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

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Annex: Scientific results

1) Single-tree effects on soil organic matter properties of a xanthic Ferralsol in the central Amazon

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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 $\times$ 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	polyphenol	C-to-N	polyphenol-to-N
		[mg g^{-1}]	[mg g^{-1}]	ratio	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 fertilizer nitrogen did not lower the C-to-N ratios of the particulate organic matter, whereas the fixed nitrogen of the pueraria actually decreased the POM C-to-N ratios. However, despite these nitrogen additions to soil in the agroforestry systems, more weakly decomposed plant material accumulated than below bacaba and visia, representing primary and secondary forest sites, respectively.

The high nitrogen content in the particulate organic matter of the pueraria soils may explain the high nitrogen mineralization rates under pueraria compared to soils under cupuaçu and pupunha measured at the same site (E. Elias, unpubl. data). Not only the total amount of nitrogen, but rather the quality and hence availability of the nitrogen seemed to increase nitrogen mineralization. In the studied soils, this was the case with high nitrogen contents and low C-to-N ratios in the light organic matter fraction (POM).

3.2 Processes of SOM replenishment in Ferralsols of the central Amazon

Partially decomposed leaves and roots first entered the particulate organic matter. POM decomposition and humification progressed from POM associated with large aggregates to those with small aggregates with decreasing C-to-N ratios (Table 5). The carbon and nitrogen POM stocks generally decreased with decreasing aggregate size. The POM associated with small aggregates (0.25-0.5 mm) was largely humified plant material, whereas POM from large aggregates (1-2 mm) mainly consisted of leaf and root debris. In aggregates smaller than 0.25 mm, no visible POM could be isolated.

Carbon or nitrogen distribution in different POM size fractions showed the same differences between sites as whole POM contents. Differences in smaller POM fractions (0.25-0.5 mm) between sites should indicate different effects of trees on stable SOM replenishment, large POM rather nutrient availability. For most purposes, a separation of whole POM will be sufficient to evaluate single-tree effects on SOM.

During decomposition and humification, the added organic material was incorporated into larger aggregates and successively into smaller aggregates, which was shown by soil chemical analyses. This result supports the hierarchical model of aggregation of Tisdall and Oades (1982), which could not be verified by using only the carbon distribution in aggregate separates. The strongly humified POM is incorporated into the fraction 0.25-0.5 mm, since (i) it contained the highest proportion of POM*, (ii) no relevant amounts of 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.

References

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