Embrapa

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

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

Annual Report 1997

3. Project activities during 1997

Water and nutrient flux measurements

Distribution of throughfall and stemflow in agroforestry, perennial monoculture, fallow and primary forest in the central Amazon, Brazil

Publication submitted by Götz Schroth, Luciana Ferreira da Silva, Marc-Andree Wolf, Wenceslau Geraldes Teixeira and Wolfgang Zech (abstract)

The partitioning of rainwater into throughfall, stemflow and interception loss when passing through plant canopies depends on properties of the respective plant species, such as leaf area and branch angles. In heterogeneous vegetation such as tropical forest or polycultural systems, the presence of different plant species may consequently result in a mosaic of situations with respect to quantity and quality of water inputs into the soil. As these processes influence not only the water availability for the plants, but also water infiltration and nutrient leaching, the understanding of plant effects on the repartitioning of rain water may help in the optimisation of land use systems and management practises. We measured throughfall and stemflow in a perennial polyculture, three monocultures, spontaneous fallow and primary forest during one year in the central Amazon, Brazil. The effect on rainwater partitioning was measured separately for four useful tree species in the polyculture and for two tree species in the primary forest. Throughfall at two stem distances and stemflow differed significantly between tree species, resulting in pronounced spatial patterns of water input into the soil in the polyculture system. For two tree species, peachpalm for fruit (*Bactris gasipaes*) and Brazil nut trees (*Bertholletia excelsa*), the water input into the soil near the stem was significantly higher than the open-area rainfall. In the primary forest, such spatial patterns could also be detected, with significantly higher water input near a palm (*Oenocarpus bacaba*) than near a dicotyledoneous tree species (*Eschweilera sp.*). The consequences of such rainwater redistribution patterns are discussed with respect to the increased danger of nutrient leaching in areas of high stemflow.

Soil water measurements

In the present phase of the project, the spatial variability of soil physical and hydrological properties are studied. The measured parameters include: soil hydraulic conductivity, bulk density, soil texture and porosity. Soil moisture contents are measured using time domain reflectometry (TDR) in depths 10cm, 30cm, 90 and 150cm and soil tension (tensiometers) at 10, 30, 90, 150 and 250cm depths. The instruments were installed in all plots as described previously, and the data were collected during the second half of 1996, 1997 and during the current year. Preliminary analysis of the soil water availability within an agroforestry system revealed a pronounced "single tree effect". The soil moisture near the pupunhas were often low compared to soils under other plants. This is probably one reason for the low abundance of other plants near the pupunhas in both the agroforestry system and monoculture. At the topsoil in the primary forest, however, we observed high soil water contents. These results have to be interpreted using an integrated analysis of all other parameters measured in these systems. We intend to develop a simulation model to explain these differences of soil water contents in different land use systems.

Chemical analysis of rainfall, stemflow and soil solution

Analyses of nutrient fluxes with rainfall, stemflow and soil solution were conducted during the first half of 1997, until they were interupted by the intensive dry season caused by El Niño between August and Dezember. The last data points were taken during the first months of 1998. Now, two years of nutrient data are available, which will be analysed during the next months. The soil solution data will be combined with the soil water fluxes which are currently computed in Bayreuth to give the total nutrient fluxes through the systems. These results will be available in 1999, principally because of the time required for the adaptation of soil water flux models to the specific conditions of the experiment.

Above-ground biomass and nutrient accumulation

Mean aboveground biomass of 4-year-old castanha trees of the AF-System (both treatments) was 30.4 kg (32.5 kg in the 100%, and 28.3 kg in the 30% treatment). The mean above-ground biomass of pupunha (fruit) trees weighed 33.6 kg (with 40.8 in the 100%, 26.5 kg in the 30% treatment), the mean above-ground biomass of cupuaçu trees was 4.14 kg (with 4.51 kg in the 100%, and 3.77 kg in the 30% treatment). Mean biomass of pupunha (fruit) was about the same in the monoculture (38.8 kg), whereas the cupuaçu trees of the respective monoculture were surprisingly significantly smaller (2.02 kg) than the trees of the AF-System 100% (ANOVA, tested pairwise as planned comparisons, $\alpha = 0.05$). This was the only significant difference in mean tree biomass found among the treatments.

Highest aboveground biomass was found for the pupunha monoculture (37.4 t/ha, sub-system „8a„) with the pupunha (fruit) trees in high density, interplanted with pupunha (palm-heart) plants. Also the biomass of the system with all 2500 plants/ha managed for palm-heart (sub-system „8b„) was very high (17.5 t/ha). The two treatments of the AF-System had an aboveground biomass of 10.4 t/ha (100% fertilizer) and 8.84 t/ha (30% fertilizer); this difference was not significant. The monoculture of cupuaçu had the lowest aboveground biomass of only 0.447 t/ha due to its low planting density (223.2 trees/ha) and the low biomass of the single trees.

The nutrient accumulation of the aboveground biomass was compared with the nutrients applied by the fertilizer. A high (formal) surplus of fertilizer was calculated compared to the amount accumulated. A formal surplus by a factor of 40 to 50 for N and a factor of 100 for K was found for an average castanha or cupuaçu tree during the first 21 months of growth. In the last year before May 1996 the fertilizer-supply of these two nutrients met about the actual demand of an average tree of these species, or was much lower (for N in castanha). It was suggested to modify the distribution of fertilizer application in time to obtain a more economic use of the fertilizer.

Root distribution and root biomass

The patterns of tree root distribution in agroforestry associations determine how the trees interact with the site and with each other. Knowing these patterns and the underlying strategies of soil exploration allows to choose tree species and design agroforestry systems for optimum use of soil resources at minimum competition. The spatial distribution of root biomass was studied by excavation and soil coring in the polycultural system 2 with urucum, castanho, cupuaçu and pupunha (either for fruit or for heart-of-palm production). Castanho and cupuacu both possess massive, long tap roots and restricted lateral root extension. The central root of urucum, in contrast, split up at a depth of 30 cm, giving way to a number of coarse laterals. As a consequence, coarse roots were essentially restricted to the upper 60 cm of the soil, but the lateral extension exceeded 3 m in places. The adventitious roots of pupunha reached high concentrations in the topsoil, where they also attained lateral lengths of 4 m. In addition, pupunha roots grew vertically along the projection of the stem to depths >1m. Root dry matter to a depth of 1 m was 50-120g m^{-2} under castanho, 25-80g m^{-2} under cupuacu, 300-500 g m^{-2} under urucum, 800-900 g m^{-2} under pupunha for heart-of-palm and 1000-1200 g m^{-2} under pupunha for fruit. Live fine root mass was in the order of 140-160 g m^{-2} under the dicot trees, 220-290 g m^{-2} under peachpalm for heart-of-palm and 330-430 g m^{-2} under peachpalm for fruit. More than two thirds of fine root dry matter to a depth of 150 cm were concentrated in the upper 30 cm. Nevertheless, there was considerable potential for complementarity in the use of soil resources with the investigated tree species, as the pronounced vertical root growth of castanha and cupuacua contrasted with the stronger lateral development of the root systems of pupunha and urucum. Moreover, castanho had its root maximum in the subsoil, possibly as a response to the competition from the associated species, suggesting a high combining ability with shallower-rooted species. On the other hand, the lateral extension of pupunha roots in the topsoil made competition a potential problem, especially if the root systems extend further with increasing age. Root-shoot ratios were in the range of 0.27-0.43 for the dicot trees, 0.29-0.49 for pupunha for fruit and 0.86-1.88 for pupunha for heart-of-palm, indicating a disequilibrium between above- and below-ground biomass in the latter species.

Soil physics

Soil physical parameters were studied and compared with soil water content measurements. The use of time domain reflectrometry (TDR) permits rapid, accurate and non-destructive measurements of the volumetric water content of soil (θ). This technique is based on the close relationship between the apparent dielectric constant of the soil (ε) and θ. Non-linear regression equations for the relationship between ε and θ, based on field data which were collected during the wet and the dry season, are presented and are compared with the models most frequently encountered in the literature. The different sources of error which, may arise when using the TDR technique under field conditions are also discussed with particular reference to the study region.

Laboratory

In addition to the scientific results produced by the project, we have trained several Brazilian technicians and scientists in modern laboratory methods, including segmented flow analysis, atom absorption spectrometry and efficient methods of plant digestion and soil nutrient extraction. At the moment, one fully trained technician (Rosangela Seixas) already supervises and trains two other technicians and three students in the methodology of the project. Knowledge of these modern methods will improve their chances of finding permanent employment in the research institutions of the region.

Single tree effects on soil organic matter and nutrient contents

The effects of different trees and annual crops on soil organic matter (SOM) were investigated as described in the annex. The different sites had pronounced differences in total SOM. Sensitive parameters for the effects of land use changes on SOM were identified. These studies will be continued for organic nutrients bound to the soil matrix. The results will be related to the studies of dissolved organic nutrients, which will be done in the second phase of the project (ENV45-2).

Nutrient fluxes and competition determined with tracer studies

After intensive discussions and field surveys have suitable sites and application techniques been identified for preliminary tracer studies of N-15 and P-32.

During a visit of Dr. Lehmann at the CENA institute in Piracicaba/Sao Paulo (USP) a cooperation could be initiated with Dr. Takashi Muraoka, the head of the nuclear laboratory department. An experimental plan was sketched to investigate the relative nutrient uptake of 6 different tree species in the SHIFT fields using P-tracer techniques. Dr. Muraoka will assist in acquiring the P-tracer and Dr. Lehmann will conduct the field trial. The samples will be sent to Sao Paulo for analysis. After discussions with Dr. Morales, head of EMBRAPA Manaus, Dr. Cravo, Scientific Director and cooperating partner of ENV-45, and Dr. Schroth these P-tracer experiments have been approved provided no health hazard is involved. After field surveys it was decided to conduct only subsurface applications of the P tracer, because the experimental plots where the installations for soil water sampling are available are used to a large extent also by other groups. Safe working conditions can only be ensured if the fields where the tracer will be applied are closed to other activities for about 6 weeks. This can only be done in the blocks D and E, where no instruments for the assessment of the water and nutrient fluxes are installed. The subsurface application is a further precaution against contamination as the soil will prevent any radiation. Preliminary experiments will be started in September 1998.

In cooperation with Jose Pereira da Silva (EMBRAPA and SHIFT Env-23) and Dr. Götz Schroth, experiments have been started to compare the N competition between different tree species in mixed cropping systems using N-15 enrichment. At the same time, this approach gave the opportunity to study the amount of N_2 fixation by pueraria which may constitute a large N input into the systems. Up to now, information about this N source and its fluxes and distribution within the cropping systems is lacking.

An inventory of the natural N-15 abundance in the different systems investigated by ENV45 were started. This approach will give basic data about the „starting point„ of the experiments involving N-15 enrichment and are indispensible for the evaluation of the tracer experiments.

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

The nutrient and water fluxes could be measured according to the work plan as indicated in the last annual reports.

5. Cooperation with EMBRAPA, University of Hamburg, University of Göttingen and University of Sao Paulo (CENA)

EMBRAPA-CPAA

The cooperation between the project and EMBRAPA is close and occurs on several different levels:

- In the laboratory, mutual assistance in technical problems is common (exchange of equipment, reagents etc.). EMBRAPA staff also conducts analyses for the project for which the project pays the reagents.
- On the coordination level, there is frequent exchange of information and opinions of project staff mainly with Wenceslau Teixeira as well as Dr. Cravo and Dr. Gasparotto.
- On EMBRAPA's "chefía" level, the project is increasingly recognized as important for EMBRAPA's research activities, and the project members have been invited by the new EMBRAPA director, Dr. Morales, to participate in EMBRAPA meetings just as other researchers.

University of Hamburg

The coordination between ENV 45 (Bayreuth) and ENV 23 (Hamburg, Institute of Applied Botany) was very close during 1997, both projects were coordinated in Manaus by the same person (G. Schroth).

Cooperation with ENV 42 (BFH Hamburg) occured commonly on the technical level. On the scientific level, information and data were exchanged between the projects

University of Göttingen

Contacts with the project "Importance of N_2 Fixation in secondary and primary forest sites in the central Amazon" were made and possible cooperation were discussed with Dr. Antje Thielen.

University of Sao Paulo, Centro de Energia Nuclear na Agricultura CENA

A cooperation with CENA in Piracicaba/Sao Paulo was started to conduct joint research using P tracers. During a visit in Piracicaba, Dr. Takashi Muraoka from CENA and Dr. Lehmann were preparing an experimental plan for studying the nutrient uptake of different tree species in the polyculture systems of the SHIFT fields. This cooperation is the prerequisite for this study as CENA is providing essential expertise and laboratory facilities.

6. Conclusions

The project was extremely successful in its final year of the first project phase. The final evaluation and presentation of the results will need a thorough analysis of the data. The complexity of the observed processes require an integrated analysis. Implementing models for simulating the ecosystem dynamics would enhance the information we could draw from the measured data. Steps into this direction are highly encouraged.

First steps for preparing the second project phase were done. This will ensure an uncomplicated and rapid start of the experiments in the course of 1998.