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Soil structure evolution under two soil management systems in a clay oxisol from Cerrado region

Évolution de la structure d'un sol ferrallitique argileux de la région des Cerrados sous deux systèmes de culture

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The sustainability of crop production in oxisols of Cerrado Region depends on the understanding of soil structural evolution processes. Modifications in soil structure were followed for 4 years allowing the comparison of two soil management systems: conventional plowing with heavy disk harrow (**CCL**), and zero-tillage (**PDC**). Structural characterization was achieved by morpho-structural analysis, allowing the identification of horizons and homogeneous pedological units (***HPU***). From samples taken from most representative HPUs it were performed: pH, acidity, CEC, nutrient status, bulk and particle densities, pore size distribution from pF curves, pedo-structural characteristics from soil swelling curves, organic matter status, and micromorphological observations.

Morphological differences were identified between surface horizons. Under **CCL**, the structural state evolved to a compaction, with well developed angular blocky ***HPU***s, high inter-aggregate cohesion and a sufficient macroporal space. Root growth and crop performance, however, were menaced by the lack of pore continuity. In **PDC**, results have shown an improvement in soil structure, with moderate resistance and inter-aggregate cohesion, and well developed subangular blocky ***HPU***s. Pore space, besides being not different from compacted horizons found in **CCL**, have a favorable continuity. Significant gains in yields were observed in **PDC**, showing a better nutrient status. Benefit/cost relationship in **PDC** has enhanced net income, reflecting the better structural condition.

Soil structure evolution studies were important to verify the improvement in soil quality and health under no-till, an alternative soil management system for sustainable crop production in Brazilian Cerrado Region.

Keywords : oxisols, cerrado region, structure evolution, management systems, morpho-structural analysis, tropical acid savannas
Mots clés : sol ferrallitique, cerrado, structure, gestion des sols, morphologie, savanne, système de culture

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Introduction

The Cerrado Region, present in 23 % of Brazil's Territory, constitutes the equilibrium among the different morphoclimatic and phytogeographical dominions of South America. Nowadays, this region is partially occupied by poor native and improved pastures (110 million ha), annual and perennial crops, including reforestation (16 million ha), and no more than 78 million ha under natural vegetation, which varies between open grassland to isolated areas of closed forests.

Under natural vegetation, morpho-structural analysis shows that Oxisols[1], which predominates and are the most utilized soils in the region, present favorable physical characteristics, such as depth, aeration and elevated porosity, leading to a rapid internal drainage and easy cultivation (Blancaneaux et al., 1993). These factors, associated with a gently undulated relief, confer to these soils an elevated potential for an intensive mechanized agriculture, since their chemical deficiencies are corrected. The intensive and rational occupation of the region would make it possible to produce more than 9 million t of meat and 150 million t of grains (Goedert et al., 1980). However, when cultivated, these soils present modifications in their physical-hydric behavior, causing severe degradation, accentuated with the use of inadequate soil management systems, leading to soil compaction and water erosion (Freitas, 1994). In this manner, conventional or traditional crop management systems utilized in the region based upon tillage with disks (plow or harrow) are threatening the potential yield of crops (Goedert and Lobato, 1986). The reduction soil production capacity is a consequence of intensive and continuous utilization of inappropriate agricultural equipment in soil tillage operations. Zero-tillage, with direct seeding into crop residues, associated with other practices (crop rotation or succession, cover crops, integrated pest, disease and weed control, etc.) is reversing

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[1] **Latossolos in the Brazilian classification; Sols ferralitiques typiques in the French; Oxisols in the 7th approximation (USA); and, Ferrisols for the FAO classification.**

these trends. Considering its fragility, the sustainability of crop production in oxisols of the Cerrado Region, depends on understanding the evolution processes in soil structure under cultivation.

Material and methods

This study was carried out in the region of Goiânia, Center-West Region of Brazil, where acid savanna vegetation, called "Cerrado", predominates. The main part of this region is characterized by a sub-humid (wet/dry) tropical climate, with an average precipitation of 1500 mm, concentrated in the period of October to April. In this location, a clayey dystrophic dark-red oxisol (Typic Haplustox) predominates, mainly in gently undulated topography, developed under a detric-lateritic covering from the Quaternary period. It is a deep soil where kaolinite and iron oxides predominates.

Alterations in soil structure were followed over four years allowing the comparison of two soil management systems in experimental plots with an annual crop succession of corn (Zea mays L.) and irrigated common beans (Phaseolus vulgaris):

a. **CCL** – Conventional soil tillage system with heavy disk harrow plowing, 10 to 15 cm deep, followed by disk harrowing, with non-selective herbicide incorporation.
b. **PDC** – Zero-tillage system, with direct seeding into the preceding crop residues and weed control with a non-selective systemic herbicide (glyphosate).

morpho-structural analysis

This non-conventional procedure, proposed for Brazilian tropical acid savanna soils, allowing the identification of pedological horizons, as well as the description and characterization of homogeneous pedological units (HPUs), was utilized for structural studies. Characterizations were carried out in October 1991 (two years after experimental plot installation) and August 1994.

In samples taken from the most representative HPUs, in selected pedological horizons, were determined: chemical properties (pH, acidity, nutrient status, CEC, C and N); bulk and particle densities (EMBRAPA, 1979); pore size distribution based on soil water retention (pF) curves (Freitas and Blancaneaux, 1994); and, pedo-structural characteristics, based on soil swelling curves (Braudeau, 1993). Organic matter status was studied by the physical fractionation proposed by Feller et al. (1991) and described by Gavinelli et al. (1995).

Results and Discussion

The set of observations obtained allows us to compare two long-term management systems by observing the differences between conventional (**CCL**) and zero-tillage (**PDC**) systems, studied in experimental plots under controlled and essentially equal initial situations. Soil morphological description of different pedological horizons or layers under the situations considered allows us to verify the evolution of a clayey dark-red oxisol, by comparison with the soil under natural savanna vegetation. In this situation, described by Freitas et al. (1996), a very fragile blocky structure is observed, with a weak cohesion (weak fine to medium subangular blocky structural elements), as well as a strong fine granular substructure, characteristic of this microaggregated oxisol. The observation of structural modifications of this soil under cultivation is possible by the analysis of its morpho-structural condition (Fig. 01).

Under conventional management system (**CCL**) the processes of a structural degradation of the soil as a compacted layer was observed. The strong subangular blocky structure observed in 1991 has developed to strong angular blocky in the *Ap_2B* horizon (12 to 30 cm deep) restricting organic matter and biological activity to superficial horizons. In deep horizons (*BA* and *Bw*), structural condition is the same as check situation (weak to moderated subangular blocks which breaks into strong fine granular). This degradation restricts root growth and biological activity below the depth of 12 cm, affecting water movement, besides being apparently porous. For the zero tillage system (**PDC**), the modification of a rounded crumb structure in the surface (*Ap_1*) into rounded crumbs associated with small/medium subangular blocks was observed. In subsuperficial horizons (*Ap_2* and *Ap_2B*), structure has been described as strong subangular blocky, with some alterations in the substructure when we compare 1991 and 1994, modifying from subangular to subangular with tendency to angular blocky. This was observed in a relatively dense and still porous layer (*Ap_2B*), allowing a deeper root growth below 25 cm. In complementary observations, organic matter has been described as common to abundant and biological activity as very strong and strong throughout the profile in both characterizations.

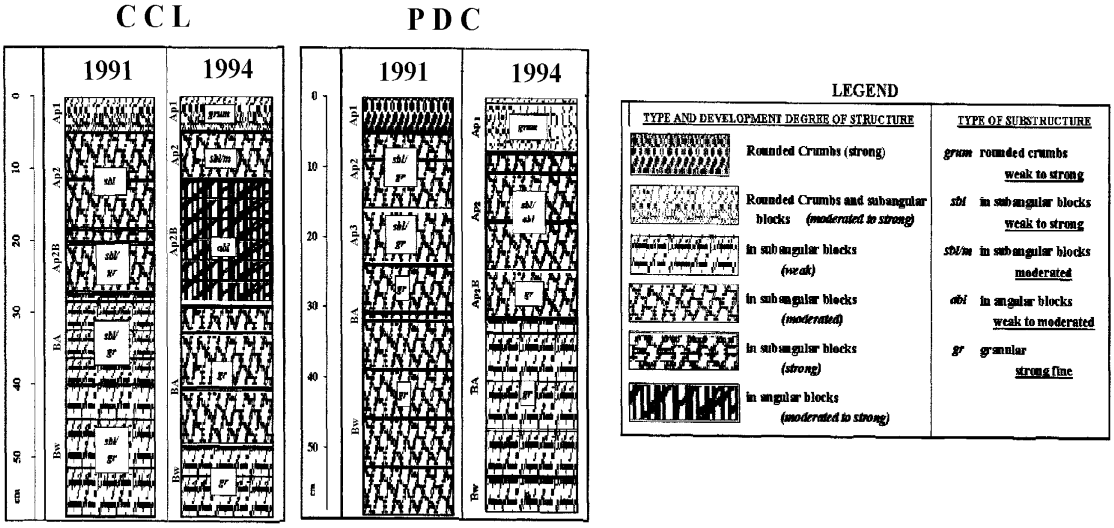

Fig. 1. Schematic morphological description of the main HPUs of each horizon identified in 1991 and 1994 including structure and substructure (after Freitas **et al. 1997)**

Soil morphological description allowed the identification of different soil horizons, which have been differentiated by their color (in relation with the presence of organic matter) and structural state (degree of development, predominant size and type of structural elements, as well as substructure). Based on this, samples were collected, representing the main HPU identified in the layers more susceptible to the effect of soil management, where a series of chemical and physical-hydric determinations was run.

Chemical properties

Table 1 shows that, after two years of cultivation (1991), it has been a relative enhancement in superficial layers in **CCL** and **PDC**. However, a better P distribution in **PDC** in depth is clear when compared to **CCL**. There is a tendency of a better P distribution in superficial layers, mainly in 1994. In **CCL** an accumulation of P up to

12 cm, is observed, probably related to the organic material in surface horizons (Muzilli, 1981). The dilution effect of P in soil layers observed should be analyzed based on soil P fractionation, since organic fraction has been given as the key to understand P use efficiency by plants (Silva et al., 1996). Significant gains in yields were observed in **PDC**, showing a better nutrient status.

Physical-hydric properties

Table 2 presents the data obtained in 1991 and 1994. In **CCL**, bulk density has been constant throughout the profile. In superficial horizons (Ap_1, Ap_2 and Ap_2B), density values were high, even for samplings carried out 45 days after soil tillage with heavy disk harrow. Bulk densities in subsuperficial horizons (*BA* and *Bw*) were considered elevated in comparing with reference profiles (1,09 kg.dm^{-3}).

In **PDC**, high values were observed in 1991 in surface horizons (1.37 and 1.38 kg.dm^3), not representing a severe physical impedance considering the root growth observed and the strong subangular blocky structure described. In 1994, density values were still high in Ap_2 horizon (8 to 25 cm deep) without any restriction to root growth.

		Horizon	Depth	pH	H+Al^1	Ca+Mg	K	S	CEC^2	P^3	C^4	N
			cm	H_2O			cmol.kg^{-1}			mg.kg^{-1}	g . 1 0 0	g^{-1}
1991	**C C L**	***Ap₁***	0- 5	**5.4**	**5.9**	**2.6**	**0.62**	**3.3**	**9.2**	**24**	**1.60**	**0.09**
		Ap₂	5 - 19	**4.9**	**6.6**	**1.1**	**0.31**	**1.4**	**8.0**	**9**	**1.55**	**0.07**
		AB	19-28	**4.9**	**4.6**	**1.0**	**0.12**	**1.1**	**5.7**	**1**		
		BA	28-41	**5.0**	**4.0**	**0.9**	**0.08**	**1.0**	**5.0**	**1**	**0.89**	**0.04**
		Bw	41-60	**5.4**	**2.8**	**1.0**	**0.04**	**1.1**	**3.9**	**1**		
	P D C	***Ap₁***	0 -5	**5.7**	**5.6**	**3.8**	**0.39**	**4.2**	**9.8**	**35**	**1.39**	**0.13**
		Ap₂	5-16	**5.5**	**6.4**	**2.4**	**0.24**	**2.7**	**9.1**	**34**	**1.27**	**0.12**
		Ap₃	16-24	**5.2**	**6.6**	**1.3**	**0.11**	**1.4**	**8.0**	**12**	**1.05**	**0.10**
		Bw	24-31	**4.8**	**4.6**	**0.6**	**0.07**	**0.7**	**5.3**	**1**	**0.49**	**0.08**
1994	**C C L**	***Ap₁***	0-5	**5.5**	**6.3**	**2.5**	**0.70**	**3.2**	**9.5**	**26**	**1.78**	**0.16**
		Ap₂	5-12	**5.3**	**6.4**	**2.3**	**0.43**	**2.8**	**9.2**	**41**	**1.72**	**0.15**
		Ap₂B	12-30	**4.7**	**6.6**	**0.9**	**0.12**	**1.0**	**7.6**	**11**	**1.43**	**0.12**
		BA	30-50	**4.8**	**4.4**	**0.8**	**0.10**	**0.9**	**5.3**	**1**	**0.94**	**0.09**
		Bw	50-70	**5.3**	**2.1**	**1.3**	**0.05**	**1.4**	**3.5**	**1**	**0.57**	**0.07**
	P D C	***Ap₁***	0-8	**5.7**	**5.4**	**3.0**	**0.46**	**3.5**	**8.9**	**29**	**1.74**	**0.17**
		Ap₂	8-25	**5.1**	**5.6**	**1.2**	**0.12**	**1.3**	**6.9**	**10**	**1.33**	**0.14**
		AB	25-32	**5.1**	**3.6**	**0.8**	**0.09**	**0.9**	**4.5**	**1**	**0.88**	**0.11**
		BA	32-55	**5.4**	**3.6**	**0.9**	**0.08**	**1.0**	**4.6**	**1**	**0.72**	**0.09**

[1] ***Potential acidity at pH 7 with calcium acetate***

[2] ***CEC based on H+Al determined at pH 7 with calcium acetate***

[3] ***Exchangeable P in solution of KCl 0,05** N + H_2SO_4 0,025 N*

[4] *Organic Carbon determined by digestion with dichromate*

Table 1. Soil chemical characteristics of described horizons in 1991 and 1994

Modification in pore size distribution were observed considering four equivalent diameter classes, as proposed by Freitas *et al.* (1996; 1997), after definitions proposed by Stengel (1990), and Bruand and Cousin (1995), with basis on Hg intrusion studies, as follows:

- **micropores**: equivalent diameter (**e.d.**) < than 3 µm, corresponding to the arrangement of clay minerals and organic particles, as well as some coarse particles (sand and silts) and microaggregates.
- **mesopores**: **e.d.** between 3 and 9 µm, corresponding to the clayey structural porosity determined between tensions of 33 and 100 kPa, which includes available water.

- **fine macropores**: pores between 9 and 50 µm, responsible for slow soil drainage.
- **coarse macropores**: **e.d.** > 50 µm, responsible for rapid drainage and soil aeration.

Table 2 shows a significative variation in pore size distribution when surface (Ap_2) and subsuperficial (*BA*) horizons are compared. A decrease in microporal volume follows an increase in total porosity in all profiles examined. In **CCL**, even with elevated densities observed, a minimal macroporal volume (e.d. above 9 µm) of 0.107 m^3.m^{-3} was observed in Ap_2 horizons in 1991. The same is observed in the cohesive horizons (Ap_2B) described in 1994, which presents a total porosity of 0.5 m^3.m^{-3} with a macroporal volume of 0.15 m^3.m^{-3}. In this, important variations in mesoporal volume were observed according with the low volumes of water availability normally found in oxisols. In **PDC**, very low macroporal volumes were observed in 1991 (0.08 m^3.m^{-3}, with 0.027 m^3.m^{-3} above 50 µm). Following its evolution, even with essentially equal densities, macroporosity raised to 0.14 m^3.m^{-3}.

		Pedological	Bulk	Pore Size Distribution (e.d. in µm)				Total	Swelling Coefficients	
		Horizon	Density	< 3	3 a 9	9 a 50	> 50	Porosity	K_o	K_r
			kg.dm^{-3}	-------------------- m^3 . m^{-3} ----------------						
1991	**C C L**	Ap_2	1.38	0.343	0.027	0.038	0.079	0.487	0.129	0.264
		Ap_2B	1.27	0.280	0.042	0.091	0.118	0.531		
	P D C	Ap_2	1.37	0.336	0.072	0.052	0.027	0.487	0.048	0.199
		Ap_2B	1.41	0.357	0.026	0.046	0.052	0.481	0.093	0.332
		BA	1.20	0.296	0.056	0.083	0.123	0.558		
1994	**C C L**	Ap_2B	1.34	0.330	0.021	0.044	0.103	0.498	0.045	0.411
		BA	1.23	0.308	0.047	0.050	0.137	0.541	0.006	0.456
	P D C	Ap_2	1.36	0.335	0.016	0.047	0.096	0.494	0.011	0.310
		BA	1.09	0.273	0.063	0.060	0.203	0.598	0.014	0.212

Table 2. Soil bulk density, pore size distribution based on Soil Water Retention (pF) Curve, and pedo-structural characteristics based on soil swelling curves (after BRAUDEAU, 1993).

Pedo-structural characteristics were studied, with basis on two coefficients:

K$_o$: structural swelling – function of structural stability in relation to macropore drying and an indicator of inter-aggregate cohesion; and,

K$_r$: main swelling – function of particle arrangement and micropore geometry, indicating the internal cohesion in aggregates or structural elements.

Based on these, a very high inter-aggregate cohesion is observed in **CCL**, in special in Ap_2 in 1991, and in Ap_2B (1994), related with morphological description, as well as with mechanical impedance and infiltration capacity determinations. In **PDC**, high K_o values observed in the layer of 16 to 31 cm (Ap_2 e Ap_2B) indicated a high intra-aggregate cohesion. K_r values indicated a moderated to weak internal cohesion.

Pedo-structural study confirms some important observations made during morpho-structural description, putting in evidence cohesion differences. An elevated inter-aggregate cohesion is related to a higher mechanical resistance and a root growth impediment, as verified in the Ap_2 horizon in **CCL**. By other side, the dense layer identified in

PDC (*Ap_2*), shows a high internal cohesion, but a weak inter-aggregate cohesion. Associated with pore continuity, this densification is not an impediment to root growth.

Field observations indicating very porous HPUs, are confirmed by micromorphological analysis hold in 1994. Fig. 2 shows differences among the pore distribution in superficial horizons, even with equal pore size distribution (Table 2). Comparing samples taken in equivalent depths, a localized distribution of pores is observed in *Ap_2B*/**CCL**, alternating porous clods with massive ones. In thin sections of *Ap_2*/**PDC**, however, porosity is well distributed throughout the whole sample, with a clear pore continuity, from a favorable aggregate arrangement and confirming the observations made during morphological description in the field (Freitas, 1996).

<u>Soil Organic Matter (SOM)</u>

Three compartments were considered for the analysis of SOM status: plant debris (20-2000 μm); silt-organic complex (2-20 μm); clay-organic compartment (0-2 μm).

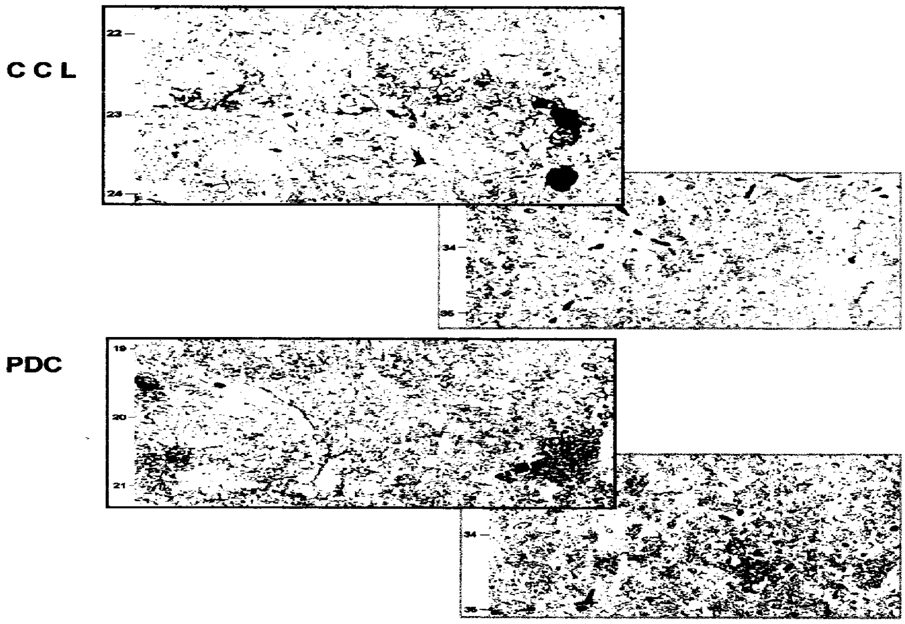

Fig. 2. Inverse view of uvitex-impregnated thin sections taken from main HPUs in considered pedological horizons during the 1994's characterization.

SOM physical fractionating allowed to precise management system effect by comparing C contents, C/N ratios and C stock (Table 3). A tendency of bigger C stocks in plant debris fraction is observed in **PDC**, explained by the protection effect of soil aggregation, built under the zero tillage, as well as residue mineralization, in relation with the improvement of soil structure. By other side, high C stocks are observed in the clay-organic compartment (0-2 μm), favored by a better contact between clay minerals and fresh OM.

		Soil Management Systems					
	Fraction	**CCL**	**PDC**	**CCL**	**PDC**	**CCL**	**PDC**
		0 to 10 cm		***10 to 20 cm***		***0 to 20 cm***	
Carbon Content	**0 - 2000**	2.7	3.5	1.4	1.9		
(mgC.g^{-1} of dried soil)	**2 - 20**	8.2	8.2	9.2	6.7		
	0 - 2	8.8	8.1	10.7	8.1		
C/N Ratio	**20 - 2000**	15	16	10	15		
	2 - 20	15	19	23	19		
	0 - 2	13	13	14	14		
Organic Stock	**20 - 2000**	**2.9**	**4.1**	**1.8**	**2.7**	**4.7**	**6.8**
(tC.ha^{-1})	**2 - 20**	9.1	9.5	11.9	9.1	21.0	18.6
	0 - 2	9.7	9.4	13.8	11.1	23.5	20.5
	Sum (0– 20)	**18.8**	**18.9**	**25.7**	**20.2**	**44.5**	**39.1**
	Total	***21.7***	***23.0***	***27.5***	***22.9***	***49.2***	***45.9***

Table 3. Carbon contents, C/N ratio and C stock for the different granulometric fractions

For the sum of fine fractions (< 20 µm), considering the 0-20 cm layer, **CCL** allowed similar C stockage similar or lightly superior to **PDC**. In a general manner, plant debris compartment (20-2000 µm) is given as a good indicator of soil organic stock evolution.

Conclusions

Soil structure evolution studies were important to verify the improvement in soil quality and health under no-till, an alternative soil management system for sustainable crop production in Brazilian Cerrado Region.

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Mots clés : sol ferrallitique, cerrado, structure, gestion des sols, morphologie, savanne, système de culture