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

Annual Report 1998

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

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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).

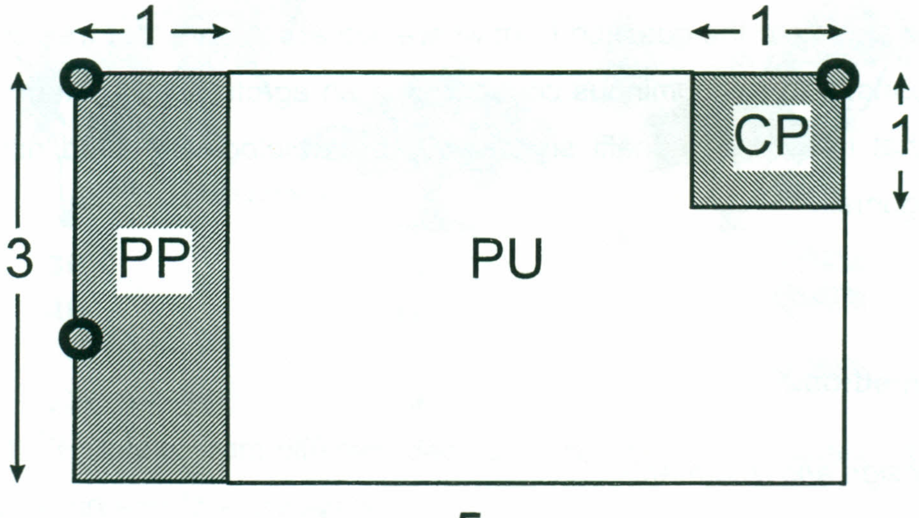

Fig. 1 Layout of the experiment, circles show positions of cupuacu in area CP and pupunha in area PP; ^{15}N was applied either in CP, PP or PU area (CP cupuacu, PP pupunha, PU pueraria); distances in [m].

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 δ^{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

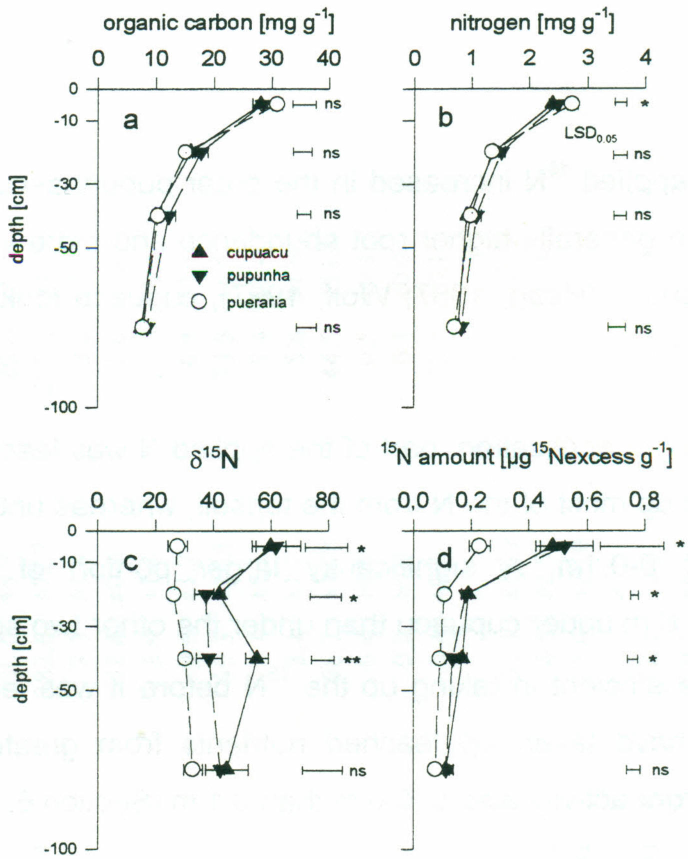

Fig. 2 Soil carbon and nitrogen contents and ^{15}N enrichment under cupuacu, pupunha and pueraria five months after application of ^{15}N in November 1997; only sites where ^{15}N was applied; asterics denote significant effects at $p<0.05$ * and 0.01 ** (ANOVA); means and standard errors (n=3).

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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