PHYSICAL PROPERTIES OF SOILS UNDER INTENSIVE AGRICULTURAL MANAGEMENT

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ABSTRACT: Pedologic alterations after long-term sugar cane (*Saccharum officinarum*) cropping cycles under traditional soil management systems were studied on a farm in Bariri, SP, Brazil. A toposequence was established to evaluate the effects of the soil position in the relief in changing soil physical attributes. Morphological field descriptions and laboratory analyses were carried out on vertical profiles of the upper, middle and lower thirds of a Typic Haplorthox slope. Soil bulk density and macroporosity changed along the toposequence reflecting on soil hydrodynamics, especially in the lower slope parts. At sites with high clay levels, empty spaces were filled forming block shaped structures together with the micro-aggregate structure. The intensive cultivation induced the greatest soil structure alterations, even at the deepest layers. The study pointed out the importance of performing detailed morphological observations in vertical profiles, due to the great variation on pedological attributes over short distances. Compacted soil sections were observed side-by-side with desaggregated mottles in the same soil profile. This fact evidenced that both vertical (in each profile) and horizontal gradients (along a toposequence) need to be considered in studies of time sequence variation of pedological parameters.
Key words: soil management, toposequence, aggregates, soil micromorphology.

PROPRIEDADES FÍSICAS DE SOLOS SUBMETIDOS A PRÁTICAS INTENSIVAS DE MANEJO

RESUMO: O presente trabalho foi realizado numa propriedade agrícola situada no município de Bariri, SP, em área cultivada com cana-de-açúcar (*Saccharum officinarum),* onde foram estudadas algumas alterações pedológicas decorrentes de um longo período de exploração agrícola com sistema tradicional de manejo do solo. Foi estabelecida uma condição de topossequência para que pudesse ser avaliada a importância da posição dos solos no relevo sobre as modificações de alguns dos seus atributos físicos. As observações foram realizadas em campo e laboratório, em perfis verticais situados nos terços superior, médio e inferior da encosta em um Latossolo Vermelho. Houve alterações na densidade do solo e da macroporosidade, com reflexos na hidrodinâmica do solo, principalmente nas posições mais baixas do relevo. Nos sítios mais argilosos houve preenchimento dos espaços vazios, com a formação de estrutura em blocos, ocorrendo concomitantemente com a estrutura microagregada. Os tratos culturais promoveram grandes alterações na estrutura dos solos, mesmo em camadas relativamente profundas. O estudo ressaltou a importância de observações morfológicas detalhadas dos perfis de solo, em face da grande variabilidade dos atributos pedológicos a uma curta distância. Foram observados, num mesmo horizonte do perfil, setores compactados ao lado de bolsões desagregados, o que atesta a necessidade de serem considerados tanto os gradientes verticais (em cada perfil) como os laterais (ao longo da topossequência) no estudo das variações temporais dos parâmetros pedológicos.
Palavras-chave: manejo do solo, topossequência, micromorfologia do solo, agregados.

INTRODUCTION

The search for agro-socioeconomical sustainability and new production system paradigms are the greatest challenges of modern agriculture, which envolves among other technological practices, an adequate soil management.

The deep clayey well-structured soils, under smooth relief, found at the central region of the State of São Paulo, favored the use of intensive soil management practices. As agriculture expanded, these same practices were incorporated to medium textured soils, leading to severe soil degradation processes after a period of time that are now requiring a great deal of efforts and inputs to revert the situation and attain soil recovery for a desirable productivity.

The damaging effects resulted from inadequate soil resource management can be clearly observed along a toposequence. The reduced water infiltration rate due to a soil macroporosity decrease induces the superficial water run off and fine particles dragging from upper to lower slope positions (Cintra et al., 1983; Centurion & Demattê, 1985). The intensive soil use under traditional management resulted in unfavorable physical effects on soil quality, evidencing the need for a new philosophy in relation to soil management practices (Tavares Filho et al., 1999). Thus, there is a great concern not only on the amount of nutrients to be added but also on the bulk soil physical conditions in which rooting systems are to develop (Hénin et al., 1960).

This research aimed at identifying changes in physical attributes of a Typic Haplorthox located along a toposequence, cultivated with sugarcane under a traditional soil management system and evaluating the relief slope effect on these attributes.

MATERIAL AND METHODS

This study was carried out in an agricultural area of Bariri, located in the central region of the State of São Paulo, Brasil, which is part of the Ocidental Planalt Geomorphological Province, geographically located at 22º04'S and 48º42'W. The area was deforested during the 1930 decade, when a coffee plantation was introduced. This crop was substituted by sugarcane in 1978, which was eversince grown under the same traditional soil management system. The region shows a plainy to smoothly waved relief and the studied area corresponds to a 4% convex slope 2,000 m long.

According to the Köppen's classification, the climate is Cwa, characterized as a tropical humid, with a dry winter and average monthly temperature ranging from 18ºC to 22ºC; rainfall during the driest month is around 30 mm and the pluviometric index ranges between 1,100 and 1,700 mm. The dry season extends from April to September and heavy rainfall predominates from January to February. The native vegetation of the region corresponds to large isolated residual patches of the tropical latifoliate forest.

The soil was classified as Typic Haplorthox and, lithologically, the parent materials are derived from the Bauru Group rocks, overlaying basaltic rocks and their derivations (IPT, 1981).

Soil samples were collected in 1999 in a three-year-old sugarcane crop, along a toposequence, where the slope was separated in upper, medium and lower thirds. The sampling points were determined after soil morphological analyses, when the following soil profile characteristics were identified: a superficial layer (0.1-0.2 m) with continuous soil mobilization; a subsuperficial layer (0.2-0.3 m) that better reflects the effects of anthropic action; and a deeper layer (0.6-0.7 m), practically not affected by sugarcane management practices.

Samples were submitted to granulometric and aggregate stability analyses, according to EMBRAPA (1979). Soil porosity and density were determined on samples collected by volumetric rings. Some soil horizons were individually sampled for micromorphological analysis, particularly in places where soil structure damage by soil management was evident in comparison to deeper intact layers. In this case, intact samples were collected in Kubiena boxes, impregnated with a mixture of orthoftalic resine T208, styrene monomer (diluent) and butanox (catalizer) and after, dissecated and sectioned in thin layers to be investigated by petrographic microscopy (Bullock et al., 1985; Castro, 1989).

Water infiltration tests were performed in the three parts of the slope using a constant charge permeameter, model IAC (Bertolani, 1998), modified from the Permeameter of Guelf developed by Reynolds & Elrick, (1985). The readings were made using 6 cm-water column hydraulic charges until constant values.

The analysis of aggregate distribution and stability in different particle-size classes was performed according procedure proposed by EMBRAPA (1979): the soil sample is disposed over a kit of several sieves adapted to a device (Yoder, 1936) that promotes a vertical oscillation at 40 rpm within a recipient filled with water, during 30 minutes, resulting aggregates with diameters ranging from 6.35 to 2.00 mm; 2.00 to 1.00 mm; 1.00 to 0.50 mm; 0.50 to 0.250 mm and 0.250 to 0.125 mm. The ponderal median diameters (PMD) were calculated according to KIEHL (1979).

Soil macroporosity and soil density data were submitted to analysis of variance in a completely randomized design with 10 replications. The samples were collected between rows, within a minimum distance of 25 m, and were statistically evaluated by paired mean contrasts using the Student t test ($P < 0.05$).

RESULTS AND DISCUSSION

Morphology and granulometry

Soil profile morphological descriptions along the selected toposequences evidenced finer texture classes in the lower third of the slope, which should be due to possible lateral clay translocation along the hillside (Soares, 2001).

Dark-reddish brown (2.5YR 3/4 wet) was the predominant soil color, except for B1, B2 and Bw in profile 1, and Bw1 in profile 2 that were dark red (2.5YR 3/6 wet). The dark red color in deeper layers is due to a more intense iron oxide influence from basaltic alterations which were similar to the Bw soils studied by Cooper (1999) (Table 1).

Table 1 - Soil morphological attributes.

Horizon		Color	Texture*	Structure	Consistence			Transition
					Dry	moist	saturated	
	m			Profile 1 - Upper third slope				
Ap	0-0.09	Dark reddish-brown, 2.5YR 3/4	Sandy	Granular, small, weak, and single grains	Loose to soft	Loose to highly friable	Slightly plastic and sticky	Wavy and abrupt
BA	0.09-0.45	Dark reddish-brown, 2.5YR 3/4	Sandy	Massive that breaks into medium blocks	Very hard	Highly friable	Slightly plastic and sticky	Plane and gradual
B1	0.45-0.75	Dark red, 2.5YR 3/6	Medial	Subangular blocks, medium, weak, weak waxy	Hard to slightly hard	Highly friable	Plastic and sticky	Plane and gradual
B2	0.75-0. 95	Dark red, 2.5YR 3/6	Medial	Subangular blocks that break in medium blocks	Slightly hard	Highly friable	Plastic and sticky	Plane and gradual
Bw	0.95-1.30	Dark red, 2.5YR 3/6	Medial	Granular, very small, weak	Soft	Highly friable	Plastic and sticky	
				Profile 2 - Medium third slope				
Ap1	0-0.08	Dark reddish-brown, 2.5YR 3/4	Medial	Medium blocks, moderate and granular, medium to small, moderate, and single grains	Hard	Friable	Plastic and sticky	Soft and gradual
Ap2	0.08-0.38	Dark reddish-brown, 2.5YR 3/4	Medial	Compact blocks, large and medium, weak waxy	Extremely hard	Firm	Plastic and sticky	Soft and gradual
Bw1	0.38-0.70	Dark red, 2.5YR 3/6	Clayey	Medium blocks, moderate that break	Hard	Friable	Plastic and sticky	Soft and gradual
Bw2	0.70-1.30	Dark reddish-brown, 2.5YR 3/4	Clayey	Microgranular, small, moderate	Soft	Highly friable	Plastic and sticky	
				Profile 3 - Lower third slope				
Ap	0- 0.10	Dark reddish-brown, 2.5YR 3/4	Medial	Granular, medium to large, moderate to strong	Loose and soft	Loose to highly friable	Very plastic and very sticky	Wavy and abrupt
AB	0.10-0.40	Dark reddish-brown, 2.5YR 3/4	Clayey	Large compact blocks	Extremely hard	Very firm	Very plastic and very sticky	Plane and gradual
Bt	0.40-0.95	Dark reddish-brown, 2.5YR 3/4	Clayey	Blocks, medium to moderate, weak waxy	Hard	Friable and firm	Very plastic and very sticky	Plane and gradual
Bw	0.95-1.30	Dark reddish-brown, 2.5YR 3/4	Clayey	Microaggregate, granular, small, weak	Soft	Highly friable	Very plastic and very sticky	

*Texture determined in field by the tactile method.

Fine particle translocation from higher positions in the slope, favoring clay re-orientation, is compatible with the weak clay-film (or clay-coat) attribute in latossolic to textural transition horizons, inferring that these are transitional soils (Bw/Bt) in the lower relief positions. The presence of microaggretates is common, in this position which in accordance to Sánches (1981), is favored by iron oxides, thus forming grains of the same size of sand, which might cause relatively high values in the sand fraction or pseudo-sand particles (Espindola & Galhego, 1981).

Soils from the higher positions had a more expressive sandy texture, with granular structure and loose grains at the surface, laid on a block structure with compacted layers, resistant to root penetration, which is visible through morphological and micromorphological analysis. The amount of washed sand observed in the Ap horizon might be due to a residual quartz grain due to downward clay movement, enhanced by frequent soil mobilization. High levels of natural clay or water-dispersed clay are suggestive of possible colloid mobility (Table 2)

Porosity was an attribute extremely reduced in compacted blocks; however, it was high in sub-adjacent horizons, with presence of galleries and macropores in sub-surface horizons. There are thin and medium roots along all profiles, even in virtually compacted layers, with

Table 2 - Soil granulometric attributes.

Horizon		Granulometry				Textural Class	Natural clay	Organic matter
		Coarse sand	Fine sand	Silt	Clay			
Profile 1 - Upper third slope								
----------- m -----------		----------------- g kg^{-1} -----------------					----------- g kg^{-1} -----------	
Ap	0-0.09	360	450	50	140	Sandy loam	140	140
BA	0.09-0.45	350	440	60	150	Sandy loam	140	120
B1	0.45-0.75	300	420	80	200	Sandy clay loam	200	90
B2	0.75-0.95	340	400	40	220	Sandy clay loam	220	80
Bw	95-130	310	410	60	220	Sandy clay loam	210	70
Profile 2 - Medium third slope								
Ap1	0-0.08	290	380	70	260	Sandy clay loam	260	120
Ap2	0.08-0.38	270	400	70	260	Sandy clay loam	260	120
Bw1	0.38-0.70	230	350	90	330	Sandy clay loam	50	70
Bw2	0.70-1.30	260	340	70	330	Sandy clay loam	0	90
Profile 3 - Lower third slope								
Ap	0-0.10	270	310	100	320	Sandy clay loam	300	170
AB	0.10-0.40	280	300	90	330	Sandy clay loam	310	170
Bt	0.40-0.95	220	270	90	420	Sandy clay	0	90
Bw	0.95-1.30	210	270	100	420	Sandy clay	0	70

large roots, presenting a tendency of horizontal growth, as well as along the weakness planes and cracks among blocks. Similar observations were made by Lima (1995), studying modifications in Oxisols attributes, cultivated with sugarcane in the State of São Paulo. Granulometric analysis revealed an abrupt change in clay levels from A to B layers in soils at lower position. In this way, along the slope clay content increased downwards, moving from sandy-loam (layers Ap and BA in the upper profile) to sandy-clay-loam in the other profiles, except for the horizons Bt and Bw from the lower third profile, which presented sandy-clay texture.

Aggregate stability in water

The aggregates or secondary particles are sand, silt and clay particles from the mineral fraction grouped with organic matter (the humificated fraction) under the influence of iron oxides as cementing agent (Harris et al., 1966; Guerif, 1986).

In the superficial layers, agricultural soil management effects might be related to the macroestructure decay favoring smaller diameter (< 2 mm) aggregates (Aina, 1979). Under these conditions, pulverization of soil constituents may occur, accompanied by the reduction in organic matter and consequent formation of larger diameter aggregates (Russel & Russel, 1961). There was a considerable decrease in soil aggregate stability under intensive cultivation. To exemplify this fact, at the soil surface only 7.5%, 3.6% and 11.7% of larger than 2 mm-aggregates in were found the upper, medium and lower layers respectively (Table 3).

More than 80% of the aggregates was comprised in the median diameter (< 1.00 mm). The aggregate accumulation in classes lower than 1.00 mm in diameter occur in cultivated land because they are more stable under fast wetting and are not destroyed by well conducted agricultural practices (Tisdal & Oades, 1982).

In the upper third slope, the continuous soil usage caused favorable conditions to <1.00 mm-aggregate formation, which were little affected by management actions. Clay contents in these soils were higher than those found by Soares & Espindola (2001) in a neighbour area under native forest. Even though in the surface layer of soils under forest the PMD was clearly higher, around 3.4 mm, while in the present soil it was 0.55 mm, with less than 20% of <1.00 mm-diameter aggregates in the soil under forest. This value reached almost 80% in cultivated areas, which evidence the relevance of organic matter on aggregate size and stability. Large reduction in aggregate size and stability is observed when native forest is substituted by cultivated land.

The most expressive PMD values were observed in the lower third slope, under relief conditions that favored a more clayey environment. The resistence to external applied forces is dependent upon the organization of elemental constituents as clay and iron oxides (Guerif, 1986). In general, soils presented aggregation indexes (PMD) higher than 0.5 mm, which, as stated by Kiehl (1979) are relatively more resistent to brittling and dispersion, thus, less susceptible to pedologycal attribute alterations when submitted to agricultural management.

Soil porosity and density

Soil bulk porosity had a lower average in the upper third slope, clearly associated to a more sandy texture. The micropore volume was also smaller as a consequence of weak soil structure in this landscape (Table 4). Higher values were observed in deeper layers and in lower slope positions corresponding to 0.50 m^3 m^{-3}. In these layers, average microporosity increased, indicating a higher proximity among primary and secondary particles, favored in clayey environments.

The agricultural machinery traffic caused modifications in aggregate size, which is intimately related to the small to large pore ratio (Silva & Mielniczuk, 1998). In the surface layers, average macroporosity was not different (P < 0.05) among relief positions. The same occurred for soil density, which might be due to intensive management practices in the sugarcane crop, making the soil upper layers more uniform (Lucarelli, 1997). In the soil sub-surface, macroporosity was higher in more sandy areas (0.138 m^3 m^{-3}) revealing sand fraction importance to this attribute (Table 5). The smaller values were found in the slope medium third (0.100 m^3 m^{-3}), which was considered by Vomocil & Flocker (1966) as a critical limit to sustain satisfactory production conditions.

Table 3 - Water stable aggregate distribution.

Toposequence position	Depth	Aggregate size (mm)						PMD*
		6.35 - 2.00	2.00 - 1.00	1.00 - 0.50	0.50 - 0.25	0.25 -0.125	< 0.125	
	m	kg kg^{-1}						mm
Upper third	0-0.1	0.075	0.060	0.125	0.299	0.262	0.179	0.6696
	0.2-0.3	0.061	0.048	0.085	0.300	0.341	0.165	0.5784
	0.6-0.7	0.051	0.043	0.131	0.298	0.273	0.204	0.5536
Medium third	0-0.1	0.036	0.082	0.170	0.294	0.209	0.209	0.5564
	0.2-0.3	0.026	0.039	0.103	0.254	0.196	0.382	0.3970
	0.6-0.7	0.108	0.084	0.161	0.245	0.215	0.187	0.8428
Lower third	0-0.1	0.117	0.155	0.225	0.234	0.140	0.129	1.0099
	0.2-0.3	0.176	0.132	0.163	0.216	0.147	0.166	1.1650
	0.6-0.7	0.150	0.177	0.221	0.195	0.117	0.140	1.15880

*PMD (ponderal median diameter).

Table 4 - Soil porosity in a sugarcane area (ten replicate averages).

Toposequence position	Soil porosity *								
	0-0.1 m			0.2-0.3 m			0.6-0.7 m		
	BPd	Mp	mp	BPd	Mp	mp	BPd	Mp	mp
	m^3 m^{-3}								
Upper third	0.43	0.20	0.23	0.40	0.14	0.26	0.40	0.13	0.27
Medium third	0.46	0.17	0.29	0.43	0.10	0.33	0.47	0.14	0.33
Lower third	0.49	0.16	0.33	0.49	0.11	0.38	0.50	0.16	0.34

*BPd – Bulk porosity, Mp – Macroporosity and mp – Microporosity.

Table 5 - Soil macroporosity and density in relation to relief position in a sugarcane area*.

Toposequence position	Soil macroporosity			Soil density		
	0-0.1 m	0.2-0.3 m	0.6-0.7 m	0-0.1 m	0.2-0.3 m	0.6-0.7 m
	m^3 m^{-3}			kg dm^{-3}		
Upper third	0.201 a	0.138 a	0.127 a	1.267 a	1.512 a	1.666 a
Medium third	0.169 a	0.100 b	0.141 a	1.299 a	1.485 a	1.504 b
Upper third	0.201 a	0.138 a	0.127 b	1.267 a	1.512 a	1.666 a
Lower third	0.167 a	0.114 a	0.159 a	1.374 a	1.423 a	1.288 b
Medium third	0.169 a	0.100 b	0.141 b	1.299 a	1.485 a	1.504 a
Lower third	0.167 a	0.114 a	0.159 a	1.374 a	1.423 a	1.288 b

*Means followed by the same letters do not differ by t test (P < 0.05).

In the deeper and more clayey soil layers there was a macroporosity difference ($P < 0.05$) along the toposequence, with higher values in the lower third slope (0.159 $m^3 m^{-3}$), corresponding to lower soil density values (1.288 kg dm^{-3}) and higher aggregate stability.

Water infiltration in the soil

The water infiltration rate in the soil is the major pedological attribute to detect soil alterations due to cultivation (Cintra et al., 1983), which is here confirmed, since the infiltration rate was affected by the relief position and agricultural practices (Table 6).

Water infiltration rate in the surface layer (0 – 0.1 m) in the medium third slope was 3.5 mm min^{-1} (Table 6). This low rate might be attributed to soil structure degradation as a consequence of soil compactation by intense sugarcane agricultural practices. In a similar soil type and relief, but under citrus exploitation, which is a less demanding species, Soares (2001) found water infiltration rates of 21.2 mm min^{-1}. In the present research, values of 13.25 mm mm^{-1} were found in the surface layer in the upper third slope, due to sandy texture in this relief position.

Table 6 - Water infiltration in a sugarcane soil field determined through the Guelph permeameter (hydraulic pressure of 6 cm).

Toposequence position	Soil depth		
	0-0.1 m	0.2-0.3 m	0.6-0.7 m
	mm min^{-1}		
Upper third	13.25	3.50	29.25
Medium third	3.50	4.25	30.50
Lower third	4.25	4.50	14.75

In the 0.2 to 0.3m-depth layer smaller water infiltration rates were observed, with average values of 3.5 mm min^{-1}, while in a neighboring area under native forest, Soares & Espindola (2001) found 58 mm min^{-1}. This low value might be explained by the intensive sugarcane machinery use, with frequent surface soil revolving, thus reducing sub-surface macroporosity. Another fact to be taken into account is the organic matter reduction endangering soil aggregation and increasing filling up of empty spaces with water dispersed clay from higher relief positions.

Profile evaluation at 0.6 to 0.7 m depth presented higher average values of water infiltration with a downward decrease tendency, probably due to the small effect of cultural practices and to higher clay content in deeper layers, which might explain aggregate resistence to applied external forces (Guerif, 1986). Clay content facilitates the unitary particle aggregation which, according to Dexter (1988) is the upmost factor in soil structure stabilization.

The lower water infiltration rates in lower density soil sites and higher macroporosity are due to non-connected pores with low pedality, which difficults water infiltration. This situation is explained by micromorphological analysis that also identified a transition Bw/Bt (Table 7).

Micromorphological observations

Thin layer microscope observations revealed alterations in porous space geometry, due to agricultural practices, negatively affecting agricultural land. The natu-

Table 7 - Some soil micromorphological attributes.

Soil depth m	Matrix context	Micro-structure and pedality	Porosity	Associated structures
		Profile 2 - Upper third slope		
0.2-0.3	Enaulic matrix background associated to gefuric forms	Sub-angular blocks and moderate pedality	Piled-pores and unconnected macropores	Biological macropores
0.6-0.7	Enaulic matrix background with gefuric sites	Oval and spheric micro-aggregates with strong pedality	Inter-aggregated and connected pores	
		Profile 4 - Medium third slope		
0.2-0.3	Porphyric matrix background	Sub-angular blocks and weak pedality	Piled-pores and micro-crakings	Organic and ferruginous material
0.6-0.7	Enaulic matrix background with porphyric sites	Round micro-aggregate with strong pedality	Inter-aggregated macropores	Illuvial clay coats
		Profile 6 - Lower third slope		
0.2-0.3	Porphyric matrix background	Micro-structure in blocks and weak pedality	Isolated macropores and planar pores	Illuviation cutans and isotic plasma
0.6-0.7	Enaulic and Porphyric matrix background	Micro-structure with strong pedality / structure in blocks with weak pedality	Intra and Inter-aggregated pores	Bw/Bt transition environment

rally constituted pedological structures and those modifications due to agricultural management are presented in Table 7.

The compactation defined in the morphological subsurface field analysis was confirmed by the microaggregate proximity, with craking and decreased porosity, giving rise to planar pores (Figures 2 and 4), which explain the great water infiltration rate reduction (Lima, 1995). Some soil resistence was also observed altering its structure, the probable cause being related to the mineralogical composition (presence of iron oxides) favoring higher resistance mainly of small aggregates (diameter < 250 (m) Tisdal & Oades (1980).

A macroporosity decrease was also observed in the subsurface horizon due to alteration in pore cavities caused by intense agricultural use, since in deeper layers these effects are rarely noticed. The crushing and the filling of empty spaces originated cracked forms and a block structure in an originally microaggregate site. Micropores of the neighbor soil under forest are irregular and interconnected (Soares & Espindola, 2001); those seen in this research were probably also similar before agricultural use, being, now planar and disconnected.

Comparing soil photomicrographs of several relief positions, a higher clay concentration is confirmed in the lower slope positions, with well-defined attributes in the chromas of deeper layers, clay illuviation being also evident (Figure 3) and Bw/Bt transition in the toposequence basis (Figure 5). The original soil structure was modified where anthropic action was stronger, resulting blocks and prisms along with a porphyric matrix background (Figures 2 and 4).

Micromorphological analysis allowed the evaluation of the magnitude of the subsurface compactation; these observations evidenced that macroporosity decreases neither represented a strong restriction to root growth nor to microbiological activities. Compactation did not affect the micropore environment and isolated macropores might guarantee soil soluction flow (Figure 1).

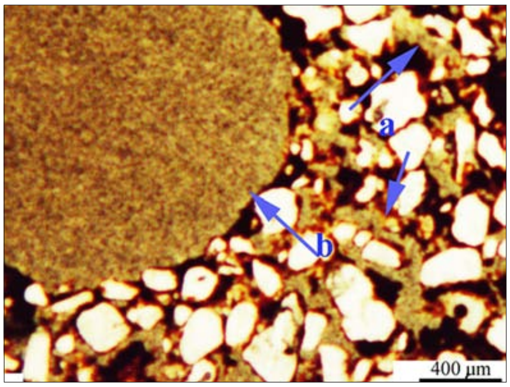

Figure 1 - Soil photomicrograph of the upper third-toposequence at the 0.2-0.3 m depth: (a) flattened macropores and (b) isolated biological pores.

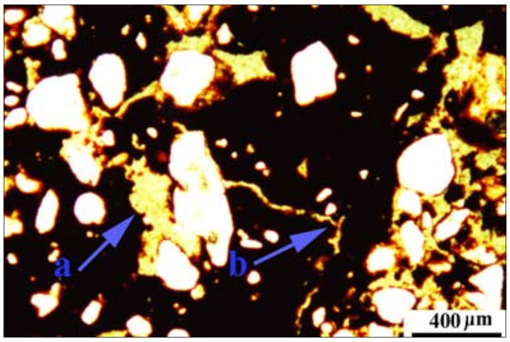

Figure 2 - Soil photomicrograph of the medium third-toposequence at the 0.2-0.3 m depth: (a) unconnected pores and (b) planar and oblique microcracking.

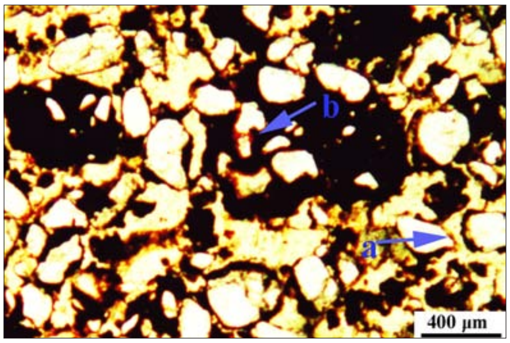

Figure 3 - Soil photomicrograph of the medium third-toposequence at the 0.6-0.7 m depth: (a) connected irregular pores and (b) illuvial clay coat.

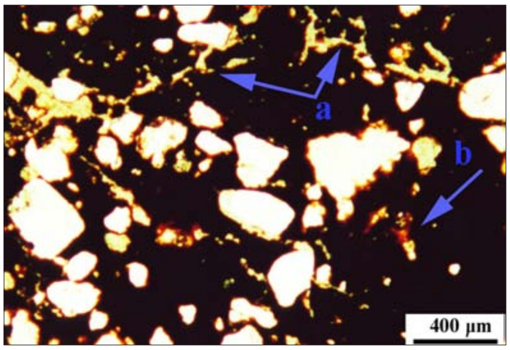

Figure 4 - Soil photomicrograph of the lower third-toposequence at the 0.2-0.3 m depth: (a) porphyric matrix background and intra-aggregated cracks; and (b) clay cutans (ferri-argilan).

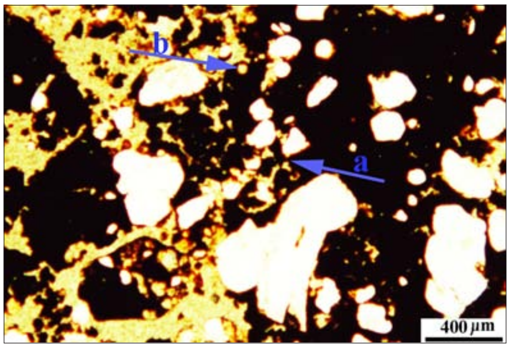

Figure 5 - Soil photomicrograph of the lower third-toposequence at the 0.6-0.7 m depth, transition horizon Bw/Bt: (a) enaulic matrix background, micro-aggregate structure, strong pedality; and (b) porphyric matrix background.

CONCLUSIONS

Porosity was low in soil subsurface and high in subjacent horizons, presenting biological galleries and isolated macropores; compacted horizons showed granular structure sites.

The intense machinery traffic reduced the subsurface water infiltration capacity. Higher values were found in more stable structure positions with higher clay contents.

The tradicional surgacane management caused aggregate size modifications, with an increase in of micro/macropore ratio.

Physical attribute alterations were more evident at soil surface, at higher relief positions, where cementing material mobilization to lower positions was observed, decreasing aggregate stability.

REFERENCES

AINA, P.O. Soil changes resulting from long-term management practices in Western Nigeria. **Soil Science Society of America Journal,** v.43, p.173-177, 1979.

BERTOLANI, F.C. Caracterização física dos solos de uma microbacia degradada em Vera Cruz, SP. Campinas: UNICAMP/FEAGRI, 1998. 85p. (Dissertação - Mestrado).

BULLOCK, P.; FEDOROFF, N.; JONGERIUS, A.; STOOPS, G.; TURSINA, T. **Handbook for soil thin section description.** London: Waine Research Publication, 1985. 152 p.

CASTRO, S.S. **Micromorfologia de solos**: Pequeno guia para descrição de lâminas delgadas. São Paulo: USP/FFLCH, 1989, 87p. (Boletim Informativo).

CENTURION, J.F.; DEMATTÊ, J.L.I. Efeitos de sistemas de preparo nas propriedades físicas de um solo sob cerrado cultivado com soja. **Revista Brasileira de Ciência do Solo**, v.3, p.263-266, 1985.

CINTRA, F.D.L.; MIELNICZUK, J.; SCOPEL, I. Caracterização do impedimento mecânico em um Latossolo Roxo do Rio Grande do Sul. **Revista Brasileira de Ciência do Solo**, v.7, p.323-327, 1983.

COOPER, M. Influência das condições físicas-hídricas nas transformações estruturais entre horizontes B latossólico e B textural sobre diabásio. Piracicaba: USP/ESALQ, 1999. 128p. (Tese - Doutorado).

DEXTER, A.R. Advances in characterization of soil structure. **Soil & Tillage Research**, v.11, p.199-238, 1988.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. Serviço Nacional de Levantamento e Conservação de Solos. **Manual de métodos e análise de solo**. Rio de Janeiro: EMBRAPA, CNPS, 1979.

ESPINDOLA, C.R.; GALHEGO, H.R. Pseudo-partículas texturais em solos basálticos da região Central do Estado de São Paulo. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 18., Salvador, 1981. **Resumos.** Salvador: SBCS, 1981. p.22-23.

GUERIF, J. Résistance en traction des agrégats terreux: influence de la texture, de la matière organique et de la teneur en eau. **Agronomie**, v.8, p.379-386, 1986.

HARRIS, R.F.; CHESTERS, G; ALLEN, N. Dynamics of soil aggregation. **Advances in Agronomy**, v.18, p.107-169, 1966.

HÉNIN, S.; FEODOROFF, A.; GRAS, R.; MONNIER, G. **Le profil cultural:** Principles de physique du sol. Paris: Masson, 1960. 320p.

KIEHL, E.J. **Manual de edafologia:** Relações solo-planta. São Paulo: Ceres, 1979. 262p.

INSTITUTO DE PESQUISAS TECNOLÓGICAS DO ESTADO DE SÃO PAULO. **Mapa geológico do estado de São Paulo.** São Paulo: IPT, 1981. Escala 1:50.000.

LIMA, J.M.J.C.L. Alterações das propriedades dos solos cultivados com cana-de-açúcar. Piracicaba: USP/ESALQ, 1995. 164p. (Tese - Doutorado).

LUCARELLI, J.R.F. Alterações em características de um Latossolos Roxo submetido a diferentes sistemas de manejo. Campinas: UNICAMP/ FEAGRI, 1997. 87p. (Dissertação - Mestrado)

REYNOLDS, W.D.; ELRICK, D.E. In situ measurement of field-satured hydraulic conductivity, sorptivity and the a-permeameters using the Guelph permeameter. **Journal of Soil Science**, v.140, p.292-302, 1985.

SÁNCHES, P.A. **Suelos del tropico:** Características y manejo**.** San José: IICA, 1981. 634p.

SILVA, I.F.; MIELNICZUK, J. Sistemas de cultivo e características do solo afetando a estabilidade de agregados. **Revista Brasileira de Ciência do Solo**, v.22, p.311-317, 1998.

SOARES, J.L.N. Degradação de solos cultivados ao longo de uma seqüência topográfica em Bariri, SP. Campinas: UNICAMP/FEAGRI, 2001. 157p. (Tese - Doutorado).

SOARES, J.L.N.; ESPINDOLA, C.R. Atributos físicos de um argissolo sob mata nativa em Bariri, SP. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 28., Londrina, 2001 **Resumos.** Londrina: SBCS. 2001. p.18.

RUSSEL, E.J.; RUSSEL, R.W. **Soil conditions and plant growth**. 9.ed. London: Longmam & Green, 1961. 770p.

TAVARES FILHO, J.; RALISCH, R.; GUIMARÃES, M.F.; MEDINA, C.C.; BALBINO, L.C.; NEVES, C.S.V.J. Método do perfil cultural para avaliação do estado físico de solos em condições tropicais. **Revista Brasileira de Ciência do Solo**, v.23, p.393-399, 1999.

TISDAL, J.M.; OADES, J.M. The management of ryegrass to stabilize aggregates of a red-brown earth. **Australian Journal of Soil Research**, v.18, p.415-422, 1980.

TISDAL, J.M.; OADES, J.M. Organic matter and water-stable aggregates in soils. **Journal of Soil Science**, v.33, p.141-163, 1982.

VOMOCIL, J.A.; FLOCKER, W.J. Effect of soil compaction on storage and movement of soil, air and water. **American Society for Agricultural Enginnering**, v.4, p.242-246, 1966.

YODER, R.E. A direct method of aggregate analysis of soil and a study of the physical nature of erosion losses. **Journal of American Society**, v.28, p.337-351, 1936.

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