Capítulo 11

Physical properties of soils under degraded areas in the Central Amazon

Características das propriedades físicas do solo sob áreas degradadas na Amazônia Central

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SUMMARY: With the objective of understanding the characteristics of soil physical properties over degraded areas for afforestation purposes, morphologic features of soil profile, soil bulk density, soil hardness and penetrability were discussed in three different plantation sites after agricultural use, and compared with a Central Amazon primary forest site near Manaus. Experimental sites were established at CAMES and Serraria under Ferralsols and at Maués under Fluvisols. In most soil profiles of Ferralsols, thickness of A horizon was small and soil texture was clayey. The Fluvisols profiles near a small creek in Maués, presented a thick A horizon and sandy clay texture. Plantation plot at CAMES in the degraded area, soil hardness was higher, but bulk density was lower than in the 20 year old secondary forest plot. This indicates that some soil physical properties were not recovered during a 20 year period after the abandonment of agricultural use. In the Serraria site, bulk density, soil hardness and soil resistance to penetration were higher in the plantation plot with only climax species than in the primary forest plot, but the plantation plot of climax mixed with pioneer tree species improved soil properties. However it was observed that tillage practices would more effectively improve the growth of planted trees. We concluded that after similar agricultural use, Ferralsols around Manaus presented higher compaction when compared to the Fluvisols in Maués plots. Recovery or improvement of Ferralsols physical properties without any

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artificial treatment after agricultural activity was difficult. For rehabilitation of degraded lands on Ferralsols, we recommend the planting of pioneer tree species and/or soil preparation, such as tillage.

Key-words: soil physical properties, plantation, degraded area, Ferralsols, Central Amazon.

RESUMO: Com o objetivo de estudar as características físicas, morfológicas, a densidade, a dureza e a penetrabilidade do solo de áreas degradadas para fins de reflorestamentos, foram comparadas três diferentes áreas com plantios após o uso agrícola e uma área com floresta primária, na Amazônia Central, próximo a Manaus. Os locais experimentais foram estabelecidos na CAMES e na Serraria sob Latossolos e em Maués sob Fluvisolos. Na maioria de perfis de Latossolos, o horizonte A era estreito e a textura do solo era argilosa. Os perfis sob Fluvisolos em Maués, apresentaram um horizonte A profundo e de textura argilo-arenosa. Na maior parte do plantio degradado, na área da CAMES, a dureza do solo foi elevada, porém a densidade foi menor do que na área de floresta secundária. Isto indica que algumas propriedades físicas não se recuperaram durante um período de 20 anos após o abandono do uso agrícola. Na Serraria, a densidade, a dureza e a resistência do solo à penetração foram mais elevadas nos plantios com espécies clímax do que na floresta primária, mas o plantio com espécies clímax em consórcio com espécies pioneiras podem melhorar estas propriedades do solo. Entretanto, observou-se que as práticas de preparo do solo (aração e gradagem) contribuem para o crescimento das espécies plantadas. Concluiu-se que após o uso agrícola, os Latossolos próximos a Manaus apresentaram uma compactação mais elevada quando comparado aos Fluvisolos em Maués. A recuperação ou a melhoria das propriedades físicas dos Latossolos, sem nenhum preparo do solo após a atividade agrícola, foi muito limitada. Para a reabilitação de áreas degradadas sob Latossolos, é recomendado o plantio de espécies pioneiras e/ou o preparo do solo, com aração e gradagem.

Palavras-chave: Propriedades físicas do solo, plantios, área degradada, latossolos, Amazônia Central.

INTRODUCTION

Ferralsols (FAO, 1990; ISSS 1998a) or "Latossolos" (EMBRAPA, 1999) or Oxisols (USDA - Soil Survey Staff, 1999) are mainly distributed in the Central Amazon region near Manaus (Sombroek 1984), specially on the plateaus of non flooded areas - "terra firme" (Chauvel, 1982, Ferraz *et.al.*, 1998). These soils are developed over tertiary deposits (Bigarella and Ferreira, 1984). Ferralsols are largely distributed in tropical regions, mainly South and Central America and Central Africa, with scattered areas elsewhere. Strong weathering and leaching over a long time have resulted in a soil rich in iron and aluminum oxides (Jordan, 1985). Physical characteristics of these soils usually are quite favorable for cultivation, because of their depth, high permeability and stable micro-structure. Also they are less prone to erosion, but Ferralsols are chemically poor, having a low cation exchange capacity (ISSS, 1998a). Despite good physical properties, nutrient reserves are easily depleted by agricultural practices, while inactivation of phosphorus is major problem (ISSS 1998a). Two or three years of cropping or tramping by animals may make deep cultivation desirable, especially to increase the water acceptance. Physical analyses had shown that when bulk density of the soil is higher than 1.35 g cm^{-3} mechanical impedance may restrict root development (Van Wambeke, 1991). Arruda Mendes (1989, apud Van Wembeke, 1991) found that bulk densities above 1.10 g cm^{-3} restrict root penetration in oxic horizons containing 64 % clay. FAO/UNESCO (1971) summarized the characteristics and some problems concerning Xanthic Ferralsols that they classified in the Amazon basin area. Sometimes these soils are extremely high in clay content (more than 70 %). This may cause rather poor workability as the soil gets hard in the dry season and sticky during the rainy season. Also root penetration can be difficult, probably because of oxygen deficiency in the dense soil mass.

In the Central Amazon region near Manaus, deforestation for agricultural land use was less than in eastern Amazon because of the low fertility of soils (Sombroek, 1984). However, on the plateau under Ferralsols, land use change with deforestation is in progress for agricultural activities and/or pasture after slash and burn of the primary forest. After few (two or three) years of land use, physical and chemical soil degradation occurred. For land management, sustainable land use is essential, but these degraded areas were difficult to reforest naturally, and this process takes a long period of time. On the other side, afforestations can be effective for rehabilitation of degraded areas.

However, in this region of Amazon, degraded areas under Ferralsols after agricultural use can presents some problems, as soil compaction. Soil physical properties are also one of the important factors for tree growth. Dedecek et al. (2001) reported that different of soil physical properties with different tillage systems will affect the tree growth in eucalyptus stands under Oxisols (Ferralsols) in São Paulo State. One of the challenges for the rehabilitation of degraded area with afforestation is to understand the status the soil physical conditions.

The objective of this paper is to gather basic information of soil physical properties over degraded areas for afforestations in central Amazon area, compared with natural forested sites. Soil physical properties such as bulk density of soil, soil hardness and soil resistance to penetration were measured to discuss evaluation of the experimental sites.

MATERIAL AND METHODS

Research areas

Experimental sites under plantation forest after agricultural activity were established at CAMES (Cooperativa Agrícola Mista Efigênio Sales, AM-010, km 41), Serraria in Presidente Figueiredo (BR-174, km112) and Maués, near Rio Maués açu (about 250 km east from Manaus). General information of experimental plots are presented in Table 1. All sites were located in the Amazonas State. Plantation design of experimental sites and initial growth of planted trees was summarized for CAMES by Nakamura *et al.* (2000), and for Serraria by Barbosa *et al.* (2000). In Serraria, we established a surveyed plot with different tree species and different soil preparation (tillage and no tillage), and also surveyed a secondary forest plot (CAMES) and primary forest plot (Serraria) near the plantation site. In Maués we established three plots in different micro-topographic positions. Soil type of CAMES and Serraria was Ferralsols (ISSS 1998a; Latossols, EMBRAPA, 1999 or Oxisols, Soil Survey Staff, 1999) and Maués was Fluvisols (ISSS 1998a; Entisol, Soil Survey Staff 1999; Table 1).

Soil profile description

Soil profile description was performed using FAO Guidelines (1990) in each plot..

Bulk density

Bulk density was determined by core method (Black and Hartge, 1986). A 100 mL soil sampling core cylinder was used for sampling through the profile. We collected triplicate samples from each horizon and measured for each sample weight after oven drying for 24 hours at 105 °C. The average values were calculated for bulk density. Organic matter was not

Table 1 - General description of experimental sites established in The Central Amazon.

Site	Plot	Soil type FAO[*2]	USDA[*3]	Topographic position and land form	Tree species or forest type	Age (years)	Soil preparation
CAMES	CFL	Ferralsols	Oxisols	plateau;flat	Mogno[*5]	3	No tillage
	CBO[*1]	N.C.[*4]	N.C.	plateau;bottom of gentle slope	Jatoba[*6]	2	No tillage
	CSF	Ferralsols	Oxisols	plateau;flat	Secondary forest	≥20	-
Serraria	STL	Ferralsols	Oxisols	plateau;flat	Pau-de-balsa[*7] with climax spp.[*8]	4	Tillage
	SNT	Ferralsols	Oxisols	plateau;flat	Pau-de-balsa[*7] with climax spp.[*8]	4	No tillage
	SDA	Ferralsols	Oxisols	plateau;flat	Climax spp.[*8]	4	No tillage
	SPF	Ferralsols	Oxisols	plateau;flat	Primary forest	uncertain	-
Maués	MA1	Fluvisols	Entisols	near creek;flat	Climax spp.[*9]	1	No tillage
	MA3	Fluvisols	Entisols	near creek;gentle slope		1	No tillage

[*1] Disturbed soil by anthropic activity

[*2] Classified by ISSS Working Group RB (1998a)

[*3] Classified by Soil Survey Staff (1999)

[*4] Not classified, soil type was Ferralsols (FAO) and Oxisol (USDA)

[*5] *Swietenia macrophylla*

[*6] *Hymenaea courbaril*

[*7] *Ochroma pyramidale*

[*8] *Swietenia macrophylla; Dypterix odorata;*

[*9] *Trattinikia burserifolia; Parkia multijuga; Parkia pendula; Hymynaea courbaril; Ceiba pentandra; Schyzolobium amazonicum; Swietenia macrophyla; Buchenavia pavifolia; Azadirachta indica; Cedrela Odorata; Tectona grandis*

separated because of their less content and no sieving was necessary due to the absence of gravel above 2 mm.

Soil hardness

In each horizon at the profile wall five measurements (repetitions) were performed with the soil hardness meter (Yamanaka's method, Pedological Society, 1990).

To evaluate in detail the effect of tillage on the soil hardness, sub plots were established in the plots with and without tillage, and also in the primary forest. Five sub plots were established in a different climax species plantation with pau-de-balsa at each plot, except in the primary forest. In each sub plot, we measured soil hardness by Yamanaka's method. Ten measurements were performed in each horizon.

Penetrability

Soil resistance to penetration was measured to evaluate penetrability and soil compaction. Handy dynamic cone penetrometer (Ohnuki, 1999) was used for measurement until 2 m depth. The principle of this equipment is the same as by the cone penetrometer (Bradford, 1986). In each plot, measurements were done in triplicates, and during the wet season.

RESULTS

Morphologic properties

At Maués Fluvisol thickness of A horizon is 30 to 40 cm and organic matter is distributed deeper in the soil, while at CAMES and Serraria sites, the thickness of this horizon is less than 15 cm. One exception at CAMES site is the A horizon in the CBO (Table 2) profile which is exceptionally thick with 25 cm, due secondary deposition of organic matter from anthropic activity. In the past 15 years this area received the vegetation debris after several cuttings of the secondary vegetation. Soil texture in the CAMES and Serraria sites was clayey through the profile. In the Maués site, sandy clay texture was observed in the field until 25 cm depth (BA horizon), and changed to clay below this depth.

No stones and gravel were observed in all surveyed profiles.

Fine subangular blocky structure dominated in the upper part of STL plot and changed to nutty subangular structure clearly below 30 cm. Strong fine to medium size of granular and angular blocky structure was observed in the surface layer in the CFL. Granular to subangular blocky structure was dominated in SPF and CSF plots. Due to sandy texture, granular structure dominated the upper part of profile in Maués profiles.

At the Serraria plots many fine roots were observed until 90 to 100 cm depth in the "pau-de-balsa" plantation plots (STL and SNT). Primary forest plot at Serraria (SPF) and secondary forest plot at CAMES (CSF) also presented many roots until 20 cm depth. On the "mogno" plantation plot (CFL) at CAMES site fewer roots were observed in the profiles.

Bulk density

Bulk density of the surveyed soils is presented in Table 2. All plots at CAMES and Serraria have clayey soils (Table 2a,b). Bulk density of surface soil varies from 0.9 g cm^{-3} (degraded area at Serraria) to 0.6 g cm^{-3} (plantations and primary forest; Table 2b). In the lower horizons bulk densities increases to 1.0 - 1.2 g cm^{-3} in both sites (Table 2a,b). At the Maués site, bulk

Table 2 - Soil bulk density in profiles at different sites of three experimental areas in Central Amazon.

a. CAMES

Plot*	Horizon	Depth cm	Density g cm^{-3}
CFL	Ap	0 - 6	0,84
	BA	6 - 16	0,98
	B1	16 - 29	1,02
	B2	29 - 53	1,03
	B3	53 - 83	1,05
	B4	83 - 110	1,05
CSF	A-AB	0 - 2	0,85
	B1	2 - 5	1,11
	B2	5 - 13	1,05
	B3	13 - 29	1,04
	B4	29 - 43	1,11
	B5	43 - 83	1,06
CBO	Ap	0 - 7	0,86
	ApB	7-25	1,13
	2B1	25 - 53	1,11
	2B2	53 - 66	1,04

b. Serraria

Plot	Horizon	depth cm	Density g cm^{-3}
SDA	Ah	0 - 5	0,93
	AhB	5 - 25	1,27
	BA	25 -50	1,19
	B1	50 -68	1,19
	B2	68 -105	1,21
	B3	105 - 145	1,21
STL	Ap	0 - 17	0,63
	Bh1	17 - 43	0,88
	Bh2	43 - 65	1,03
	B1	65 - 110	1,06
	B2	110 - 145	1,11
SNT	Ah	0 - 5	0,60
	AhB	5 - 13	1,03
	BA1	13 - 30	1,14
	BA2	30 - 53	1,14
	B1	53 - 80	1,14
	B2	80 - 110	1,08
	B3	110 - 145	1,14
SPF	Ah	0 - 2.5	0,63
	AB	2.5 - 13.0	0,95
	BA	13 - 30	1,13
	B1	30 - 50	1,09
	B2	50 - 80	1,01
	B3	80 - 120	0,98
	B4	120 - 145	1,00

c. Maués

Plot*	Horizon	depth cm	Density g cm^{-3}
MA1	A	0 - 5	1,22
	AB	5 - 20	1,42
	BA	20 - 35	1,35
	B1	35 - 55	1,34
	B2-B3	55 - 80	1,25

* For plot name and description see Table 1

density was 1.2 g cm^{-3} in the surface horizon and also increases to 1.3 - 1.4 g cm^{-3} in the lower horizons (Table 2c). Due the sandy clay texture in the profile, bulk density in the Maués site is higher than those in the CAMES and Serraria sites.

Soil hardness

Soil hardness, measured by Yamanaka's method, of top layer varies from 0.8 to 13.3 kg cm^{-2} at CAMES sites, and from 1.1 to 3.4 kg cm^{-2} at Serraria, and from 1.4 to 2.7 kg cm^{-2} at Maués plantation plots (Table 3). The values of surface layer was lower in primary forest at Serraria (SPF) and secondary forest at CAMES (CSF) as in the plantation plots in each of these sites.

Below subsurface layers, soil hardness varies from 3.5 to 19.0 kg cm^{-2} at CAMES sites from 1.8 to 15.4 kg cm^{-2} at Serraria, and from 5.1 to 11.1 kg cm^{-2} at Maués.

Penetrability

Results for soil penetrometer test for each plot were described by the Nc value (Ohnuki 1999) in the Figure 1.

Table 3 - Mean values of soil hardness (Yamanaka's method) in profiles at different sites of three experimental areas in Central Amazon.

a. CAMES

Plot	Horizon	Depth cm	Mean kg cm^{-2}	SD
CFL	Ap	0 - 6	13,3	7,9
	BA	6 - 16	19,0	6,7
	B1	16 - 29	8,7	1,7
	B2	29 - 53	9,6	1,2
	B3	53 - 83	8,5	2,2
	B4	83 - 110	12,1	1,8
CSF	A-AB	0 - 2	0,8	0,1
	B1	2 - 5	3,5	1,5
	B2	5 - 13	9,1	2,7
	B3	13 - 29	7,9	1,4
	B4	29 - 43	7,6	2,2
	B5	43 - 83	6,3	2,1
CBO	Ap	0 - 7	2,9	1,1
	ApB	7 - 25	11,3	5,2
	2B1	25 - 53	11,8	8,7
	2B2	53 - 66	12,6	2,5
	3AB	66 - 84	5,9	1,8
	3B1	84 -96	5,6	1,7

b. Serraria

Plot	Horizon	Depth cm	Mean kg cm^{-2}	SD
SPF	Ah	0 - 3	1,1	0,6
	AB	3 - 8	1,8	0,3
	AB	8 - 15	3,7	1,4
	BA	15 - 25	5,3	1,5
	BA	25 - 35	5,8	3,3
	B1	35 - 50	8,3	2,0
	B1	50 - 65	4,8	0,5
	B2	65 - 80	3,7	1,1
	B3	80 -100	4,0	1,2
STL	Ap	0 - 3	2,1	0,8
	Ap	3 - 8	2,3	0,5
	Ap	8 - 15	2,6	0,9
	Ap	15 - 25	2,7	1,3
	Bh1	25 - 35	5,9	1,6
	Bh1	35 - 35	4,8	1,3
	Bh2	35 - 65	5,2	2,1
	Bh2	65 - 80	4,0	0,5
	B1	80 - 100	4,2	1,2
SNT	Ah	0 - 3	3,4	0,9
	Ah	3 - 8	3,7	1,4
	AhB	8 - 15	6,3	1,0
	BA1	15 - 25	7,5	2,2
	BA1	25 - 35	8,4	3,3
	BA2	35 - 50	6,6	1,3
	B1	50 - 65	5,4	1,0
	B1	65 - 80	5,9	0,2
	B2	80 - 100	3,0	0,1
SDA	Ah	0 - 3	3,3	1,5
	Ah	3 - 8	5,7	3,4
	AhB	8 - 15	11,0	3,6
	AhB	15 - 25	15,4	7,4
	AhB	25 - 35	7,3	1,0
	BA	35 - 50	5,6	1,1
	B1	50 - 65	5,5	0,6
	B1	65 - 80	4,6	0,4
	B2	80 - 100	5,6	1,9

c. Maués

Plot	Horizon	Depth cm	Mean (kg cm^{-2})	SD
MA1	A	0 - 11	2,7	0,3
	AB	11 - 19	10,4	2,2
	BA	19 - 34	11,1	1,1
	B1	34 - 53	5,9	1,1
	B2	53 - 68	5,6	1,8
	B3	68 - 85	5,8	2,1
MA3	A1	0 - 13	1,4	0,8
	A2	13 - 26	9,3	0,9
	BA	26 - 44	5,1	1,1
	B1	44 - 53	5,5	1,1
	B2	53 - 64	5,8	1,0
	B3	64 -81	6,3	0,9

* For plot name and description see Table 1

Nc values were calculated from numbers of impact needed to penetrate 10 cm, until 2 m depth. Higher values represents higher resistance to penetration.

Strong resistance (Nc $\geq$ 5) was observed below subsurface layer between 10 to 50 cm depth in most of the plots. Below this point, resistance decreased. In the clayey soil at CAMES and Serraria, the values were stable until 90 to 100 cm depth. Below this depth, values increased until 200 cm, except for SPF plot in the Serraria. The soil with sandy clay texture at Maués, resistance increased gradually from 20 cm depth until 100 cm and stabilized until 200 cm depth.

DISCUSSION

Differences of soil physical properties between plantations and primary or secondary forest

To evaluate the soil degradation after agricultural activity, soil physical properties under the plantation plot and primary or secondary forest plots were compared. In CAMES, bulk density was lower in the mogno plantation (CFL) than in the secondary forest (CSF) until 70 cm depth (Figure 2a), but soil hardness was higher in the CFL than in CSF (Figure 3a) through all the profile. Only surface soil was very soft, but A horizon was very thin with only 1 to 2 cm thickness in CSF. This site was also used for agriculture until 20 years ago and revegetated by natural succession. This means that influence of degradation with agricultural activity is still to observe and this soil property still presents very different values from the soil under primary forest, as suggested by the results of penetrability test (Figure 1a). In the plot located at the lower topography (CBO) the resistance of penetration below 30 cm was the lowest among the plots at CAMES (Figure 1a), probably due to anthropic influence. From profile observation, secondary deposition of organic matter occurred until 100 cm depth and many large pores results from biological activity. Many roots were also observed until 90 cm depth. Tree growth and survival rate around this plot was high compared with other plot (Iida and Nakamura, in prep.) because of the high porosity and the small resistance in the profile.

In the Serraria plots bulk density through profile in the plantation with only climax species (SDA) was the highest among all plots (Figure 2b). Those of primary forest plot (SPF) and climax plantation with pau-de-balsa plot (SNT) were low and not different until 30 cm depth in two plots. Below 30 cm depth, bulk density was lower in the SPF than in the SNT. We observed many roots of pau-de-balsa in the SNT, so bulk density in the SNT was lower than those of in the SDA. Arruda Mendes (1989) found that bulk densities higher than 1.10g cm^{-3} can restrict root penetration in oxic horizons. In SNT and SDA plots, the bulk density was over 1.1 g cm^{-3}, but values in the SNT plot are lower than those in the SDA plot. This suggests that plantation with fast growth pioneer species over degraded areas improve soil bulk density. As soil hardness in SNT is lower than that of in SDA (Figure 3b), improvement of soil was also suggested from the results of soil hardness. But both bulk density and soil hardness in plantation plot (STL) did not recover at the level of in the primary forest plot (SPF).

Effects of soil tillage on soil physical properties

The differences of soil hardness between the plots with and without tillage (STL and SNT respectively) were clear (Figure 4). Values in the STL were low with 2.1 to 5.9 kg cm^{-2} but high in the SNT plot, with 3.4 to 8.4 kg cm^{-2} (Table 2b). Until 60 cm depth, values are also lower in the STL than in the SNT plot (Figure 4). These results suggests that tillage effects are not restricted to the tillage layer, but influences also the horizons below the tillage layer. The effect of tillage on soil hardness (Figure 5), as expected, indicates the lowest values in the primary forest plots. Compared with tillage (STL) and without tillage (SNT) plots, values are lower in STL than in SNT, until 20cm depth. This result also suggests that tillage treatment promotes low soil hardness especially in the tillage layer. These measurements were performed at dry season. Even in the dry season, lower soil hardness were observed until 20cm depth in tillage layer.

When we observed the bulk density, lower values were observed in the tillage plot (STL) until 110 cm depth (Figure 6). Differences in the top layer were not so clear, becoming

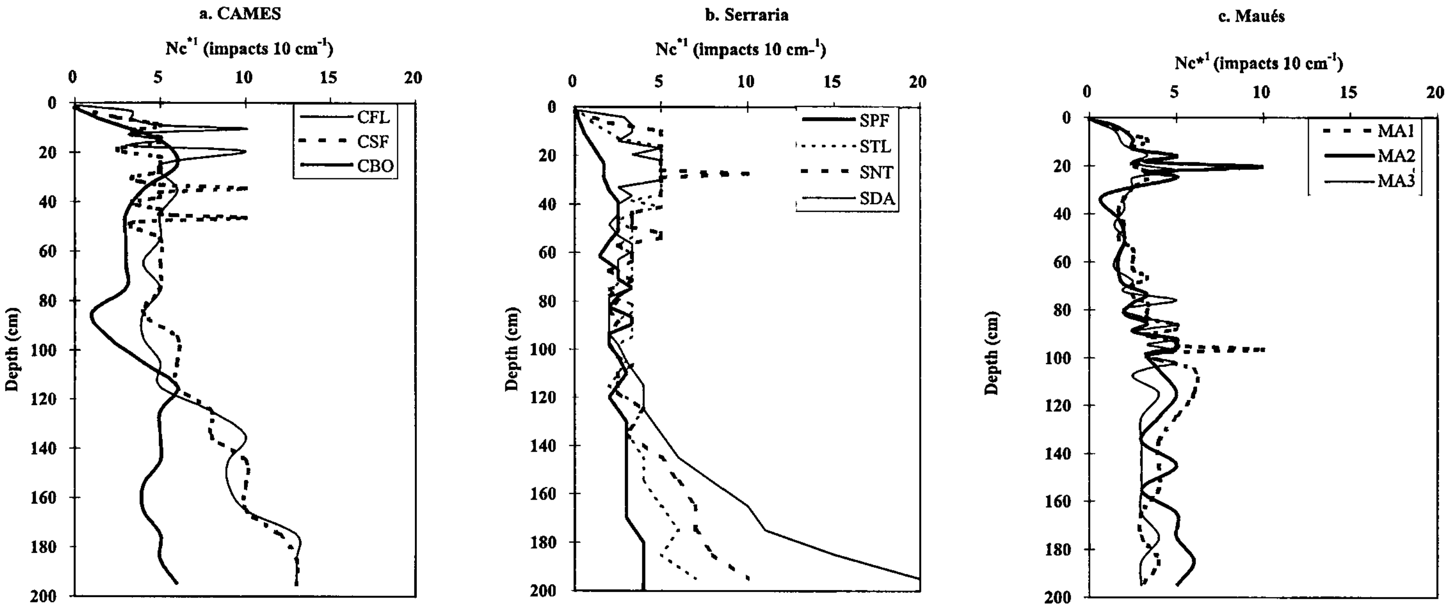

Figure 1 - Soil resistance to penetration measured by handy dynamic cone penetrometer at different plots of three experimental sites in Central Amazon.
*1: Nc value was calculated from numbers of impacts needed penetrate 10 cm depth.
For plot name and description see Table 1.

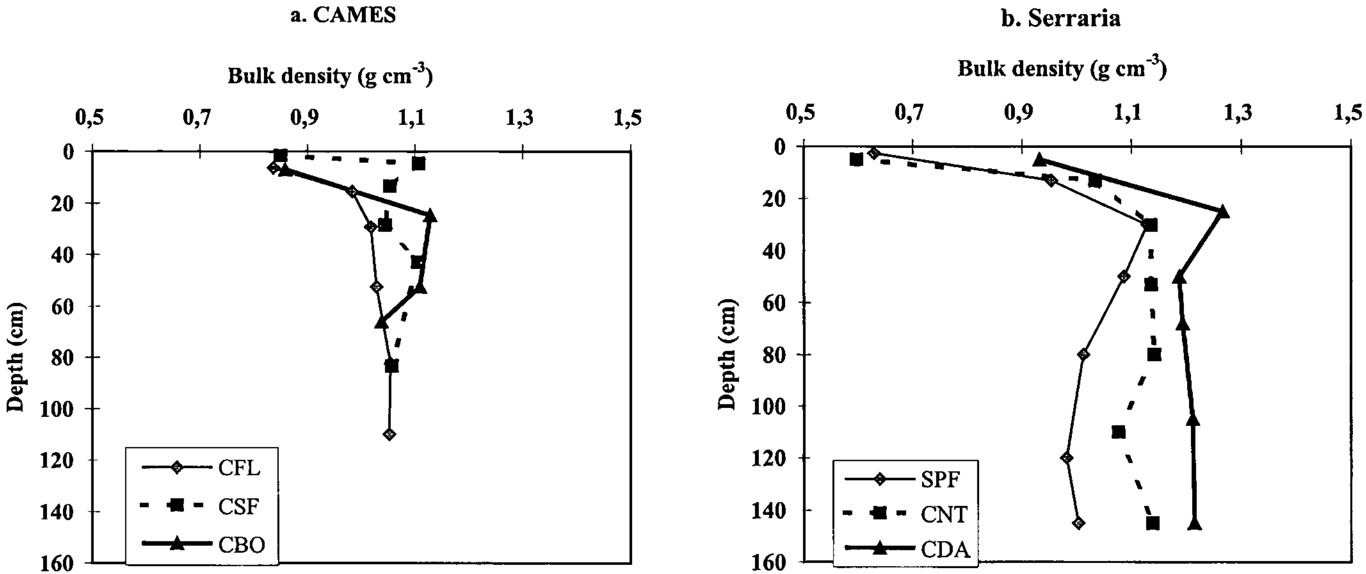

Figure 2 - Bulk density at soil profiles in plantation plots and primary (SPF) and secondary (CSF) forests at CAMES and Serraria in Central Amazon. For plot name and description see Table 1.

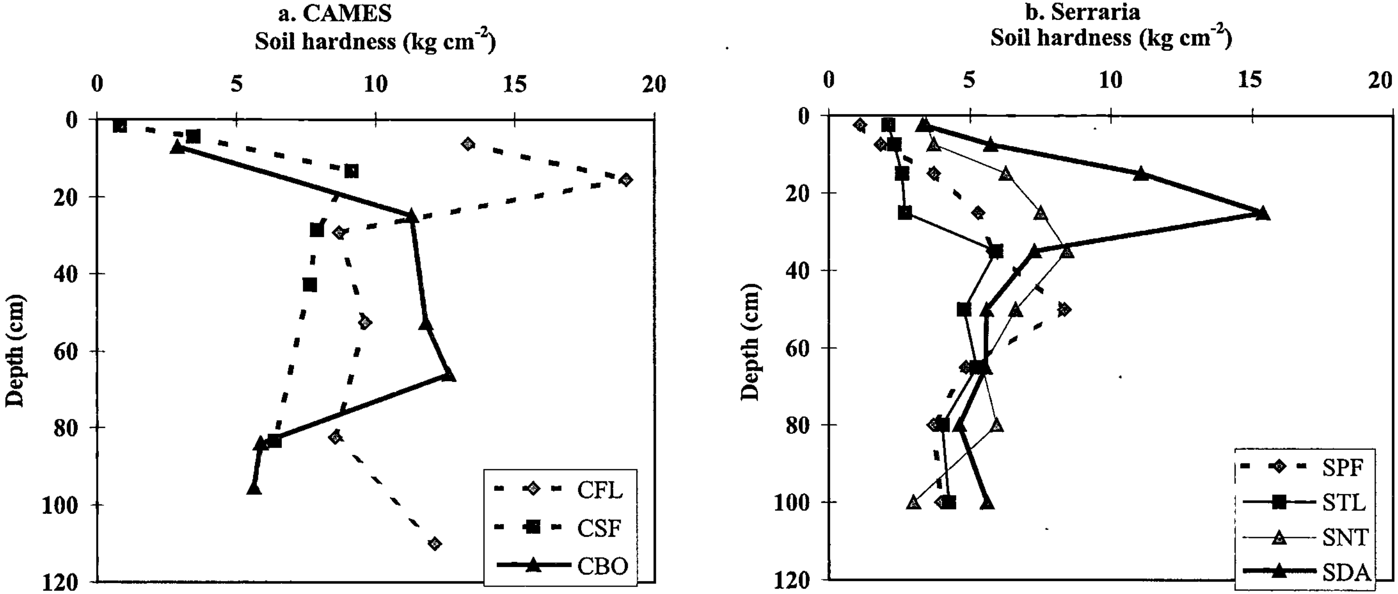

Figure 3. Soil hardness measured by Yamanaka's method at soil profiles in plantation plots and primary and secondary forests at CAMES and Serraria in Central Amazon.
For plot name and description see Table 1.

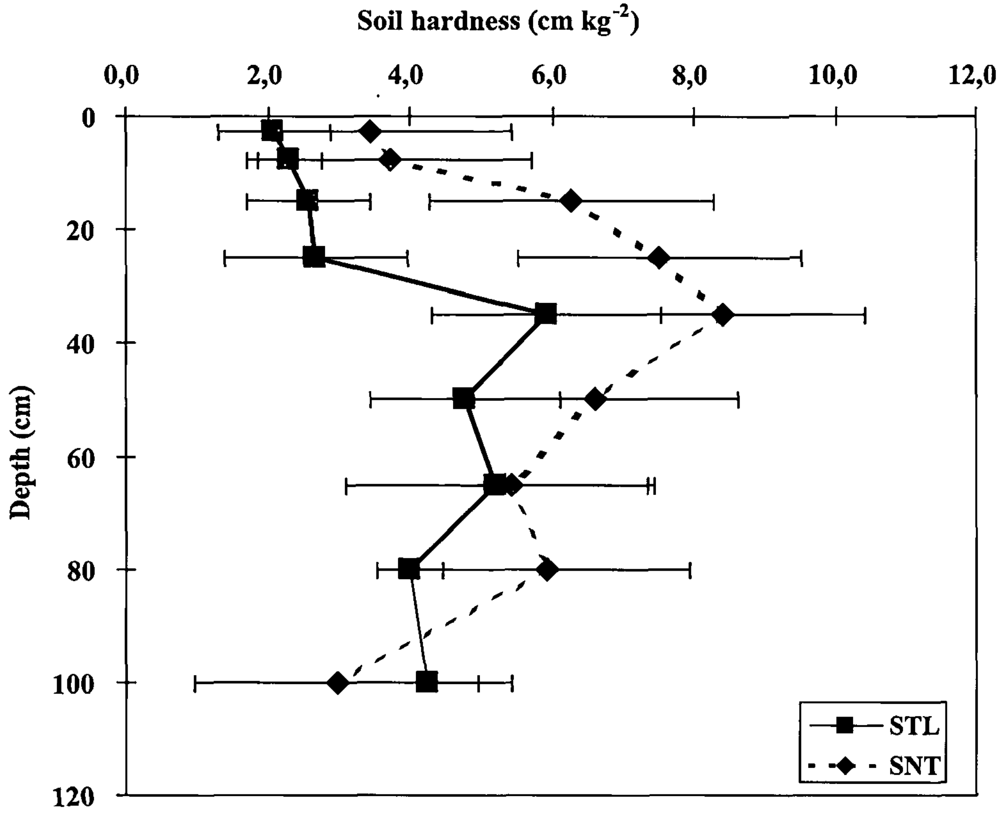

Figure 4 - Mean soil hardness (n=5) measured by Yamanaka's method in soil profiles with different soil preparation system (with tillage; STL, without tillage; SNT) in afforestation at Serraria, Presidente Figueiredo-AM.
For plot name see Table 1.

evident between 15 and 65 cm depth. As tillage practice increase macropores in tillage layer, bulk density was decreased. The result of the bulk density reflected the values of soil hardness. Low values of soil hardness, corresponds to low bulk density.

Results from soil penetrometer tests, indicates low resistance to penetration in the SPF plot until 40 cm depth. Differences of resistance to penetration in each plot were observed between 100 to 200 cm depth. Values in STL and SNT plots were intermediate between the plots at SDA and SPF. Resistance of in STL was lower than in the SNT plot. This means that tillage practices promote the decrease of resistance to penetration.

We concluded that tillage practice decreased the bulk density and soil hardness. This means that soil compaction (caused previously by tractors) also decreased by tillage practices. Comparing tree growth of both plots, indicated that initial growth of trees in site with tillage was higher than in the site without tillage (Barbosa *et al.* 2000). This result also suggest that improvement of soil physical properties, such as bulk density and soil hardness, will affects the tree growth. As mentioned above, plantation of pioneer tree species on the degraded land improve soil density and hardness. However, tillage activity showed to be more effective to

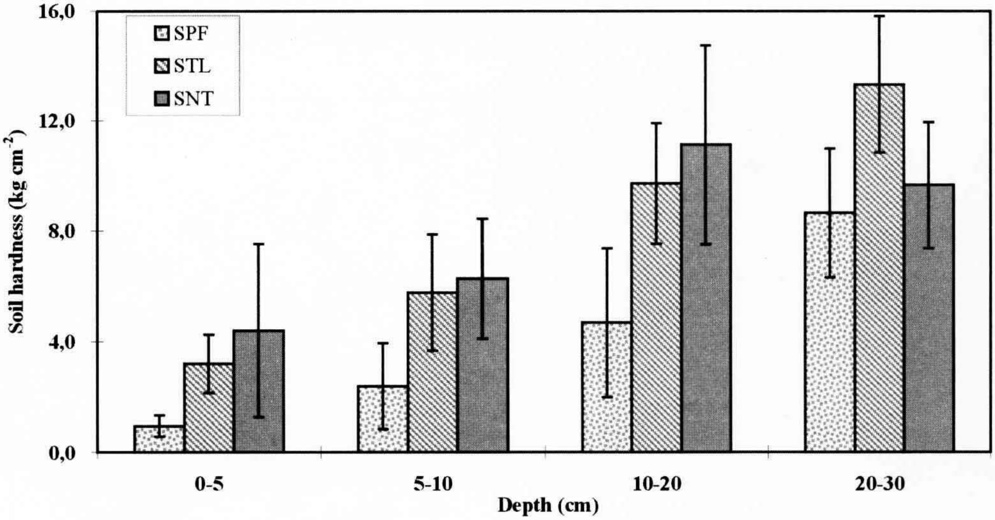

Figure 5 - Mean soil hardness (n=10) measured by Yamanaka's method at five different areas: primary forest (SPF), afforestation after tillage (STL) and afforestation without tillage(SNT) forest at Serraria, Presidente Figueiredo-AM.

improve these properties on the degraded areas.

Characteristics of soil physical properties under the degraded areas

Soil physical properties such as bulk density, soil hardness and resistance to penetration can be considered as good soil quality indicators when the obtained values from the plantation sites at degraded areas after agricultural activities are compared with primary forest site under the Ferralsols. On the other way, soil hardness and penetrability were better under the Fluvisols even after agricultural activities during few decades as in the case of Maués site. These properties between Ferralsols and Fluvisols were quite different. In the Fluvisols, sand fractions are high and bulk density was higher than those in the Ferralsols. As a result of sandy clay texture of the soil there are more macro and micro pores, and so drainage water after rain is higher in the Fluvisols. Because of this difference in texture, degree of soil degradation in the Fluvisols may be not have severe influence on the growth of planted trees, which is expected to be good in this site. On the other side, Ferralsols presented a high clay content. There are over 73 % of clay at CAMES and about 88 % at Serraria. In the plantation plot (CFL) clay content was 73 %, and up to 80 to 90 % in the secondary forest plot (CSF) at CAMES. Consequently soil hardness and bulk density were high, because of the very high clay content of these two plots. In the CAMES sites, the growth of planted trees and their survival rate was low (Iida and Nakamura, in prep.). In the mogno plantation, high water tension in the soil was observed at 20 cm depth in the planting holes even in the dry season (Nakamura, in prep.). This means that water stagnation occurred in the planting holes, influenced by the very high clay content in this plot. We suppose that important factors for the low growth and survival rates of the trees in this site is rather the poor workability as the soil gets hard in the dry season and sticky during the

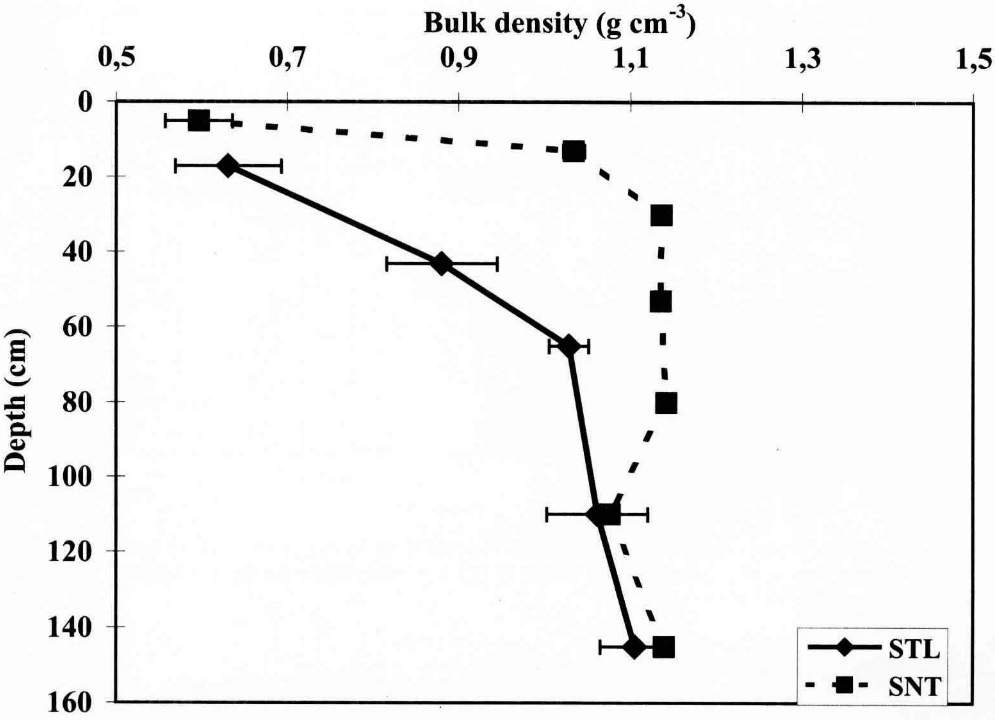

Figure 6 - Mean bulk density in soil profile with different soil preparation system (with tillage: STL, and without tillage: SNT) in afforestation at Serraria, Presidente Figueiredo-AM.
For plot name and description see Table 1.

rainy season, due to the high clay content (FAO/UNESCO 1971). The dense soil mass can also promote oxygen deficiency, which make root penetration difficult (FAO/UNESCO 1971). The high soil resistance to penetration observed in CAMES (Figure 1a) could also result of oxygen deficiency with dense soil mass in the root zone. On the other hand, despite the very high clay content (about 85 %) in the Serraria plot, we found that the effect of planting pioneer tree species improves the soil physical properties, and soil tillage practices had even a better influence on tree growth.

CONCLUSION

Considering the availed degraded sites after agricultural activity, the recovery of soil physical properties by revegetation through natural succession, may take more than 20 years. The plantation of pioneer tree species improves soil physical properties, such as bulk density and soil hardness, however tillage practice are more effective, promoting also the tree growth.

The recovery of soil physical properties, after degradation by agricultural activity, was difficult without any anthropic interference. For the rehabilitation of degraded land with afforestation over Ferralsols, plantation of fast growing pioneer tree species and/or soil preparation, as tillage, are recommended, in order to increase the growth of planted trees.

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