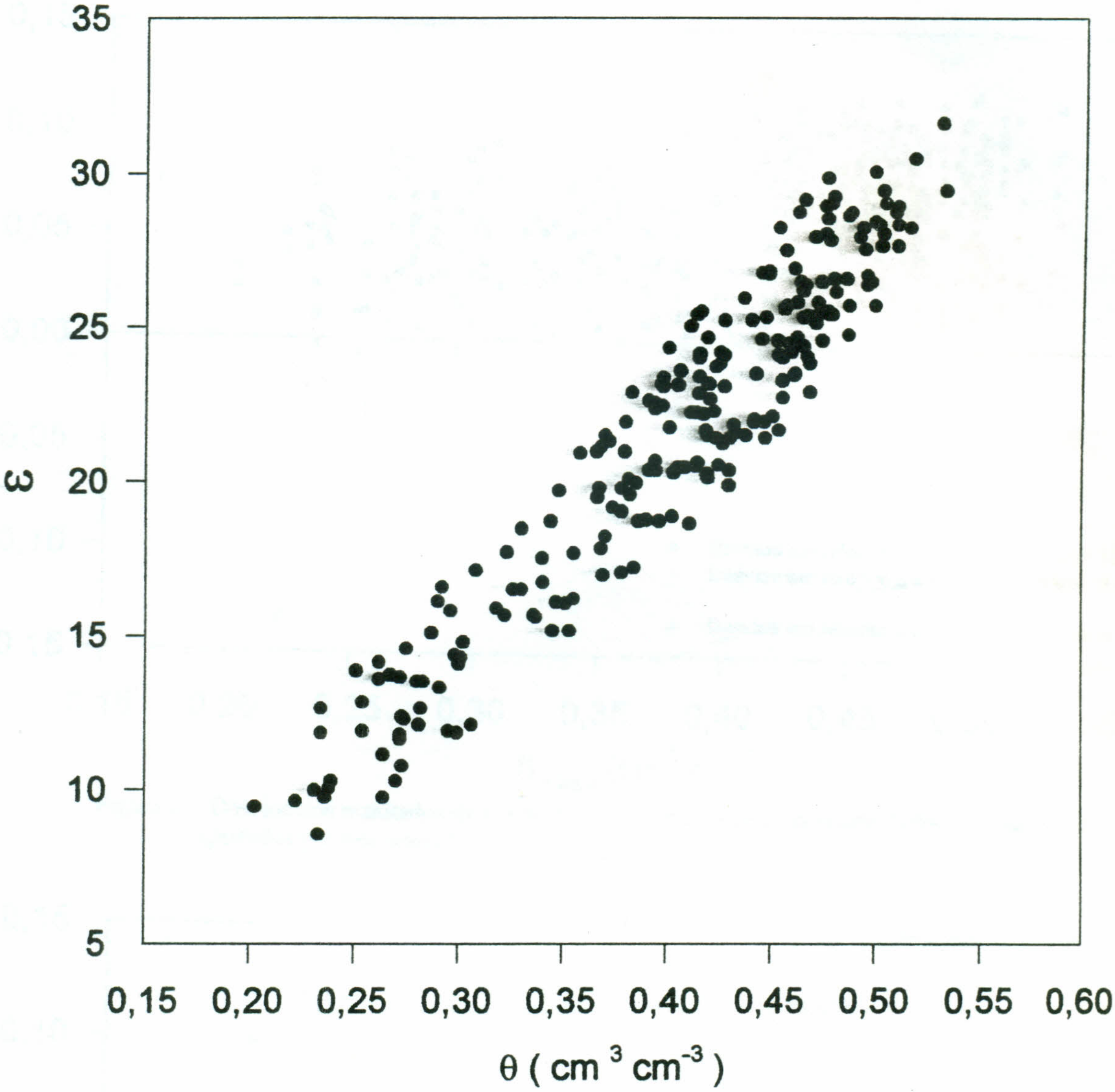

Figura 1 - Relação entre a constante dielétrica aparente do solo (ε) e umidade volumétrica (θ).

Embrapa

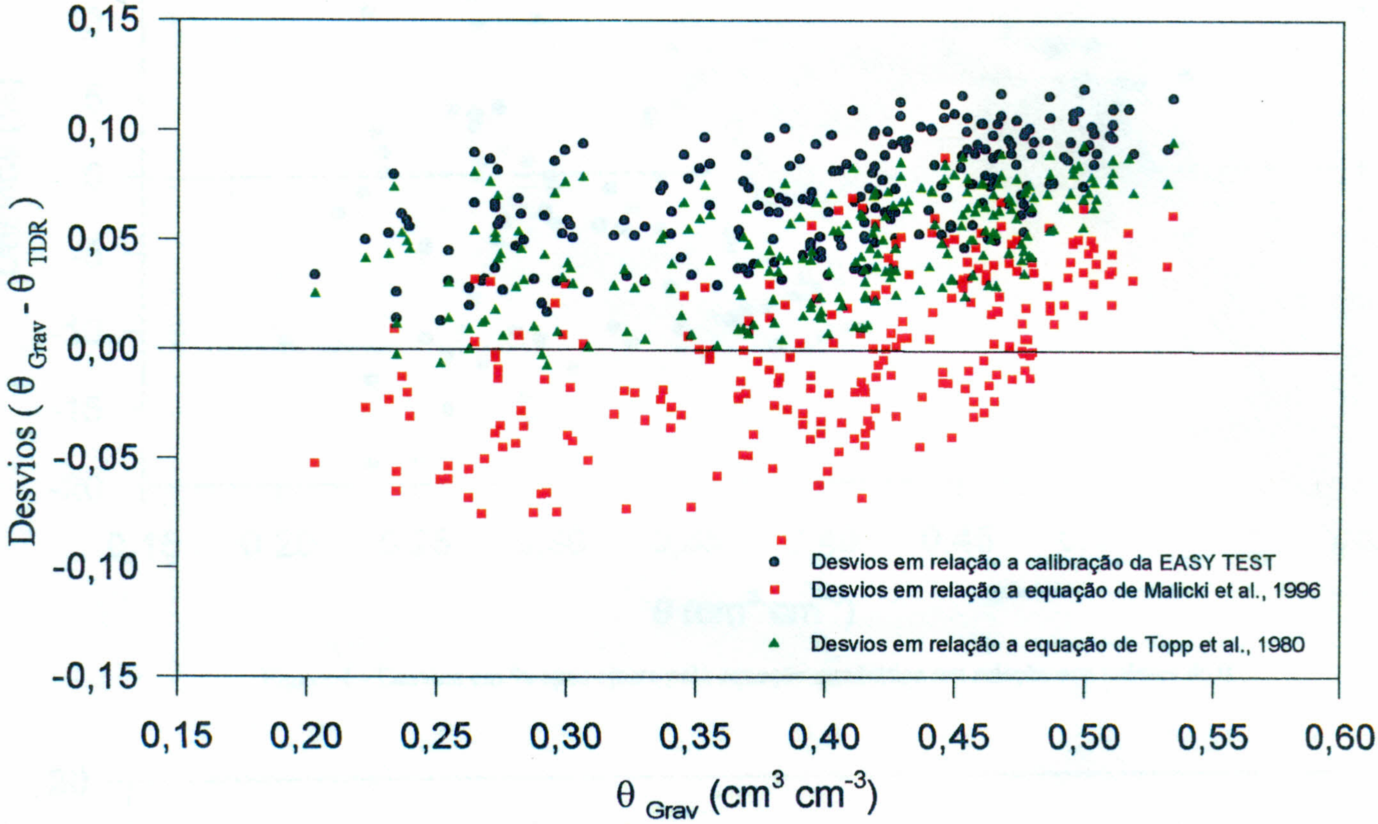

Figura 2 - Desvios dos resultados da avaliação da θ estimada pela constante dielétrica aparente do solo (ε), ajustados por tres equações.

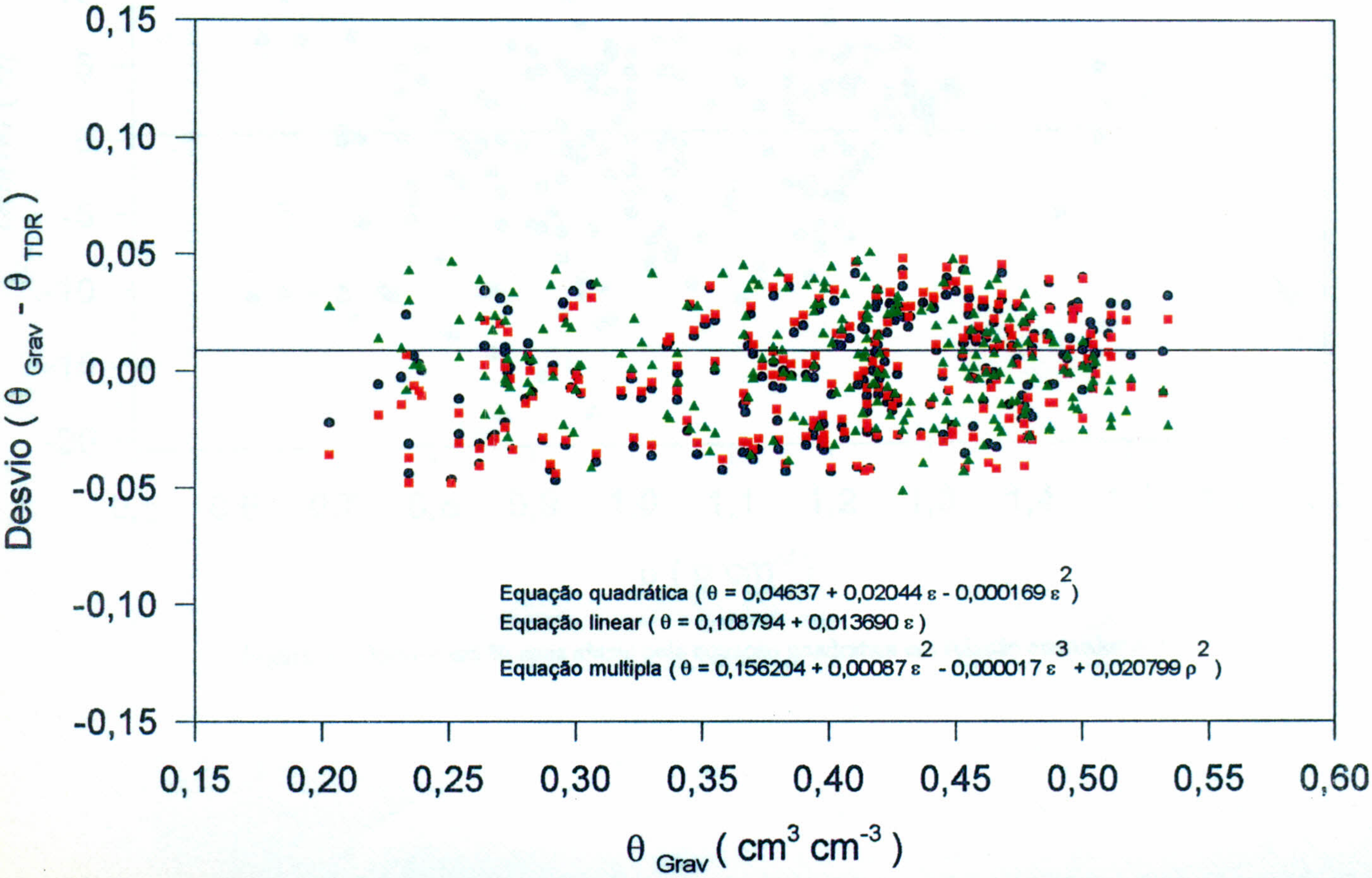

Figura 3 - Desvios após ajuste dos dados com as equações linear e quadrática para os valores da ε e múltipla para os valores da ε e ρ.

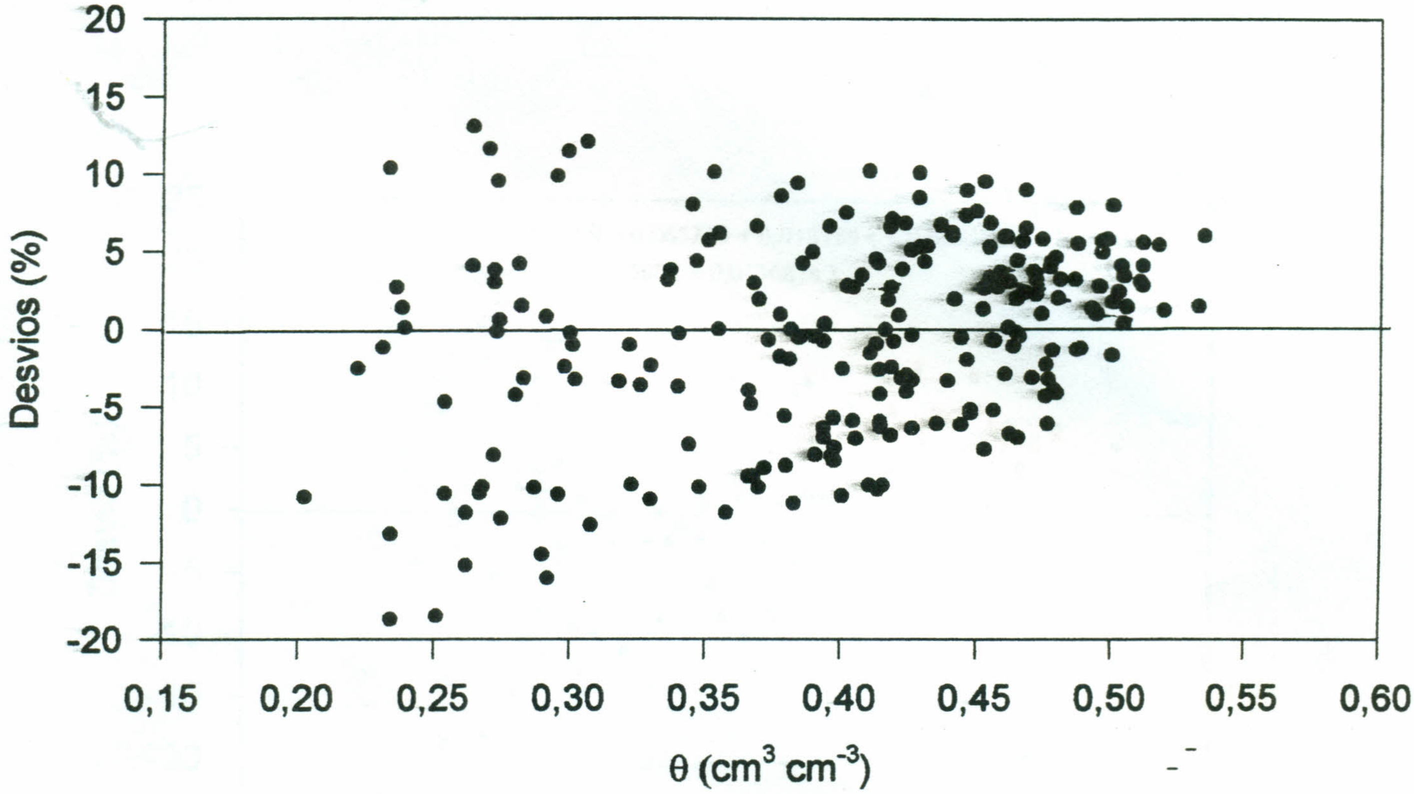

Figura 4 - Desvios em % após ajuste pela equação quadrática em relação aos valores de θ.

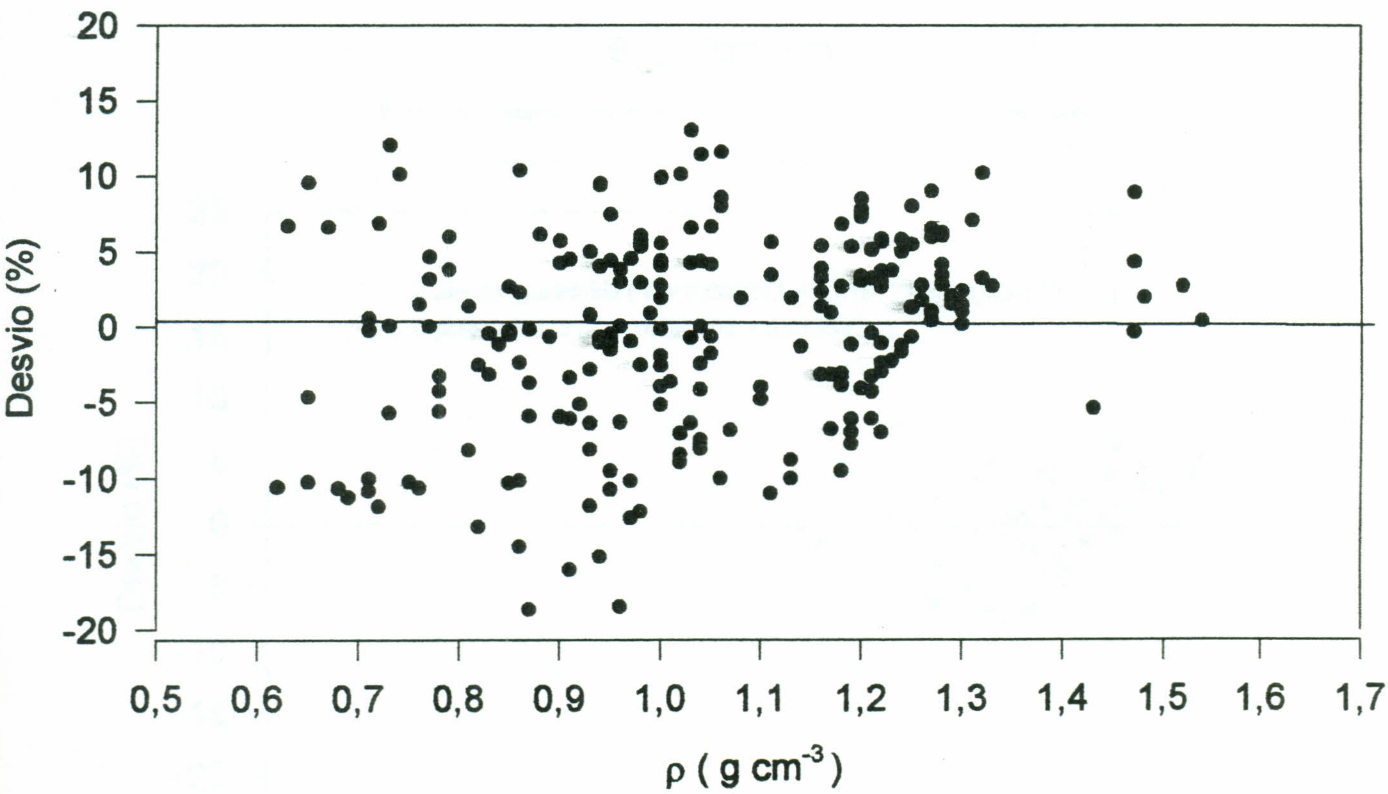

Figura 5 - Desvios em % após ajuste pela equação quadrática em relação aos valores de ρ.

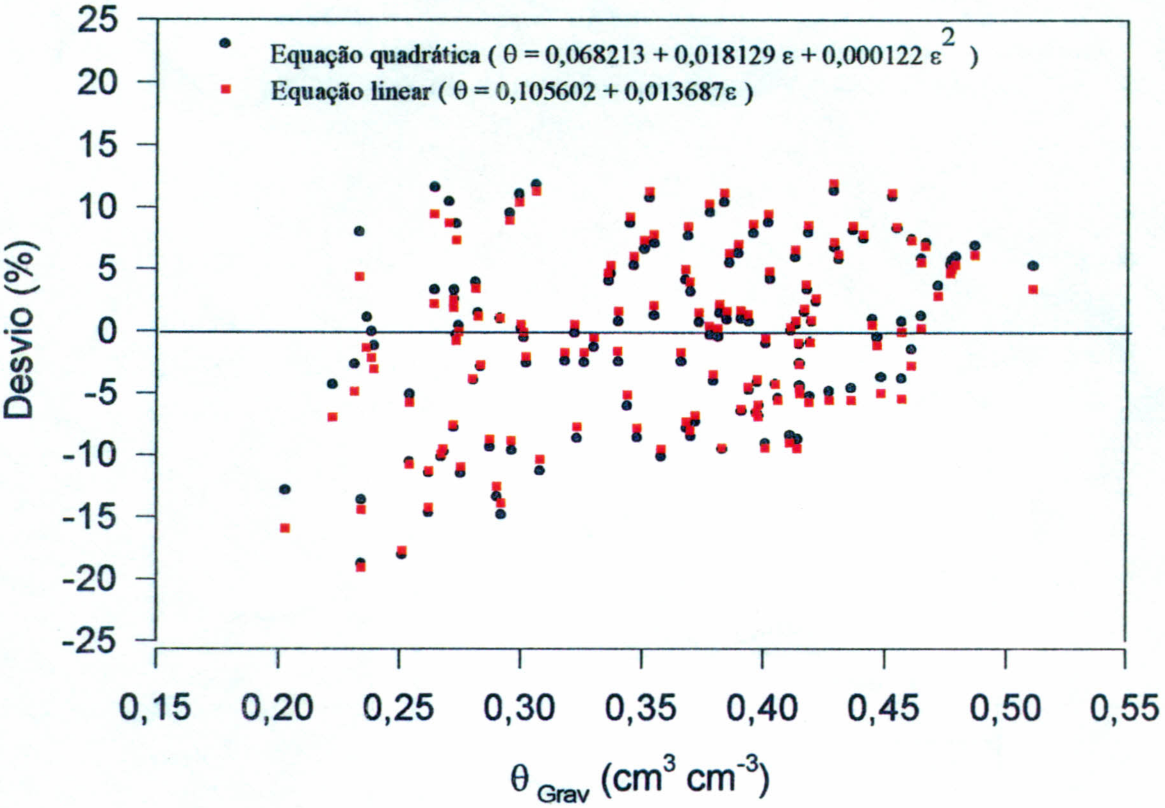

Figura 6 - Desvios em % após ajuste pela equação linear e quadrática para amostras com ρ menor que 1,1 g cm^{-3}

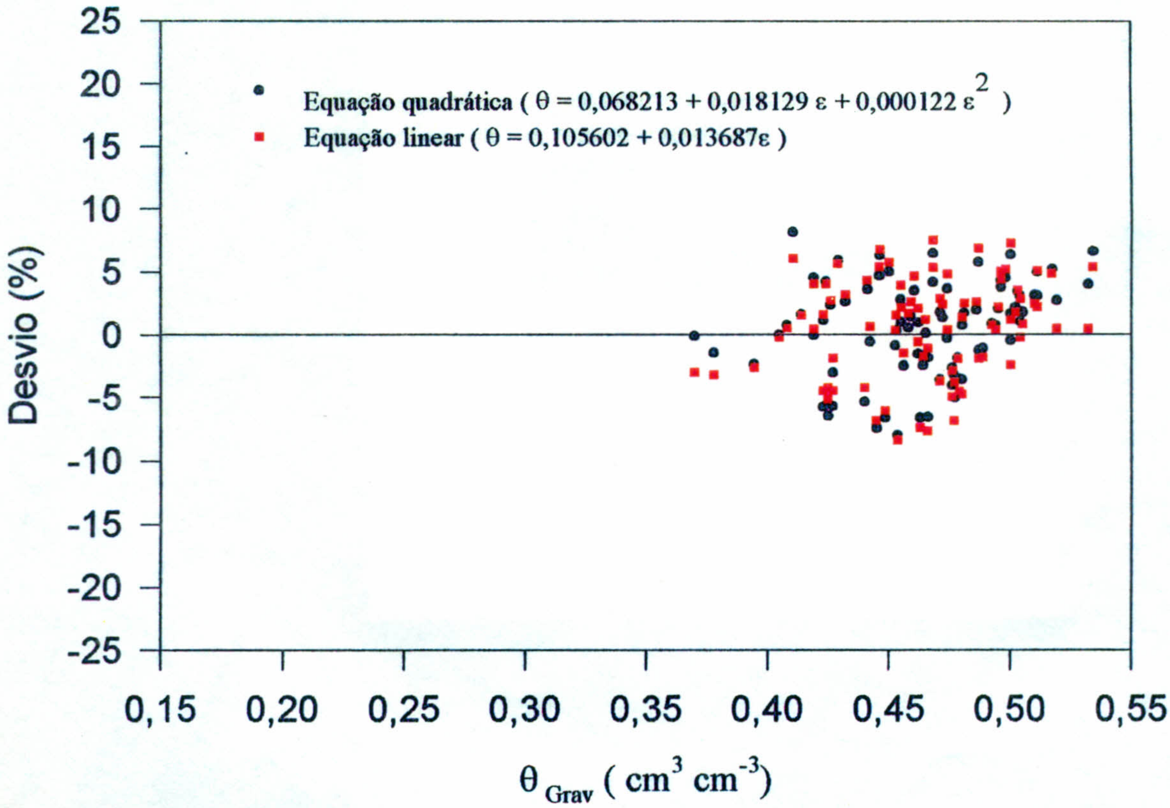

Figura 7 - Desvios em % após ajuste pelas equações linear e quadrática para amostras com ρ maior ou igual a 1,1 g cm^{-3}