Institute of Soil Science and Soil Geography, University of Bayreuth

and

Empresa Brasileira de Pesquisa Agropecuaria - Amazônia Ocidental (EMBRAPA)

SHIFT Project ENV 45/2

BMBF No. 0339641 5A

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

Annual Report 1999

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Project leader: Prof. Dr. Wolfgang Zech

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

Annual Report 1999

Compiled by: Johannes Lehmann and Klaus Kaiser

Abstract

This is the annual report of the SHIFT project "Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus". The experiments started during the first year of the second phase of this project were continued, such as studies about the effect of trees on soil phosphorus and sulfur availability, dissolved organic nutrients in rainfall, throughfall, stemflow and soil solution. Additionally, we focussed on the effects of cover crops on tree nutrition, soil nutrient and water dynamics. Soil nitrogen and phosphorus uptake was investigated using different N-15 and P-32 tracer experiments. The fate of fertilizer nitrogen was studied with N-15 labelled ammoniumsulfate in plant, soil, soil extracts and soil solution. In laboratory incubations, the effect of leaf quality on decomposition and incorporation of nutrients into soil organic matter was studied as affected by soil microbes and soil fauna.

Contents

1 Introduction

This is the second annual report of the second phase of the research project "Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus". The report summarizes the project activities during 1999.

In the first part of the report, the project team is presented, the activities and the most important results are summarized. Furthermore, the planned activities are briefly sketched and the cooperation with other projects and institutions demonstrated. In the second part, the different experiments are described in more depth. More detailed information will be available during the workshop in September 2000.

2 The ENV 45 research group

The following staff of the University of Bayreuth (UBT) and the EMBRAPA participated in the project activities during the reported period:

Name and affiliation	Function
Prof. Dr. Wolfgang Zech (UBT)	German project leader
Dr. Manoel da Silva Cravo (Embrapa)	Brazilian project leader
Dr. Johannes Lehmann (UBT)	German project coordinator in Manaus
Wenceslau Geraldes Teixeira (Embrapa)	Brazilian project coordination; soil physics and water dynamics
Dr. Klaus Kaiser (UBT)	dissolved organic nutrients
Jose Pereira da Silva Jr. (Embrapa)	soil microbiologist
Andre Wetzel (UBT technician)	^{15}N analyses, fractionation
Jean Dalmo Marques (CNPq fellow)	soil water measurements, soil physics
Francis Wagner Silva Correia (CNPq fellow)	microclimatology, climatological stations
Maria do Socorro S. da Mota (CNPq fellow)	soil nutrient dynamics
Maria Elizabeth de Assis Elias (CNPq fellow)	plant nutrient dynamics
Carla Eloiza Vabose Campos (CNPq fellow)	soil P availability (tree effects)
Fernanda Villani (CNPq fellow)	soil P availability (amendments)
Doris Günther (student UBT)	single-tree effects on soil P and S pools

Erik Bähr (student UBT)	dissolved organic nutrients
Harald Dinkelmeyer (student UBT)	fate of applied fertilizer nitrogen
Andreas Renck (student UBT)	fast nutrient and water fluxes in top- and subsoil
Daniel Seitz (Diplomand UBT)	nutrient leaching during litter decomposition as affected by soil fauna (in cooperation with ENV 52)
Inka Peter (UBT)	nutrient fluxes
Tatiane Pacheco Fernandes (student Pelotas)	soil nutrients in microbial biomass
Roger Borges da Silva (student Pelotas)	soil nutrients in microbial biomass
Lucerina Trujillo Cabrera (student INPA)	subsoil nutrient contents
Luciana Ferreira da Silva (Embrapa)	field technician
Marcia Pereira de Almeida (Embrapa)	laboratory technician
Luiz Gonzaga (Embrapa)	field worker

The technical staff and the students were extremely hard working and the extensive programme could not have been accomplished without their intense committment to the project.

3 Project activities during the report period

The project activities, first results and some conclusions are only briefly presented here. Further information can be drawn from the annexes and from the publications (section 7). More detailed information will be available during the workshop in September 2000 in Hamburg, where 7 oral and about 20 poster presentations were registered from this project.
The studies described were conducted at the experimental site of the SHIFT Terra firme project "Recultivation of abandoned monoculture areas through mixed cropping systems in the Central Amazon" at the Embrapa Amazonia Ocidental, Manaus.

3.1 Single-tree effects on soil nutrient dynamics

The effects of tree on soil nutrients with an emphasis on P were measured as already described in the last annual report and in various publications (section 7). Preliminary results from adsorption experiments (adsorption isotherms) indicate lower adsorption in soils under annatto than cupuacu (annex 5), which complement earlier findings, that P availability is higher under annatto. During the last year, we concentrated more on the assessment of the distribution of P pools within the system. The amount of inorganic but also of organic P was found to be heterogeneously distributed within the mixed tree cropping system (annex 1). This will require sophisticated sampling and assessment strategies as outlined for soil physical parameters in annex 10.

Subsoil N contents were higher under fertilized tree crops than in the secondary vegetation, indicating N losses by leaching. This was also described in earlier reports. Additionally, the soil under the fertilized tree crops showed higher biomasses of denitrifyers than the unfertilized timber trees, which were positively correlated with the denitrification potential (annex 7). Also the soil fauna was found to have a high influence on N input into soil as demonstrated with three diplopode species using ^{15}N technique (annex 8).

The legume cover crop ensured a more rapid and larger nutrient cycling than without a cover crop. In low-C soils only pueraria was able to elevate microbial C contents (annex 12). These results also explained the higher N availability and N contents in soil particulate organic matter under pueraria shown in earlier reports. However, the higher soil mineral N contents underneath the pueraria could not efficiently be used by the tree crop, if the tree was not fertilized with other nutrients than N. Therefore, Paullinia cupana did not develop an extensive root system without fertilization and could not exploit the nutrient reserves underneath the cover crop. This led to N accumulation in the subsoil, which can probably not be used by the tree crop (annex 9), as it was also shown between cupuaçu and peachpalm for the subsoil (Annual report 1997) and the topsoil (Annual report 1998).

3.2 Water and nutrient fluxes

3.2.1 Soil water measurements

The soil water measurements continued throughout 1999 underneath the four tree crops and the legume cover crop. The comparison between the measurements executed with manual and automatic equipment showed the constraints of the weekly determinations, which may impede the assessment of the rapid soil water fluxes (annex 4).

It was further demonstrated that the cover crop increased the amount of available soil water (annex 6). This may have been an effect of reduced evaporation from the soil surface, but the processes are not fully understood up to now and warrant further research.

3.2.2 Soil solution nutrient measurements

The measurements and data analyses of the soil water were continued. They were coupled with water flux models to obtain nutrient fluxes. The N isotope contents were assessed and total leaching of applied N fertilizer was calculated as affected by tree species. These data will be presented at the SHIFT Symposium in Hamburg.

3.2.3 Dissolved organic nutrients

In rainfall, throughfall, stemflow and soil solution, dissolved organic carbon, nitrogen, ^{15}N, phosphor and sulfur were analyzed (annex 2). The organic forms were fractionated into hydrophilic and hydrophobic compounds. With increasing soil depth, the DOC concentrations increased under both primary forest species and decreased slightly under *Vismia*. Dissolved organic nitrogen (DON) comprised up to 90% of total N in soil solution. The DON concentrations under all investigated species remained unchanged with increasing soil depth or even increased. This suggests, that organic N is more mobile compared to DOC and is an important N species to be considered when assessing N leaching.

3.3 Fate of applied N fertilizer in mixed cropping systems

The uptake of applied fertilizer N was studied in the mixed cropping system. The biomass and ^{15}N contents, as well as soil ^{15}N contents were measured at 4 dates after fertilization throughout one year. Brazil nut was taking up most of the applied fertilizer N, whereas cupuacu showed the lowest uptake, indicating the danger of N leaching (annex 3). Brazil nut took up more of its N from the fertilized area underneath the neighboring trees than from under the own canopy.

The high ^{15}N values in the soil solution underneath cupuacu indicated higher leaching than under all other trees at the start of the rains (annex 11). In the topsoil, trees had no effect on leaching of the applied tracer, as water movement was very rapid in the highly permeable soils (annex 4).

4 Planned activities during 2000

The current experiments will be continued throughout 2000. Additional activities comprise:

- effects of cover crops on soil water availability and water use by cupuacu,
- effects of different organic soil amendments on soil P sorption and plant availability,
- the modelling of water and nutrient fluxes.

5 Comparison with the work and time plan of the project

The experiments were conducted within the proposed time plan, and we were able to expand our activities within the objectives of the project through the work of Brazilian students.

6 Cooperation with other projects and institutions

EMBRAPA

The cooperation between the German and Brazilian partner (EMBRAPA) is very close on the technical level (mutual assistance in the laboratory and field work), on the scientific level (joint research activities, including Embrapa researchers into project activities, participation in Embrapa research wherever interests meet and participation is wanted) and on the coordination level (demonstration of research activities, knowledge transfer). The project is very active in capacity building of local technicians, workers and students (see section 2) with the equipment and techniques employed in the experiments.

SHIFT projects

The cooperation between ENV 45 and ENV 23 (University of Hamburg; Prof. Lieberei) was very close during 1999. The laboratory work was jointly organized, the field work coordinated and several experiments initiated. Equipment is frequently shared and led to a very constructive work atmosphere. Several publications and contributions to symposia were done together. Collaborative work included rhizosphere effects on soil P (W. Marino), biological N fixation and nutrient fluxes in microbial biomass (J. Pereira), an overview over ENV45 work and a review about multi-strata agroforestry (G. Schroth). For the next year, several coordinated studies are presently discussed.

Cooperation with ENV 42 (BFH Hamburg; Prof. Bauch) has proven to be very important and fruitful. On the technical level, equipment is jointly used and the field work coordinated. The data analyses and interpretation make a close coordination imperative. Joint publications demonstrate the intense collaboration. The study about soil nitrification and denitrification was jointly organized (annex 7). Another study about the aggregation and nutrient distribution as affected by different tree species using thin sections is envisaged. We sincerely appreciate the outstanding support given especially by Prof. Bauch. He always takes his time to help in any scientific and administrative matter.

With ENV 52 (SMNK Karlsruhe; Prof. Beck), the technical cooperation is also very close, and equipment is frequently shared. A German student is jointly supervised in the area of nutrient fluxes from litter to soil as affected by soil fauna using ^{15}N techniques (annex 8). Within the planned activities of ENV 52 for its next phase, ENV 45 will play an integral part in the assessment of topsoil nutrient fluxes as affected by litter manipulation (see proposal ENV 52/2).

With ENV 102 (ZEF Bonn; Prof. Vlek), we plan to start an experiment on subsoil nutrient dynamics in fallow vegetation, which will be initiated during the coming months.

With ENV 29 (subproject Nitrogen Dynamics, Dr. Kern), joint experiments were done on soil N dynamics and N fluxes, which are currently being included in a publication.

The work atmosphere at the Embrapa and within the SHIFT projects is extremely productive and we want to express our sincere thanks to all the collaborating technicians, students and scientists.

Other institutions

The collaborative work with the Centro Energia Nuclear na Agricultura CENA (Dr. Takashi Muraoka) in Piracicaba/Sao Paulo on root activity determinations with radioisotopes proved to be very successful. The experiments could be conducted together and first results were already presented at an international conference at CAIE in February 1999.

The technical cooperation with the Bayreuth Institute of Terrestrial Ecosystem Research BITÖK, and the Institute of Plant Ecology, Dr. Gerhard Gebauer, (University of Bayreuth) were very fruitful and ensured that a large number of isotope analyses (^{15}N) and nutrient analyses could be done in a short time. The work of the technician in Bayreuth, Andre Wetzel, at the isotope laboratory funded by SHIFT ENV 45 made it possible that the ^{15}N analyses could be conducted in the way presented here.

The cooperation with Prof. Bernd Huwe from the Soil Physics Group at the University of Bayreuth is very close as the Brazilian coordinator Wenceslau Teixeira is completing his PhD studies with Prof. Huwe in Bayreuth. For the next year, modeling exercises will be intensified to learn more about the obtained data and calculate leaching losses. Dr. Oleg Menyailo from the Soil Physics Group, University of Bayreuth, and Institute of Forestry, Krasnojarsk, Russia, joined the project for one month in January 1999 and started measurements of the nitrification and denitrification under different agroforestry and wood tree species in comparison to secondary and primary forest sites. The analyses will be continued in Bayreuth and Krasnojarsk. Sites were chosen to link results of ENV 45 with ENV 42.

7 Presentations and publications

The project staff participated at various conferences and several publications are in preparation or already submitted.

Publications in international, refereed journals:

Schroth G, da Silva, Seixas R, Teixeira WG, Macedo I and Zech W 1999 Subsoil accumulation of mineral nitrogen under monoculture and polyculture plantations in a ferralitic Amazonian upland soil. Agricultural Ecosystems and Environvironment 75: 109-120.

Schroth G, da Silva LF, Wolf MA, Teixeira WG and Zech W 1999 Distribution of throughfall and stemflow in multi-strata agroforestry, perennial monoculture, fallow and primary forest in central Amazonia, Brazil. Hydrological Processes 13: 1423-1436.

Schroth G, D'Angelo S, Schaller M, Haag D and Rodrigues MR 1999 Root research methods for humid tropical agroforestry systems - a management perspective. In Workshop sobre sistema raticular: Metodologias e estudos de casos. Embrapa Aracaju, pp 219-230.

Schroth G, Teixeira WG, Seixas R, da Silva LF, Schaller M, Macedo I and Zech W 2000 Effect of five tree crops and a cover crop in a multi-strata agroforestry at two fertilization levels on soil fertility and soil solution chemistry in central Amazonia. Plant and Soil: in press.

Schroth G, Seixas R, da Silva LF, Teixeira WG and Zech W 2000 Nutrient concentrations and acidity in ferralitic soil under perennial cropping, fallow and primary forest in central Amazonia. European Journal Soil Science: in press.

Lehmann J, da Silva Jr. JP, Trujillo L and Uguen K 2000 Legume cover crops and nutrient cycling in tropical fruit tree production. Acta Horticulturae: in press.

submitted for publication:

Lehmann J and Muraoka T 2000 Tracer applications for assessing nutrient pathways in multi-strata agroforestry systems. Agroforestry Systems, Special Publication, submitted.

Lehmann J, da Silva Jr. JP, Schroth G and da Silva LF 2000 Nitrogen use of mixed tree crop plantations with a legume cover crop. Plant and Soil: submitted.

Lehmann J, Günther D, Mota MS, Almeida M, Zech W and Kaiser K 2000 Single-tree effects on soil P and S pools in a multi-strata agroforestry system. Agroforestry Systems, Special Publication, submitted.

Lehmann J, Cravo MS and Zech W 2000 Single-tree effects on soil organic matter properties of a Xanthic Ferralsol in the central Amazon. Geoderma, submitted.

Lehmann J, Muraoka T and Zech W 2000 Root activity patterns in a tropical agroforest determined by ^{32}P, ^{33}P and ^{15}N applications. Agroforestry Systems, submitted.

Schroth G, Barros E, Rodrigues MRL and Lehmann J 2000 A review of plant-soil interactions in multi-strata agroforestry systems with perennial crops. Agroforestry Systems, Special Publication, submitted.

Schroth., G., Salazar, E., da Silva Jr., J.P., Seixas, R. and J.L.V. Macêdo 2000 Soil N mineralization under tree crops and cover crop in multi-strata agroforestry in central Amazonia: spatial and temporal patterns. Exp. Agric.: submitted.

Presentations:

Dinkelmeyer H, Lehmann J, Treter U and Zech W 1999 Stickstoffdynamik im System Boden-Pflanze perenner Mischkulturen in Zentralamazonien. German Society of Tropical Ecology, Annual Meeting 1999, Ulm.

Figueiredo NN, Macedo JLV, Cravo MS and Lehmann J 1999 Evaluation of the nutrient contents of cupuassu (*Theobroma grandiflorum*) as a function of different levels of fertilizers. 2nd Conference on Fruit Tree Production in the Tropics and Subtropics, Bonn 1999. p. 37.

Günther D, Lehmann J, Kaiser K, Treter U and Zech W 1999 Einzelbaumeffekte auf Phosphor-Pools eines xanthic Ferralsols in einem Agroforstsystem in Zentralamazonien. German Society of Tropical Ecology, Annual Meeting 1999, Ulm.

Lehmann J and Muraoka T 1999 Tracer applications for assessing nutrient pathways in multi-strata agroforestry systems. In F Jimenez and J Beer (eds.) Multi-strata agroforestry systems with perennial crops. CATIE, Turrialba, Costa Rica. pp. 175-179.

Lehmann J, da Silva Jr. JP and Trujillo L 1999 Leguminous cover crops in tropical fruit tree production. 2nd Conference on Fruit Tree Production in the Tropics and Subtropics, Bonn 1999. International Society for Horticultural Science. p. 9.

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Marques JDO, Teixeira WG and Lehmann J 1999 Physical and chemical characterisation of a soil profil up to 3m depth in the central Amazon (Caractericação de parâmetros físico-químicos de um latossolo amarelo, na região Amazônica). Soil Science Society of Brazil, Annual Meeting 1999, Brasilia. Session 6: T037-6.

Teixeira WG, Marques J D de O, Huwe B 1999 Spatial variation in small scale of soil wetness evaluated by different methods. In: Proceedings of Congresso Latino Americano de La Ciencia del suelo – Santiago – Chile - CLACS-99. CD – ROM

Teixeira WG, Schroth G, Marques JD, Lehmenn J, Cravo M, Huwe B, Zech W 1999 Indicators for the sustainability of land use systems on degraded areas of the Terra firma in the Amazon Basin: soil characteristics and parameters for transport processes. In: Proceedings of 10^{th} International Soil Conservation Organization, Purdue.

8 Conclusions

The field experiments initiated in the first year were continued and several of them were completed. The analyses of the large amount of soil solution and extracts sampled will take several more months. Several publications could already be submitted to international journals. The project will still continue to expand the contacts to other projects within SHIFT and the Embrapa to initiate experiments which elaborate on the central aim, i.e. to give recommendations on how to design land use systems which are sustainable in terms of their water and nutrient fluxes.

Annex: Scientific results

1) Heterogeneity of soil P pools in a multi-strata agroforestry system

Doris Günther, Johannes Lehmann, Klaus Kaiser, Uwe Treter, Wolfgang Zech

1. Introduction

Soil P dynamics can be determined with a variety of analytical methods. The sequential extraction after Hedley et al. (1982) and Tiessen et al. (1984) offers the possibility of examining various inorganic and organic P pools differing in their origin and plant availability (Cross and Schlesinger, 1995). This analytical tool has been only rarely used for tropical soils (Cross and Schlesinger, 1995), but may yield valuable information about the pathways of P in tropical soils (e.g. Beck and Sanchez, 1995; Selles et al., 1997). The incorporation of added fertilizer can be followed and the tree-specific effects on P availability tested. This is especially important in strongly weathered tropical soils which possess a high P-fixing ability due to their high oxide contents. Cross and Schlesinger (1995) showed that hydroxide inorganic P and total organic P fractions constituted a large portion of P in weathered tropical soils in contrast to less developed soils, where acid inorganic P dominates.

In this study, we present the effects of different fruit and timber tree species in a multi-strata agroforestry system on inorganic and organic P pools of a Ferralsol in the Amazon basin. The samples were taken over the whole plot to assess the heterogeneity of the P distribution.

2. Materials and Methods

In September 1997, soil samples from 0-5 cm depth were taken at irregular distances from the trees as shown in the result graphs. The trees were arranged in a completely randomized design with three replicates. The sites were under *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum. (cupuacu); *Bactris gasipaes* Kunth. (peach palm); *Bertholletia excelsa* Humb.&Bonpl.; *Bixa orellana* L. and *Pueraria phaseoloides* (Roxb.) Benth. in a multi-strata agroforestry system. Additionally, sites were chosen with spontaneous gramineous vegetation, in secondary regrowth of *Vismia* spp. and in the primary forest under *Eschweilera* spp. und *Oenocarpus bacaba*. The trees in the agroforestry system were fertilized in May 1997 (Table 1). The pueraria received only lime, the secondary and primary forest sites and the grass did not receive any fertilizer. P was sequentially extracted according to a modified Hedley procedure (Table 2). Inorganic P was analyzed using the molybdate ascorbic acid method (Murphy and Riley, 1962). Total P was analyzed with a ICP-OES.

3. Results and Discussion

The highest P contents were found in intermediate soil pools, a fact which is typical for highly weathered tropical soils. The lowest P contents were determined for the easily available and residual P fractions. With the exception of the residual P, the fertilized soils under the agroforestry tree species showed a significantly higher total P content in the individual pools than in the area between the trees. Very important is the aspect that the amount of fertilization could not explain the different P values under the tree species of the agroforestry system. Soils under *Theobroma grandiflorunm* had lower easily and intermediately available P contents than the other trees of the polyculture system despite the fact that it received 7, 4, and 2 times more fertilizer than peachpalm, Brazil nut, and annatto, respectively. The low P return from the litter of cupuaçu, which has low quality and as a consequence low decomposition, may be the reason for the low amount of available soil P under cupuaçu.

Under the canopies of the same tree species a high variation of the P contents were found especially under peachpalm. The total P values of the soils in the peachpalm row differed from 194 to 516 µg g^{-1}. This fact could be explained by uneven fertilizer distribution. This may seriously affect results drawn from single tree samplings. Therefore, composite samples from at least four trees are recommended in such systems with point application of fertilizer. But not only inorganic soil P contents were higher underneath the canopies of the trees than the surrounding soil, but also organic P. This may indicate an input of organic P forms such as leaf litter or prunings. The uneven organic P distribution similar to the inorganic P distribution, however, could mean that also inorganic fertilizer was directly incorporated into organic soil P pools, probably by soil microbial transformation. The sites under the unfertilized legume cover crop pueraria had 2 times higher soil P contents than those under adjacent unfertilized natural vegetation. It can be assumed that pueraria uses the P from the fertilized area under the tree crops and enrich the soil between the trees.

The survey of the spatial distribution of the soil P pools gave valuable information on the effects of the trees on soil P and the fate of P in the agroforestry system.

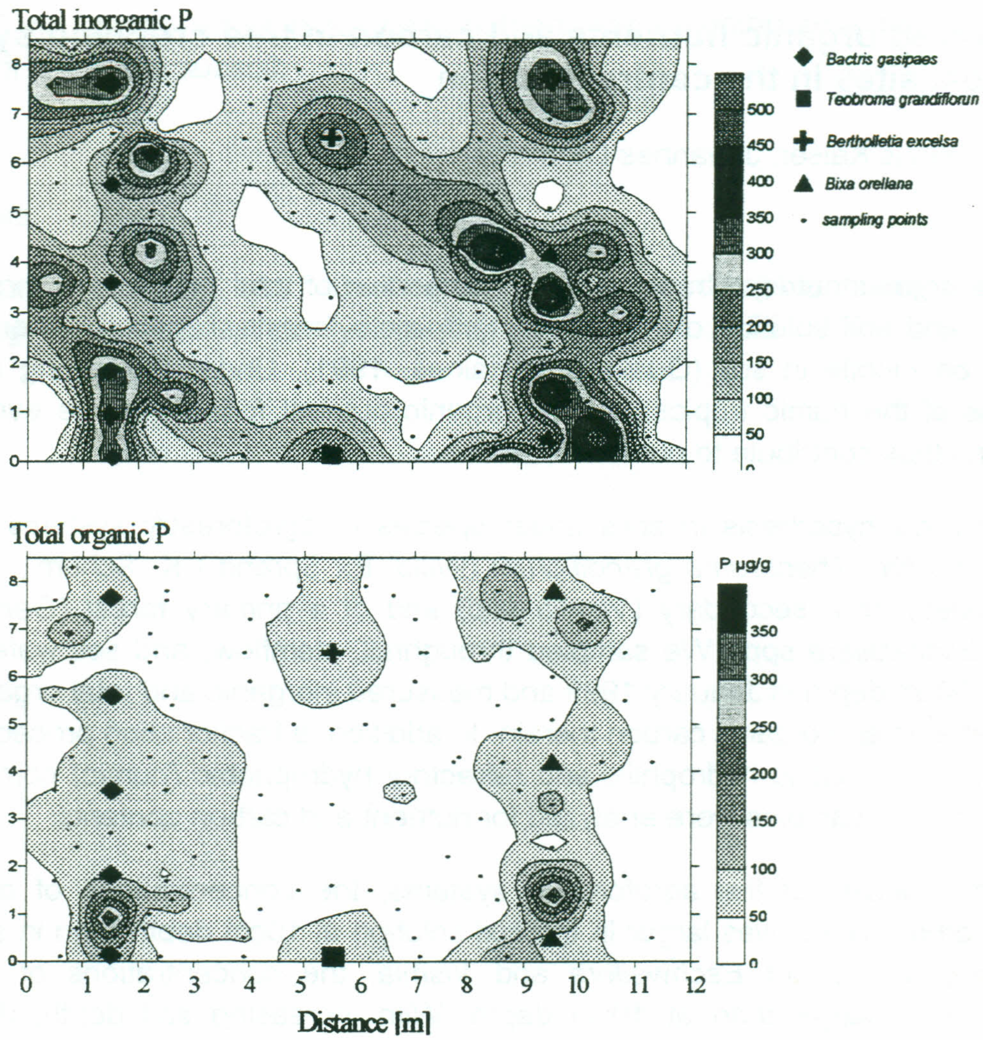

Figure 1 Spatial distribution of soil inorganic and organic P in an agroforest with four different fruit and timber trees on a Xanthic Ferralsol in the central Amazon.

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2) Dissolved organic nutrients and carbon in tree cropping systems and forest sites in the central amazon

Erik Bähr, Klaus Kaiser, Johannes Lehmann

Dissolved organic nutrients represent a large portion of total nutrients in throughfall, stemflow, and soil solution of forests. In temperate forests, organic nutrients were found to be mobile in soil (Qualls and Haines, 1991). Under the strong leaching conditions of the humic tropics, soluble organic nutrient forms may be even more mobile and thus contribute to nutrient losses.

We tested this hypothesis in soils under species of agroforestry systems (*Bactris gasipaes* Kunth., *Theobroma grandiflorum* (Willd. Ex Spreng.) K. Schum., *Pueraria phaseoloides*), of a secondary (*Vismia* spp) and of a primary forest (*Oenocarpus bacaba*, *Eschweilera* spp). We sampled throughfall, stemflow, and soil water at 10, 60, and 200cm depth in January 1999 and measured inorganic and total organic N, S and P contents and organic carbon therein. In addition, a fractionation procedure was used to separate labile hydrophilic and refractory hydrophobic (humic) compounds. The fractionated samples were analyzed for nutrient and carbon contents.

Under the species of the agroforestry systems, the concentrations of dissolved organic carbon (DOC) was larger in the soil solution at 10cm depth than in stemflow and throughfall. Under *Eschweilera* and *Vismia*, the concentrations of DOC in stemflow were larger than at 10cm depth. With increasing soil depth, the DOC concentrations increased under both primary forest species and decreased slightly under *Vismia*. Dissolved organic carbon in throughfall and soil solutions of the agroforestry and secondary forest stands were mainly in the hydrophilic fraction. The proportions of hydrophobic DOC in soil solutions decreased with depth. In contrast, the proportions of hydrophobic DOC under secondary and primary forest species were largest in the subsoil. This result is opposite to those of temperate forests were DOC decreases with soil depth and subsoil DOC is mainly hydrophilic. Dissolved organic nitrogen (DON) comprised up to 90% of total N. The DON concentrations under all investigated species remained unchanged with increasing soil depth or even increased. This suggests, that organic N is more mobile compared with DOC. This agrees well with observations in temperate forests. But in contrast to temperate ecosystems, DON was predominately in the hydrophobic fraction at our site. The largest dissolved organic sulfur (DOS) concentrations occurred in the topsoil. Here, up to 80% of total S were organically bound. The concentrations of DOS increased strongly with soil depth. Thus, DOS was less mobile in these soils than DOC. In all compartments of the investigated forests, DOS was entirely in the hydrophilic fraction. Dissolved organic phosphorus (DOP) was not detectable in any solution.

Our results show that dissolved organic matter contained a predominate proportion of nutrients in throughfall, stemflow and soil solutions of agroforestry systems and forests of the central amazon. Organic nutrient forms contribute especially to the leaching of N into the subsoil.

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3) Fate of applied fertilizer N in mixed tree cropping systems

Harald Dinkelmeyer, Johannes Lehmann, Klaus Kaiser, Wolfgang Zech

Introduction

Large amounts of N were leached into the subsoil under different trees of the agroforestry system as seen from the subsoil nitrate accumulation (Schroth et al., 1999). However, the magnitude of leaching seemed to be different between the tree species (Schroth et al., 1999) although direct evidence is missing so far. Also the root activity differed greatly between species. In this experiment, we want to monitor the fate of applied N in the soil and the plant .

Methodology

Theobroma grandiflorum (Willd. ex Spreng.) K. Schum. (cupuacu); *Bactris gasipaes* Kunth. (peach palm); *Bertholletia excelsa* Humb.&Bonpl.; and *Bixa orellana* L. were planted in a multi-strata agroforestry system. The trees were fertilized according to local recommendation under the canopy in an area of 4 m^2. In a time series, the soil mineral N contents (KCl extraction), the N in soil solution and the foliar N contents were determined. At the same time, also the ^{15}N contents were measured.

The aim of the study was to investigate the fate of ^{15}N in the soil-plant system of a mixed cropping system of *Bactris gasipaes* (peachpalm), *Theobroma grandiflorum* (cupuaçu), *Bertholletia excelsa* (Brazil nut) and *Bixa orellana* (annatto). The ^{15}N tracer (10 atom% ^{15}N enriched $(NH_4)_2SO_4$) was applied before the rainy season (January 1999) and its way in the plant-soil system was monitored until to the end of the rainy season (April 1999). Leaves were sampled from all investigated trees 14, 36, 69 and 96 days after the isotope application. Samples of the total aboveground biomass and the soil were taken 2 and 14 weeks after the application at 0-10, 10-30, 30-50, 50-80, 80-120, 120-200cm depth (200-300, 300-400 and 400-500cm only at 14 weeks). 20g soil were extracted with KCl and analyzed for NH_4 and NO_3. Additionally, the extracts were destilled and the N isotope composition was measured in the destillates as well as in bulk soils and biomass.

Results and Discussion

A total amount of 7.5% of the applied ^{15}N were found below the rooting zone (>200cm) fourteen weeks after the fertilizer application. Under annatto no relevant N leaching took place, but under cupuaçu (15.2% of the applied ^{15}N), peachpalm (9.6%), and brazil nut (4.5%) N was leached into the subsoil. Due to this nutrient leaching we recommend a reduced fertilization (from 39.5Kg ha^{-1} to 36.5Kg ha^{-1}) for the mixed cropping system (7-8 years old). After two weeks the biomass took up nearly 26% and at the end of the rainy season (after further twelve weeks) 47% of the applied ^{15}N. Annatto and Brazil nut took up a significant higher ($p<0.05$) amount of the applied ^{15}N compared to peachpalm and cupuaçu two and fourteen weeks after application. Only 2.5% were not accounted for two weeks after the application and were probably lost by denitrification. Further twelve weeks later the loss through denitrification was about 25% of the total applied ^{15}N (Table 1).

Annatto, cupuaçu and peachpalm took up more than 90% of the N fertilizer under their own canopy. After two weeks Brazil nut took up more than 70% of the N fertilized to the neighboring tree crops (peachpalm: 40%; annatto: 25%; cupuaçu: 8%). At the end of the rainy season Brazil nut even took up more than 80% from the neighboring trees (peachpalm: 42%; annatto: 36%; cupuaçu: 6%). Furthermore, peachpalm and Brazil nut could prevent nutrient leaching with their deep roots and take up N from the subsoil N pool better than annatto and cupuaçu. Brazil nut was able to effectively capture N and may contribute to nutrient recycling in the agroforest. However, this nutrient capture may also lead to nutrient competition and fertilizer placement and amount has to be adjusted accordingly.

Table 1: ^{15}N recovery 14 weeks after the application of ^{15}N, at the end of the rainy season in April 1999; values in one column followed by the same letter are not significantly different at P<0.05; means and standard errors (n=3).

	Recovery of ^{15}N in the plant-soil system [%]				
Tree	Biomass		Soil		Total
Cupuaçu	3.70b	±0.43	6.98a	±0.78	10.68
Brazil nut	16.76a	±3.64	6.69a	±1.91	23.45
Peachpalm	3.69b	±0.54	8.40a	±1.07	12.09
Annatto	22.88a	±7.18	6.24a	±1.47	29.12
Total	47.03		28.31		75.34

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4) Rapid water dynamics in a highly aggregated Xanthic Ferralsol

Andreas Renck, Johannes Lehmann

Introduction

The weekly measurement of soil water suction and the monthly measurements of soil solution nutrient contents were supplemented by high resolution determinations of soil water and nutrient fluxes. With these measurements, we wanted to find out the short-term dynamics of soil water as a tool to evaluate the short-term nutrient leaching losses.

Methods

In a soil pit a data logger system connected to tensiometers and TDR was installed up to a depth of 3.5 m under pueraria in an agroforestry system with *Theobroma grandiflorum* (cupuacu); *Bactris gasipaes* (peach palm); *Bertholletia excelsa* (castanho); and *Bixa orellana* L. (annatto) with a cover crop of *Pueraria phaseoloides*. The instruments were installed between cupuacu and pupunha under pueraria. Readings were done every 5 min during the first month, every 15 min thereafter. Manual TDR probes were installed at 0.1, 0.3, 0.9, 1.5 amd 2.5 m depth under all tree species in a randomized complete block design with three replicates. Measurements were done in weekly intervals.

Results

The weekly measurements did not reflect the "true" soil water dynamics. This became clear from the comparison between the manual and automatic measurements of the soil water suction (Figure 1). This may have important implications for the assessment of water movement and therefore nutrient leaching. The soil water changes are extremely dynamic as already shown in the last annual report. If it is not possible to assess these dynamic changes, soil water and soil nutrient flux calculations will not be satisfactory.

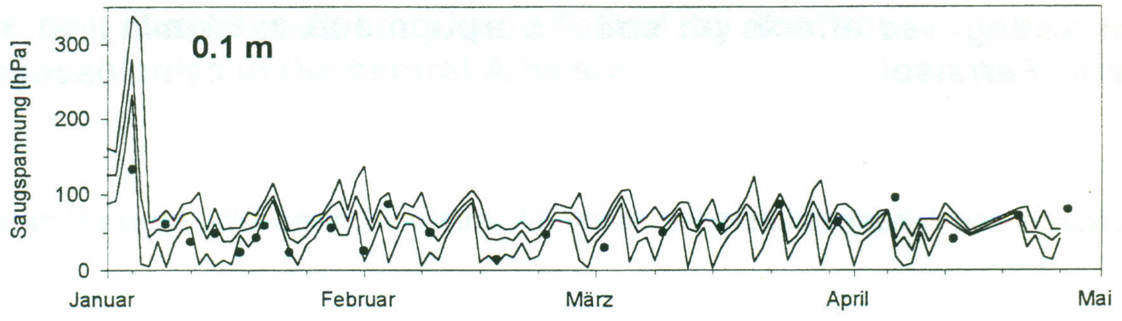

Fig. 1 Comparison of the soil water suction at 0.1 m depth measured with manual tensiometers (dots) and with the datalogger system (lines, daily means, minima and maxima).

5) Contrasting tree effects on soil P sorption and availability on a Xanthic Ferralsol

Carla Campos and Johannes Lehmann

The Ferralsols of the central Amazon are highly weathered and often have low available nutrient contents. Even in fertilized soils available P contents can be low due to high P fixation by oxides. Perennial plants in managed or natural ecosystems may keep P in available form through a rapid P recycling between plant biomass and soil.

The central objective of this study was the investigation of the availability of soil P as affected by two tree species with widely different P return. Two composite soil samples were taken at 0.5 m distance from four individual trees of *Theobroma grandiflorum* and *Bixa orellana* and combined. Soils from trees at three levels of fertilization were collected. The field experiment was replicated three times using a randomized complete block design with a split plot arrangement for species and main plot for level of fertilizer. For a bioassay, soil under the canopy of the same tree species was collected and *Pueraria phaseoloides* was planted in pots in four replicates. Soil P availability was analyzed using Mehlich extraction, adsorption isotherms and sequential extraction according to Hedley.

Phosphorus adsorption did not increase with an exposure longer than 8 hours. Therefore, adsorption isotherms can be done within 8 hours in the studied soils. In general, about 50% of the added P were adsorbed by the soil matrix. The adsorption decreased for soils which received higher amounts of P fertilizer, indicating that adsorption sites were already occupied by P from previous fertilization. Soils under *Theobroma* adsorbed more of the added P than soils under *Bixa*. This can be explained by the high amounts of organic P which is present in soils under *Bixa* as an effect of high P recycling through litterfall.

The use of the described methodologies for assessing the various forms of P in soil and the P fixing ability was better able to characterize P availability than commonly used soil P analyses. Furthermore, the effects of fertilizer application can be better evaluated. *Bixa* was identified as a tree species which is better able to keep added P fertilizer in available form than *Theobroma*.

6) Soil water availability as affected by the cover crop *Pueraria phaseoloides* in the central Amazon

Jean Marques, Wenceslau Teixeira, Johannes Lehmann

Cover cropping is a common technique in fruit tree plantations of the tropics. One of the many reasons for planting a cover crop is the improvement of soil physical properties, an improved nutrient cycling, input of atmospheric N_2 by biological fixation and reduction of erosion. Whether and to what extent cover crops`can influence soil water contents through effects on evaporation losses is not known for Xanthic Ferralsols in central Amazonia. In order to study the effects of the cover crop *Pueraria phaseoloides* on soil water cycling, TDR probes (time domain reflectometry) were installed at 0.1 m increments to 1 m depth. Soil water measurements were done weekly for 5 months. Precipitation and interception were measured automatically and manually. Transpiration and stomatal conductance were determined with a porometer. Continuous measurements were done during 10 hours for leaves exposed to direct sunlight and for shaded leaves. The results show that about 80 % of the rainfall can be stored as interception by the cover crop. This also decreases the danger of soil surface sealing by direct rain impact (splash). The maximum radiation was 1800 and 900 μmol m^{-2} s^{-1}, with an estimated transpiration of 25 and 17 mmol m^{-2} s^{-1} for sun-exposed and shaded leaves, respectively. The mean soil water storage under pueraria amounted to 436 mm, which was higher than the amount observed under bare soil with 386 mm. These results show that under the experimental conditions, there is a higher soil water availability under the cover crop that in bare soil due to reduced evaporation from the soil surface. Under these conditions, a cover crop may play an important role in water conservation and hence crop production on Xanthic Ferralsols of the central Amazon.

7) Single tree-effects on denitrification and soil microbial biomass in agroforestry systems and natural forests of the Amazon region

Oleg Menyailo, Johannes Lehmann, Oliver Dünisch, Manoel da Silva Cravo, Josef Bauch, Wolfgang Zech

Soil microorganisms are the dominant processors of soil C and N as well as dominant global sources of N_2O and major sources of CO_2. Variation of soil microbial biomass and its activity may to a large extent control actual emission of greenhouse gases. In order to predict fluxes of greenhouse gases from soils, knowledge of the microbial biomass will be of importance. Tropical forest ecosystems are one of the main natural source of CO_2 and N_2O. Whereas enhanced N_2O and CO_2 fluxes after conversion of tropical forests to grassland were reported by many authors, the effect of conversion to agroforestry an plantation forestry is much less studied. The aim of the present study was to find the effect of tree species used in agroforestry system in Amazonian region and natural forests on the total biomass of heterotrophic microorganisms (BH), which is mainly responsible for CO_2 emission, and on the biomass of denitrifiers (BD), which control N_2O emission. Both biomasses were studied using the kinetic method. Using trees-mediated soil changes we intended to explain variation of microbial biomasses by variation of soil properties.

Conversion of tropical forests to agroforestry in Amazonian region caused changes in different groups of soil microbial community. Most commonly used fruits species cupuaçu (*Theobroma grandiflorum*) and annatto (*Bixa orellana*) increased BD 2-3 times. Development of secondary forests with the dominant species *Vismia* spp also increased BD. The difference between the timber tree species *Andiroba* and *Ceiba pentandra* was not significant, and these species did not significantly change BD compared to the primary forest species.

The BH was also affected by tree species. The highest BH was found in soil samples beneath *Ceiba pentandra* compared to all other tree species ($P<0.05$). The lowest BH was found in soil samples beneath cupuaçu, annatto and *Eschweilera*. Cupuaçu and annatto did not differ significantly in their effect on both biomasses studied. The effect of *Eschweilera* on BH was significantly different from that of *Andiroba* ($P<0.03$) and *Vismia* ($P<0.05$).

We also wanted to find relationships between the biomasses studied and soil microbial activities. The BD was negatively related to the net N mineralization and basal respiration rates, and positively to net nitrification and denitrification rates ($P<0.05$). BH was positively related to the net N mineralization, basal and substrate-induced respiration rates. As the two measured biomasses were oppositely related to the processes related to the production of greenhouse gases, we calculated the ratio of BD to BH (D/H ratio) and made all further calculations with this ratio. The D/H ratio has shown stronger relationships to almost all of the microbiological activities. The D/H ratios were negatively related to the net N mineralization, basal and substrate-induced respiration rates. Also significant relationship was found between D/H ratios and denitrification, the relationship was even stronger than between denitrification and BD. The latter suggested that the D/T ratio should be taken into account for modeling or predicting greenhouse gases emission from the studied soils.

8) Litter quality effects on decomposition by diplopodes and ^{15}N recovery of central Amazonian agroforestry tree species

Daniel Seitz, Johannes Lehmann, Marcos Garcia, Werner Hanagarth, Klaus Hoffmann, Wolfgang Zech

Few attempts have been made to investigate the role of single soil fauna species in controlled laboratory incubation to describe litter decomposition in tropical agroforestry systems. Since a few macrofaunal species can be largely responsible for weight loss, studying these might reveal some basic information about the macrofaunal influence on decomposition. Leaves of different tree-species were incubated in semi-microcosms above soil for 45 days. Leaf-litter enriched from seven species of interest for central Amazonian agroforestry was incubated with three species of diplopods, *Pycnotropis sigma*, species A2 and A3 (not yet identified) and two control treatments (with and without litter) in a randomized complete block design with six replicates. The third diplopod species was used on three litter species only. Animals were replaced on death. 50 mL water was applied every four days and percolate was collected one day later. Samples were pooled to four samples for analyses of inorganic and organic N and one composite sample for ^{15}N isotope analysis. At the end of the experiment after 6 weeks, litter and animal weights were determined, as well as total N and isotope ratios in litter, animals and soil samples. Leaves were additionally analyzed for water-soluble polyphenols.

Litter weight loss decreased in order *Bactris gasipaes*>*Bixa orellana*>*Pueraria phaseoloides*>*Paullinia cupana var. sorbilis*>*Bertholletia excelsa*>*Vismia cayennensis*>*Theobroma grandiflorum* without diplopods and with *Pycnotropis sigma*. Decomposition of *Bixa* was highest with abundance of A2 an A3. During incubation with A3 decomposition of *Paullinia* was less then *Bixa* and *Bertholletia* showed the lowest weight loss. All litter species decomposed more rapidly with than without diplopods. The weight loss was not correlated with initial polyphenol-to-N ratios of the leaves. Decomposition of *Bactris* leaves was mainly mitigated by microfauna and mechanical leaching.

Nitrogen leaching was highest in *Bactris* and *Pueraria* and did not correspond with ^{15}N accumulation in animals. In incubation with *Bixa*, ^{15}N contents in the soil corresponded with accumulation in the animals. Nitrogen release in *Bactris* was mainly mitigated by microfauna, while in *Bixa* most nitrogen was released by the animals during defecation.

9) Cover crop and fertilization effects on nutrient dynamics in fruit tree cropping in the central Amazon

Lucerina Trujillo, Johannes Lehmann, Manoel da Silva Cravo

The soils in the central Amazon are highly weathered and have low nutrient contents. Therefore, fertilization is essential for fruit tree production. Nitrogen may additionally be supplied by biological N fixation of a legume cover crop, which is often planted in tropical fruit tree plantations. However, the effectiveness of the atmospheric N from the legume for tree N nutrition, and the combined effects of fertilization and cover cropping on the soil N dynamics and nutrient uptake by the fruit tree has rarely been assessed in tropical cropping systems with perennial plants. Therefore, we studied the soil and plant N dynamics as affected by fertilization and intercropping with a legume.

Soil samples up to 4 m depth were taken under guarana (*Paullinia cupana*) and in the middle between the trees at the end of the rainy and the end of the dry season. Treatments were full fertilization and control with and without intercropping with *Pueraria phaseoloides* in a completely randomized design with four replicates. Samples were extracted with KCl and analyzed for ammonium and nitrate. Subsamples were incubated for 36 days to measure potential N mineralization. At 0-0.1 m depth, we also analyzed the N in microbial biomass by fumigation extraction.

Topsoil nitrate contents were lower at the end of the wet season, whereas subsoil nitrate contents showed the opposite effect. This can be explained by high leaching of the mobile nitrate. Subsoil nitrate contents slightly increased due to fertilization indicating losses of applied N. The nitrate contents to a depth of 2 m were higher between the trees where the legume cover crop was growing showing an excess of N input partly caused by the legume which could not be used by the tree. However, even without a legume intercrop large amounts of nitrate were found in the subsoil between the trees, but only when the trees were not fertilized. With fertilization there were no differences in subsoil nitrate contents between and underneath the trees. This can be explained by the more vigorous tree growth of fertilized trees which have a larger nutrient demand and exploit a larger soil volume. Without a legume cover crop, the guarana can utilize the excess N in the subsoil between the trees. With a legume cover crop, more mineral N is available at the topsoil which is subsequently leached into the subsoil.

The results indicate large risks of nitrate leaching and a lack of available N at the end of the rainy season. The tree was able to use N from the subsoil and between the trees. However, without adequate fertilization with other nutrients than N and also with a cover crop, the N availability was higher than the demand by the tree. This lead to N leaching. Therefore, N fertilization could be reduced to more efficiently utilize the soil inherent N sources and the N supplied by the legume cover crop.

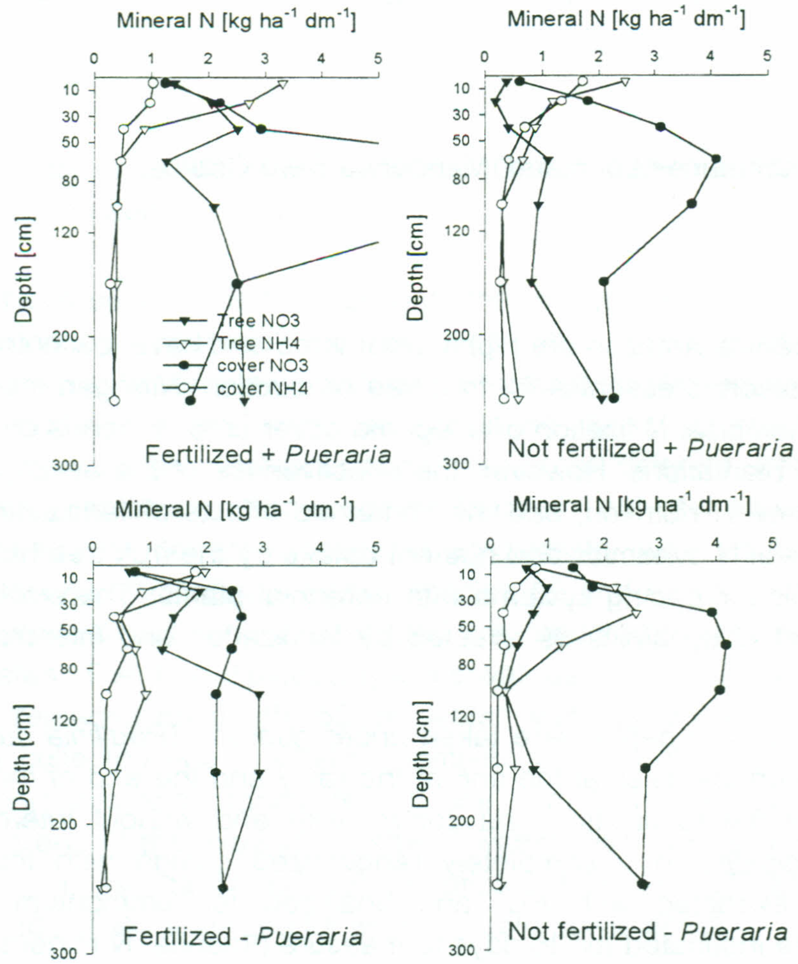

Figure 1 Soil mineral N distribution under Paullinia cupana with and without fertilization and cover-cropping in the central Amazon.

10) Variability of soil physical parameters in agroforestry research

Wenceslau Geraldes Teixeira and Bernd Huwe

Soil spatial variability has been recognized and documented at different scales (Beckett and Webster, 1971; Jury et al., 1991;Warrick, 1998). Many soil physical properties vary with transient soil features and some are not normally distributed and time and spatial dependent.

Agroforestry research has to cope with the soil variability, because the experiments are normally carried out at large treatment plots, with an inherent spatial variability between plots, while measurements among system components within the plots, may be spatially dependent. These inherent soil variability if not take in account may obscured treatment effects or lead to misinterpretations of results.

We will emphasize in this review concepts to accommodate spatial variability of soil physical parameters in order to build predictive models at field scale of flow and transport problems, and sampling procedures to allow comparisons of soil physical properties among treatments.

Sources and structure of soil variability

The sources of soil spatial variability have been grouped in two broad categories, systematic and random. The natural systematic variability is a gradual or marked change in the soil properties as a function of their genetic development.

Systematic variability caused by variation of parental material and intensity of soil forming factors such as chronosequence, toposequence, climasequence, biosequence, landforms such as mountains, plateaus, basins, valleys, and geomorphic elements such as summit, shoulder and backslope, can be observed even at relatively short distances.

The heterogeneity of many soils presently reflects variations of the Holocene climate as well as cryoturbate features of Pleistocene glacial – interglacial periods of the Quaternary (Kutílek and Nielsen, 1994).

Systematic variability is simultaneously and concurrently, superposed by changes in soil properties that varies randomly and as consequence its measurements. It becomes extremely complex and difficult to interpret for predictive use (Youngs, 1983).

Random variations, also called stochastic variations, are also caused by natural processes like soil formation factors, parent material, biological activity and changes that result from human management activities, such as agricultural activities like clearing, ploughing, subsoiling, irrigation and drainage.

The placement or imperfect broadcasting of fertilizer or dung, row cultivation, and the growth of row or tree crops, all has a tendency to superimpose additional heterogeneity in the soil properties. In agrosilvopastoral system the intense grazing frequently produce dung or urine patches.

In some tropical areas biogenetic factors seem to be a dominant source of soil surface variability. Mound building by termites and ants, and worm cast, produce heterogeneity faster than it can be smoothed out by diffusion and mixing (Moormann and Kang, 1978). The termites mound alteration in soil physical and chemical properties are persistent and are reflected in variable growth of crops even when mounds are flattened for mechanized agriculture (Moormann and Kang, 1978).

Oilpalms form a common element in the secondary regrowth of shifting cultivated land in the moister parts of West Africa. It is commonly found in sites where were old palm plantations that the soil surface bulk density lowering with distance from the trunk of former palms until 2 m to 3 m. Similarly, organic carbon content is consistently higher, not only in the surface but also in the subsuperficial horizon. Consequently most sites near to the former palm trunk exhibit better soil conditions than the adjacent site soil (Kang, 1977).

In shifting cultivation agriculture, the preclearing vegetation or cultivation during the previous year, influences strongly the performance of annual crops in Africa (Kang and Moormann, 1977). Higher soil variability of abandoned pastures in relation to primary forest has also been found in Amazon basin (Correa and Richard, 1989).

Soil alterations by clearance of the Amazonian forest were evaluated in relation to pore size distribution. Results indicated a significant reduction of the water available as a consequence of mechanical action in the clearance and posterior management practices (Grimaldi et al., 1993; Teixeira et al., 1996a).

Patterns on throughfall and stemflow in multi-strata agroforestry lead to a mosaic of situation with respect to quantity of water inputs into the soil (Schroth, et al.1999), hence creating spatial soil water patterns.

Representative elementary volume (REV) or Representative elementary area (REA)

A practical definition of a representative elementary volume (REV) or representative elementary area (REA) is the smallest volume or area of soil that contains a representation of microscopic variations in all the forms and proportions present in the system (Bear, 1988). Hence it does not only depend on the physical parameter investigated but also variability of the soil under study. Moreover, values of a REV of the same property for different soils are not identical (Warrick, 1998).

In soil physics, the soil sample generally involves a volume or area of soil to be measured resulting in a continuous real number. Therefore, statistical properties such as mean and variance of a physical property of a soil cannot be predicted correctly without estimating the representative elementary volume (REV) or representative elementary area (REA) (Iwata et al., 1995).

Sample sizes smaller than the REV may not yield a reliable estimate of the average property and are often characterized by a large variability (Hendrickx et al., 1994; Rice and Bowman, 1988). It should be stressed that this is not primarily a statistical problem but has a physical significance. Sample sizes larger than the REV do not yield additional information and do not further reduce the variability of the measurement.

The procedure usually adopted to estimate REV of a physical soil property is to measure samples with different sizes; the smallest sample size whose means and medians show stable values can be chosen as the REV. In practice, sample size is determined not only by the magnitude of the variance, but also to provide an operational convenience in a measurement method (Iwata, 1995; Miyazaki, 1993).

Sampling techniques

No attempt will be made herein to review details of statistic sampling procedures. They are mainly presented to encourage agroforestry researchers to consider the value of these techniques for future sampling schemes to evaluate soil physical properties. Detailed discussion about sampling scheme are found in Webster and Oliver (1990), Snedecor and Cochran (1989), Kempthorne and Allmaras (1986),and Cochran (1977).

An understanding of the true definitions about accuracy, precision and bias is important to select methods of measurements and to avoid some impediments in the subsequent statistical analysis.

The accuracy of a measurement refers to the correctness in estimates the true value, whereas precision is a measure of the deviation of results from the mean value, hence high precision demonstrates only the reproducibility of the analysis, and it does not necessary imply accuracy of the results.

Precision can be greatly increase with enhance of the number of replications (Tan, 1996; Kempthorne and Allmaras, 1986). Whether precision or accuracy is more important depends on the specific situation being investigated, although both properties are obviously desired for reliable data.

Bias refers to systematic difference between the statistical mean and the true value (Kempthorne and Allmaras, 1986). Bias can be minimized by use of standardized materials, correct data acquisition and calibration procedures. Bias associated with installation and maintenance of access tube in soil moisture measurements with neutron probes are discussed by Willians and Sinclair (1981) and in TDR technique by Teixeira et al. (1999) and Weitz et al. (1997).

The number of observations needed to characterize a soil properties in a certain sampling unit is determined by the variance of the property, the confidence level chosen, and the tolerance deviation about the mean, which is acceptable by the objectives of the investigation.

If an estimate of the variance from the property desired to be evaluated is available, then an assessment of the number of samples necessary in the next sampling, to obtain a given precision with a specified probability may be obtained using Equation 1 (Petersen and Calvin, 1986; Snedecor and Cochran, 1989).

$$n = \frac{Z_{\alpha}^{2} s^{2}}{D^{2}} \qquad \text{[Equation 1]}$$

Where Z is the standardized normal variance at level of probability ?; s^2 is the variance and D is the tolerance or specified acceptable error. Values assumed by Z are presented in some statistical books (Steel et al., 1997; Snedecor and Cochran, 1989).

To exemplify the use of this procedure, suppose that the estimate of the mean value of bulk density determined in a previous studies was 1500 kg m^{-3} and the its variance 200 kg m^{-3}. The calculated number of sample (n) necessary to estimate the bulk density with a 95% of confidence with a tolerance of 10% of deviation of mean value is seven samples.

$$n = \frac{(1{,}96)^2 (200)^2}{(150)^2} = 6{,}8 \approx 7$$

While adoption of high confidence level in statistical approaches is common found in some studies of soil properties, in many soil physical properties, we must frequently accept either a lower confidence level or higher confidence interval to maintain a sampling scheme within feasibility.

The coefficients of variations of many soil physical properties are shown by Wilding (1985), Jury et al. (1991), and Warrick, (1998). However the value presented by these authors is only guidance. It is always better to determine previously or to recover a formerly studies in the same area to achieve more confident values about the variance.

The use of Equation 1 implicates to assume that the population has a Gaussian or normal distribution and, the measured values are independent. The violation of the first assumption is not very serious if the number of samples is large enough that we can invoke the central limit theorem.

Failure of the normal approximation occurs mostly when the population contains some extreme individuals that dominate the sample average causing an asymmetric skew (Beckett and Webster, 1971). Standard procedures for ascertaining the type of probability distribution function (pdf) are Shapiro-Wilk's W test; Kolmogorov-Smirnov test for 2 samples (Steel et al., 1997; Parkin and Robison, 1989) or graphical methods like the fractale diagrams (Jury et al., 1990).

The probability distributions of statistical parametric test are in most of the cases, based on the assumption of normal distribution of the data. However, parameters like saturated and unsaturated hydraulic conductivity have been showing frequently log-normal distributions (Lauren et al., 1988; Nielsen et al., 1973). The transformation of lognormal data can lead to normalization. In practice a variable is considered to be lognormal distributed if the logarithm of the variable is normally distributed.

Identification of extraneous values and recommended rules for designating them are discussed by Dixon et al. (1986). Discrepant datum with strongly disparity from the bulk of the measurement, normally caused by sampling fault, untypical soils conditions etc., should be identified and eliminated.

In many experiments is useless to attempt control or to compare determined parameters to such a degree unless sufficient replications are used for detection of hypothesized treatment effects. The required replication needed to detect with determined accuracy to achieve a least significant difference can be calculated using the Equation 2 (Teixeira et al., 1996b; John et al., 1981; Cassel and Bauer, 1975).

$$n = \frac{Z_{\alpha}^{2} s^{2}}{(LSD)^{2}}$$ [Equation 2]

Where n is the number of replication; LSD is the least square difference and Z, ? and s are the same parameters defined in Equation 1.

We exemplify the use of equation 2 with a followed hypothetical situation. In a research program about soil water the standard deviation of soil moisture content was estimated to be of 0.10 m^3 m^{-3} within the plots replications measurements. In this conditions, to detected a significant difference with at $p<0.05$ of 0.05; 0.10 and 0.20 m^3 m^{-3} among treatments, the number of replications calculated with Equation 2 are respectively 31, 7 and 2 samples per treatment.

A practical inference about this statistical approach is that if the sampling scheme has a reduced number of replications and/or the soil property has a high variance, only greater differences among treatments can be detected in spite of true treatment effects could be happening.

Sampling repeatedly in time should be composed by several dispersed samples, and the exact location of each sampling point should be marked permanently. At the next sampling period, sample should be collected as close as possible to the original points, thus holding effects of spatial variability to a minimum (Sisson and Wierenga, 1981).

Subsampling

In many types of soil investigation, the use of subsampling or multistage sampling is advantageous. Whit this technique, the sampling unit is divided into a number of smaller elements and only parties of these units, so-called subunits, are sampled.

The primary advantage of subsampling is that it permits the estimation of some characteristics of the larger sampling unit without the necessity of measuring the entire unit (Petersen and Calvin, 1986). At each stage of sampling, an additional component of variation, the variation among smaller elements within the larger units, is added to the sampling error (Petersen and Calvin, 1986, Cochran, 1977). Therefore, subsampling will usually decrease the precision with which the soil property is estimated.

The sampling scheme could be designed more efficient, and therefore less costly, by using an adequate combination of the number of sampling and subsampling units, that provide the maximum precision at a given cost or that provides a specified precision at the lowest cost.

The statistical procedures to estimate the optimum subsampling rate are presented by Cochran, (1977) and Petersen and Calvin, (1986).

Santos and Vasconcelos (1987) and Ike and Clutter (1968) showed practical uses of subsampling technique to evaluate soil properties.

Composite sampling

When only the average value of a soil property is needed, a substantial saving in sampling and analytical costs can be realized by composting samples. Bulking of equal amounts of individual samples reduces analytical effort and can provide a site mean, but gives no information on the variability within the site (Ball and Willians, 1968).

A number of field samples representing the soil population under study are thoroughly mixed to form a composite which is then subsampled for submission to the laboratory. Composite sampling plan should only be used for properties which are unaffected by physical disturbance, like particle-size, particle density, specific surface and gravimetric soil water content.

The number of samples needed to estimate the mean of the composite depends on the variability of the property and the desirable level of confidence (Petersen and Calvin, 1986; Ball and Willians, 1967).

Independence of samples

Effects of agroforestry research on soil physical parameters are often existent, and experienced researchers and farmers are convinced of them, but statistical verification of these differences sometimes failed, most of times due to the spatial dependence among the samples.

Frequently soil properties measured at nearby locations vary less than those measured further apart, indicating that the samples may be not independent of each other.

The distances between two sampling sites at which respective samples are judged to be independent has to be determined. This distance, called "the range of influence", characterizes the spatial variability of the soil. With geostatiscal concepts it is possible to validate the basic assumptions of independence or to take into account the possible autocorrelation between measurements in estimating the variance of the mean (Vauclin et al., 1984).

The violation of independence of the sample may be a serious limitation to sampling schemes in agroforestry system. When the objective is to compare differences among system components, hence the samples are taken within the plot (i.e. to determine single tree effect) the samples may be not independent.

Gajem et al. (1981) studied the spatial dependence of 12 soil properties measured along different transects found these soil properties were correlated with each other over a distance that varied from a few centimeters to several meters.

Russo and Bresler (1981) determined that soil hydraulic properties were correlated over distances as follows; 21 m for saturated hydraulic conductivity, 55m for saturated soil water content, 25 m for residual water content and 35m for sorptivity.

Campbel (1978) found ranges of 30 m and 40 m for the sand content of two different soil types and Vieira et al. (1981) found the steady-state infiltration rates of Yolo loam soil to be spatially dependent with a 50-m range.

The spatial dependence and may also be a function of time (Sadding et al., 1985) and, most studies of the spatial variability of the physical properties of soils have been done on bare soil, in agroforestry research, the presence of plant cans modifies the structure of the spatial dependency.

Geoestatistical methods have been show to be able to reduce the sampling effort by using the variance in the neighborhood of each observation (Vieira, 1981; McBratney and Webster, 1983).

In agroforestry research, not infrequently, the vast sampling network of soil water studies that needed more at one day to read, cause error due to changes in time. In this situations networks should be arranged in blocks or series of replicates such that all treatments with the blocks were sampled before moving onto the next replicate. This procedure may permit that the effects of time will be balanced across all treatments and partially removed form the analysis of variance (John et al., 1981).

Other alternative to reduce the likelihood to obtain incomplete and useless data set, is the selection of only some few representative locations in the whole network to collect data. This technique is related with the concept of temporal stability, where some locations conserve the property to represent the mean and extreme values of the field water content or water potential at any time along the year (Gonçalves et al, 1999; Vachaud et al., 1985).

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11) Nutrient leaching in mixed tree cropping systems

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Introduction

Ferralsols of the central Amazon are low in available nutrients. Additionally, leaching rates are very high and may lead to large losses of applied fertilizers. Very little is known about the ability of tree crops to reduce nutrient leaching and retrieve nutrients from the subsoil. Therefore we studied the leaching losses of applied ^{15}N tagged fertilizer during one rainy season.

Methods

TDR, tensiometers and suction cups were installed under *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum. (cupuaçu); *Bactris gasipaes* Kunth. (peachpalm); *Bertholletia excelsa* Humb.& Bonpl. (Brazil nut); *Bixa orellana* L. (annatto) in a multi-strata agroforestry system. TDR were installed at 0.1, 0.3, 0.9 and 1.5 m, and suction cups at 0.1, 0.6 and 2 m depth in three replicates. Additionally, a soil pit was dug up to 3 m depth. TDR and tensiometers were inserted at 0.1, 0.3, 0.9, 1.5, 2.5, 3.5 and 4.5 m and suction cups at 0.1, 0.6, 1.2, 2, 3 and 5 m depths from the side. The instruments reached below the canopy of *Theobroma* and *Bactris* and *Pueraria phaseoloides* (Roxb.) Benth. (pueraria). Additionally, a data-logger system was installed with TDR at 0.1 and 0.9 m, and tensiometers at 0.1, 0.3, 0.9, 1.5, 2.5 and 3.5 m depths. A mobile meteorological station was built next to the soil pit. ^{15}N was applied as ammonium sulfate (10 atom%^{15}N excess) at 1g ^{15}N per tree. Soil water measurements and soil solution sampling were done in weekly intervals. Soil solution was directly analyzed after freeze-drying.

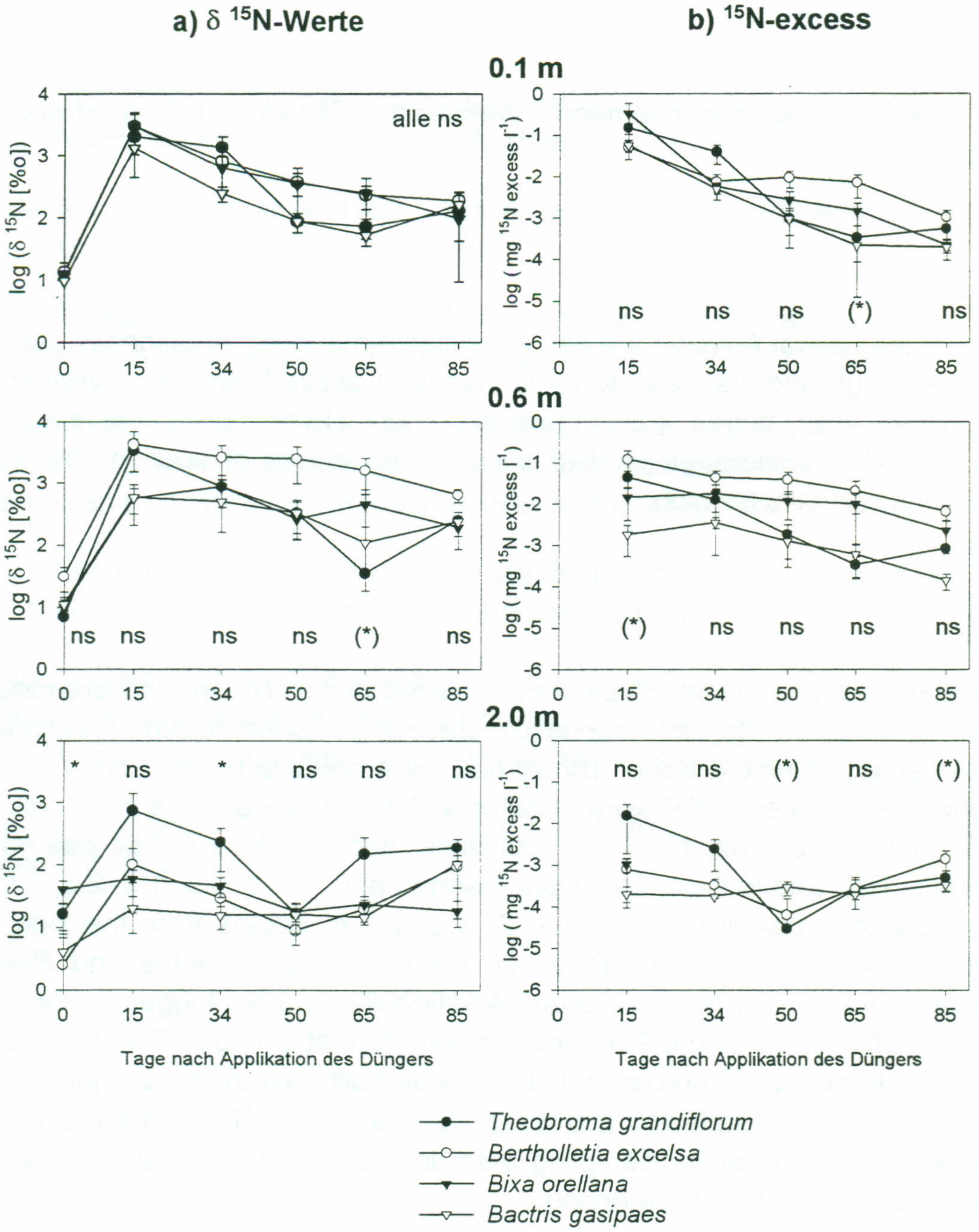

Figure 1 ^{15}N values of soil solution under *Theobroma*, *Bactris*, *Bertholletia* and *Bixa* at 0.1, 0.6 and 2.0 m depth before (day 0) and after the application of ^{15}N-enriched fertilizer; means and standard errors (n=3).

Results and Discussion

The increase of the ^{15}N signatures even at 2m depth indicated rapid leaching of fertilizer N already after a few days after application (Figure 1). A large portion of the applied ^{15}N was found in the dissolved organic matter, stressing the importance to include organic nutrient species in nutrient budgets. Additionally, it could be shown that this organic N species were mobile in soil. The tree species had only a limited effect on the amount of N and ^{15}N in the topsoil solution after fertilization (Figure 1). The water movement was probably too fast to be affected by the trees during the rainy season, and topsoil mineral N contents were generally high. In greater depths, nitrate in the soil solution was significantly enriched with ^{15}N under *Theobroma* compared to the other tree species. High organic N contents were found in the soil solution of *Bertholletia* at 2m depth. Consequently, the highest ^{15}N contents in the soil at 2 to 5m depth were found under *Theobroma*, followed by *Bertholletia* (Figure 1). Generally high mineral N contents in the subsoil indicate that N leaching was high under all trees. Cutting *Bactris* for heart of palm harvest may have caused an additional input of N into the soil through root turnover, as non-labelled N was found in large quantities thereafter. Cutting may be more suitable at other times of the year when leaching losses are less likely to happen than at the onset of the rains.

The trees affected leaching losses of applied N to a different extend, and *Bactris* and *Bixa* were better able to do so than the other investigated species. However, losses of applied fertilizer N can not entirely be prevented considering the extremely rapid soil water percolation under the studied humid tropical conditions and the highly permeable soils.

12) Microbial biomass as affect by litter quality and fertilization on a Xanthic Ferrasol

Jose Pereira Silva Jr., Roger Silva, Tatiana Fernandes, and Johannes Lehmann

The soils of the Brazilian Amazon region are generally poor and acid. Xanthic Ferralsols are the predominant soils on "terra firme" ecosystems in this region. The topsoil organic matter is the main reserve of nutrients in these soils. After conversion of forests to agriculture by use of slash-and-burn soil preparing systems, the organic matter is almost completely destroyed. The restoration of biogeochemical cycles and nutrient fluxes is an important step to improve soil capacity for a sustainable agriculture system. Microbial biomass represents an important compartment of the nutrient fluxes. Therefore, we conducted a laboratory incubation to investigate the effects of litter from different species (*Theobroma grandiflorum*, *Bactris gasipaes*, *Bertholletia excelsa, Bixa orellana* and *Pueraria phaseoloides*) and fertilization with N and P on C, N and P in microbial biomass of the topsoil (0-5 cm) with high organic C contents and of an underlying horizon (10-15 cm) with low organic C contents of a Xanthic Ferralsol.

The soils used in this study were collected from a natural forest area. 150 g of soil were incubated with 246 mg of air-dried leaves or with N or P fertilizer (according to local recommendations) or both using four replicates per treatment. The incubation was conducted in controlled conditions during 78 days. Samples were collected after 15, 36, 50 and 78 days of incubation. The N, P and C in microbial biomass were determined by the fumigation-extraction method. Statistical analyses were done with ANOVA using a completely randomized design.

Results

These preliminary data show that the microbial biomass was influenced by the type of soil (with large or little amounts of C), litter quality and fertilization (Figure 1). In general, the soil from the superficial soil layer had a higher level of C in the microbial biomass. This is expected because this soil had also higher level of soil organic matter. The effects of different litter applications and fertilization depended on soil C, as well. In the topsoil, the microbial biomass was not influenced by litter applications and fertilization. In the soil with little amounts of C, however, the litter application had a significant effect on C in microbial biomass. Soil microbial biomass was highest after application of *Pueraria phaseoloides* plus fertilization with N and P, which even reached values which were not significantly lower than those of the topsoil. The N and P analyses are presently carried out and will present during the workshop.

These preliminary results indicated the large potential of *Pueraria phaseoloides* to increase the microbial biomass and probably to accelerate nutrient fluxes through microbial biomass under very poor soil conditions.

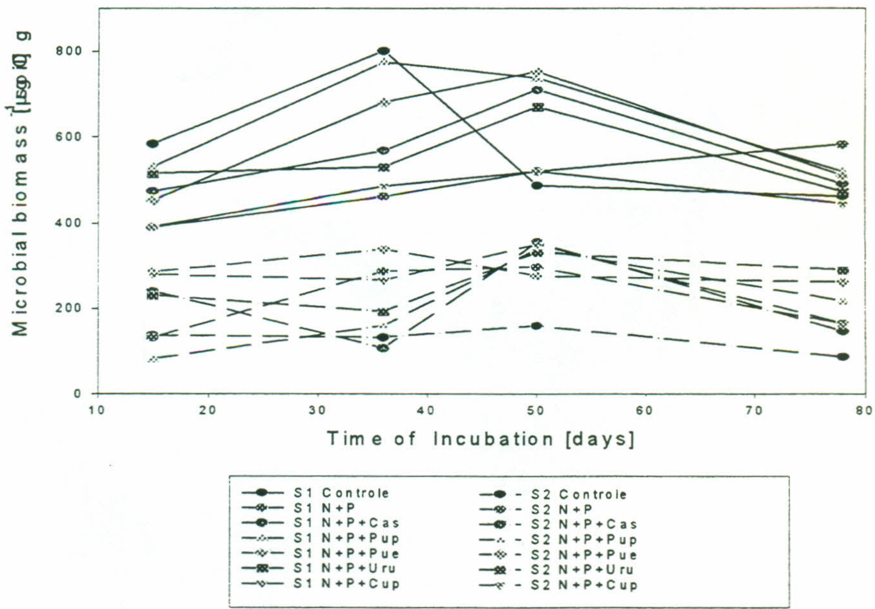

Figure 1 Microbial C in soils with high and low amounts of organic matter affected by litter and N and P applications (n=4).