Institute of Soil Science and Soil Geography, University of Bayreuth

and

Empresa Brasileira de Pesquisa Agropecuaria - Amazônia Ocidental (EMBRAPA)

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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

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Annual Report 1998

Compiled by: Johannes Lehmann and Klaus Kaiser

Abstract

This is the first annual report of the second phase of the SHIFT project "Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus". During Mai to December 1998, additional equipment was acquired, tested, shipped to Manaus and installed. A soil pit was dug and instrumented until December. Experiments were started including studies about the effect of trees on soil carbon and nitrogen contents, soil phosphorus availability, dissolved organic nutrients in rainfall, throughfall, stemflow and soil solution. The area of soil nitrogen and phosphorus uptake was investigated using different N-15 and P-32 tracer experiments. The fate of fertilizer nitrogen was studied with 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. The results shown in this report demonstrate that nutrient cycling may benefit from mixed cropping since the tree species exhibit large differences in their effects on soil nutrients contents and fluxes.

Contents

Embrapa
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Data aquisição: —
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1 Introduction

This is the first 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 since the start of project phase in Mai 1998.

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 as far as first results are already available.

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
Doris Günther (Diplomand UBT)	single-tree effects on soil P and S pools
Eric Bähr (Diplomand UBT)	dissolved organic nutrients
Harald Dinkelmeyer (Diplomand UBT)	fate of applied fertilizer nitrogen
Andreas Renck (Diplomand 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 Trujilo 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.
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 organic matter and nutrient contents

Soil organic matter, N, P and S contents were measured as affected by agroforestry tree species as well as trees from secondary and primary forest. Soils were physically (particle size, density and aggregate fractionation) and chemically fractionated (sequential fractionation of P and S) and analysed (organic and inorganic nutrient forms, lignin, carbohydrates).
Soils in the primary forest had highest C and N contents (annex 1), although they were not fertilized in contrast to the agroforestry tree species, but had the lowest P contents (annex 2 and 3). Cupuacu proved to increase C contents more than the other agroforestry tree species, probably due to their low quality litter and consequently reduced decay rates. P contents, however, were lower in soils under cupuacu than under the other agroforestry trees despite the fact that cupuacu recieved more P fertilizer. The high root abundance and activity (see 3.4) of cupuacu at the topsoil and the large P recycling by leaf litter of e.g. urucum may explain this result. The contents of labile N in soils under pueraria were very high probably due to N_2 fixation and explain the high N mineralization under pueraria. Also soil P contents were high although pueraria was not fertilized with P.
An incubation experiment with different leaf litter and levels of fertilization indicated that P was more limiting for microbial growth than N (annex 9). This emphasizes the need for research on P dynamics.
Soil nutrient contents and acidity showed pronounced seasonal dynamics as an effect of fertilization (annex 3). The effect of the levels of fertilization on soil acidity probably exceeded the sampling depth of 0.4 m. The effect of the application of lime, however, was restricted to the upper 0.05 m. Urucum proved to be very nutrient

demanding for potassium, magnesium and calcium.

3.2 Water and nutrient fluxes

The flux measurement equipment consisting of TDR, tensiometers and suction cups was installed under *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum. (cupuacu); *Bactris gasipaes* Kunth. (pupunha, peach palm); *Bertholletia excelsa* Humb.&Bonpl. (castanha); *Bixa orellana* L. (urucum) in a multi-strata agroforestry system using 100% fertilization (according to local recommendation). TDR were installed at 0.1, 0.3, 0.9 and 1.5 m depth, suction cups at 0.1, 0.6 and 2 m depth in three replicates. Additionally, a soil pit was dug up to 3m 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 from the side. The instruments reached below the canopy of cupuacu and pupunha 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 depth. A mobile meteorological station was built next to the soil pit.

3.2.1 Soil water measurements

The calibration of the TDR equipment was continued and the spatial variation of the soil water contents evaluated (annex 12). The response of the tensiometers to rain events was very fast even to depth of 0.9 m (annex 8). This was surprising, as the Ferralsols at the experimental site are very clayey. However, the aggregate structure of the soil is very strong (annex 1) and the porosity high and bulk density low (annex 10) indicating the possibility of a pronounced macropore flow. This would explain why immediately after a rain event, large amounts of water are percolating even into the subsoil. It may also help to explain why nutrients are rapidly leached and accumulated in the subsoil. This result clearly shows that studies about subsoil nutrient contents are indispensible with respect to these soils.

3.2.2 Soil solution nutrient measurements

The installation of the suction cups followed the concept of the water measurements. In the soil solution, we measured the ammonium and nitrate contents, total N and P and the ^{15}N contents in all N fractions. Analyses of the cations will follow.

After fertilization (ammonium sulfate, TSP and micronutrients; amounts see annex 2), the ammonium contents rapidly increased in the topsoil (annex 8). A few weeks later, the nitrate contents followed to rise. P could only be detected in traces in the topsoil, and may only be leached shortly after the fertilizer application.

3.2.3 Dissolved organic nutrients above and below ground

In rainfall, throughfall, stemflow and soil solution, dissolved organic carbon, nitrogen, ^{15}N, phosphor and sulfur were analysed. The organic forms were fractionated into hydrophilic and hydrophobic compounds. The dissolved organic carbon was higher in stemflow than in the soil solution and further decreased with increasing depth (annex 4). The data on the dissolved organic nutrients are still incomplete and will soon be available.

3.3 Nutrient competition and transfer

Several experiments were conducted with ^{15}N tracers which were either applied as fertilizer underneath the tree canopies (annex 5) or broadcast in different areas of the cropping system (annex 7). The foliar ^{15}N contents were measured as well as soil contents, in some experiments also soil solution ^{15}N contents.

In a mixed cropping system with cupuacu and pupunha with associated pueraria, pueraria was more effective in taking up the applied tracer than the tree species, cupuacu being more effective than pupunha. Cupuacu tended to take up more of its N from the area between the tree rows where the pueraria was grown. This may indicate that cupuacu could profit more from the N in the soil underneath the pueraria, which probably derived to a large extent from biological N_2 fixation. Measurements of the natural ^{15}N abundance in systems with high and low soil coverage with pueraria indicated that the trees took up fixed N from the pueraria. A profit for the total N budget could not be shown.

In a second experiment with four indigenous tree species, urucum, cupuacu and pupunha took up more than 90% of their fertilizer N from their own fertilized area underneath the canopy two weeks after fertilization. Castanha, however, took up only 29% from its fertilized area, but 45% from the neighboring pupunha. Castanha seems to exploit a larger area of the soil than the other investigated tree species, and may be more suitable for the prevention of nutrient leaching between tree rows. The common practice to spread the fertilizer around the stem seems not appropriate for castanha.

3.4 Areas of nutrient uptake

In the cropping system mentioned above, the root activity was determined by measuring the uptake of labelled P, which was applied in holes at different depths (annex 6).

Castanha and pupunha had a higher root activity below 0.1m than in the topsoil, whereas urucum and cupuacu took up most of the acquired P from 0.1m depth, cupuacu even 75%. According to these results, castanha and pupunha may be better able to utilize subsoil nutrients and prevent nutrient leaching than the other two species. However, they may be less able to utilize immobile nutrients like P, which is fertilized and mainly stays in the topsoil.

3.5 Implications for land use design – concluding remarks

At this stage of the project, concluding remarks can only be preliminary, and no attempt is made to present a resumé on the experiments yet. However, already now we can say that the investigated tree species differed largely in their effects on water and nutrient fluxes. This can be used to manipulate water and nutrient fluxes by choosing tree species with the desired properties and by choosing management options to vary them (planting density, pruning etc.). It could be clearly shown that the plant species interact in the mixed cropping system which are beneficial for them (e.g. N uptake from underneath the pueraria, fertilizer uptake below neighboring plants). In following experiments, we will try to directly show that this can result in more sustainable plant production; in addition we will give recommendations for principles of land use systems based on mixed cropping which lead to a better use of nutrients and water than monocultures.

4 Planned activities during 1999

The current experiments will be continued throughout 1999. Additional activities comprise:

- the investigation of the N contribution of pueraria to fruit tree species in comparison with uptake of fertilizer N (using ^{15}N technology),
- the measurements of subsoil nutrient contents including ^{15}N,
- the determination of the effects of ground cover (e.g. pueraria) on ecosystem functions and the performance of fruit trees (water and nutrients),
- the assessment of N fluxes from litter to soil and output by leaching using ^{15}N,
- the improvement of our understanding firstly of nutrient fluxes in soil and secondly of soil physical properties as mediated by biological agents (roots, soil microbes, soil fauna) using tracer techniques,
- the modelling of water and nutrient fluxes.

5 Comparison with the work and time plan of the project

The purchase and installation of the equipment could be done within the time plan. During the last months of 1998, the experiments were started covering all areas envisaged in the proposal. We consider the initiation of the second phase of the project to be highly effective and a large amount of innovative results and important conclusions can already be presented here.

6 Cooperation with other projects and institutions

EMBRAPA

The cooperation between the German and Brazilian partner (EMBRAPA) is very close on a technical level (mutual assistance in the laboratory and field work), on a scientific level (joint research activities, including Embrapa researchers into project activities, participation in Embrapa research wherever interests meet and participation is wanted) and on a 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 1998. 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. Colaborative 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 a 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. A study about soil nitrification and denitrification will connect the data of both projects, which was started recently. Several joint experiments are planned for 1999 including work in fallow enrichment with different trees and the nutrient dynamics in the plant-soil system. To optimize this collaboration even on a higher level, a coordination meeting was organized in February and a further one will take place in the near future in Hamburg together with the Profs. Lieberei, Bauch, Beck and Zech. We highly appreciate the deep support given especially by Prof. Bauch. He always takes his time to help and advise.

With ENV 52 (SMNK Karlsruhe; Prof. Beck), the technical cooperation is also very close, and equipment is frequently shared. A German Diplmand is jointly supervised in the area of nutrient fluxes from litter to soil as affected by soil fauna. 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.

Contacts with the project "The role of N_2 fixation in secondary and primary forest sites in the central Amazon" were made (ZEF Bonn; Prof. Vlek) and several activities planned in close collaboration in the area of subsoil nutrient dynamics in fallow vegetation, which will be initiated by the end of 1999.

Scientific contacts also exist to the SHIFT projects ENV 29 (subproject Nitrogen Dynamics, Dr. Kern) with soil nitrogen flux measurements and to ENV 25 (Embrapa CPATU) with discussions about a cooperation in modelling.

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.

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, collaborative experiments are planned to study the soil heterogeneity and water fluxes as affected by aggregation and to gather data for a modeling exercise.

Dr. Oleg Menyailo from the Soil Physics Group, University of Bayreuth, and Institute of Forestry, Krasnojarsk, Russia, joined the project for one month to start 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 1998 Subsoil accumulation of mineral nitrogen under monoculture and polyculture plantations in a ferralitic Amazonian upland soil. Agric Ecosys Environm: in press.

Schroth G, da Silva LF, Wolf MA, Teixeira WG and Zech W 1998 Distribution of throughfall and stemflow in multi-strata agroforestry, perennial monoculture, fallow and primary forest in central Amazonia, Brazil. Hydrological Processes: in press.

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.

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 1998 Tracer applications for the assessment of nutrient pathways in agroforestry systems. In Proceedings of the II Brazilian Congress on Agroforestry, Nov. 24-27, Embrapa-CPATU, Belem, Brazil. pp. 42-45.

Lehmann J, Schroth G, Teixeira W, Zech W and Cravo MS 1998 Nutrient and water dynamics in a multi-strata agroforestry system. In Proceedings of the II Brazilian Congress on Agroforestry, Nov. 24-27, Embrapa-CPATU, Belem, Brazil. pp. 38-41.

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, Günther D, da Mota S, Kaiser K, Treter U and Zech W 1999 Single-tree effects on soil P pools in a multi strata agroforestry system. In F Jimenez and J Beer (eds.) Multi-strata agroforestry systems with perennial crops. CATIE, Turrialba, Costa Rica. pp. 120-123.

Marques, J.J.; Schulze, D.G.; Teixeira, W.G.; Curi, N. 1998 Pyrophyllite in soils from the western Amazon Region. In: Annual Meeting of Soil Science Society of America, Baltimore. Abstracts. pg. 322.

Mota S da, Lehmann J, and Schroth G 1998 Dinamica da acidez num Latossolo Amarelo em diferentes sistemas de uso da terra na Amazonia. In Proceedings of the II Brazilian Congress on Agroforestry, Nov. 24-27, Embrapa-CPATU, Belem, Brazil. pp. 74-76.

Teixeira, W.G.; Schroth, G.; Marques, J. D.; Lehmann, J.; Cravo, M.; Huwe, B.; Zech, W. 1998 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.10th International Soil Conservation Organization, Purdue (accepted).

8 Conclusions

The preparations and the implementation of the equipment for the second project phase were very efficient. Several new experiments were started and some highly important results could already be presented in this first annual report, which are summarized in section 3. The project activities and the first results must be seen as a profound success already in the first year. This success was only made possible by the large work force of technicians in Germany and Brazil, by students and the enthusiastic work atmosphere of all participants. The large staff number including technicians and students should not be reduced, but must be kept during the next years to continue the successful project work. Especially, the position of the Bayreuth technician must be continued full-time throughout the experimental period of the project. The project will 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) Single-tree effects on soil organic matter properties of a xanthic Ferralsol in the central Amazon

Johannes Lehmann, Manoel da Silva Cravo

1. Introduction

Minimization of unproductive nutrient losses and a closed nutrient cycling are important preconditions of sustainable land-use management. Adding to the problem of nutrient leaching, the Ferralsols of central Amazonia are characterized by severe nutrient limitations (Cravo and Smyth, 1997). Therefore, nutrient conservation and the replenishment of nutrient contents are vital for crop production on these soils.

The objectives of this study were, (i) to identify soil pools which are sensitive to land-use changes on the terra firme, (ii) to evaluate the potential of different trees to increase soil organic matter (SOM) contents and (iii) to elucidate the mechanisms of SOM replenishment in Ferralsols of the central Amazon.

2. Materials and Methods

The methodology was explained in an earlier report (Annual report 1997), and is not repeated here.

3. Results and Discussion

3.1 Single-tree effects on aggregation and sensitive SOM pools

The aggregate stability was significantly higher in soils under cupuaçu than under pueraria, the other sites being in between (Table 1). High aggregate stability could not be explained with any investigated physical (Table 1) or chemical soil pool (Table 2). Castro Filho et al. (1998) concluded from long-term experiments in Eastern Brazil that litter input with high C-to-N ratios increased aggregate stability. This would explain the higher aggregate stability of soils under cupuaçu in comparison to the other agroforestry species, but not in comparison to the fallow (Vismia; Table 1) and primary forest sites (bacaba; Table 1).

Table 1 Ratio of MWD_{wet}-to-MWD_{dry}, carbon and nitrogen contents [mg g^{-1} fraction] and stocks [mg g^{-1} bulk soil] and C/N ratios in bulk soil and particulate organic matter (POM) of soils (0-0.5 m) under cupuaçu, pupunha, pueraria, vismia and bacaba on the terra firme near Manaus; values in one column followed by the same letter are not significantly different at p<0.05 (n=3)

Sites	MWD_{wet}-to-MWD_{dry} ratio	---------- C ---------- bulk soil	POM content	POM stock	---------- N ---------- bulk soil	POM content	POM stock	---- C-to-N ---- bulk soil	POM
cupuaçu	0.89 a	31.0 b	289 b	6.31 b	2.5	13.7	0.29 b	12 c	21 ab
pupunha	0.84 ab	25.3 b	238 c	3.59	2.4	11.1 c	0.18 b	11 c	22 ab
pueraria	0.82 b	27.9 b	258 bc	2.78 c	2.4	14.6 a	0.17 b	11 c	18 b
vismia	0.84 ab	29.7 b	340 a	6.74 b	2.2	13.1	0.28 b	14 b	27 a
bacaba	0.83 ab	47.4 a	277 b	12.60	2.9	11.7	0.54 a	16 a	24 ab
effect[1]	(*)	**	**	*	ns	*	*	**	(*)

[1] (*) p<0.1; * p<0.05; ** p<0.01

Bulk soil SOM was significantly higher in the primary forest under bacaba than at all other sites (Table 1). Differences of POM stocks were a lot clearer than of the bulk soil, and soils from bacaba sites had 4.5 times higher POM than soils under pueraria. Also cupuaçu was more efficient in replenishing POM pools than pueraria ($p<0.05$) and pupunha (non-significant trend). The carbon contents of the aggregate fractions, however, were not showing the differences between sites as well as the carbon contents of POM, but with the same trends (Table 3). The aggregate fraction 0.25-0.5 mm showed the single-tree effects the most, being also the fraction where carbon contents increased the most by separating POM* (POM from within the aggregates) and the primary particles (Lehmann et al., 1999).

The bulk soil nitrogen contents were not significantly different, but sites showed significant effects of single trees on POM nitrogen contents and stocks (Table 1). Soils under pueraria had high POM nitrogen contents, which could be explained by its high foliar and root nitrogen contents (Table 4). Due to the low amount of POM, however, the nitrogen stocks of pueraria soils were low. On the other hand, the nitrogen contents in the fraction 0.25-0.5 mm were significantly higher under pueraria than the other sites apart from bacaba (Table 3). The high quality of the pueraria litter with low C-to-N and polyphenol-to-N ratios (Table 4) probably led to a fast carbon and nitrogen mineralization, which explains the fast incorporation of nitrogen into aggregates and the low total amount of POM under pueraria. The opposite was observed for bacaba, where POM nitrogen contents were low but the stocks were high. The long-term organic matter and nitrogen input into the soils under primary forest increased carbon and nitrogen contents in bulk soil and POM stocks. Low litter quality may have promoted the SOM stabilisation in POM and the whole soil. Thus, soils under bacaba possessed high contents of unoxidized lignin together with high VSC-to-N and C-to-N ratios but low carbohydrates contents in POM and total SOM (Table 1 and 2). This may serve as a way of nutrient preservation in order to release only as many nutrients as needed for plant growth. The fact that still high amounts of nitrogen are found in the subsoil of the primary forest sites compared to the secondary forest (G. Schroth, personal communication), emphasizes the need for a temporary nutrient sink in SOM.

Table 2 Lignin, acid-to-aldehyd ratio, cellulosic and non-cellulosic sugars in bulk soil and particulate organic matter of soils under cupuaçu, pupunha, pueraria, vismia and bacaba on the terra firme near Manaus; values in one column followed by the same letter are not significantly different at p<0.05 (n=3)

Sites	VSC[1] [mg g^{-1}C]		Ac-to-Al ratio[1]		VSC-to-N ratio[1] [‰][3]		CS[1] [mg g^{-1}C]		NCS[1] [mg g^{-1}C]		NCS-to-CS ratio	
	bulk	POM	bulk	POM	bulk	POM	bulk	POM	bulk	POM	bulk	POM
cupuaçu	16.8	30.9	0.36	0.22	209 b	650 b	45.6 a	29.1 a	263	181 c	5.9 c	6.2 b
pupunha	18.2	42.8 a	0.57	0.24	196 b	895 b	39.6 a	30.8 a	352	320 a	9.1 b	11.0 a
pueraria	14.8 b	29.2	0.48	0.24	170 b	497 b	38.4 a	25.5	313	258 a	8.7 b	10.2 a
vismia	16.1	17.7 b	0.34	0.24	220 b	458 c	27.8 b	22.1 b	412	184 c	15.0	8.3 a
bacaba	25.2 a	43.4 a	0.37	0.25	407 a	1014	15.0 c	20.9 b	289	213 b	19.7 a	10.2 a
effect[2]	(*)	*	ns	ns	**	(*)	***	*	ns	**	*	(*)

[1] VSC lignin compounds, CS cellulosic sugars, NCS noncellulosic sugars, Ac-to-Al ratio of acids to aldehydes of the vanillyl compounds

[2] (*) p<0.1; * p<0.05; ** p<0.01; *** p<0.001

[3] VSC-to-N ratio × 1000

Unexpectedly, the high foliar nitrogen contents of pupunha did not result in a high POM nitrogen content and stock. Also the nitrogen contents in POM fractions from smaller aggregates confirmed this result (Table 5) being an important difference to the other sites and to results from temperate regions (Zech et al., 1997). The organic matter derived from pupunha did not seem to enter POM and may not contribute to stable SOM as indicated by the low soil carbon contents under pupunha.

Table 3 Carbon and nitrogen contents of aggregate fractions with 2-1, 1-0.5, 0.5-0.25, 0.25-0.02 and <0.02 mm diameter of soils under cupuaçu, pupunha, pueraria, vismia and bacaba on the terra firme near Manaus; means and level of significance (n=3); values in one row followed by the same letter are not significantly different at p<0.05

	Fraction	cupuaçu	pupunha	pueraria	vismia	bacaba	effect[1]
	2-1	25.9	25.8	28.6	28.8	31.6	ns
	1-0.5	26.6	21.0	22.8	22.9	29.8	ns
Carbon	0.5-0.25	18.2 bc	16.0 bc	20.9 b	13.8 c	27.6 a	**
	0.25-0.02	34.2 b	27.7 b	29.7 b	35.5 b	53.8 a	*
	<0.02	37.7	29.4	33.6	38.2	38.9	ns
	2-1	2.43	2.44	2.77	2.56	2.62	ns
	1-0.5	2.46	2.03	2.18	2.05	2.40	ns
Nitrogen	0.5-0.25	1.76 ab	1.60 b	2.16 a	1.30 b	2.22 a	*
	0.25-0.02	2.98	2.59	2.73	2.92	3.72	ns
	<0.02	3.55	3.05	3.62	3.39	3.48	ns
	2-1	10.7	10.6	10.3	11.2	12.0	ns
	1-0.5	10.8 b	10.3 b	10.5 b	11.1 b	12.4 a	*
C-to-N	0.5-0.25	10.4 b	10.0 b	9.7 b	10.6 b	12.5 a	*
	0.25-0.02	11.2	10.5	10.6	11.7	13.9	**
	<0.02	10.6	9.6	9.3	11.3	11.2	ns

[1] ns not significant; **, * signficant at p<0.01 and p<0.05, respectively

The VSC signatures and the carbohydrate contents under pupunha were very high compared to the other soils. The foliar and root polyphenol contents could not explain this accumulation of lignin (Table 4). The low effects of pupunha on SOM and even on nitrogen contents in POM may be explained by the low total amounts of leaf litter compared to pueraria and low root abundance in the uppermost surface soil layer (0-5cm) producing few litter together with their low polyphenol-to-N ratios.

Table 4 Nitrogen, polyphenol contents, C-to-N and polyphenol-to-N ratios of cupuaçu, pupunha, pueraria and vismia leaves and roots (diameter < 2 mm from 0-0.1 m depth)

Sites		N [mg g^{-1}]	polyphenol [mg g^{-1}]	C-to-N ratio	polyphenol-to-N ratio
cupuaçu	leaves[1]	17.7	10.0	28.3	0.57
	roots[2]	10.5	10.4	44.0	0.99
pupunha	leaves	39.2	11.3	11.8	0.29
	roots	8.6	2.6	52.1	0.30
pueraria	leaves	46.2	16.6	8.9	0.36
	roots	16.8	3.0	26.6	0.18
vismia	leaves	13.8	29.7	33.2	2.15
	roots	8.1	19.6	55.5	2.42

[1] mixed sample from old and young leaves

[2] fine roots (<2mm)

The soil carbon replenishment under cupuaçu was an enrichment of low degradable litter with low nitrogen contents and high C-to-N and polyphenol-to-N ratios. Also the POM lignin and plant derived sugars made up a large proportion of the carbon, whereas the contents of microbially derived sugars were lowest among all sites. In POM but also in the bulk soil, the ratio of NCS-to-CS was lowest under cupuaçu, indicating a low microbial degradation of plant litter.

Table 5 Amount, carbon and nitrogen contents and stocks of particulate organic matter from 2-1, 1-0.5 and 0.5-0.25 mm fractions of the surface soils layer at 0-5cm under cupuaçu, pupunha, pueraria, vismia and bacaba on the terra firme near Manaus (n=2)

	Fraction [mm]	cupuaçu	pupunha	pueraria	vismia	bacaba
	2-1	0.89	0.90	0.68	1.31	2.54
Weight [%]	1-0.5	0.57	0.71	0.37	0.68	1.62
	0.5-0.25	0.60	0.38	0.32	0.46	0.77
	2-1	306	260	251	328	284
C content [mg g^{-1}]	1-0.5	238	201	208	227	255
	0.5-0.25	228	177	256	289	309
	2-1	2.72	2.31	1.64	4.12	7.14
C stocks [mg g^{-1}]	1-0.5	1.25	1.43	0.79	2.24	4.13
	0.5-0.25	1.36	0.59	0.78	1.30	2.42
	2-1	14.8	12.0	14.1	14.2	11.9
N content [mg g^{-1}]	1-0.5	13.2	10.9	13.4	15.5	11.7
	0.5-0.25	13.5	10.6	16.8	15.1	14.0
	2-1	0.13	0.11	0.10	0.18	0.31
N stocks [mg g^{-1}]	1-0.5	0.07	0.08	0.05	0.11	0.19
	0.5-0.25	0.08	0.04	0.03	0.07	0.11
	2-1	21.1	21.6	17.9	23.1	24.0
C/N ratio	1-0.5	18.1	18.5	15.5	21.2	21.8
	0.5-0.25	17.0	16.6	15.2	19.3	22.1

High NCS-to-CS ratios were found in the bulk soils of the primary (bacaba) and secondary (vismia) forest sites indicating a high proportion of microbially derived sugars (Table 2). On the other hand, the C-to-N ratios were significantly higher than below trees relevant for agroforestry systems (Table 1), which would hint at low decomposition rates. The low C-to-N ratios of soils in the agroforestry system (cupuaçu, pupunha and pueraria) were caused by fertilization and the biological nitrogen fixation of the pueraria. The added visible POM smaller than 0.25 mm were found and (iii) the smaller fraction 0.02-0.25 mm showed the highest carbon contents of all aggregate fractions. This is also confirmed by the shift of the VSC values, Ac-to-Al, VSC-to-N and C-to-N ratios from the aggregates 0.5-1 to 0.25-0.5 mm (Annual report 1997).

4. Conclusions

Using aggregate fractionation together with the chemical characterisation of SOM, the processes of incorporation of plant litter into stable SOM could be successfully studied in the strongly aggregated Ferralsols. Thus, it could be shown that aggregation promoted the stabilisation of SOM, but SOM did not increase aggregate stability. The particulate organic matter was an important and valid indicator of the effects of different organic inputs on SOM properties. It could be used for assessing the effects of land-use or single trees on SOM of the studied Ferralsols. In the fraction 0.25-0.5 mm strongly humified POM was incorporated into aggregates, being the most sensitive to land-use changes among the aggregate fractions.

Total SOM and POM contents were significantly larger under trees in the primary forest than in the agroforestry systems or fallow. Cupuaçu increased SOM contents in comparison to pupunha or pueraria, which could be related to the low quality organic matter of cupuaçu litter. Despite the similarly low foliar C-to-N ratios of pupunha and pueraria, pupunha did not replenish nitrogen contents of the labile soil organic matter.

The investigation of factors controlling humification should be intensified. The relationship between soil aggregation and SOM is still poorly understood but could yield relevant information about SOM stabilization in these strongly aggregated soils.

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2) Single-tree effects on soil P pools in a multi-strata agroforestry system

Doris Günther, Johannes Lehmann and Klaus Kaiser

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 in comparison to secondary vegetation and primary forest sites on inorganic and organic P pools of a Ferralsol in the Amazon basin. The S pools were also assessed, but could not be presented here due to the length of this contribution.

2. Materials and Methods

In September 1997, soil samples from 0-5 cm depth were taken at 50 cm distances from two trees per plot and combined. The trees were arranged in a completely randomized design with three replicates. The sites were soils 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 recieve any fertilizer. P was sequentially extracted according to a modified Hedley procedure (Table 2). Inorganic P was analysed using the molybate ascorbic acid method (Murphy and Riley, 1962). Total P was analysed with a ICP-OES.

Table 1 Fertilizer applications to useful trees in a multi-strata agroforestry system before soil sampling in May 1997, with N and S as ammonium sulfate (21.2% N; 24.2% S) and P as triple super phosphate (22% P).

Species	No. of	N		P		S	
	[plants ha^{-1}]	[g $plant^{-}$	[kg ha^{-1}]	[g $plant^{-1}$]	[kg ha^{-1}]	[g $plant^{-}$	[kg ha^{-1}]
Cupuacu	93.3	95.4	8.9	77	7.2	108.9	10.2
Peach	312.5	42.4	13.3	11	3.4	48.4	15.1
Urucum	156.3	84.8	13.3	39.6	6.2	96.8	15.1
Brazil nut	93.3	42.4	4.0	22	2.1	48.4	4.5
Total	655.4		39.5		18.9		44.9

Table 2 Sequential extraction method and properties of soil phosphorus pools.

Pool	Extraction procedure[1]	Pool properties[3]
Bicarbonate-P_i	0.5M $NaHCO_3$[2], 16h	immediately plant available P; bound to
Bicarbonate-P_o	0.5M $NaHCO_3$[2], 16h	mineral surfaces
Hydroxide-P_i	0.1M NaOH[2], 16h	successively available P; bound to oxides
Hydroxide-P_o	0.1M NaOH[2], 16h	long-term availability; more strongly bound to oxides and in humic compounds
Dil.-acid-P	1M HCl[2], 16h	successively available P; Ca-bound
Acid-P	concentrated HCl, 10min, 80°C	long-term available P; Ca-bound and occluded P
Residual-P	5M HNO_3 and concentrated $HClO_4$, 200°C until dry	highly resistant P

[1] modified after Hedley et al. (1982) and Tiessen et al. (1984)

[2] soil:solution ratio of 1:5

[3] modified after Cross and Schlesinger (1995)

3. Results and Discussion

3.1 Properties of P pools without fertilization

Immediately available P was rather low in these highly weathered soils under natural vegetation (Fig.1). The largest portion of total P was found in the hydroxide-P fractions, especially P_o. This coincides well with the observations of Cross and Schlesinger (1995) that highly weathered soils have more P in successively available organic P fractions. The amounts of residual-P, however, were surprisingly low. The general P reserves in these soils are minimal, emphasizing the need for a sound nutrient management practice with special reference to P.

3.2 Fertilizer effects on soil nutrient pools

Soils beneath undisturbed forest trees and secondary forest had lower available P (bicarbonate-P_i and -P_o, hydroxide-P_i) than the soils under the useful trees in the agroforestry system due to P fertilization (Fig.1). Also successively and intermediately available P contents (diluted-acid-P, acid-P) were higher in the fertilized soils than in the natural ecosystems. However, long-term available and highly resistant P (hydroxide-P_o, residual P) did not differ, showing that initial P properties were the same between the studied sites.

3.3 Single-tree effects on P and S pools in multi-strata agroforestry systems

The soils under different tree species in the multi-strata agroforestry system showed markedly different soil P contents, which did not reflect the amount of fertilizer applications (Table 1). Soils under cupuacu had low available P contents (bicarbonate-P_i and -P_o) similar to soils under the forest trees despite the fact that cupuacu recieved even 7, 4 and 2 times more fertilizer P than peach palm, Brazil nut and urucum, respectively, while having the lowest aboveground biomass production (M. Wolf, unpublished data). Successively available inorganic P (hydroxide-P_i), however, was similar under all agroforestry trees, but still higher than in the natural and secondary forest. This was different for hydroxide-P_o, which was higher under *Oenocarpus* and vismia than at all other sites apart from urucum and cupuacu. P fertilization did not increase this P pool. The incorporation of added fertilizer P into bicarbonate-P_i and -P_o and diluted-acid-P was most efficient under peach palm, followed by Brazil nut and urucum. Cupuacu showed a very low ability to preserve added P in available P forms.

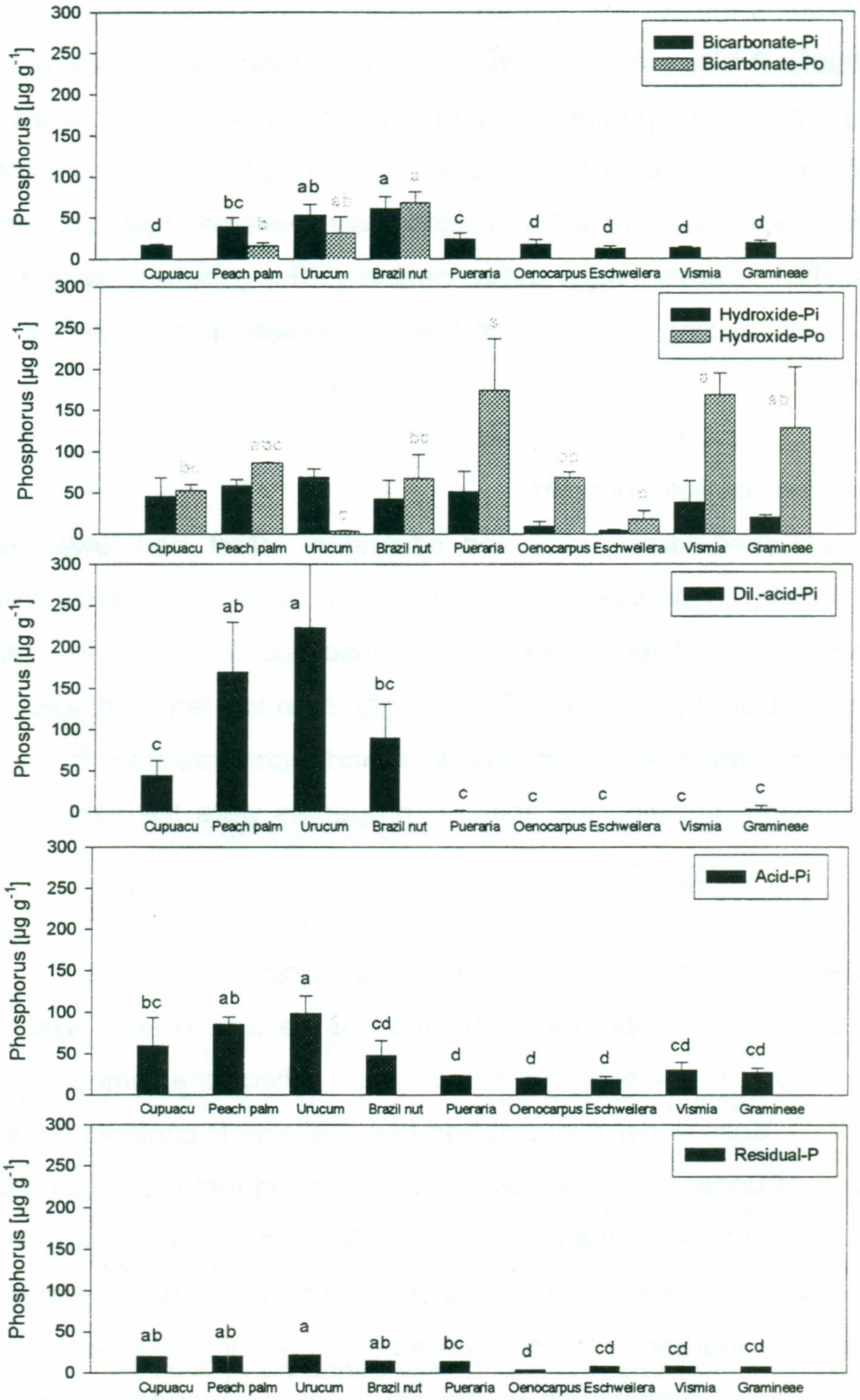

Fig.1 P pools of soils under single trees in a multi-strata agroforestry system, fallow and primary forest on the terra firme near Manaus, Brazil; means and standard errors (n=3).

4. Conclusions

The modified Hedley procedure proved to be extremely useful for the studied soil type to demonstrate the highly contrasting P dynamics of the experimental sites. The different tree species exhibited a pronounced and relevant effect on P properties in the multi-strata agroforestry system. These strongly contrasting effects have to be considered when designing multi-strata agroforestry systems and may help to improve the efficiency of nutrient cycling.

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3) Soil nutrient dynamics

DINÂMICA DO P, K, Ca, Mg E DA ACIDEZ NUM LATOSSOLO AMARELO EM SISTEMAS DE USO DA TERRA NA AMAZÔNIA

Mª do Socorro S. da Mota, Johannes Lehmann and Götz Schroth

INTRODUÇÃO

Os solos da região Amazônica são muito antigos, geologicamente relacionados com o platô terciário (MELO-CARVALHO, 1981), altamente meteorizados e ácidos, com baixa capacidade de troca de cátions (JORDAN & STARK, 1978; FRANKEN *et al.*, 1985), mantendo sua produtividade através de uma ciclagem fechada de nutrientes. Nesta Região, as áreas de cultivo ou de pastagens são abandonadas após poucos anos de uso, sendo a maior causa do desmatamento. Assim, é necessário fornecer alternativas, de maneira sustentável, para uso dessas áreas evitando desmatar novas áreas de floresta primária. Visando o levantamento de informações a serem utilizadas no desenvolvimento de sistemas de uso da terra na Amazônia, este trabalho tem como principal objetivo estudar a dinâmica da acidez e nutrientes no solo.

METODOLOGIA

A área de estudo está situada na Estação Experimental do CPAA/EMBRAPA, ao nordeste de Manaus, Amazonas. O solo é do tipo Latossolo Amarelo textura muito argilosa (Oxisol) com pH 4,0-4,5; conteúdo médio de C orgânico e N e baixa saturação de bases (SCHROTH *et al.*, 1998). A vegetação anterior era capoeira com cerca de oito anos de idade, originária de um plantio de seringueira abandonado, a qual foi derrubada e queimada manualmente em outubro de 92, sendo os sistemas agroflorestais implantados no período de fevereiro a junho de 1993. Foram avaliados quatro níveis de adubação (30% - Nitrogênio; 30%; 100% + Fósforo; e 100%) para o sistema de policultivo (sistema agroflorestal composto por cupuaçu – *Theobroma grandiflorum*, pupunha para palmito – *Bactris gasipaes*, urucum – *Bixa orellana*, castanha-do-pará

-*Bertholletia excelsa* e puerária – *Pueraria phaseoloides*) e 100% de adubação para dois monocultivos (pupunha para palmito e cupuaçu), com três repetições. Foram feitas coletas nas profundidades de 0-5; 5-10; 10-15; 15-20 e 20-40 cm. Os sistemas foram adubados no mês de novembro. Amostras de solo foram retiradas com um trado holandês, na seguinte freqüência: 1ª coleta (30 dias antes da adubação de novembro de 1997); 2ª coleta (30 dias após a adubação de novembro de 1997); 3ª coleta (60 dias após a adubação de novembro de 1997). Em cada parcela fez-se a coleta de solo por espécie, escolhendo-se, aleatoriamente, seis plantas de cada sistema. O ponto de coleta estava entre 50 a 100 cm do tronco de cada espécie arbórea; na puerária, a coleta foi feita junto ao ramo principal enraizado. As amostras de solo foram secas ao ar, trituradas com rolo de madeira e passadas em peneira granulométrica de 2 mm. A acidez (Al + H^+) foi determinada através da Agitação – Método Complexométrico e Titulação com NaOH (hidróxido de sódio), usando-se fenolftaleína como indicador (HENDERSHOT *et al.*, 1993). Ca, K, Mg e P foram extraídos através do Mehlich 3 (SEM TRAN & SIMARD, 1993). Ca, K e Mg são extraídos pela ação do nitrato de amônia (NH_4NO_3) e ácido nítrico (HNO_3), depois medidos no espectrofotômetro de absorção atômica e o P é extraído pela reação com ácido acético (CH_4COOH) e compostos fluorídricos (NH_4F), sendo medido no RFA.

RESULTADOS E DISCUSSÃO

A acidez mais alta foi no nível de adubação mais baixo (30% - N - Calcário) (Tabela 1), com diminuição gradativa até o último nível (100%). O efeito do calcário é limitado na profundidade de 0-5 cm e por isso a acidez é maior na adubação com 30% - N - Calc. em relação a adubação com 30%. Os níveis com 30% de adubação foram iguais entre si e diferentes dos níveis com 100%, os quais também foram iguais entre si. Essa maior acidez nos dois níveis com 30% é atribuída ao nível baixo de adubação.

A puerária e o urucum apresentaram a acidez mais alta em todas as profundidades (P 0,05), diferindo estatisticamente da castanha e da pupunha nas profundidades de 0-5, 5-10 e 15-20 cm e do cupuaçu na profundidade de 15-20 cm (Tabela 2). No sistema estudado, a adubação é feita em volta do tronco de cada planta. A puerária não recebe adubação e apresenta alta mineralização e lixiviação de N porque o NO_3^- carrega consigo o K, Mg e Ca (dados observados no mesmo projeto, ENV-45). Explicando porque o solo nessa espécie apresenta acidez mais elevada. FALESI & KATO (1992) citam que o urucum apresenta maior exportação de nutrientes pelas sementes em relação à cultura de soja e frutas cítricas. Pelos resultados obtidos nessa primeira coleta, o urucum apresentou o mesmo comportamento citado anteriormente, quando comparado com as espécies do sistema em estudo.

Avaliou-se os monocultivos de cupuaçu e pupunha junto com as mesmas espécies no sistema de policultivo, porém a análise de variância não constatou significância entre os sistemas em todas as profundidades. Na figura 1, observa-se o comportamento da acidez no solo para as cinco espécies avaliadas em Out/97, Jan/98, Mar/98 e Mai/98 na profundidade 0-5 cm. Nota-se que a tendência verificada na coleta de Out/97, onde o solo mais ácido foi no urucum e na puerária, foi mantida em Jan/98 para o urucum mas, não mostrou diferença para as demais espécies. O gráfico mostra um aumento na acidez do solo de todas as espécies em Jan/98, em relação a Out/98 e uma queda brusca entre Janeiro e Maio. O aumento da acidez entre Out/97 e Jan/98 é causado pela adubação nitrogenada, pois a transformação do nitrito (NO_2^-) para nitrato (NO_3^-), forma absorvida pelas plantas, acidifica o solo (PAUL & CLARK, 1996).

Os níveis de P aumentaram de outubro a janeiro, coincidindo com a adubação para todas as espécies (fig. 2). Em março o nível de P havia aumentado mais ainda, exceto para a puerária e capoeira que não recebem adubabação. De março a maio houve uma queda brusca para a castanha e pupunha indicando que essas duas espécies podem ser mais exigentes em P, nas demais espécies houve uma diminuição muito pequena.

Tabela 1: Acidez no solo [cmol (+) kg^{-1}], de acordo com os níveis de adubação, referente à primeira coleta na área experimental do projeto SHIFT em Manaus, AM. Diferentes letras após os valores em cada coluna indicam diferenças significativas.

	PROFUNDIDADE (cm)				
NÍVEIS DE ADUBAÇÃO	0 - 5	5 - 10	10 - 15	15 - 20	20 - 40
30% - N - Calc.	1.85 a	1.75 a	1.72 a	1.65 a	1.36 a
30%	1.44 b	1.61 a	1.55 ab	1.48 a	1.30 a
100% + P	1.13 bc	1.35 b	1.36 b	1.24 b	1.03 b
100%	0.91 c	1.19 b	1.18 b	1.10 b	1.00 b
LSD_5	0.35	0.26	0.26	0.22	0.13

N = Nitrogênio; Calc. = Calcário; P = Fósforo; LSD_5 = Diferença mínima significativa

Tabela 2: Acidez no solo [cmol (+) kg^{-1}], por espécie, referente à primeira coleta na área experimental do projeto SHIFT/CPAA-Embrapa, em Manaus, AM. Diferentes letras após os valores em cada linha indicam diferenças significativas.

	ESPÉCIE					
PROFUNDIDADE	Puerária	Urucum	Cupuaçu	Castanha	Pupunha	LSD_5
0 - 5 cm	1.52 a	1.43 ab	1.33 abc	1.25 bc	1.13 c	0.25
5 - 10 cm	1.63 a	1.61 a	1.50 ab	1.30 b	1.33 b	0.21
15 - 20 cm	1.46 a	1.54 a	1.30 b	1.32 b	1.20 b	0.13
20 - 40 cm	1.2459 a	1.2843 a	1.15 ab	1.15 ab	1.03 b	0.16

Pupunha e urucum apresentaram nível de K muito alto em outubro, caindo bruscamente em janeiro, mantendo-se pouco alterado de janeiro a maio para todas as espécies (fig.3). Ca e Mg foi mais alto na castanha, urucum e cupuaçu em outubro, com queda brusca em janeiro. De janeiro a maio todas as espécies mostraram um ligeiro aumento de Ca, mas uma diminuição gradativa de Mg (exceto para cupuaçu). Isso mostra que castanha, cupuaçu e urucum absorvem maior quantidade de Ca e Mg no início da época chuvosa. O mesmo foi observado para pupunha e urucum com relação ao K. Entre as cinco espécies estudadas, o urucum mostra ser a mais exigente com relação ao K, Ca e Mg, coincidindo com as observações de FALESI & KATO (1992).

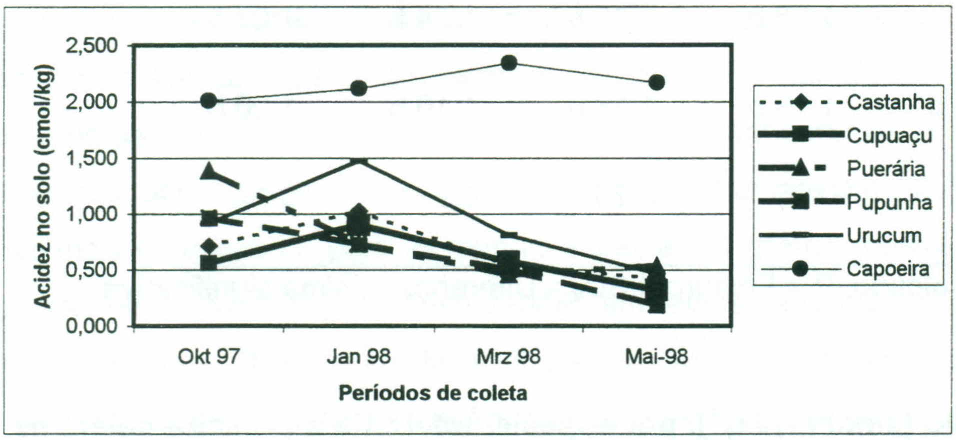

Figura 1: Acidez no solo (cmol/kg), na profundidade de 0-5 cm, para as espécies do sistema de policultivo com 100% de adubação no experimento do projeto SHIFT, CPAA/Embrapa-Manaus.

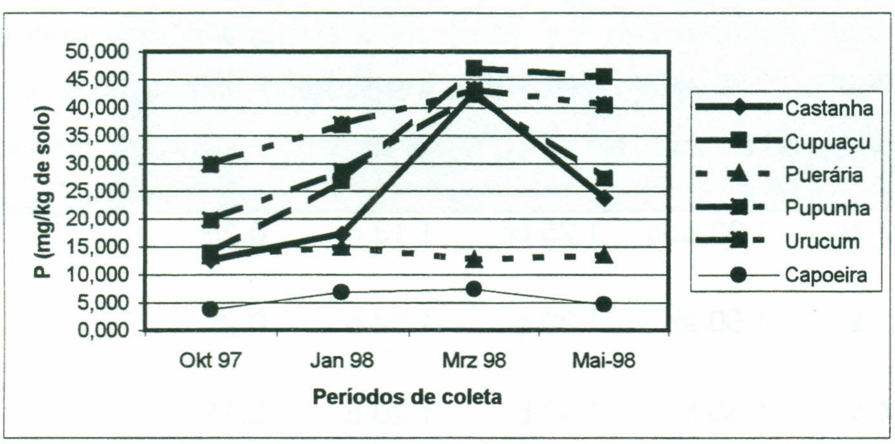

Figura 2: P no solo (mg/kg), na profundidade de 0-5 cm, para as espécies do sistema de policultivo com 100% de adubação no experimento do projeto SHIFT, CPAA/Embrapa-Manaus.

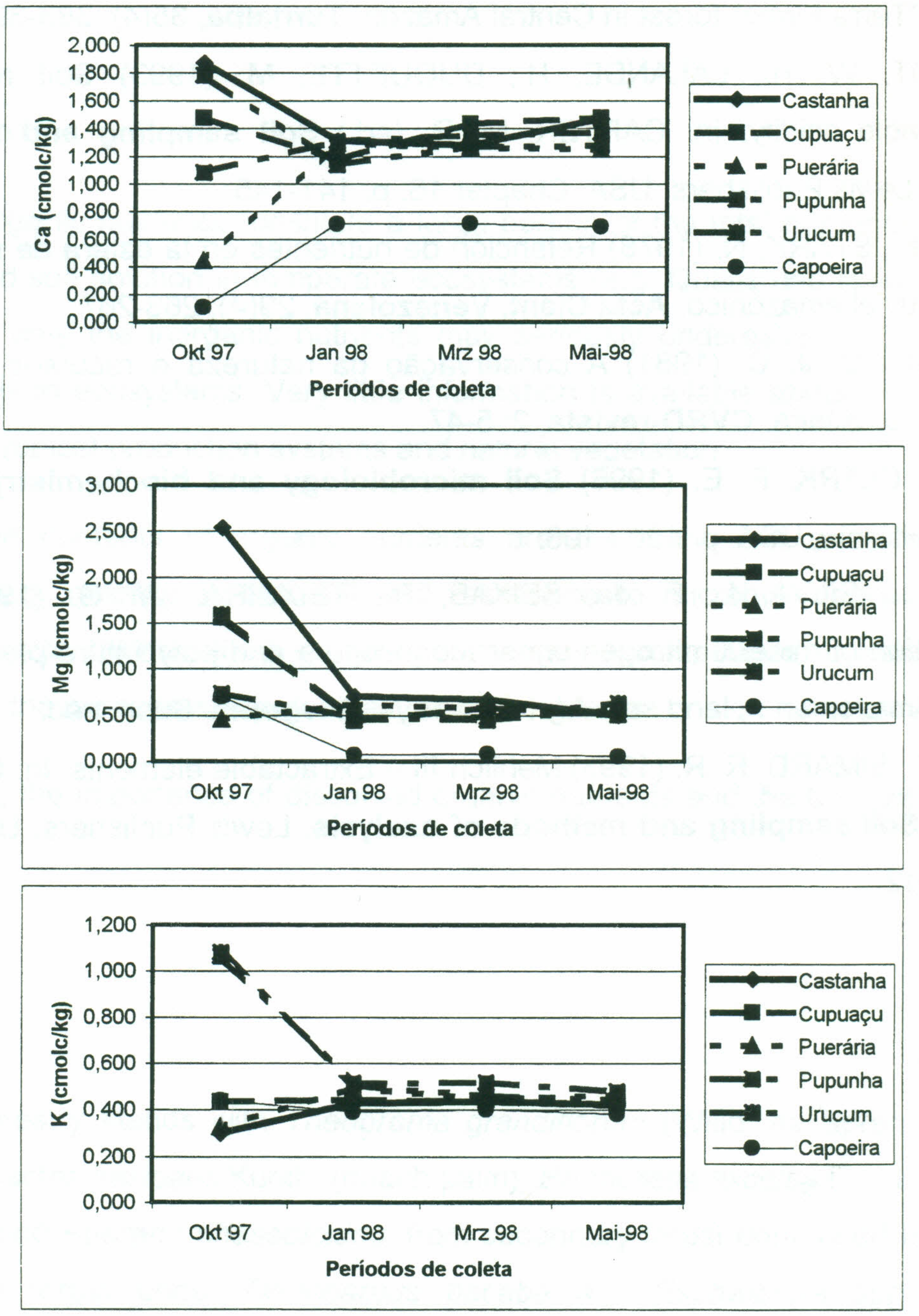

Figura 3: Níveis de K, Ca e Mg no solo (em cmolc/kg), na profundidade de 0-5 cm, das espécies em sistema de policultivo com 100% de adubação no experimento do projeto SHIFT, CPAA/Embrapa-Manaus.

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4) Dissolved organic nutrients in rainfall, throughfall, stemflow and soil solution

Erik Bähr, Johannes Lehmann, Klaus Kaiser, Andre Wetzel and Gerhard Gebauer

Introduction

Dissolved organic nutrients constitute a large portion of the total nutrients in throughfall, stemflow and soil solution in temperate ecosystems (e.g. Qualls und Haines, 1991). The analyses of only the inorganic nutrients may seriously underestimate the nutrient and carbon fluxes in ecosystems. Very little information is available about dissolved organic nutrients in tropical production systems and natural vegetation.

Not only the contents of organic nutrients are important, but also their ecological behaviour, e.g. mobility in the soil and resistance to microbial degradation. With a fractionation into hydrophilic and hydropobic organic compounds, conclusions can be drawn about the properties of organically bound nutrients.

In this study, the importance of dissolved organic nutrients and the behaviour in soil was tested.

Methods

From agroforestry stands with *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum. (cupuacu); *Bactris gasipaes* Kunth. (peach palm); *Bertholletia excelsa* Humb.&Bonpl.; *Bixa orellana* L.; and *Pueraria phaseoloides*, from secondary forest dominated by *Vismia* spp. and primary forest under *Oenocarpus bacaba* and *Eschweilera* spp. (section 6), throughfall, stemflow and soil solution at three depths (0.1, 0.6, 2 m) were sampled twice, at the end of the rainy season and the dry season. The samples were analysed for their inorganic and total organic N and ^{15}N, S and P contents and organic carbon and ^{13}C. They were fractionated using exchange resins into hydrophilic and hydrophobic organic compounds and again analysed for their nutrient and carbon contents.

At this moment, only exemplary results can be shown, since the analyses are very laborious and have not been finished yet.

Results and Discussion

The content of dissolved organic carbon was higher in stemflow than in the soil solution at the topsoil (Table 1). With increasing soil depth, the carbon contents decreased. Further analyses of the nutrient contents in the dissolved organic matter will give important information about the mobility of nutrients in soil.

Table 1 Dissolved organic carbon in throughfall, stemflow and soil solution at different depths at the end of the rainy season; pooled samples from three replicates.

	Pupunha (mg/l)	Cupuacu (mg/l)
Throughfall	3.957	5.449
Stemflow	9.687	8.638
Soil solution 10cm	4.561	5.802
Soil solution 60cm	2.375	nyd
Soil solution 200cm	1.916	2.707

nyd not yet determined

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

Harald Dinkelmeyer, Johannes Lehmann, Marcia Pereira de Almeida and Luciana Ferreira da Silva

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 (Section 6). In this experiment, we want to monitor the fate of applied N in the soil and the plant .

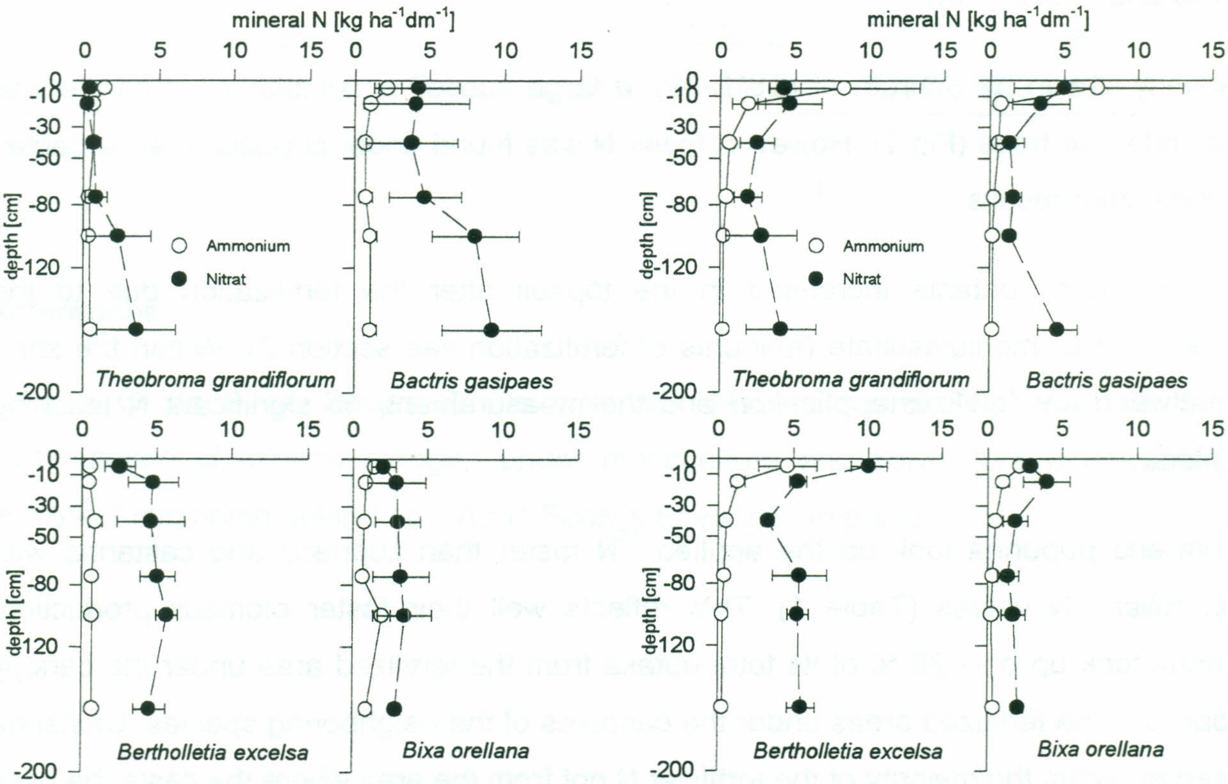

Fig. 1 Mineral nitrogen under different tree species before (left) and after (right) the application of fertilizer; means and standard errors (n=3).

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 as shown in section 6. The trees were fertilized according to local recommendation (see section 2) 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. Here, only a brief outline of the first results are presented, including the relative uptake of ^{15}N between the fertilized areas, and the soil mineral N contents before and after the fertilizer application (two weeks).

Results and Discussion

As already shown by Schroth et al. (1999), a large subsoil accumulation of nitrate was found under the trees (Fig.1). However, fewer N was found under cupuacu than expected from the earlier results.

The ammonium contents increased in the topsoil after the fertilization due to the application of ammoniumsulfate (amounts of fertilization see section 2). Within the short time between the fertilizer application and the measurement, no significant N leaching took place.

Urucum and pupunha took up the applied ^{15}N faster than cupuacu and castanha with higher foliar ^{15}N values (Table 1). This reflects well their faster biomass production. Castanha took up only 29 % of its total uptake from the fertilized area under the canopy compared to the fertilized areas under the canopies of the neighboring species. Castanha seemed to obtain the majority of the fertilizer N not from the area where the castanha itself was fertilized but from the surrounding trees. Therefore, castanha may profit more from the fertilizer applied to pupunha than around its own stem. This result is highly important for future management recommendations.

Table 1 Foliar ^{15}N contents and proportion of N uptake from fertilizer N applied to different trees in a mixed tree cropping system.

Tree species	uptake of N applied to	^{15}N [atom%excess]		proportion of total uptake [%]	
Cupuacu	Cupuacu	0.0429	±0.0058	94.3	±0.8
	Pupunha	0.0009	±0.0003	2.3	±1.0
	Castanha	0.0007	±0.0002	1.6	±0.6
	Urucum	0.0009	±0.0004	1.8	±0.9
Pupunha	Cupuacu	0.0016	±0.0005	1.22	±0.2
	Pupunha	0.1146	±0.0212	91.8	±6.1
	Castanha	0.0072	±0.0059	7.0	±6.1
Castanha	Cupuacu	0.0050	±0.0037	8.9	±4.3
	Pupunha	0.0220	±0.0121	45.7	±13.7
	Castanha	0.0095	±0.0013	28.9	±9.5
	Urucum	0.0058	±0.0025	16.6	±9.7
Urucum	Cupuacu	0.0030	±0.0011	2.6	±0.6
	Castanha	0.0017	±0.0010	1.4	±0.6
	Urucum	0.1046	±0.0188	96.1	±1.1

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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. Agric Ecosys Environm: in press.

6) Root activity patterns of different tree crops

Johannes Lehmann and Takashi Muraoka*

(* Centro Energia Nuclear na Agricultura CENA, Piracicaba, Sao Paulo)

Introduction

There are strong indications of large nutrient losses by leaching in the agroforestry system with indigenous fruit trees investigated by the SHIFT project on the terra firme (Schroth et al., 1999). The question from which depth trees take up nutrients may be of great importance when trying to minimize these nutrient leaching losses. The root distribution may differ between tree crops and of one tree between dry and wet season. Root distribution may not always reflect nutrient uptake, and physiological parameters for nutrient uptake potential like root length density or root surface may over- or underestimate nutrient uptake.

In the experiment described here, we are investigating the root activity of different tree species in an agroforestry system compared to a fallow vegetation.

Methods

In four holes per tree, hoses with an inner diameter of 3mm were inserted at a distance of 0.5m to the stem to a depth of either 0.1, 0.6 or 1.5 m. The investigated tree species were *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum. (cupuacu); *Bactris gasipaes* Kunth. (peach palm); *Bertholletia excelsa* Humb.&Bonpl. (castanha); and *Bixa orellana* L. (urucum) in a multi-strata agroforestry system and *Vismia* spp. in adjacent fallow vegetation. The experiment was laid out in a randomized complete block design.

In 11November 1999, 1 µCi of ^{32}P as orthophosphoric acid and 0.1 g ^{15}N as ammoniumsulfate (10 atom%^{15}N excess) were applied to each of the four wholes around trees. For *Bixa*, *Vismia* and *Theobroma* the youngest fully developed leaves from the upper crown, for *Bertholletia* from the lower crown, and for *Bactris* the leaflets of the youngest fully developed leaves were sampled on 18 and 24 November, on 2 and 17 December 1998, and on 8 February 1999. On 2 December, also the oldest leaves were sampled. Only on 2 December, trees with tracer applications at all depths were sampled, at the other dates only trees were chosen where the labelled nutrients were applied at 0.1 m.

The leaves were dried at 70°C for 48 hours and ground. ^{32}P activity was determined after wet digestion of 1 g oven dry mass in H_2SO_4 until the solution became clear. The radioactivity was measured on a scintilation counter for 10 min. The ^{15}N will be measured after dry combustion on an automatic CN analyser (Carlo Erba) coupled to a isotope mass spectrometer (Finnigan MAT delta E) coupled by a split interface.

Results and Discussion

Sampling procedure and timing

The position of the sampled leaves can affect the results of root activity measurements (IAEA, 1975). In our study, the counts of old and young leaves sampled on November 2 were significantly related ($r=0.61$; $P<0.001$). Therefore, only one type of leaf sample is sufficient for the studied tree species. We consider the young leaves to be easier and more homogenious to obtain. For future experiments, only the youngest fully developed leaves will be sampled.

The foliar isotope radioactivity increased slowly during the first two weeks but more rapidly during the following two weeks (Fig.1). The ideal sampling time to obtain maximum counting numbers was around 40 days after the application of the radioisotope.

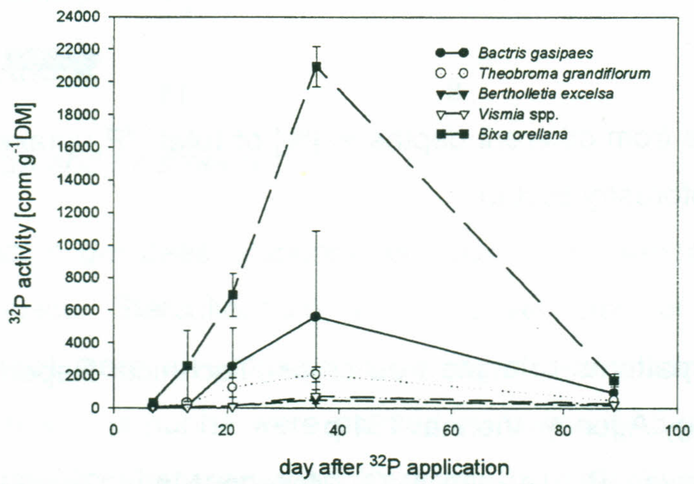

Fig. 1 ^{32}P activity in young leaves of different trees at different intervals after ^{32}P injection at 0.1 m; means and standard errors (n=3).

Root activity of different trees

The root activity was calculated as the percentage of ^{32}P uptake from 0.1, 0.6 or 1.5 m compared to the uptake from all three depths (Fig.2). *Theobroma* and *Bixa* took up the majority of their P from 0.1 m, whereas *Bertholletia* and *Bactris* showed higher P uptake below 0.1 m. *Bactris* even had higher root activity at 0.6 m than 0.1 m depth.

These results are important indications for the suitability of *Bactris* and *Bertholletia* for the recycling of leached nutrients. In the highly permeable Ferralsols at the experimental site, a deeper root activity may also reduce nutrient leaching into the subsoil. Schroth et al. (1999) observed higher amounts of nitrate in the subsoil under *Theobroma* than under any of the other tree species. This may indicate an advantage of deeper rooted trees for the reduction of leaching of fertilized nutrients.

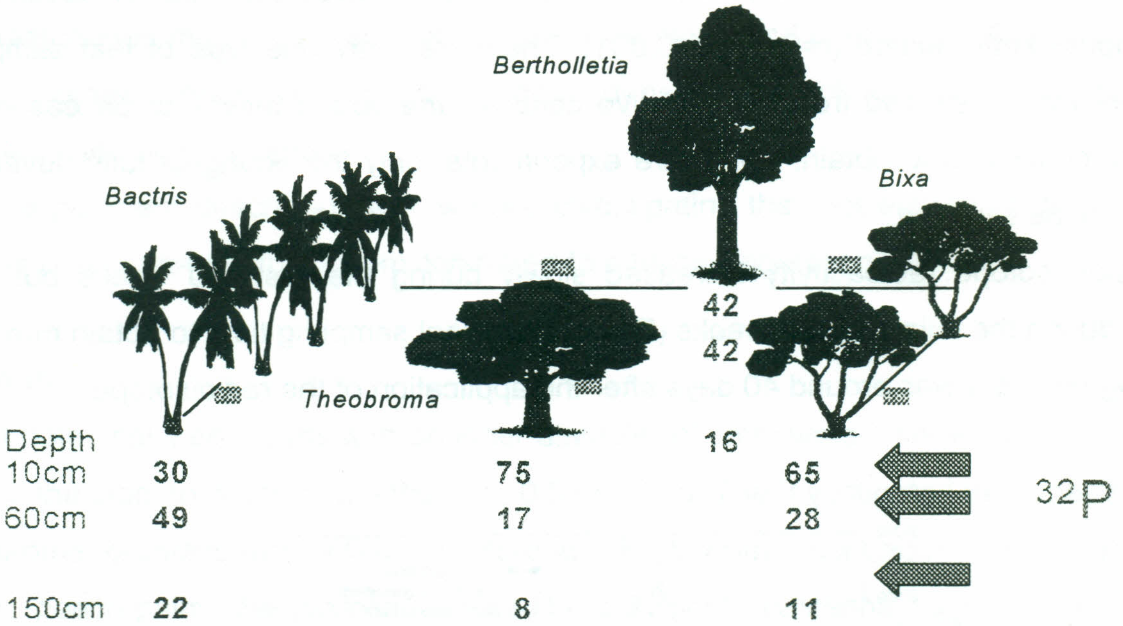

Fig. 2 Relative ^{32}P uptake from different depths in [%] of total ^{32}P uptake of four different tree species in an agroforestry system.

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7) Nitrogen use of a mixed tree crop plantation with a leguminous cover crop

Johannes Lehmann, Jose Pereira da Silva Jr., Gerhard Gebauer and Luciana Ferreira da Silva

Introduction

In mixed tree crop plantations, the leguminous cover crop plays an important role for the replenishment of N to the soil through biological nitrogen fixation. Apart from the N input, the cover crop also reduces the abundance of grasses which may compete with the tree crop for water and nutrients.

It is not known, how much of their N trees take up from the area between the tree rows, where the biologically fixed N is mineralized from leaf and root litter of the legume. Furthermore, it is not clear, if deep or shallow rooted tree species are in the same way able to utilize this N source and if they use fertilizer applied to adjacent tree crops.

In this study, we adressed the question from where two associated fruit tree crops take up their N in comparison to a leguminous cover crop in an agroforestry system. The central hypothesis is that tree crops benefit significantly from biologically fixed nitrogen of an intercropped legume.

Materials and methods

Experimental design and treatments

In this study, *Bactris gasipaes* (pupunha or peachpalm, Arecaceae) and *Theobroma grandiflorum* (cupuacu, Sterculiaceae), and a cover crop of *Pueraria phaseoloides* (pueraria, Fabaceae) were investigated in an agroforestry combination on a chromic Ferralsol. Cupuacu and pupunha were planted in rows with 5 m distance, leaving 6 m between cupuacu and 2 m between pupunha within the rows. The pupunha was managed for palmito pruduction (heart of palm) and cut every 4-5 months. Pueraria was sown between the trees.

Application of ^{15}N

Within the plots of 48×32, microplots were chosen with two pupunha and one cupuacu tree in three replicates (Fig. 1). At times of regular fertilisation at the beginning of December 1997 and at the end of April 1998, ^{15}N was applied as $(NH_4)_2SO_4$ in aqueous solution with 10 atom % excess ^{15}N at a rate of 10 kg N ha^{-1} using a manual sprayer. The ^{15}N enriched fertiliser was not added uniformly to the plots but in three different treatments either under the cupuacu, the pupunha or the pueraria. This procedure resulted in a higher concentration of ^{15}N per area under the cupuacu (1.5 g^{15}N m^{-2}) than the pupunha (0.5 g^{15}N m^{-2}) and the pueraria (0.14 g^{15}N m^{-2}), as the area occupied by these plant species increased in the same direction with 1, 3 and 11 m^2 , respectively (Fig. 1). The main plots (application to the different plants) were arranged in a randomized complete block design, the subplots (plant species) as a split plot (Little and Hills, 1978).

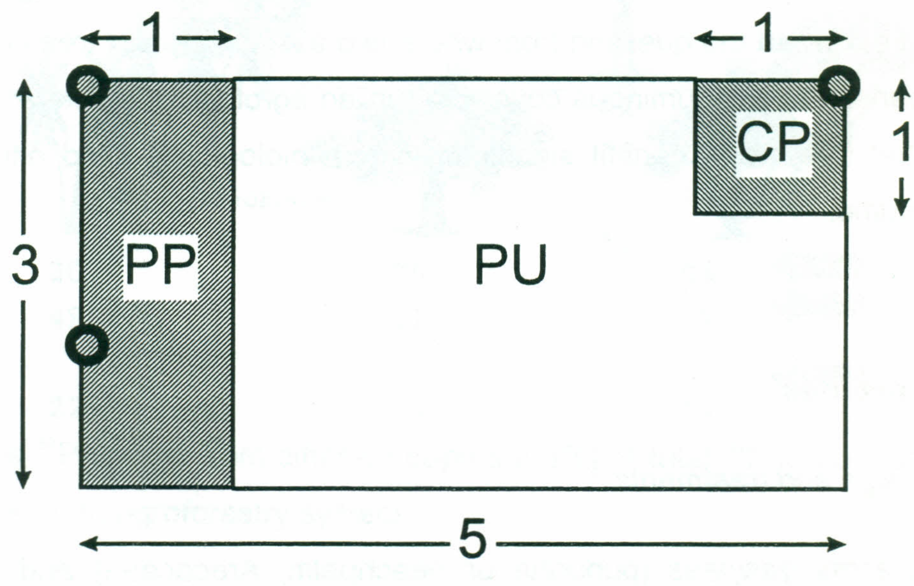

Fig. 1 Layout of the experiment, circles show positions of cupuacu in area CP and pupunha in area PP; ^{15}N was applied either in CP, PP or PU area (CP cupuacu, PP pupunha, PU pueraria); distances in [m].

Plant and soil sampling

The N isotope composition was measured in the different plant species on 15 February, 15 April, 14 May, 1 June and 14 September 1998 and in the soil at 0-0.1, 0.1-0.3, 0.3-0.5 and 0.5-1.0 m depths only on 15 April 1998. From February to June, only the youngest fully developed leaf was sampled, only the middle leaflets of pupunha but the whole leaves of cupuacu and pueraria. No significantly different N isotope composition existed between the youngest leaves and the whole plant of pueraria, therefore only the results of the latter are shown here. In November, a mixture of the whole standing biomass was obtained sampling leaves, branches and stem.

Natural ^{15}N abundance

In a second experiment, the youngest fully developed leaves were taken from cupuacu and pueraria, the middle leaflets from the youngest fully developed leaves of pupunha in the agroforestry systems described above (P1), and an agroforestry system of cupuacu and pupunha together with *Bertholletia excelsa* and *Bixa orellana* (P2) with the same planting density of pupunha and cupuacu than in P1. The different systems had different amounts of ground cover with pueraria: system P1 showed thick coverage, whereas P2 was scarcely covered. The foliar N isotope composition was measured in the different crops at the end of the dry season in November 1997, and at the end of the wet season in June 1998, and in the soil at 0-0.05 m depths on 15 November 1997 and 15 April 1998.

Analyses

The leaf samples were dried at 70°C for 48 hours. The soil samples were air dried. Afterwards, they were finely ground with a ball mill. All samples were analysed using an Elemental Analyser (Carlo Erba NA 1500) for Dumas combustion connected to an isotope mass spectrometer (FINNIGAN MAT delta E) via a split interface.

The analyses of variance was computed using a split plot design (ANOVA of STATISTICA *Version 5). In case of significant effects or interactions,* individual cell means on the respective level were compared using LSD at $p<0.05$ (Little and Hills, 1978).

Results and Discussion

Areas of N uptake

Pueraria had the highest foliar N content followed by pupunha, cupuacu having less than the other two (Table 1). One year after application, cupuacu took up more of the applied N in comparison to the total N uptake than pueraria and pupunha as seen from the high $\delta^{15}N$ values (Table 1). The amount of ^{15}N taken up in relation to dry matter equaled between the three species, since pueraria had a lot higher N contents. The other sampling dates are not demonstrated here, but showed the same tendency.

The percentage of ^{15}N uptake between the three areas of application was always highest at the respective plant area, i.e. cupuacu took up most of its N from underneath the canopy etc. Cupuacu tended to take up more N from the area under pueraria (PU) than the pupunha (PP; Table 1). This was also seen from other sampling times, where the difference proved to be significant (data not shown).

The importance of the cropping area for N uptake can be seen from the ^{15}N area uptake which is the product of the relative uptake in percent and the area respective (Table 1). For cupuacu, the area under pueraria (PU) is more important on the whole than the area underneath the canopy (CP).

Table 1 Biomass N content, N-isotope composition and proportion of ^{15}N uptake from different areas in agroforestry with cupuacu, pupunha and pueraria at the end of the dry season in November 1998, six months after application of ^{15}N at the beginning of May 1998; values in one column followed by the same letter are not significantly different at $p<0.05$ (comparison only within same plant parts; n=3).

Species	^{15}N application in area	plant part	N content [mg g^{-1}]	$\delta^{15}N$ [‰]	^{15}N amount [µg ^{15}Nexcess g^{-1}]	^{15}N uptake [%]	^{15}N area uptake [% ^{15}Nuptake %area]
Cupuacu	CP	leaves	18.6	361 a	23.8 a	80.8 a	538 cd
		branches	4.7	235 a	4.0 b	77.7 a	518 cd
		stem	3.8	296 a	4.0 b	64.2 a	428 b
	PP	leaves	18.5	9 d	0.3 b	1.1 c	22 d
		branches	5.6	23 cd	0.4 b	5.8 bc	117 d
		stem	3.7	74 bc	1.0 b	14.0 b	281 b
	PU	leaves	18.0	81 cd	5.0 b	18.2 b	1331 b
		branches	4.1	55 c	0.9 b	18.4 b	1205 ab
		stem	4.3	99 bc	1.7 b	21.8 b	1599 a
Pupunha	CP	leaves	35.6	8 d	0.4 b	1.6 c	11 d
		branches	5.8	5 d	0.0 b	1.7 c	11 d
		stem	13.5	8 c	0.1 b	2.6 c	18 b
	PP	leaves	32.0	196 b	21.9 a	85.0 a	1700 b
		branches	6.3	121 b	2.7 b	83.4 a	1668 a
		stem	22.4	107 b	8.1 b	76.4 a	1527 a
	PU	leaves	33.3	36 d	4.2 b	13.4 bc	982 bc
		branches	5.3	23 c	0.3 b	14.9 b	1093 bc
		stem	18.3	32 bc	1.6 b	21.0 b	1543 a
Pueraria	CP	whole plant	40.3	11 d	0.9 b	3.2 c	21 d
	PP	whole plant	39.7	68 cd	8.8 b	21.8 b	434 cd
	PU	whole plant	39.6	153 bc	21.3 a	75.1 a	5508 a

Table 2 Above ground biomass and ^{15}N uptake from different areas in agroforestry with cupuacu, pupunha and pueraria at the end of the dry season in November 1998, six months after application of ^{15}N at the beginning of May 1998; means and standard errors (n=3).

Species	^{15}N appl. in area	plant part	biomass [kg tree^{-1}]		biomass [Mg ha^{-1}]		^{15}N uptake [mg ^{15}Nexcess tree^{-1}]		^{15}N uptake [g ^{15}Nexcess ha^{-1}]	
Cupuacu	CP	leaves	13.3	±2.8	2.22	±0.47	305.5	±51.1	203.7	±34.0
		branches	11.5	±4.0	1.92	±0.67	47.1	±17.2	31.4	±11.5
		stem	7.2	±1.1	1.20	±0.18	30.0	±8.9	20.0	±5.9
		whole plant[1]	32.0	±7.5	5.33	±1.24	382.6	±72.7	255.0	±48.5
	PP	leaves	10.1	±2.6	1.69	±0.43	3.3	±1.8	2.2	±1.2
		branches	7.5	±1.7	1.25	±0.28	2.4	±0.8	1.6	±0.6
		stem	4.5	±0.8	0.76	±0.13	3.9	±1.4	2.6	±0.9
		whole plant[1]	22.2	±4.8	3.70	±0.81	9.6	±1.7	6.4	±1.1
	PU	leaves	10.5	±3.7	1.75	±0.62	50.3	±14.3	33.5	±9.5
		branches	8.6	±3.0	1.43	±0.49	8.1	±5.1	5.4	±3.4
		stem	5.9	±1.7	0.99	±0.28	8.4	±2.7	5.6	±1.8
		whole plant[1]	25.0	±8.3	4.16	±1.38	66.7	±19.8	44.5	±13.2
Pupunha	CP	leaves	0.9	±0.1	0.45	±0.04	0.4	±0.0	0.5	±0.1
		branches	1.1	±0.1	0.54	±0.05	0.0	±0.0	0.1	±0.0
		whole plant[1]	2.0	±0.2	0.99	±0.09	0.4	±0.0	0.5	±0.1
		whole plant[2]	1.9	±0.3		±		±		
	PP	leaves	1.3	±0.4	0.63	±0.19	31.1	±17.5	41.5	±23.3
		branches	1.5	±0.4	0.75	±0.22	4.5	±2.5	6.0	±3.4
		whole plant[1]	2.7	±0.8	1.37	±0.41	35.6	±20.0	47.5	±26.7
		whole plant[2]	1.4	±0.3		±		±		
	PU	leaves	1.6	±0.3	0.79	±0.13	6.1	±4.0	8.1	±5.3
		branches	1.9	±0.3	0.94	±16	0.7	±0.3	0.9	±0.4
		whole plant[1]	3.5	±0.6	1.73	±0.29	6.8	±3.8	9.0	±5.1
		whole plant[2]	2.1	±0.2		±		±		
Pueraria	CP	whole plant[3]	-		21.93	±0.32	-		20.2	±7.4
	PP	whole plant[3]	-		21.93	±0.32	-		44.8	±10.3
	PU	whole plant[3]	-		21.93	±0.32	-		467.2	±37.1

[1]calculated from plant parts; [2] measured by direct harvesting and weighing; [3] calculated from direct harvesting and occupied area

Fertilizer efficiency

The recovery of the applied ^{15}N increased in the order pupunha<cupuacu<pueraria (Table 3). Despite the generally higher root abundance and more vigourous growth of the palm than cupuacu (Haag, 1997; Wolf, 1997), cupuacu took up more of the applied N than pupunha.

Five months after the ^{15}N application, part of the applied N was leached down to 1m (Fig.1). Pueraria took up most of the N from the topsoil, whereas under the trees the ^{15}N accumulated at 0-0.1m. A significantly larger portion of the applied N accumulated at 0.3-0.6 m under cupuacu than under the other two species. Pueraria may have been more efficient in taking up the ^{15}N before it was leached, whereas pupunha may also have taken up leached nutrients from greater depth, since pupunha has higher root activity also at 0.6 m than 0.1 m (Section 6: Fig. 2).

Table 3 Recovery of ^{15}N applied to different areas in agroforestry with cupuacu, pupunha and pueraria at the end of the dry season in November 1998, six months after application of ^{15}N at the beginning of May 1998; values in one column or row followed by the same small or capital letter, respectively, are not significantly different at $p<0.05$; means and standard errors (n=3).

Species	recovery [%] of ^{15}N applied at			
	cupuacu	pupunha	pueraria	total area
Cupuacu	12.75 a ±2.42 A	0.32 b ±0.06 C	2.22 b ±0.66 B	15.30 b ±2.89
Pupunha	0.03 c ±0.00 C	2.37 a ±1.33 A	0.45 c ±0.25 B	2.85 c ±1.59
Pueraria	1.01 b ±0.37 B	2.24 a ±0.51 B	23.36 a ±1.85 A	26.61 a ±2.09

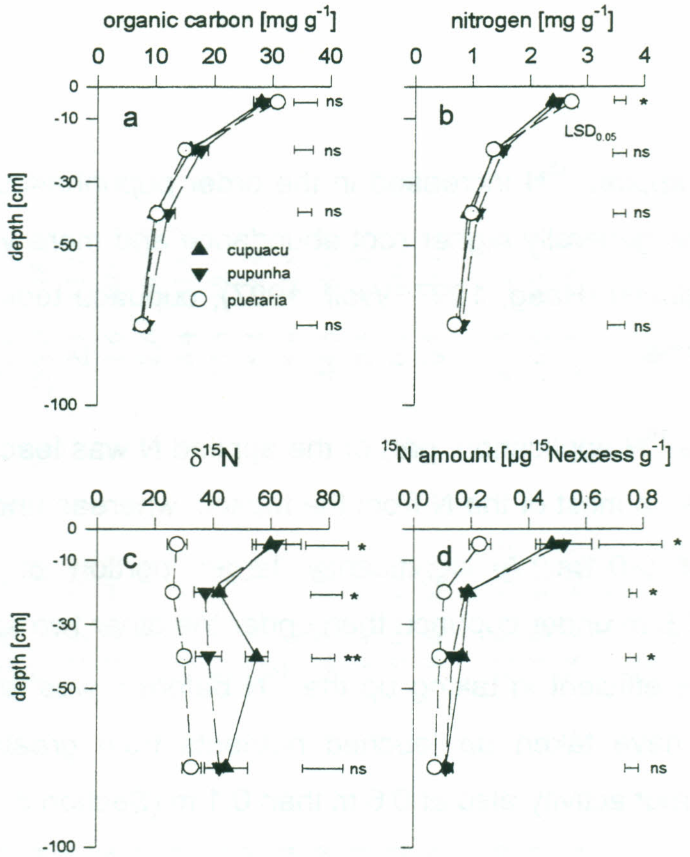

Fig. 2 Soil carbon and nitrogen contents and ^{15}N enrichment under cupuacu, pupunha and pueraria five months after application of ^{15}N in November 1997; only sites where ^{15}N was applied; asterics denote significant effects at $p<0.05$ * and 0.01 ** (ANOVA); means and standard errors (n=3).

Nitrogen benefit from N_2 fixation

Pueraria posseses higher N contents and lower $\delta^{15}N$ values than the two tree species, indicating biological fixation of atmospheric N_2. The $\delta^{15}N$ values of cupuacu and pupunha are slightly lower in P1 than P2. This may be interpreted as a transfer of biologically fixed N_2 from the pueraria to the trees. The total N contents, however, did not increase and the differences of the $\delta^{15}N$ values were not significant. Therefore, the contribution of fixed N of the pueraria to the N nutrition of the associated trees was not very high.

Table 4 Foliar nitrogen and natural ^{15}N abundance of cupuacu, pupunha and pueraria in an agroforestry system with high (P1) and low (P2) abundance of pueraria; means and standard errors (n=3).

Species	System	End of dry season		End of wet season	
		N [mg g^{-1}]	$\delta^{15}N$ [‰]	N [mg g^{-1}]	$\delta^{15}N$ [‰]
Cupuacu	P1	17.74 ±0.52	4.06 ±0.56	14.82 ±0.61	4.08 ±0.33
Cupuacu	P2	17.35 ±0.74	4.64 ±0.53	14.10 ±0.95	4.70 ±0.81
Pupunha	P1	28.91 ±0.46	4.90 ±0.48	37.34 ±4.87	5.02 ±0.59
Pupunha	P2	31.80 ±1.61	5.19 ±0.20	34.85 ±2.47	6.83 ±0.18
Pueraria	P1	43.52 ±0.65	2.16 ±0.08	44.26 ±2.35	1.72 ±2.15
Pueraria	P2	38.71 ±0.64	2.75 ±0.33	37.13 ±2.02	0.97 ±1.95

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8) Fast soil solution nutrient and water dynamics in top- and subsoil

Andreas Renck, Johannes Lehmann, Klaus Kaiser, Jean Marques and Wenceslau Teixeira

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 want to find out the short-term dynamics of applied fertilizer.

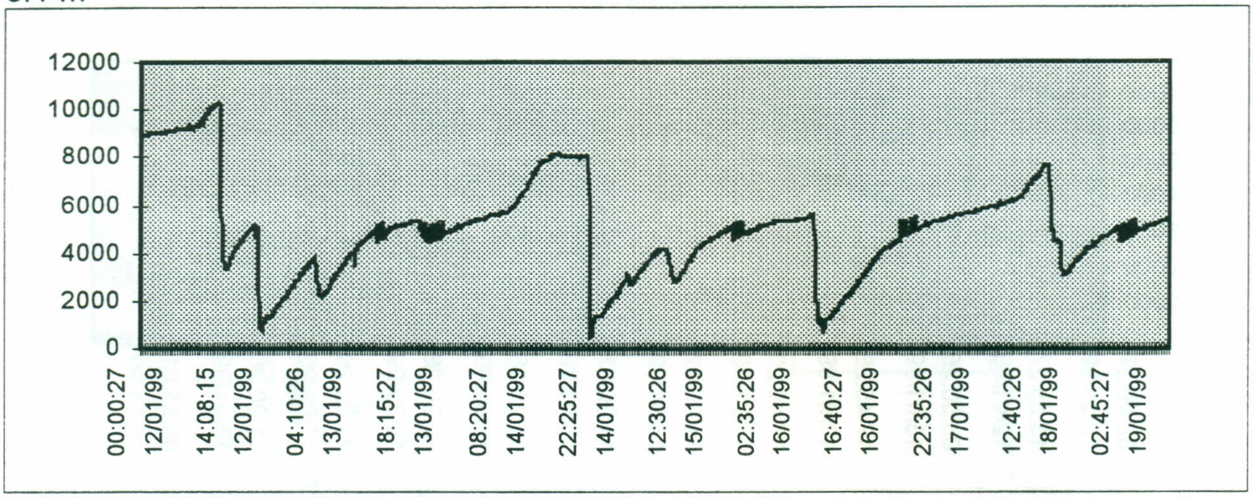
Methods

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. (urucum) with a cover crop of *Pueraria phaseoloides* (experimental design see Fig.2 in annex 6). The instruments were installed between cupuacu and pupunha under pueraria. Readings were done every 5 min during the first month, every 15 min thereafter. Suction cups were inserted up to a depth of 5 m under pueraria, cupuacu and pupunha. Solution was extraced by continuous vacuum application with a portable pump. Samples were gathered in dark glass bottles and collected weekly. Nitrogen analyses were done on a multi-flow analyser (Skalar). A combined fertilizer (ammoniumsulfate, TSP and micronutrients) was applied in mid January around the tree stems.

Results

After a rainfall event, the soil water suction at 0.1 m depth increased immediately (Fig. 1), and fast responses were seen even up to a depth of 0.9 m. This result may indicate that nutrients may be leached very fast even in these soils with high clay contents. The N concentrations in the soil solution relevantly increased at 0.1 m depth during the same time period (Fig. 2), as shown for *Bactris*. First, the ammonium concentrations increased, but nitrate contents followed rapidly indicating a fast nitrification in the studied soils.

0.1 m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02:35:26 16/01/99
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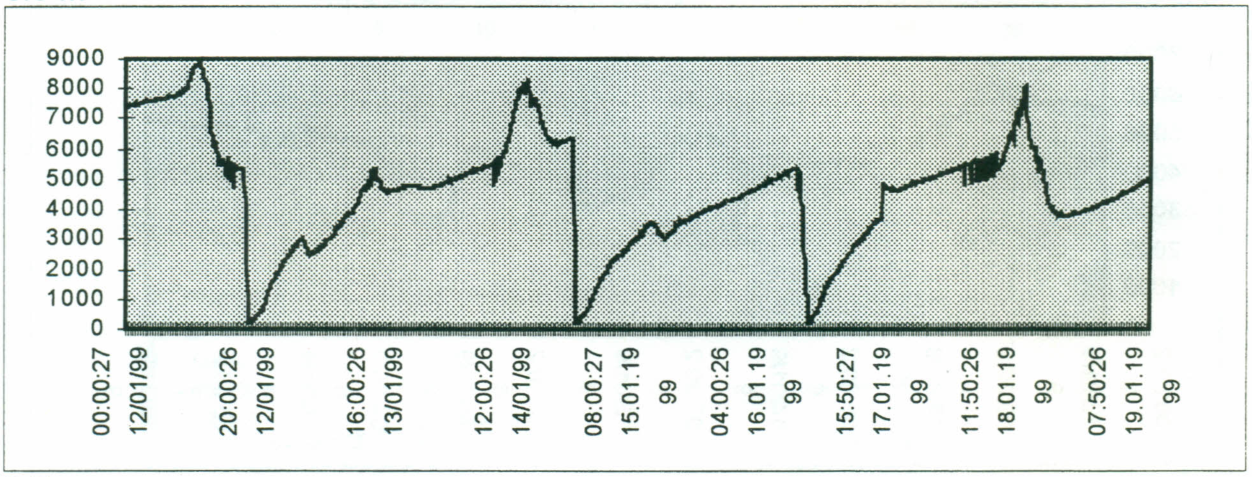
0.3 m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12:00:26 14/01/99
08:00:27 15.01.19 99
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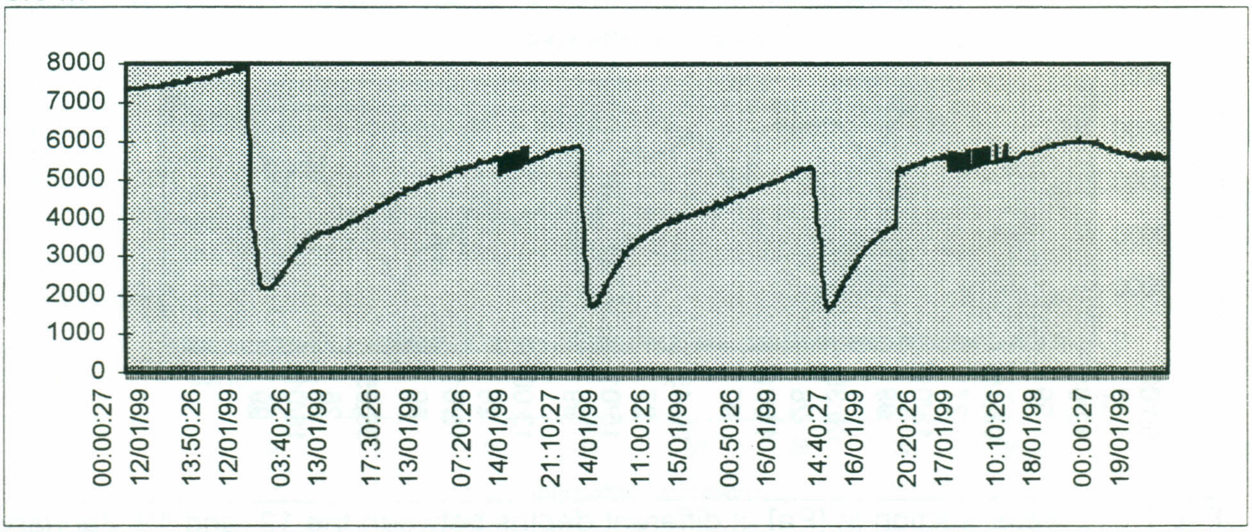
15:50:27 17.01.19 99
11:50:26 18.01.19 99
07:50:26 19.01.19 99

0.6 m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20:20:26 17/01/99
10:10:26 18/01/99
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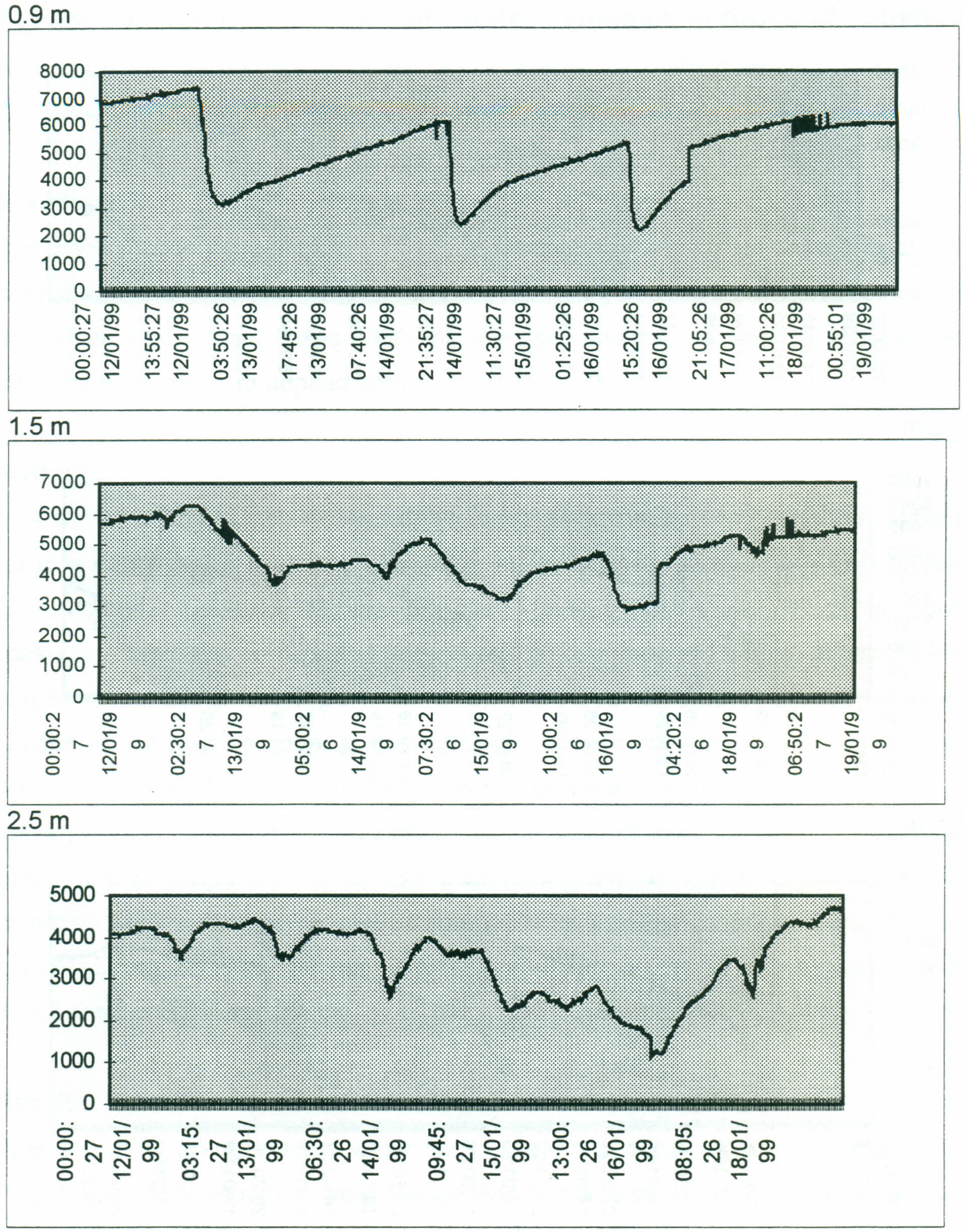

Fig. 1 Soil water suction in [Pa] at different depths between the 12. and 19. January 1999.

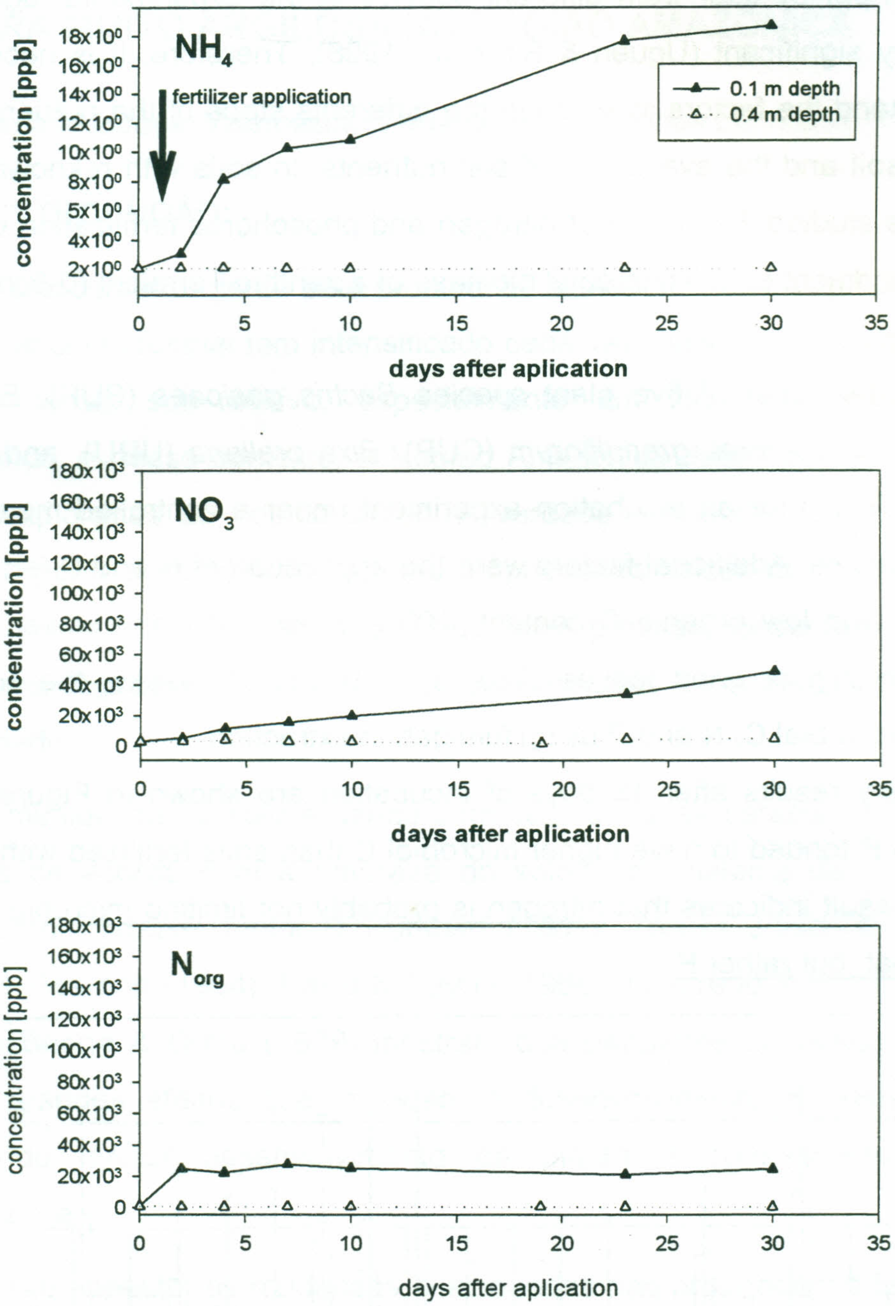

Fig. 2 Ammonium, nitrate and organic N dynamics in the soil solution at 0.1 and 0.4 m depths under *Bactris gasipaes*.

9) Soil nutrient amendment with leaves of varying quality

Tatiane P. Fernandes, Roger B. Silva, Jose Pereira and Johannes Lehmann

The nutrient input by litter from different species in the experimental agroforestry system is very significant (Uguen & Silva Jr., 1998). Therefore, it is necessary to better understand the factors involved in the differents steps of the nutrient transfer from litter to soil and the availability of soil nutrients. In soils with reknown nutrient limitations, we studied the impact of nitrogen and phosphorus fertilization combined with litter amendment on the microbial biomass of a xanthic Ferralsol (0-5cm and 10-20cm).

We used the leaf litter of five plant species *Bactris gasipaes* (PUP), *Bertholetia excelsa* CAS), *Theobroma grandiflorum* (CUP), *Bixa orellana* (URU), and *Pueraria phaseoloides* (PUE) for an incubation experiment under a controlled moisture and temperature regime. Additional factors were the application of N and P fertilizer and soil with high and low organic C content. 100 g of air dried and sieved soil was incubated with 2 g of dried leaves. After 3, 6, 9 and 12 weeks, the soils were analysed for microbial C, N and P using fumigation extraction.

First preliminary results after 18 days of incubation are shown in Figure 1. Soils amended with P tended to have higher microbial C than soils fertilized with N or the control. This result indicates that nitrogen is probably not limiting microbial biomass growth the most, but rather P.

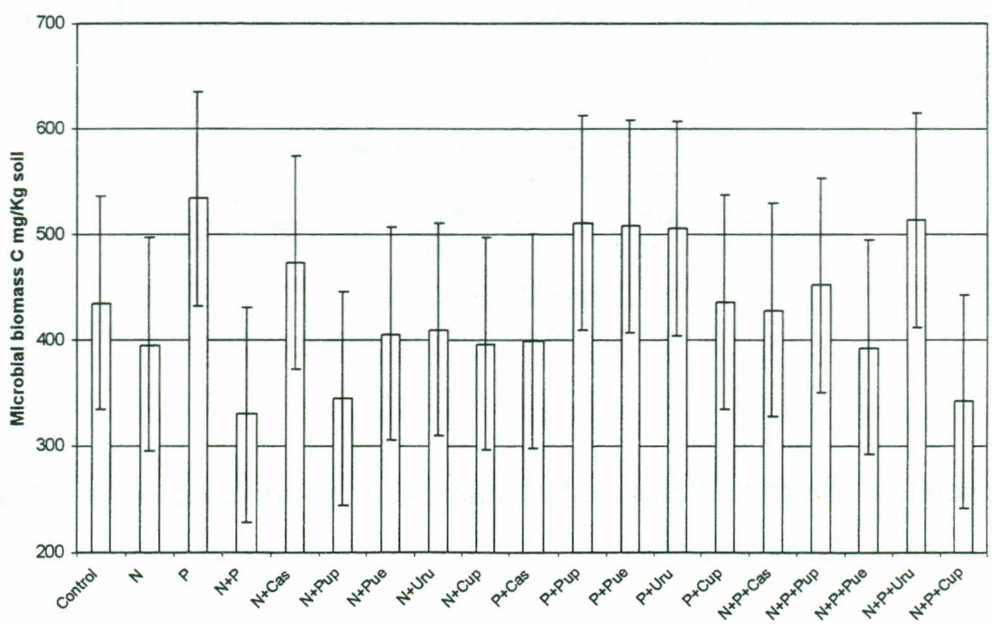

Figure 1. Effects of amendments of N, P and different litter types on microbial biomass carbon in soil

10) Physical and chemical characterisation of a soil profil up to 3m depth

CARACTERIZAÇÃO DE ALGUNS PARÂMETROS FÍSICOS E QUÍMICOS DE UM PERFIL DE 3M EM LATOSSOLO AMARELO TEXTURA MUITO ARGILOSA NA REGIÃO AMAZÔNICA

Jean Dalma Marques, Wenceslau Teixeira and Johannes Lehmann

1 INTRODUÇÃO:

O crescente aumento pela procura de alimentos e outros produtos agrícolas de importancia industrial tem intensificado cada vez mais a questao do aumento de area de terras sob cultivo, especialmente em locais de baixa densidade demografica, e nesse contexto, a Regiao Amazonica detem a grande maioria das terras inexploradas do tropico umido. A verdade e que o problema nos tropicos comeca a partir do conhecimento das propriedades fisicas do solo. Alem disso, o manejo inadequado e o cultivo continuo, sem praticas conservacionistas, podem levar a uma degradacao irreversivel do solo em seus aspectos fisicos, biologicos e de fertilidade

A medida que o solo e usado com cultivos, suas caracteristicas fisicas sao alteradas de acordo com a natureza do solo e do sistema de cultivo utilizado. Trabalhos de Trouse Junior & Humbert (1961), Trouse Junior & Baver (1962), Tackett & Pearson (1964), Eavis & Payne (1968), Charreou & Nicou (1971), Nicou (1972) e Baena & Dutra (1979) mostram que pequenos aumentos na densidade causam grandes efeitos que impedem o desenvolvimento do sistema radicular, acarretando menor desenvolvimento da planta e consequentemente menor produtividade.

Neste aspecto, as mudancas ocacionadas nas propriedades fisicas sao uma das primeiras que se fazem sentir, variando em sua intensidade de acordo com o sistema de cultivo usado. As mudancas fisicas sentidas no corpo do solo sob diferentes sistemas de cultivo sao consequencias de mudancas ocorridas principalmente na estrutura, com efeito na densidade, porosidade e aeracao, causando modificacoes na retencao e movimento da agua no solo, sendo que estes dois ultimos sao os que mais interferem tambem nas propriedades quimicas dos solos.

O solo nao deve apenas fornecer os nutrientes necessarios para os processos metabolicos do crescimento das plantas; deve tambem fornecer um regime favoravel de agua, ar e calor para um funcionamento proprio da planta. Em muitas circunstancias, a absorcao de nutrientes do solo e limitada por um excesso ou falta d'agua, deficiencia de oxigenio, ou inadequada proliferacao de raizes resultantes de densidades altaas que impedem o crescimento das raizes. Uma estrutura desfavoravel e fator limitante a producao agricola e deve ser considerada como um parametro de fertilidade do solo.

O presente trabalho tem o objetivo fornecer informações sobre as características físicas tais como: granulometria, curva de retenção de umidade e densidade das partículas, bem como informações químicas de um perfil de solo de 3.00m de profundidade, constituinte de um sistema agroflorestal com o intuito de contribuir para o conhecimento básico e o uso racional das terrras da Amazônia, já que o uso excessivo ou inadequado torna o solo desfavorável ao bom desenvolvimento das plantas.

2 MATERIAL E MÉTODOS:

2.1 DELINEAMENTO EXPERIMENTAL:

Para a caracterização física do solo foi aberto um transecto de 3m de profundidade, próximo de espécies de pupunha-palmito, cupuaçu, urucum e puerária, tendo uma dimensão de 2,5 m e 2,5 m x 3,0 m de onde foram retiradas as amostras de solo. Para maior confiabilidade em todas as amostras retiradas foram feitas 05 repetições, sendo os dados analisados através de suas médias. A distância do perfil até as espécies plantadas era de 2 m. As profundidades dos pontos de coleta das amostras para a realização das análises físicas tiveram a seguinte variação: 10 cm até 1 m de profundidade; 20 cm até 2 m de profundidade e 25 cm até 2.75 m de profundidade.

2.2 ANÁLISES FÍSICAS:

Cilindros previamente preparados e pesados (tara) foram preenchidos com as amostras de solo para obtenção das curvas de retenção de água. O método utilizado foi o da panela de pressão de Richard. As amostras de solo saturadas foram colocadas em placas de cerâmica saturadas e submetidas as seguintes pressões: 0, 3.2, 10, 32 e 63 cm de coluna de água e 0.1, 0.2, 0.3, 1, 3 e 15 bar até atingirem a drenagem máxima da água contida nos seus poros, correpondente à tensão aplicada. As amostras antes de serem submetidas a variações de tensões eram devidamente pesadas.

Para determinação granulométrica pesou-se 20 g de solo em um Becker e adicionou-se 10 ml de NaOH e 100 ml de H_2O agitando-se e deixando-se em repouso por um período de 12 horas. Após esse período colocou-se as amostras no agitador elétrico por 15 minutos, sendo logo em seguida feito a separação das frações do solo (areia grossa e areia fina) com a utilização de peneiras 0.20 mm e 0.05 mm para cada fração, respectivamente. O teor de argila e silte foram quantificados através de sua sedimentação.

A densidade de partículos foi determinada utilizando o método do balão volumétrico. Pesou-se 20 g de amostra em recipiente de alumínio de peso conhecido, levou-se à estufa e deixou-se por um período de 6 a 12 horas a temperatura de 105° C. A amostra seca e pesada foi transferida para balão volumétrica de 50 ml por meio de um funil, depois adicionou-se álcool etílico através de uma bureta de 50 ml, agitando bem o balão para evitar formação de bolha de ar, essa operação foi mantida até a ausência de bolha e completava-se o volume do balão até a aferição, anotando-se o volume gasto de álcool.

As características químicas estudadas foram, pH em água, fósforo, potássio, cálcio, magnésio, alumínio, carbono, ferro, zinco, mangânes, cobre e matéria orgânica. Todas as análises foram realizadas segundo a metodologia descrita por EMBRAPA, 1979.

3. RESULTADOS E DISCUSSÕES:

Os valores percentuais correspondentes às frações de argila, silte e areia, bem como os valores médios das variações de umidades das amostras sob várias pressões obtidos no perfil são apresentados nas Tabelas: 01 e 02. Analisando a composição granulométrica do solo, nota-se o alto teor de argila nas camadas de 70 cm à 120 cm com média de 733.43 (g kg^{-1}), mantendo-se um comportamento similar até as camadas mais profundas (250 à 275 cm). As camadas superficiais apresentam características para terem uma boa permeabilidade, tendo teores de argila baixos e altos teores de areia.

Tabela: 01 - Análise granulométrica do perfil de 3m seguindo o método tradicional.

Profundi-dades [cm]	densidade dos min. [Mg m^{-3}]	densidade do solo [Mg m^{-3}]	areia grossa [g kg^{-1}]	areia fina [g kg^{-1}]	silte [g kg^{-1}]	argila [g kg^{-1}]	poros. [%]	classificação textural
0-10	2.56	0.82	169.7	44.2	196.2	589.8	68.0	argiloso
10-20	2.53	0.97	220.0	51.5	149.2	579.3	61.7	argiloso
20-30	2.56	1.00	166.2	37.3	161.2	635.3	60.9	argiloso
30-40	2.56	0.90	162.3	41.0	142.5	654.3	64.8	muito argiloso
40-50	2.53	0.83	153.2	37.8	145.2	663.8	67.2	muito argiloso
50-60	2.59	0.95	155.3	37.3	106.2	701.3	63.3	muito argiloso
60-70	2.59	0.97	129.7	37.3	119.5	713.5	62.5	muito argiloso
70-80	2.56	0.97	115.8	35.1	119.3	729.8	62.1	muito argiloso
80-90	2.56	0.96	116.4	33.0	119.1	731.5	62.5	muito argiloso
90-100	2.56	0.97	108.8	32.7	125.7	732.8	62.1	muito argiloso
100-120	2.56	0.97	101.3	31.0	127.9	739.8	62.1	muito argiloso
120-140	2.50	0.94	93.2	27.6	173.5	705.8	62.4	muito argiloso
140-160	2.56	1.00	96.4	27.0	173.4	703.3	60.9	muito argiloso
160-180	2.53	1.04	81.6	27.4	222.1	669.0	58.9	muito argiloso
180-200	2.53	1.04	76.9	21.6	207.8	693.8	58.9	muito argiloso
200-225	2.56	1.04	70.5	21.4	228.8	679.3	59.4	muito argiloso
225-250	2.56	1.05	63.8	22.9	236.0	677.3	59.0	muito argiloso
250-275	2.50	1.07	64.3	21.3	211.4	703.0	57.2	muito argiloso

O comportamento da umidade volumétrica sob diferentes pressões revela que as camadas superficiais são as que tem a capacidade de reter menas água, já que tem uma alta macroporosidade e maior atividade microbiana, fazendo com a água seja facilmente retirada. Nas camadas de 10 à 60 cm o ponto pF 4.2 apresenta uma variação de umidade em torno de 0.20 à 0.27 $cm^3\ cm^{-3}$. Após a camada de 60 cm o comportamento da umidade é homogêneo até 1.40 cm de profundidade. Um aumento de retenção de água é verificado a partir dessa profundidade até 2.75 cm, chegando a uma faixa de 0.38 cm^3/cm^3. A alta retenção de água a partir da camada de 1.40 cm é em decorrência do aumento da densidade do solo que a 2.75 cm é de 1.07 g cm^{-3}.

Tabela: 02 - Valores médios das variações de umidades volumétricas em diferentes pressões obtidas em diversas profundidades em latossolo amarelo.

Prof. [cm]	pF 0.0	pF 0.5	pF 1.0	pF 1.5	pF 1.8	pF 2.0	pF 2.2	pF 2.5	pF 3.0	pF 3.5	pF 4.2
0-10	0.61	0.55	0.50	0.42	0.41	0.40	0.39	0.37	0.35	0.34	0.20
10-20	0.55	0.51	0.48	0.44	0.43	0.42	0.41	0.40	0.38	0.37	0.24
20-30	0.54	0.51	0.48	0.44	0.44	0.42	0.42	0.40	0.39	0.37	0.27
30-40	0.55	0.47	0.46	0.41	0.41	0.39	0.39	0.37	0.36	0.35	0.25
40-50	0.57	0.47	0.45	0.40	0.39	0.37	0.37	0.35	0.33	0.32	0.23
50-60	0.55	0.49	0.48	0.44	0.43	0.41	0.41	0.39	0.37	0.35	0.26
60-70	0.52	0.48	0.46	0.43	0.41	0.40	0.39	0.39	0.37	0.35	0.28
70-80	0.52	0.49	0.47	0.44	0.43	0.42	0.40	0.40	0.38	0.36	0.29
80-90	0.54	0.50	0.48	0.45	0.43	0.42	0.40	0.40	0.37	0.36	0.28
90-100	0.53	0.50	0.49	0.45	0.44	0.43	0.41	0.41	0.39	0.37	0.29
100-120	0.53	0.51	0.50	0.47	0.45	0.44	0.43	0.42	0.40	0.38	0.30
120-140	0.56	0.51	0.50	0.46	0.44	0.43	0.42	0.41	0.40	0.38	0.30
140-160	0.54	0.51	0.50	0.49	0.47	0.46	0.45	0.44	0.42	0.41	0.32
160-180	0.54	0.52	0.51	0.49	0.47	0.46	0.45	0.44	0.43	0.41	0.34
180-200	0.54	0.52	0.50	0.49	0.48	0.47	0.46	0.46	0.44	0.43	0.35
200-225	0.54	0.51	0.49	0.48	0.47	0.47	0.46	0.45	0.44	0.43	0.35
225-250	0.54	0.51	0.50	0.49	0.48	0.47	0.46	0.46	0.44	0.43	0.36
250-275	0.54	0.51	0.51	0.50	0.49	0.48	0.48	0.47	0.46	0.45	0.38

Os resultados das análises químicas são apresentados na tabela: Os valores obtidos de matéria orgânica mostram uma gradativa diminuição dso teores desta variável em profundidade. Este fato está vinculado a maior deposição superficial de resíduos vegetais (folhas, galhos) resultando em um teor mais elevado de matéria orgânica na superfície.

Tabela 3: Analises chimicas do perfil de 3m.

Prof.	pH	Corg	P	K	Ca	Mg	Al	Fe	Zn	Mn	Cu
[cm]		[g kg^{-1}]	[mg dm^{-3}]		------ [cmol dm^{-3}] ------			--------- [mg/dm^{-3}] --------			
0-10	4.1	29.1	12	18	0.85	0.67	2.12	318	2.65	7.13	0.20
10-20	4.0	21.2	6	13	0.35	0.30	2.24	403	1.41	1.25	0.27
20-30	4.1	20.2	4	10	0.24	0.21	1.95	357	1.29	1.17	0.19
30-40	4.1	12.5	2	5	0.17	0.13	1.68	357	1.17	1.09	0.10
40-50	4.1	8.3	1	3	0.22	0.13	1.17	294	1.06	1.34	0.06
50-60	4.1	62.1	1	2	0.18	0.12	1.17	240	0.74	2.18	0.19
60-70	4.1	52.9	1	2	0.16	0.13	1.08	196	0.74	1.44	0.11
70-80	4.2	52.5	1	3	0.16	0.13	0.82	116	0.56	1.18	0.20
80-90	4.2	59.9	1	3	0.17	0.13	0.84	81	0.62	0.36	0.20
90-100	4.3	34.0	1	2	0.13	0.10	0.76	24	0.45	0.28	0.03
100-120	4.3	34.7	1	2	0.15	0.11	0.63	25	0.64	0.29	0.06
120-140	4.7	2.3	1	4	0.18	0.11	0.32	25	0.63	0.15	0.14
140-160	4.5	2.1	1	4	0.16	0.09	0.35	14	0.37	0.25	0.21
160-180	4.6	1.8	1	4	0.12	0.07	0.28	7	0.37	0.26	0.16
180-200	4.7	1.2	1	4	0.10	0.06	0.28	5	0.38	0.33	0.09
200-225	4.8	1.0	1	5	0.14	0.06	1.23	15	0.34	0.27	0.06
225-250	4.8	2.3	1	5	0.16	0.07	0.21	5	0.38	0.30	0.14
250-275	4.7	3.6	1	8	0.18	0.10	0.17	3	0.36	0.41	0.11

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11) Biomass production of *Bactris gasipaes* managed for palmito production

Johannes Lehmann

Introduction

The biomass production of the trees and the leguminous cover crop are basic information, which are needed for the evaluation of productivity of the cropping systems, and for the carbon and nutrient balances. A number of data were collected in the study of Wolf (1997), and biometric relationships were developed to enable the calculation of above-ground biomass without actually harvesting and weighing the trees.

For *Bactris gasipaes* (pupunha) managed for palmito, no biomass determinations were done, nor were any biomatric relationships presented. For single leaves of pupunha for fruit production, however, Wolf (1997) was able to give thorough information. Therefore, we were determining shoot biomass and we are presenting some suggestions for biometric relationships for pupunha managed for palmito production.

Methods

We were harvesting and weighing 12 pupunha shoots at the time of harvesting. Since representative subsamples of the palm trees are difficult to obtain, the whole trees were dried until constant weight and weighed. From each tree, a randomly chosen leaf was weighed separately. At the same time, biometric measurements were done including the height of the shoot (to the tip of the youngest leaf), rachis width and length of a single leaf as described in Wolf (1997). The results are presented here in comparison to the biometric data for single leaves of Wolf (1997).

Results

The water content of the pupunha shoots are very high and an average biomass of only 1.8 kg per tree was measured for trees which are ready for harvesting with an average height of 3.4 m (Table 1). This is far less than the estimates of 7.0 kg per tree by CR de Moraes given in Wolf (1997). For the polyculture systems and the monoculture, it adds up to 0.5 and 4.3 Mg ha^{-1}. The above-ground biomass of pupunha is very low in comparison to e.g. cupuacu with an estimate of 30 kg per tree.

The leaf model presented by Wolf (1997) for pupunha for fruit production seems to overestimate the biomass of single leaves (Table 1). The reason may lie in the fact that it was developed for mature leaves; the new leaves of the pupunha for palmito production may have a lower mass. In our study, the rachis length is a better predictor for leaf weight than the rachis width (Fig.1). The relationship between shoot length and total above-ground biomass is reasonably good (Fig.1) and may be used as an estimate within the heights for which it was developed.

Table 1 Above-ground biomass of whole pupunha shoots and single leaves, shoot height, rachis width and length, and the biomass predicted with the models developed here and the models from Wolf (1997).

Tree No.	total dry weight [kg]	height [m]	water content [%]	leaf weight [kg]	rachis diameter [cm]	rachis length [m]	leaf weight 1 [kg]	leaf weight 2 [kg]
1	1.978	3.52	91.0	0.412	1.8	2.34	0.305	0.617
2	1.002	2.24	85.7	0.207	1.9	1.60	0.178	0.224
3	1.802	3.60	67.2	0.170	1.6	1.40	0.143	0.167
4	2.641	2.46	81.1	0.207	1.6	1.90	0.229	0.342
5	1.964	4.37	84.3	0.234	1.7	2.14	0.271	0.473
6	1.081	2.20	84.6	0.176	1.2	1.63	0.183	0.234
7	1.066	2.13	85.8	0.189	1.1	1.70	0.195	0.258
8	1.518	3.20	91.1	0.254	2.0	2.25	0.290	0.548
9	1.887	3.65	81.1	0.198	1.5	1.88	0.226	0.332
10	1.553	3.54	78.6	0.194	1.2	1.78	0.209	0.289
11	2.672	5.00	85.2	0.249	1.3	1.80	0.212	0.297
12	3.005	5.17	83.3	0.198	2.3	2.00	0.247	0.392
Mean	1.775	3.42	83.2	0.224	1.6	1.87	0.224	0.348
SE	0.193	0.3	1.8	0.019	0.1	0.08	0.014	0.039

1 predicted with the model shown below using rachis length

2 predicted with the model of Wolf (1997) using rachis length

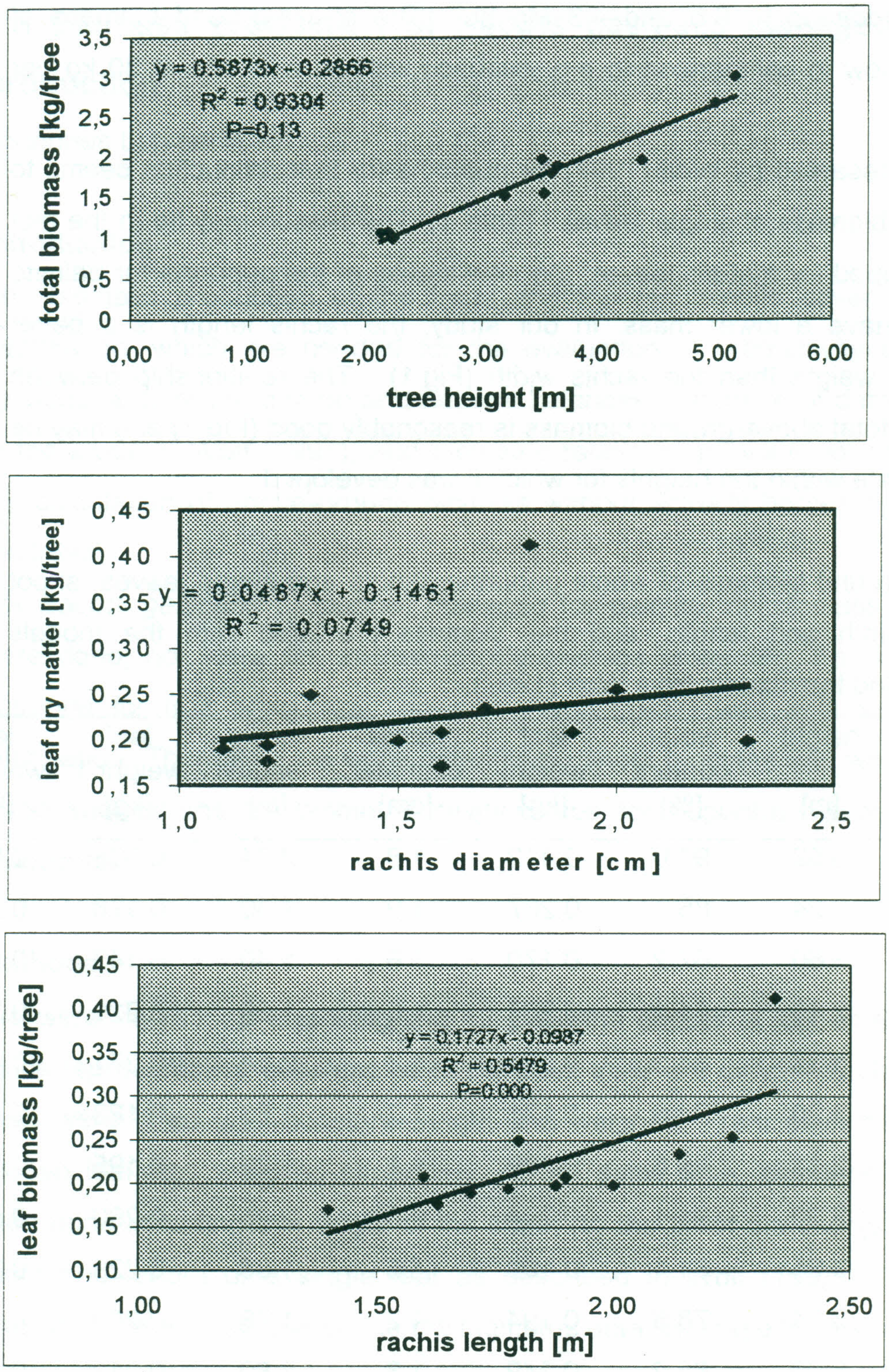

Fig. 1 Biometric relationships of tree biomass and single leaf biomass of pupunha for palmito production (n=12).

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12) Spatial variation in small scale of soil wetness evaluated by different methods

Wenceslau Geraldes Teixeira, Jean Dalmo de Oliveira Marques and Bernd Huwe

Introduction

Soil water content θ in the field can be evaluated by direct or indirect methods. Among the direct - mostly destructive - procedures the gravimetric one is regarded as highly reliable and thus often preferred. Advantages of the direct determination are simplicity of principles and equipment. However, a major disadvantage is that the measurements can not be carried out *in situ* and that the sampling itself is destructive. In recent years Time Domain Reflectometry (TDR) became a widely used non-destructive method to evaluate θ. It is based on the determination of the dielectric constant of the soil ε by determination of the propagation velocity of electromagnetic waves. Its main disadvantage is the need of specific calibrations for some classes of soils and the high costs of the equipment. The characterization of the spatial variability of θ in the small scale may provide information that allow a better understanding of the deviations between values determined by different methods. The need of accurate measurements of θ for their use in calibrations of water balance models requires the knowledge of the spatial variability of θ as a essential factor for the choice of optimal methods and procedures.

Material and Methods

Evaluations of dielectric constants ε and samplings for the determination of θ and bulk density ρ, were carried out in four profiles of a Xanthic Ferralsol with high clay content (Latossolo Amarelo - Brazilian Classification) at the Experimental Station of Embrapa – Amazônia Ociental, in Manaus – AM - Brazil. The samples were taken near the soil surface (Profiles 1 and 3), in 0-5 and 5-10 cm of depth. Three undisturbed core samples and three disturbed auger samples were collected at each depth. The ε was determined in advance at six points with the probe inserted vertically and three points horizontally in each depth. In the subsurface (Profiles 2 and 4) disturbed samples were taken in 25-30 and 30-35cm, and undisturbed samples were collected in the depth of 27,5-32,5cm. For the determination of ε, a commercial device (EASY TEST®) with two transmission lines of 100 mm length, a diameter of 2 mm and a distance of 16 mm between the lines, was used. With the obtained ε – values the volumetric water contents were calculated with the empirical equations of Topp et al., (1980); Malicki et al, 1996 and Teixeira et al., 1997. The samples were weight and oven dried at 105° C for 48 hours. Analyses of variance were computed and means were compared by Tukey's test at the $p< 0,05$ level. The objective of this experiment was i) compare different methodologies and procedures for the determination θ near the soil surface and in the subsoil ii) compare the orientation of TDR probes in the soil.

Results and Discussion

Volume evaluated and probe orientation

A crucial question in comparing methods for determination of θ refers to the volume of the measurements in the soil. The estimation of the evaluated volume is relatively easy in direct method. In this study cylinders of 100cm^3 were used. The disturbed samples were collected with a small soil auger $\approx$5cm that was inserted 10 cm deep, parallel to the surface of the soil. The sensitivity region of the TDR probes were assumed to resemble a cylinder that surrounds the transmission lines, concentrating the sensitivity in an area of $\approx$5cm with $\approx$11cm length (Figure 1). Thus, the evaluated volume of soil in all methods contained approximately the same volume, facilitating the comparison between the methods. In contrast to our assumption works of Baker & Lascano, 1989 and Zegelin et al., 1989, showed that the volume evaluated by the propagation of the electromagnetic waves presents an elliptic rather than a cylindrical form around the transmission lines, and a limited sensitivity extends much farther(Figures 2 and 3). However, the sensitivity of TDR in larger distances as well as the geometry of the transmission lines is still in discussion. The results presented in the Table 1 show that the TDR measurements with probes vertically and horizontally inserted were very similar for all empirical equation under study. However, larger transmission lines may exhibit results different from those due to larger integration volumes, and thus being more subject to the effects of the spatial gradients of θ, especially when installed vertically. The horizontal installation of transmission rods reduced the effect of the vertical gradients of θ considerably. However, this installation has the cost of the excavation and disturbance of the soil.

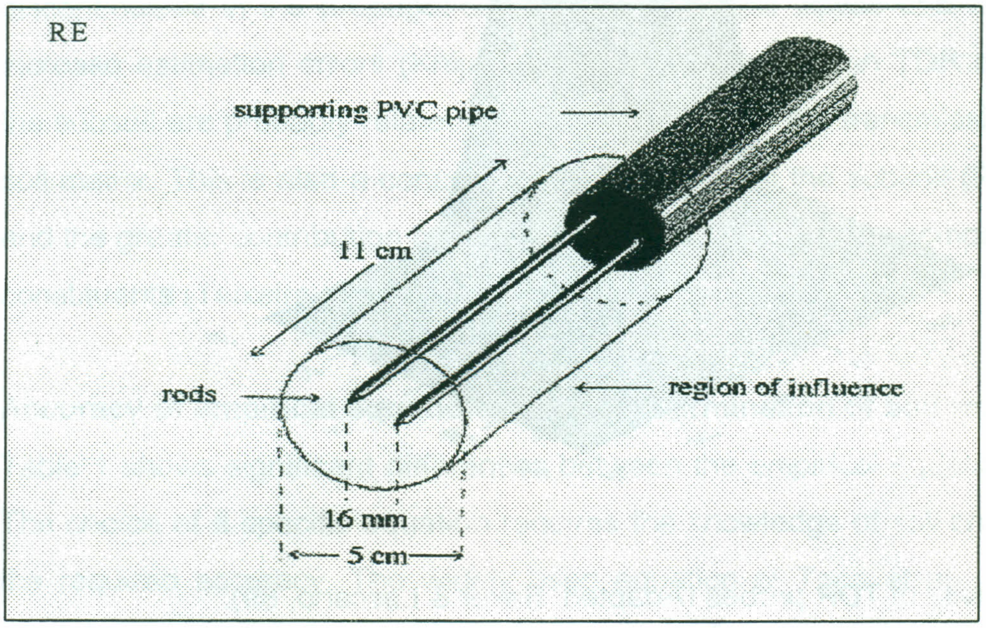

Figure 1 – Geometric characteristics and sensitivity volume of Easy Test – TDR probe (Adapted Easy Test ,s.d.)

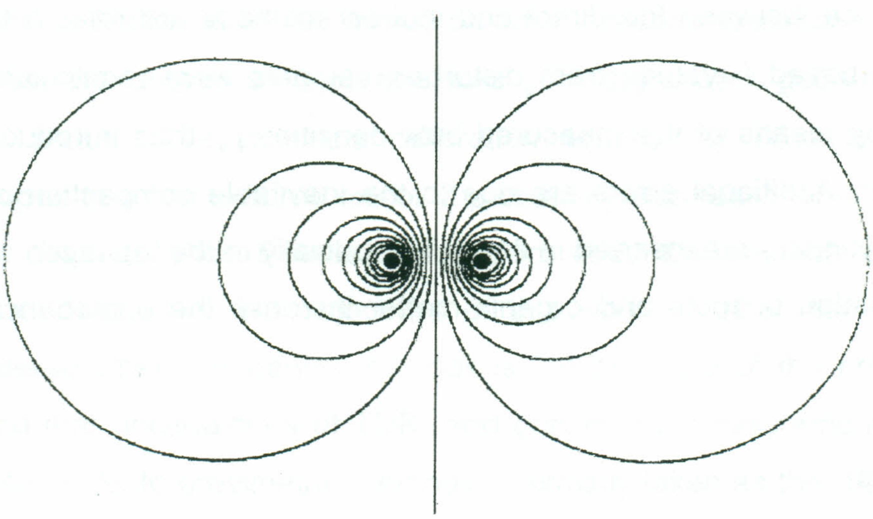

Figure 2 – Dimensionless electric field distribution normal to the direction of probe insertion for two-wire probe (Zegelin et al., 1989).

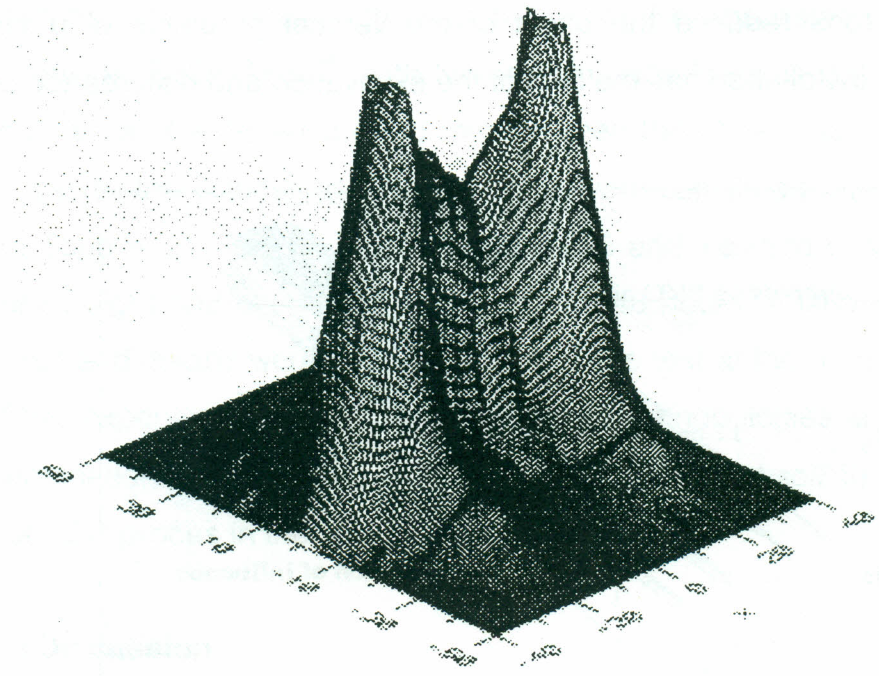

Figure 3 – Sensitivity of TDR probes (Adapted Baker & Lascano, 89).

Topsoil and subsoil measurements

The greater difference between the direct and indirect methods are related to the fact that the mass based θ–values from disturbed samples were recalculated to volumetric values by means of the measured bulk densities ρ, thus introducing a new source of error. Additional errors are due to the inevitable compaction of the sample, when the cylinders are inserted in the soil, especially in the top layer, where the larger concentration of roots and organic matter increase the disturbances of sampling procedure.

Soil characteristics

The tendency of the data to show smaller vertical gradients in the subsoil horizon (2 e 4) is obviously correlated with the fact that the gradients of the underlying physical properties of the soil decrease considerably with increasing depth due to the reduced biological activity. Values of ρ in the subsoil layers increase with depth (data not shown). Further, higher contents of organic matter can cause an underestimation of ε as indicated in previous work of Topp et al. (1980) and reconfirmed by works of Herkelrath et al. (1991). Later, works of Malicki, et al., 1996; Roth et al., 1992; Roth et al., 1990; Dirksen & Dasberg, 1993, Teixeira et al., 1998 showed significant effects of ρ on ε. The presence of macropores can cause discontinuities in the propagation of electromagnetic waves and thus considerably increase estimation errors (Knight, 1992). Smaller errors in TDR measurements in the subsoil are probably related to a better contact of the transmission lines with the soil matrix. This is also a consequence of higher θ in the subsoil (Profiles 2 and 4), and the greater contribution of water to the dielectric constant compared to other soil constituents (Teixeira et al., 1998 and Roth et al., 1990).

Accuracy of empirical equations for the determination of soil wetness

Table 1 shows significant differences between the empirical equations under study. The choice of a specific equation requires the knowledge of soil characteristics and the required accuracy. The widely used equation of Topp et al., 1980 was found valid for mineral soils with low clay content. Deviations in soils with high clay contents are caused by the monomolecular layer of water, which induces a dielectric behavior of the water molecules different from free water (Bohl & Roth, 1994). The equation of Malicki et al., 96 avoids partially this specific surface problem because it is a bivariate function $\theta=f(\varepsilon,\rho)$, and soils generally show a good correlation between ρ and texture. The empirical calibration equation of Teixeira et al., 1997 was developed in a fine textured oxisol. It probably yields reasonable results in soils with similar characteristics. Detailed discussions about the empirical calibration equation are not included in the objectives of this work. Another aspect that has to be considered when comparing methods is the accuracy of the procedure. Literature showed that uncertainties of TDR- and gravimetric measurements are of the same magnitude. As to gravimetric methods - normally taken as the „true" value of θ - the principal sources of errors are: the sampling scheme; uncertainties in the equilibrium time when drying the sample; the presence of colloidal material, that show high capacity of retention of water even when exposed to high temperatures; the presence of organic material that can oxidize and or volatize; difficulties in maintaining a constant temperature in the oven; the precision of the used balance; and especially errors in the determination of ρ (Gardner, 1986; Blake & Hartage, 1986). The knowledge of principles and limitations of each method are the essential for the choice of methods and procedures. The small scale variability of θ can cause erroneous estimates, which can be partially compensated by increasing the number of measurements as well as a vertically stratified sampling design, especially near the surface. However, for many problems, the improvement may be small compared to the uncertainties and errors introduced by the use of a single average and thus ignoring the spatial distribution as a whole - especially when dealing with transport problems.

Table 1 – Soil wetness (θ) measured with direct and indirect methods.

Profile	Depth.	Volume	**Direct Method**		**Indirect Method** Time Domain Reflectometry (TDR)					
			Disturbed Samples	Undisturbed Samples	Probe orientation in Soil					
					Horizontal	**Vertical**	Horizontal	**Vertical**	Horizontal	Vertical
					Teixeira et al., 97		Malicki et al.,96		Topp et al.,80	
	cm	cm^3			θ (m^3 m^{-3})					
1	0-5	≈100	0,2773b	0,4080a	0,2873b	+	0,3037b	+	0,2466b	+
1	5-10	≈100	0,3680a	0,3726a	0,3414a	+	0,3612[a]	+	0,3026a	+
Mean	0-10	≈200	0,3226ab	0,3903a	0,3143ab	0,3341ab	0,332ab	0,3554ac	0,2746b	0,2988bc
3	0-5	≈100	0,2760bc	0,3297a	0,3091ac	+	0,3252[a]	+	0,2716bc	+
3	5-10	≈100	0,3297a	0,3280a	0,3546a	+	0,3730[a]	+	0,3186a	+
Mean	0-10	≈200	0,3079b	0,3288b	0,3318b	0,3318b	0,3490[a]	0,3376b	0,2950b	0,2842b
2	25-30	≈100	0,3682cd	0,3927§b	0,4251a	+	0,4306[a]	+	0,3837bd	+
2	30-35	≈100	0,3730c	0,3927§b	0,4334a	+	0,4388[a]	+	0,3906b	+
Mean	25-35	≈200	0,3706b	0,3927b	0,4292a	0,4209a	0,4347[a]	0,4271a	0,3871b	0,3801b
4	25-30	≈100	0,3375d	0,3911§bc	0,4097ac	+	0,4238[a]	+	0,3701bcd	+
4	30-35	≈100	0,3416c	0,3911§b	0,4202a	+	0,4342[a]	+	0,3794b	+
Mean	25-35	≈200	0,3395e	0,3911bcd	0,4149ad	0,4205ac	0,4290[a]	0,4346a	0,3748b	0,3796b

(§) One sampling for both depths collected between 27,5-32,5cm.

(a) Values within lines followed by the same letter are not different by Tukey p< 0,05.

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13) Foliar nutrient dynamics

COMPORTAMENTO DA ABSORÇÃO E TRANSLOCAÇÃO DE POTÁSSIO (K), CÁLCIO (Ca), MAGNÉSIO (Mg), NITROGÊNIO (N) E FÓSFORO (P)*

Maria Elisabeth de Assis Elias, Reinhard Lieberei** and Götz Schroth**

(* scholarship financed by Cnpq in colaboration with ENV45;
** Institute of Applied Botany, University of Hamburg)

Summary

The aim of the study was to investigate the nutritional status of some Amazonian tree species of economic importance: cupuaçu [*Theobroma grandiflorum* (Willd. ex Spreng). Schum.], pupunha (*Bactris gasipaes* Kunth), castanha-do-Brasil (*Bertholletia excelsa* H. B. K), urucum (Bixa *orellana)* e puerária [*Pueraria phaseoloides* (Roxb.) Benth] established under agroforestry systems and monoculture, with varying levels of fertilizer application. The leaves of five species were collected. Nutrient analyses of leaves from two sampling dates are reported. The results suggest that *Theobroma grandiflorum* and *Bertholletia excelsa* are less demanding of nutrients than the other species, or possibly they are more efficient in nutrient absorption. The high leaf nutrient content of *Pueraria phaseoloides*, *Bactris gasipaes* and *Bixa orellana* growing in agroforestry systems shows their importance in nutrient cycling, suggesting that these species are of high value in agroforestry systems.

1. INTRODUÇÃO

Nos sistemas agrícolas os nutrientes são componentes primordiais para o desenvolvimento das culturas. Dentre estes encontram-se o potássio (K), Cálcio (Ca), Magnésio (Mg), Nitrogênio (N) e o Fósforo (P) que estão envolvidos nos mecanismos fisiológicos da planta. Considerando este fato verifica-se que a disponibilidade de nutrientes de forma balanceada é fundamental para o desenvolvimento das plantas e a sustentabilidade dos sistemas. Nas regiões onde os desequilíbrios das culturas apresentam-se em função dos baixos níveis de fertilidade dos solos, o conhecimento do processo de nutrição das plantas tem grande relevância no aprimoramento do manejo nutricional das culturas. Estudos tem mostrado que o baixo nível de fertilidade dos solos de terra firme da região amazônica, tem dificultado o desenvolvimento de determinadasculturas, como por exemplo citrus (*Citrus sinensis*) (MARTEL, FALCÃO & CLEMENTE, 1996)). Neste contexto, a avaliação do estado nutricional das plantas, por meio da diagnose foliar pode ser uma ferramenta importante na pesquisa e diagnóstico no campo da nutrição das plantas.

A investigação do comportamento nutricional das espécies em função de diferentes níveis de adubação, é essencial para compreensão das exigências nutricionais intrínsecas de cada espécie , permitindo desta forma conhecimentos para melhores justes nos níveis e épocas de adubação nos sistemas agrícolas. Levando em consideração este fato e os complexos problemas de fertilidade dos solos da Amazônia, o presente trabalho tem como proposta estudar o comportamento da absorção e translocação de nutrientes em quatro espécies estabelecidas em áreas de sistemas agroflorestais e de monocultivo, em função de diferentes níveis de adubação. As espécies arbóreas estudadas, ocorrem na região amazônica, apresentam múltiplos usos , portanto são de interesse econômico.

2. MATERIAIS E MÉTODOS

O experimento é composto por 18 tratamentos, distribuídos em 5 blocos (A-E) com 5 repetições. Cada tratamento dentro dos blocos é ao acaso. As parcelas possuem uma área de 48 x 32 m. O arranjo das parcelas é determinada pela forma alongada e irregular da área experimental. Com objetivos comparativos, foram estabelecidos 4 sistemas de policultivos (sistemas de 1-4) e 4 monocultivos (sistemas 6-9), e ainda dosagens de adubação em diferentes níveis: alta (100%) e baixa (30%). Na área experimental os estudos estão sendo avaliados em 4 policultivos (sistema 2) e 2 monocultivos (sistemas 7 e 8), somando portanto um total de 6 parcelas por bloco. A figura 2 apresenta os arranjos nos policultivos, constituídos pelas espécies: cupuaçu (*Theobroma grandiflorum)*, pupunha (*Bactris gasipaes)* , castanha (*Bertholetia excelsa)*, urucum (*Bixa orellana*) e puerária (*Pueraria phaseoloides)* utilizada como cobertura de solo entre as fileiras de plantas. Nos sistemas 7 e 8 dos monocultivos foram estabelecidas as espécies pupunha e cupuaçu respectivamente (Figura 3). De cada parcela foi selecionada aleatoriamente 6 árvores para coleta das amostras, com exceção da puerária cuja as plantas da amostragem ficaram entre as fileiras das espécies arbóreas.

As coletas no campo iniciaram-se em novembro de 1997, período antes da adubação, a segunda coleta foi em janeiro um mês após a adubação, no início do período chuvoso, a terceira foi em março 3 meses após a adubação, a quarta foi em maio 5 meses após a adubação e a quinta em agosto um mês após adubação, no início do período seco (Tabela 1). Até agosto/98 foram feitas 5 coletas de campo e destas já foram feitas as analises foliares da primeira e segunda coletas.

Tabela 1. Período de coleta e adubação no primeiro ano de estudo

Ordem de coletas	Período das coletas	Período de adubação
1º	Novembro/97	dezembro/97
2º	Janeiro/98	junho/98
3º	Maio/98	
4º	Agosto/98	

As amostras consistiram de material foliar oriundas das 5 espécies que estão sendo estudadas. As folhas foram retiradas em quatro pontos cardeais de três posições do ramo: parte superior, mediana e inferior, oriundos da parte mediana da copa . O preparo das amostras para analise, consistiu de limpeza das folhas, secagem em estufa com circulação forçada de ar a 65^{0}C e trituração. As análises das amostras foram feitas através de um processo de digestão foliar com ácido sulfúrico (H_2SO_4) segundo o método de (WALINGA et al., 1989). O método passou por adaptações e teve como parâmetro de referência o sistema nacional de controle de qualidade de análises vegetais que apresenta bom padrão de qualidade. Para controle foi utilizado folhas de laranjeira, visto que não foi possível utilizar dados comparativos das mesmas espécies estudadas. Na tabela 2 pode ser verificado através dos dados que o elemento mais variável para o método utilizado foi o Ca, os demais elementos mostraram resultados satisfatórios. O método utilizado apresenta vantagens em relação a outros métodos por permitir que no mesmo extrato foliar seja possível medir as concentrações dos 5 macronutrientes de interesse deste estudo (N, P, K, Ca, e Mg). As leituras dos teores de N e P nos extratos foliares mostraram-se bem adaptadas a análise automatizada com analisador de fluxo contínuo. Os teores dos cations foram lidos no espectrofotômetro de Emissão óptica.

Tabela 2. Concentrações de elementos minerais em folhas de laranjeira como controle de qualidade.

Variáveis	Teores dos nutrientes mg/Kg				
	N	P	K	Ca	Mg
média	26.6	1.5	13.2	28.5	4.0
Desvio padrão	0.7	0.1	1.2	4.6	0.4
N	8	8	7	5	8

3. RESULTADOS E DISCUSSÃO

As tabelas de 3 a 7 apresentam as concentrações de N, P, K , Ca e Mg em função de 4 níveis de adubação (30-N, 30, 100 e 100 + P).

Tabela 3. Concentrações de nutrientes (mg/kg) em folhas de cupuaçuzeiro.

Elementos avaliados	Ordem de coleta	Níveis de adubação 30%-N	30%	100%	100%+P
N	1º	19,3	16,5	17,2	18,1
	2º	18,3	17,3	18,4	18,6
	3º	20,0	18,6	18,5	19,1
P	1º	0,9	0,9	0,8	1,0
	2º	0,9	0,9	1,01	1,0
	3º	1,0	1,0	1,1	1,0
K	1º	4,6	4,4	3,9	5,4
	2º	3,7	3,4	4,4	4,3
	3º	3,7	3,2	3,7	4,0
Ca	1º	5,4	4,8	5,9	4,7
	2º	4,3	3,9	3,5	4,3
	3º	4,2	5,4	5,1	5,5
Mg	1º	2,3	3,1	3,2	3,0
	2º	1,8	3,1	2,8	3,0
	3º	1,9	3,1	3,0	3,4

Tabela 4. Concentrações de nutrientes (mg/kg) em folhas de castanheira.

Elementos avaliados	Ordem de coleta	Níveis de adubação 30%-N	30%	100%	100%+P
N	1º	19,1	19,6	18,1	18,1
	2º	18,1	18,8	18,4	18,3
	3º	18,1	19,1	18,3	18,6
P	1º	0,8	0,9	0,8	0,8
	2º	0,8	0,9	0,9	0,8
	3º	0,8	0,9	0,9	0,8
K	1º	5,8	5,8	5,6	6,2
	2º	3,8	5,3	3,8	4,0
	3º	4,09	3,67	3,48	5,31
Ca	1º	7,8	7,2	9,3	10,0
	2º	6,5	6,4	7,8	8,4
	3º	9,29	9,78	11,65	11,55
Mg	1º	2,3	2,9	3,0	3,1
	2º	2,2	2,5	3,5	3,2
	3º	2,46	55,56	4,04	4,0

Tabela 5 Concentrações de nutrientes (mg/kg) em folhas de pupunheira.

Elementos avaliados	Ordem de coleta	Níveis de adubação			
		30%-N	**30%**	**100%**	**100%+P**
N	1º	31,4	31,9	31,3	33,1
	2º	32,5	33,2	31,6	31,8
	3º	28,6	31,6	33,3	30,3
P	1º	1,6	1,7	1,8	1,7
	2º	1,8	1,8	1,8	1,8
	3º	1,8	1,9	2,1	2,0
K	1º	9,3	9,6	9,3	10,7
	2º	7,8	9,7	10,6	9,6
	3º	8,38	8,48	9,03	9,84
Ca	1º	3,4	2,8	2,9	2,4
	2º	2,3	2,6	2,1	2,2
	3º	4,12	3,57	3,73	2,77
Mg	1º	1,4	2,1	2,4	2,4
	2º	1,3	2,2	2,0	2,0
	3º	1,73	2,20	3,11	2,49

Tabela 6. Concentrações de nutrientes (mg/kg) em folhas de urucuzeiro.

Elementos avaliados	Ordem de coleta	Níveis de adubação			
		30%-N	**30%**	**100%**	**100%+P**
N	1º	27,0	25,8	26,9	27,2
	2º	29,8	28,8	28,6	27,3
	3º	27,0	26,7	27,7	27,0
P	1º	1,4	1,4	1,6	1,7
	2º	1,8	1,7	2,0	2,2
	3º	1,7	1,8	2,0	2,3
K	1º	13,4	12,0	11,8	12,6
	2º	12,4	11,2	11,2	12,4
	3º	14,08	10,70	12,17	11,32
Ca	1º	4,8	6,5	6,7	8,1
	2º	5,9	6,6	7,4	7,3
	3º	9,65	12,19	11,41	9,81
Mg	1º	6,0	3,7	3,7	3,8
	2º	2,0	3,2	3,7	4,1
	3º	1,80	3,84	4,68	4,51

Tabela 7. Concentrações de nutrientes (mg/kg) em folhas de puerária.

Elementos avaliados	Ordem de coleta	Níveis de adubação			
		30%-N	**30%**	**100%**	**100%+P**
N	1º	42,4	40,3	39,0	39,2
	2º	36,7	35,9	36,6	36,3
	3º	38,4	40,0	37,0	39,5
P	1º	1,8	1,7	2,9	2,1
	2º	1,8	1,8	2,2	2,3
	3º	2,1	2,4	2,8	2,7
K	1º	19,3	17,6	22,8	16,1
	2º	12,4	13,5	14,5	13,4
	3º	13,76	12,51	14,05	12,66
Ca	1º	4,3	4,6	3,6	5,3
	2º	4,1	4,7	5,5	4,6
	3º	5,02	6,74	6,84	6,36
Mg	1º	2,2	3,2	3,4	4,3
	2º	2,2	3,4	3,9	4,0
	3º	2,61	3,66	4,50	4,24

3.1 CONCENTRAÇÕES DOS ELEMENTOS ENTRE AS ESPÉCIES

As concentrações de N, P e K apresentarão teores mais altos nas folhas de puerária, pupunha e urucum. Enquanto que as concentrações de Ca, foi maior nas folhas de castanheira e urucum. Para o elemento Mg, foi observado concentrações maiores nas folhas de urucum, puerária e castanheira. Este comportamento do que nas de cupuaçu e castanha. (Tabelas 3 a 7). Os resultados sugerem que estas culturas são menos exigentes nestes nutrientes e que possuem a capacidade de otimizar os elementos que absorvem, visto que, mesmo nos níveis de adubação de 30%-N e 30% apresentaram altos teores destes elementos nas folhas (Tabelas 3 a 7). Para os sistemas agroflorestais o comportamento destas culturas é importante para o sistema pois (altas concentrações de nutrientes nas fohas) é importante na ciclagem de nutrientes, o que permite sugerir que estas culturas sejam componentes de alto valor nos sistemas agroflorestais.

3.2. EFEITO DA ADUBAÇÃO

Verifica-se nos resultados das concentrações foliares, que a tendência de resposta da adubação ocorre de forma diferente entre as espécies (Tabela 8). Considerando porém os poucos dados avaliados, não considera-se ainda como definitivo esta tendência, pois há a possibilidade deste efeito ter sido causado pela maior mobilidade dos nutrientes no solo, em função do período chuvoso.

Tabela 8. Resposta a adubação pelas diferentes culturas

Elementos avaliados	CULTURAS
P	Cupuaçu, urucum, puerária
K	Cupuaçu, puerária, urucum, pupunha
Ca	Castanha, urucum, cupuaçu
Mg	pupunha, urucum, puerária

4. CONCLUSÃO

Considerando os poucos dados avaliados, não é possivel ainda formular conclusões definitivas, porém as análises mostram diferenças importantes entre as espécies para a ciclagem dos nutrientes e alta variação temporal no sistema planta-solo.

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