Nutrient and water dynamics in a multi-strata agroforestry system

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Introduction

About 40 million hectars of cleared land are potentially available for crop production in the Amazon, most of which is abandoned today. In the SHIFT Programme "Recultivation of abandoned monoculture areas through mixed cropping systems in the Central Amazon", a project is underway to develop a land use system better adapted to the humid tropical conditions of the Amazon region than common production methods. Its principle is to establish mixed cropping systems and monitor all ecological, social and economic functions. In the presented project, the nutrient and water fluxes are studied and used as indicators for the stability of the agroforestry systems. Here, an overview of the activities is given and results from various studies are summarized.

Materials and methods

The project is conducted on the research station of EMBRAPA-CPAA near Manaus in the Brazilian Amazon region (3° 8' S, 59°52' W, 40-50 m a.s.l.). The mean annual precipitation is 2622 mm, air temperature 26°C and atmospheric humidity around 85% (mean values 1971-93, O.M.R. Cabral and C. Doza, unpublished). The soils are Xanthic Ferralsols according to the FAO/Unesco (1990) classification with a pH of the topsoil around 4.5 and generally low nutrient contents.

The following cropping systems are being studied: A polyculture with peachpalm (*Bactris gasipaes*) both for fruit and for palmito (heart of palm) production, cupuacu (*Theobroma grandiflorum*), Brazil nut (*Bertholletia excelsa*) and urucum (*Bixa orellana*) with a cover crop of pueraria (*Pueraria phaseoloides*) between the trees; a monoculture of peachpalm for palmito, planted at 2 by 2 m; a monoculture of peachpalm for fruit, planted at 4 by 4 m together with peachpalm for palmito at 2 by 2 m spacing; and a monoculture of cupuacu, planted at 7 by 6.4 m with a pueraria cover crop. All of these species are of major commercial interest in Amazonia, and used for the production of dye (urucum), of nuts and wood (Brazil nut), of fruit and heart of palm (pupunha) and of juice or ice-cream (cupuacu). The plantations were compared with plots of spontaneous vegetation of the same age, which were dominated by *Vismia* spp., and forest sites under *Eschweilera* sp. (matá-matá), a dicotyledoneous tree, and *Oenocarpus bacaba* (bacaba), a palm. Both forest species are relatively frequent in this forest and are of commercial interest, *Eschweilera* for its wood and *Oenocarpus* for its fruit.

The experimental plots were arranged in a randomised complete block design with five replications, of which only three were used in this study. Plot size was 24 by 32 m in the peachpalm monocultures and 48 by 32 m in all other treatments. The polyculture was studied at two fertilisation levels, full fertilisation according to local experiences (research-based recommendations do not exist for these species in the region) and 30% of this fertilisation. The monoculture was only studied at the higher fertilisation level. The peachpalm for palmito was managed by harvesting the offshoots three times per year. Urucum was cut back at about 1.5 m height once per year after the harvest between March and May to increase fruit production. The rainforest sites could not be included into the block design. For the forest species, three individuals of each species were chosen in a forest adjacent to the experimental area. At all sites, soil water and nutrient dynamics, plant nutrients, precipitation and soil organic matter (SOM) were studied as described in the separate publications cited.

Results and Discussion

Mean aboveground biomass did not differ between 4-year-old castanha trees (32.5 kg with 100%, and 28.3 kg with 30% fertilization) and pupunha (fruit) (40.8 with 100%, 26.5 kg with 30% fertilization) (Wolf, 1997). Mean aboveground biomass of cupuaçu trees was much lower with 4.51 kg at 100%,

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and 3.77 kg at 30% fertilization. Whereas the biomass of pupunha (fruit) was about the same in the monoculture (38.8 kg) and in the agroforestry system, the biomass of cupuaçu was significantly smaller (2.02 kg) in monoculture than in the agroforestry ($p < 0.05$). The reason for this may be shading and nutrient transfers from pueraria and fertilizer. Looking at the whole cropping system, highest aboveground biomass was found in the pupunha monoculture (37.4 t/ha) with the pupunha (fruit) trees interplanted with pupunha (palm-heart) (Wolf, 1997). Also the biomass of the monoculture with pupunha (palm-heart) was very high (17.5 t/ha). The two treatments of the agroforestry system had an aboveground biomass of 10.4 t/ha (100% fertilizer) and 8.84 t/ha (30% fertilizer; not significant), resulting in a LER well below unity. The monoculture of cupuaçu had the lowest aboveground biomass of only 0.447 t/ha due to its low planting density and the low biomass of the single trees.

Spatial distribution of throughfall and stemflow significantly differed between tree species (Schroth et al., 1998b). The water input into the soil near the stem was higher than in the open for peachpalm (fruit) and Brazil nut (Figure 1). Such rainwater redistribution poses the danger of nutrient leaching near the stem. Therefore, fertilizer should be placed further away from the stem in these situations. Management decisions, however, will also depend on below-ground biomass distribution and hence nutrient and water uptake.

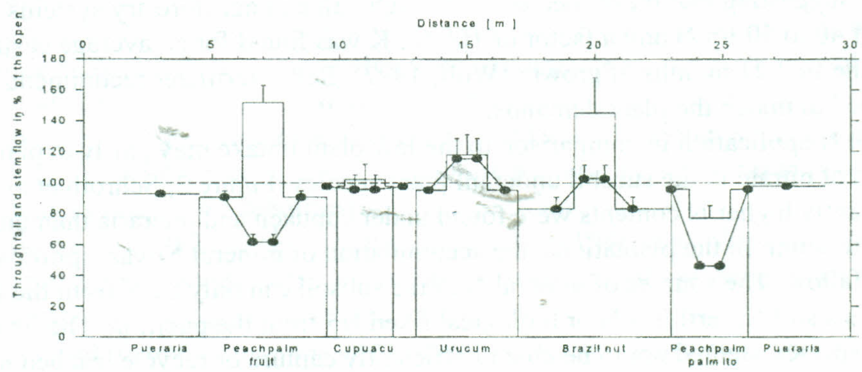

Figure 2 Transect through a polyculture plot, giving the throughfall at 40 and 150 cm stem distance (point graphs) and the sum of throughfall and stemflow (bar graphs, means and S.E.) (Schroth et al., 1998b).

Brazil nut and cupuacu both possessed tap roots and a restricted lateral root extension (Haag et al., 1998). The central root of urucum, however, split up at 30 cm depth with a large number of coarse lateral roots, which extended to more than 3 m in some places. The roots of pupunha reached high concentrations in the topsoil, and they attained the highest lateral lengths up to 4 m. Pupunha roots also had the largest root abundance at greater depths (>1m). Root dry matter to a depth of 1 m was 50-120g m^{-2} under Brazil nut, 25-80g m^{-2} under cupuacu, 300-500 g m^{-2} under urucum, 800-900 g m^{-2} under pupunha for heart-of-palm and 1000-1200 g m^{-2} under pupunha for fruit. The majority of fine roots to a depth of 150 cm were concentrated in the upper 30 cm. Still, a potential for complementary resource utilization could be seen for the investigated tree species. Pronounced vertical root growth of Brazil nut and cupuacu stood in contrast to the lateral development of pupunha and urucum root systems. Moreover, Brazil nut had its root maximum in the subsoil, suggesting a high suitability for a combination with shallow-rooted species. The lateral extension of pupunha roots in the topsoil made competition a potential problem. The competitiveness, however, will not depend on root abundance alone, but also on the efficiency of water and nutrient uptake.

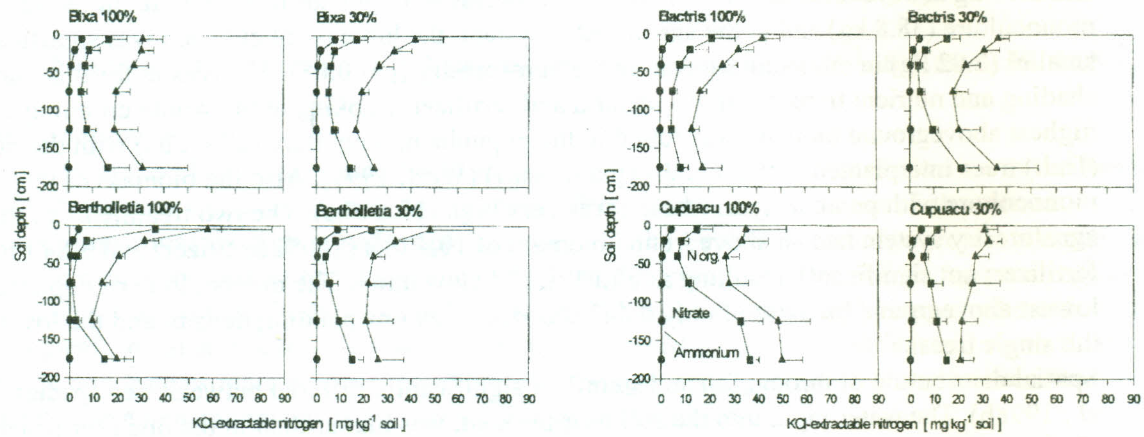

Figure 3 Profiles of mineral and organic N extractable with 1 M KCl under four different tree crop species in polyculture (full and 30% fertilisation) (means and S.E.) (Schroth et al., 1998a).

Cupuacu and Brazil nut had lower foliar nutrient contents than the other species (Elias, unpubl. data). The high nutrient contents of pueraria, pupunha and urucum show their importance in nutrient cycling, suggesting that these species are of high value in agroforestry systems. A formal surplus by a factor of 40 to 50 for N and a factor of 100 for K was found for an average castanha or cupuaçu tree during the first 21 months of growth (Wolf, 1997). Better fertilizer recommendations should be developed to match the plant demands.

The high N application in comparison to the low plant uptake may partly explain the significant amounts of nitrate in the subsoil under all plant species (Figure 2; Schroth et al. (1998a)). Significantly higher N contents were found under cupuaçu and pueraria than under peachpalm, Brazil nut and urucum. In the plantations, the accumulation of mineral N was significantly higher than under Vismia fallow. The sources of mineral N in the subsoil can only be N from the topsoil, either indigenous soil N, fertiliser N or biological fixed N_2 from the pueraria. The investigated systems and the tree species seemed not to be able to efficiently capture or recycle leached nutrients. The pathways of applied and fixed N needs to be assessed more intensively in order to improve nutrient utilization by the plants.

Preliminary analysis of the soil water availability in the agroforestry system showed a pronounced single tree effect. The topsoil moisture near the pupunhas was often very low compared to soils under other tree crops. This is one reason for the low abundance of other plants near the pupunha and confirms its competitiveness already assumed from root measurements. At the topsoil under the pueraria and in the primary forest, however, we observed high soil water contents (Teixeira, unpubl. data).

Table 1 C and N concentrations, stocks [mg g^{-1}] and C/N ratios in bulk soil and particulate organic matter (POM); values in one column with the same letter are not significantly different at $p<0.05$ (n=3) (Lehmann et al., 1998).

Sites	C			N			C/N	
	bulk soil	POM conc.	POM stock	bulk soil	POM conc.	POM stock	bulk soil	POM
cupuacu	31.0 b	289 b	6.31 b	2.5	13.7 ab	0.29 b	12 c	21 ab
pupunha	25.3 b	238 c	3.59 bc	2.4	11.1 c	0.18 b	11 c	22 ab
pueraria	27.9 b	258 bc	2.78 c	2.4	14.6 a	0.17 b	11 c	18 b
vismia	29.7 b	340 a	6.74 b	2.2	13.1 ab	0.28 b	14 b	27 a
bacaba	47.4 a	277 b	12.6 a	2.9	11.7 bc	0.54 a	16 a	24 ab
effect[1]	**	**	*	ns	*	*	**	(*)

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

The different sites had pronounced differences in total SOM (Table 1). Bulk soil SOM under bacaba was higher than at all other sites, whose contents did not differ between each other. POM stocks, however, were significantly higher under cupuacu than the other tree species of the agroforestry system. POM N concentrations were highest in soils under pueraria (Lehmann et al., 1998). This may explain the higher N mineralization under pueraria than cupuacu and pupunha (Salazar, unpubl. data) and the high subsoil N under pueraria (Schroth et al., 1998a).

Conclusions

The effects of the trees on soil properties, water and nutrient dynamics highly differed between species. To evaluate the sustainability of an agroforestry system it is important to stress the consideration of spatial variability in the studied parameters. This variability creates the possinility to develop agroforestry with a complementary use of water and nutrient resources. The cropping system with the current management is not seen as a viable solution for land use in Amazonia at the moment. However, the discovered features of single trees and the effects on crop production and sustainability so far described encourage further efforts to improve multi-strata agroforestry as a land use system for the Amazon region.

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