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Role of C nature in correlation structure of soil proprieties in forest and pasture ecosystems, eastern brazilian Amazonia

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ABSTRACT

The improvement of tropical land-use systems is an important task and still further research is necessary to explore the influence of land use and soil properties and environment. Measured soil properties down to 100 cm under a natural forest and pastures cultivated for 7 years under *Brachiaria brizantha*, 12 years under *Panicum maximum*, and 17 years under *Brachiaria humidicola*, were analyzed using principal component analysis in order to extract the correlation structures. Greatest changes following pasture establishment were noticed in the 0-10 cm layer, such as an increase in C stock and in C-derived from pasture associated with the age of pasture. However, there were some changes observed down to 40 cm depth (a decrease in soil porosity and an increase in clay dispersability). 44.7% of the 26 analyzed variables were explained by the factor 1, and was correlated with C and mainly its nature; 23.9% by the factor 2, which was positively correlated with C content and stock and total porosity; 9.87% by the factor 3, which described the evolution of soil with depth; and by 7.2% by the factor 4, which explained the total variability, describes the interrelation between the storage and the residual porosity.

KEYWORDS

C-derived from forest;
C-derived from pasture;
African grasses;
Principal component analysis (PCA).

INTRODUCTION

In the Brazilian Amazon basin, large-scale cattle's ranching tends to follow forest clearing [9]. In fact, more than 70 million of native vegetation in Brazil has been replaced by pastures for beef production[4]. It is well known that the sustainability of established pastures in the cleared areas with inherently infertile soils is generally low[1]. In fact, cultivation involves several changes in soil physical, chemical and biological properties[[6,8,12,14], including soil organic matter (SOM) quantity or quality[4,5,7,8,10]. A study of an Oxisol forest-to-pasture chronosequence located in the eastern Brazilian Amazon, has shown that change in nature and amount of carbon occurred mainly in the topsoil (0-10 cm)[12]. For instance, the increase in soil C stock in the 0-10 cm layer was followed by a depletion of C biological stability in the oldest pasture[12]. The objective of the present study is to extract the correlation structure of soil property changes that occurred after pasture establishment using principal component analysis approach in the forest and pasture chronosequence located in eastern Amazonian, state of Para.

MATERIAL AND METHODS

The studied area is located at 10 km north of Paragominas (fazenda Bosque), located in the Northeast area (2°25′ and 4°25′S-46°25′ and 48°54′ W) of the State of Pará. The mean annual temperature is 27.2°C and precipitation is 1750 mm. The period from July to November is drier with less than 50 mm of monthly precipitation[15]. The natural vegetation is a tropical forest with a low proportion of palms, i.e., resulting in forest soil (F). Three pasture (P) soils were: (1) soil under 7-year old *Brachiaria brizantha* (P7), (2) soil under 12-year old *Panicum maximum* (P12), and (3) soil under 17-year old *Brachiaria humidicola* (P17). The soils are Oxisols developed on tertiary sediments belonging to the Barreiras formation[16].

Soil samples were taken from four sides of four pits of 1.5 m wide and 1.5 m long, and 1.5 m deep, dug in the selected representative areas. Sampling was carried out at depth intervals of 10 cm up 100cm. However, only six layers instead of ten were considered for the study since i.e., 0-10cm, 10-20cm; 20-30cm; 30-40cm, 60-70cm and 90-100cm. Soil samples were then air-dried and sieved at 2 mm prior to analysis. The soils contain more than 80% clay (mostly kaolinite), are rich in iron and aluminium hydroxide, with cation exchange capacity (CEC) lower than 10cmol kg^{-1} and base saturation less than 20%[12]. Measurements of dispersible clays and other particles were carried out using the Na-resin method described by Rouiller et al.[17]. Carbon and N contents of the whole soil were determined by combustion (Carlo Erba NA 1500 Autoanalyzer). Soil pH values were determined in water and 1.0 M KCl (soil: solution ratio 2: 5 wt/wt). The CEC was measured by atomic absorption spectrometry. Bulk density was measured by weighing soil previously dried at 105ºC, sampled with 140cm^3 cylindrical soil cores. Total porosity expressed in percent of pore volume/soil core volume ratio was calculated, assuming a mean bulk density of 2.6 T. m^{-3}. Pore size distribution was derived using a Carlo Erba 2000 Hg porosimeter on 4g sieved soil (2 mm) after vacuum degasification for 2 hours. Proportions of water-stable-aggregates(WSA), i.e., with particle size>200µm were determined according to the method of Bartoli et al.[2]. The δ^{13}C values of soil samples were determined from CO$_2$ obtained by complete dry combustion at 1050ºC using a Finnigan Delta S mass spectrometer. Carbon derived from forest (Cdff) and pasture (Cdfp), expressed in T.ha^{-1}, and their percentages in each soil layer fraction were determined[12].

Statistical analyses such as notched-and-whiskers box plots and one-way analysis of variance (ANOVA) were carried out using the Stat graphics program package (version STCc's software products) using an IBM PC computer. Only factors with an explained inertia greater than 5% were selected in this study using principal component analysis. Plots of the correlation (not shown in this study) between the initial variables and the newly computed factors can help in demonstrating possible linear correlations among the initial variables (correlation circle), while the construction of the scatter diagrams for the PCA can reveal relationships or clusters among observations. Statistical parameters (mean, standard deviation, and mode) and scatter diagrams were used to study relationships between the soil variables, depth, and evolution through time. Systematic statistical tests were used to compare similarity to or variations from samples of topsoil, organic-rich horizon, or mineral horizon and those of another.

RESULTS

Organic or total C content varied between 3.33% (forest soil) and 2.92% (pasture of 12 years) and decreased with depth in the four studied soils. Carbon stock under pasture soils was similar to or 10-20% higher than that under the forest soil. The CEC was higher under pasture in the 0-10cm layer than under forest. According to physical properties, WSA were higher than 66 % in the topsoil (0-10cm), and decreased with depth (TABLE 1).

A decrease in soil porosity, mainly in the surface layers, has been observed in pasture ecosystems compared to the forest (TABLE 2). The quantity of C stock and C-derived from pasture (Cdfp) increased from the P7- to P17, i.e., from 12.5 % to 37.8 % and from 11,8 % to 32,3 %, respectively in the topsoil. Cdfp (%) was higher in the WSA as compared to the non water-stable

TABLE 1: General soil characteristics under forest (F) and pastures of 7(P7), 12(P12) and 17(P17) years

Name	Depth (cm)	Ages(years)	Clay(%)	C(%)	N(%)	ΔpH	ECEC (cmol.kg^{-1})	B.density (Mg. m^{-3})	C (T.ha^{-1})	WDC (%)
F-1	0-10	-	83.9	3.33	0.25	0.19	4.8	0.9	28.1	18.7
F-2	10-20	-	86.5	1.96	0.17	0.07	3	1	19.4	16
F-3	20-30	-	88.3	1.48	0.13	0.14	3	1.2	16.6	16.6
F-4	30-40	-	91.6	1.01	0.09	0.17	2.6	1	9.7	5.5
F-5	60-70	-	92.7	0.57	0.05	0.16	2.6	1.2	6.8	0
F-6	90-100	-	93.1	0.45	0.04	0.1	2.2	1.1	5.1	0
P7-1	0-10	7	81.7	2.94	0.29	0.35	5.8	1	29.6	18.1
P7-2	10-20	7	85.1	1.55	0.15	0.34	6.4	1.2	17.3	23
P7-3	20-30	7	87.9	1.16	0.12	0.28	5.6	1.1	13	23.2
P7-4	30-40	7	90.1	1.07	0.1	0.21	2.9	1.3	13.5	23.8
P7-5	60-70	7	92	0.73	0.07	0.11	5.9	1.2	9	0.7
P7-6	90-100	7	91.8	0.49	0.04	0.17	3.7	1.2	5.8	0
P12-1	0-10	12	83.7	2.92	0.26	0.7	8.4	1.1	32.1	16.1
P12-2	10-20	12	88.8	1.38	0.14	0.41	4.7	1.3	15.9	20.3
P12-3	20-30	12	87.9	1.02	0.09	0.37	4.4	1.3	13.3	16.9
P12-4	30-40	12	89.9	0.86	0.07	0.16	4.4	1.3	10.9	0.6
P12-5	60-70	12	92	0.57	0.05	0.06	2.3	1.3	7.3	0
P12-6	90-100	12	92.6	0.47	0.04	0.05	3	1.2	5.7	0
P17-1	0-10	17	81	3.17	0.26	0.51	7.1	1.2	37.8	21.2
P17-2	10-20	17	85.4	1.46	1.03	0.48	4.6	1.3	19.5	26.9
P17-3	20-30	17	87.7	1.09	0.09	0.37	3.7	1.3	14.6	27
P17-4	30-40	17	89.4	0.96	0.09	0.3	3.4	1.2	12.8	32.2
P17-5	60-70	17	91	0.58	0.05	0	2.1	1.3	8.1	0
P17-6	90-100	17	91.5	0.47	0.04	-0.06	2.1	1.4	6.6	0

TABLE 2: Soil physical properties under forest (F) and pastures of 7(P7), 12 (P12) and 17 (P17) years

Name	Depth (cm)	Ages (years)	WSA (%)	Total porosity (%)	Micro-porosity (%)	Storage porosity (%)	Residual porosity (%)
F-1	0-10	-	71.8	68	52	28	24
F-2	10-20	-	68.8	63	55	33	22
F-3	20-30	-	52.6	53	53	31	22
F-4	30-40	-	49.9	63	55	32	23
F-5	60-70	-	36.2	56	48	19	29
F-6	90-100	-	30.8	58	50	26	24
P7-1	0-10	7	81.1	62	49	23	26
P7-2	10-20	7	61.1	57	48	22	26
P7-3	20-30	7	62.3	58	52	19	33
P7-4	30-40	7	48	52	48	20	28
P7-5	60-70	7	58.1	54	55	21	34
P7-6	90-100	7	46.4	57	53	23	30
P12-1	0-10	12	66.7	60	47	15	28
P12-2	10-20	12	49.7	54	52	27	25
P12-3	20-30	12	49.4	52	55	27	28
P12-4	30-40	12	46.3	51	57	30	27
P12-5	60-70	12	41.9	54	56	25	31
P12-6	90-100	12	47.2	56	53	19	34
P17-1	0-10	17	76.8	56	43	24	19
P17-2	10-20	17	49	53	47	26	21
P17-3	20-30	17	41	51	48	21	28
P17-4	30-40	17	41.4	54	50	25	29
P17-5	60-70	17	29.2	51	51	22	29
P17-6	90-100	17	47.1	51	55	26	25

WSA=water-stable aggregates

TABLE 3: SOM dynamics under forest (F) and pastures of 7 (P7), 12 (P12) and 17 (P17) years

Name	Depth (cm)	Ages (years)	$\partial^{13}C$ (‰)	Cdfp (%)	$\partial^{13}C$ WSA (‰)	$\partial^{13}C$ Nwsa (‰)	Cdfp WSA %)	Cdfp nWSA(%)
F-1	0-10	-	-27.8	0.0	-27.9	-27.37	0	0
F-2	10-20	-	-27.2	0.0	-27.2	-26.94	0	0
F-3	20-30	-	-26.3	0.0	-26.7	-26.57	0	0
F-4	30-40	-	-26.5	0.0	-25.6	-24.93	0	0
F-5	60-70	-	-25.4	0.0	-25.3	-25.71	0	0
F-6	90-100	-	-25.6	0.0	-25.2	-26.05	0	0
P7-1	0-10	7	-25.9	12.5	-26.1	-25.61	11.7	11.8
P7-2	10-20	7	-26.1	7.5	-26	-25.97	8.1	6.7
P7-3	20-30	7	-26.5	0.0	-26	-26.31	4.4	1.8
P7-4	30-40	7	-26.1	2.2	-26.3	-26.14	0	0
P7-5	60-70	7	-25.7	0.0	-24.9	-25.69	3.1	0.2
P7-6	90-100	7	-25.4	1.7	-25.1	-25.37	0.9	5
P12-1	0-10	12	-22.5	34.6	-22.1	-23.15	37.3	28.2
P12-2	10-20	12	-25.6	11.3	-25.1	-25.54	14.1	9.6
P12-3	20-30	12	-25.1	8.3	-25.8	-25.69	6.4	6.2
P12-4	30-40	12	-25.7	5.5	-26.1	-25.72	0	0
P12-5	60-70	12	-25.5	0.0	-25.5	-25.63	0	0.6
P12-6	90-100	12	-25	5.03	-24.8	-24.92	3.4	8.3
P17-1	0-10	17	-22	37.8	-22.4	-22.54	35.2	32.3
P17-2	10-20	17	-24.3	20.0	-24.7	-25.13	16.6	12.5
P17-3	20-30	17	-25.2	8.2	-24.6	-25.34	14.4	8.7
P17-4	30-40	17	-25.2	9.4	-25	-25.34	4.4	0
P17-5	60-70	17	-25.5	0.0	-25.8	-25.53	0	1.4
P17-6	90-100	17	-25.3	1.5	-25.1	-25.06	0.7	7.3

Cdfp=C derived from pasture; WSA=Water-stable aggregates; nWSA=non water-stable aggregates

TABLE 4: Repartition of PCA factors after pasture establishment in eastern brazilian amazon basin

Factors/parameters	F actor 1	Factor 2	Factor 3	Factor 4
	44.69%	22.96%	9.87%	7.20%
Depth	-0.602	-0.594	0.407	-0.05
Age	0.464	-0.644	-0.27	0.254
C	0.679	0.683	0.085	-0.012
Bulk density	-0.015	-0.812	-0.305	0.34
Total porosity	0.054	0.799	0.357	-0.294
Micro-porosity	-0.725	0.027	0.022	0.046
Storage porosity	-0.36	0.472	-0.049	0.668
Residual porosity	-0.302	-0.495	-0.089	-0.719
Clay	-0.776	-0.551	0.15	-0.058
WDC (%)	0.552	0.318	-0.683	0.024
ΔpH (pH_{H20}-pH_{KCl})	0.895	0.086	-0.212	-0.093
CEC	0.796	0.223	-0.003	-0.36
WSA	0.541	0.666	0.068	-0.217
C storage	0.81	0.537	0.031	0.049
$\delta^{13}C$	0.773	-0.524	0.288	0.122
Cdfp (%)	0.971	-0.079	0.125	0.12
$\delta^{13}C$-WSA	0.711	-0.552	0.345	-0.04
Cdfp-WSA (%)	0.972	-0.064	0.118	-0.001
$\delta^{13}C$-nWSA	0.735	-0.461	0.408	0.076
Cdfp-nWSA (%)	0.931	-0.11	0.265	0.065

aggregates (nWSA) in the topsoil of P-12 and P-17.

TABLE 4 shows that the factor 1 explains 44.7% of the 26 analyzed variables (but only 19 were shown in TABLES 1, 2 and 3). The factor 2 (23.9%) was positively correlated with C content, C stock and total porosity, depth and age of the pasture. The factor 3 describes the evolution of soil with depth (TABLE 4). It represents 9.87% of the total variables, and was negatively correlated with the quality of C and to a large extent with the physical properties. The factor 4 which explained 7.2% of the total variability, describes the interrelation between the storage and the residual porosity (TABLE 4).

DISCUSSION AND CONCLUSIONS

The factor 1 is positively correlated with (i) parameters related to the quality of C ($\Delta^{13}C$ values and Cdfp percent in the whole soil, as well in the WSA and nWSA), and (ii) the physicochemical characteristics (ΔpH, CEC and WDC/total clay, (WDC/C). However, this factor is also negatively correlated with microporosity. It is therefore clear from the PCA approach that the key soil property changes due to forest clearing and pasture establishment with increasing age in the current study are: (i) C nature; (ii) interrelated physicochemical properties; and (iii) clay fabric porosity. In fact several studies have shown an increase in C stock and the change of its nature after pasture establishment[7,8,12]. In fact, at Nova Vida a good opportunity to study the conversion of forest to pasture located in the western Amazonian, Cerri et al.[4] found that the 0-30 cm layer contained 53 % more C than forest soil after 88 years of pasture, and that after 80 years of pasture 90 % of organic matter in the top 20 cm was pasture derived[5].

The factor 2 controls mainly the total porosity, WSA percentages, and C stock. An increase in C stock together with a decrease in the total porosity was observed with the increasing age of the pasture. This suggests that the factor 2 controls the depletion of physical properties after pasture establishment by decreasing total porosity probably due to trampling effect, particularly in the 0-20 cm layer, i.e., there is a decrease in water infiltration and soil aeration with depth. A negative correlation is also observed between the factor 2 and the quality or nature of C. This suggests that the main modifications in C after pasture establishment have an influence on physical properties along a soil profile, even though a greater impact is reported in the top layers. Other studies in the Brazilian Amazon basin have reported as well changes in physical properties mainly an increase in bulk density in the surface layers[3,6].

The factor 3 mainly explains the effect of C nature and physical properties, and suggests the deterioration of the former and depletion of the latter with depth. The factor 4 explains the interrelation of storage and residual porosities. However, this point remains unclear, but autocorrelations between the sizes of these two types of pores could possibly be related to an increase in the hydrophilic-hydrophobic balance on organic surfaces (decrease of short-range adhesion forces during drying processes) along the forest-to-pasture chronosequence, particularly within the upper soil layers.

Therefore, using PCA approach in a forest and pasture chronosequence located in eastern Amazon basin, state of Pará, we could extract structure correlation and show that the key soil property changes due to forest clearing and pasture establishment with increasing age mainly occurred by the change in C stock, and mainly the change in its nature as found by other studies in several part of Brazilian Amazon[4,7,8,10]. The PCA also shows that C nature was interrelated with other occurred changes, mainly the physicochemical properties (total, storage and residual porosities).

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