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Physical Indicators of Soil Quality in Oxisols Under Brazilian Cerrado

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1. Introduction

The Brazilian Cerrado makes up one of the most biodiverse savannas in the world and it harbors a mosaic of plant physiognomies that include from open forms (grasslands) to forest (dense woodlands), possessing high structural, functional and life forms diversity. Little valued traditionally, the Cerrado has been neglected in most of the conservationist initiatives because its vegetation is considered sparse and of low value.

The Brazilian Cerrado comprises an area of 2,036,448 km² [1]. Its largest part is within the Aw type of Köpen climatic classification (tropical seasonal savanna), with a rainy period, from October to March, followed by a dry period, from April to September. In this environment, the irregular distribution of the rain and the existence of short droughts constitute serious limitation for farming in the absence of irrigation.

The main soils of the Cerrado area are Latosols (Oxisols) that correspond to 46%, followed by Neosols (Entisols) with 16% and Argisols (Ultisols) with 15%. Latosols occupy a flat to gentle rolling topography in the landscape, which facilitates the mechanized management, those soils being of high potential for the production of annual and perennial crops and also pasture.

In recent decades the Cerrado has undergone various transformations as to its land use, mainly due to the high investments in soil correctives, fertilizers and various crop varieties adapted to this biome. This generated a disordered occupation of the land, with a rampant increase of

deforestation that contributed to the loss of species diversity and, concomitantly, some inadequate soils management techniques propitiated the fast degradation of that resource [2], erosion, aquifer pollution, ecosystem degradation, alteration of the soil physical, chemical and biological attributes and consequent reduction of the soil quality.

In that context, according to [3], the soil quality is expressed when the soil works within the limits of a natural ecosystem, so as to sustain biological production, promote animal and plant health, and to maintain the quality of the environment. It is usually determined by a group of physical, chemical and biological attributes, that represents the different soil characteristics and that influences its various functions. Each one of these edaphic attributes, in turn, may or may not perform well, which will influence agricultural production in a significant way.

The direct evaluation of the soil properties seems to be the most appropriate way to measure or to monitor its conservation or any degradation process underway [4]. Thus, the evaluation of the soil quality has been increasingly proposed as an integrated indicator of the environmental quality and sustainability of agricultural systems. The quantification of soil attribute alterations, due to the intensification of production systems or natural systems exploration, besides being useful in the evaluation of anthropic interference in the environment because it considers the relationship between the soil and the other aspects of the ecosystem, supplies important subsidies to the definition of rational management systems, contributing to making the soil less susceptible to the loss of productive capacity and, fundamentally, to the environmental conservation [5].

The soil quality indicator attributes are defined as measurable properties that have influence on the capacity of the soil to produce crops or on the performance of environmental functions [6]. For those attributes to be capable of indicating soil quality alterations, they should be well correlated with processes within the ecosystem; be applied in a relatively easy manner under field conditions and be appraised not only by specialists but also by producers; they should be sensitive to variations in management and climate, reflecting soil quality changes, without being influenced by accidental alterations and be components of previously existent databases [6]. For reference [7] no individual indicator is able to describe and quantify all of the soil quality aspects and not even an isolated soil function is enough, since it should have a relationship among all its attributes.

Among the various soil attributes responsible for its quality, the physical attributes stand out, the soil structure being of one of the most important indicators for plant growth, since it has a direct influence on the densification, compaction, crusting, water infiltration and soil susceptibility to erosion conditions [8]. The structure can be evaluated through the soil density, macro and microporosity, aggregate stability, and resistance to water penetration and infiltration in the soil. These indicators show the effect of the soil management, being easy to measure, with fast and reasonably precise responses [3].

Knowing the soil density is an important indicator of the soil management conditions and its value will reflect in the characteristics of the soil pore system, so as to hinder the water and oxygen supply, limiting the plant development and organisms activity [9], thus influencing

various fundamental processes that the soil exercises in its function [10]. The porosity is the volumetric fraction of the soil occupied with air and/or water and it is empirically divided in macroporosity (pores diameter > 0.05 mm) and microporosity (pores diameter < 0.05 mm). The phenomena of water infiltration in the soil (descending flow) occur mainly via the macropores, while the storage (retention) of water occurs in the micropores. The soil compaction tends to mainly reduce the macroporosity values, the reason why there is water infiltration reduction and, consequently, an increased erosion risk.

The aggregate stability varies with the inherent soil characteristics and with the management systems. The intense soil tillage provokes the aggregate breakup, being able to drastically reduce its stability. With the breakage of the aggregates, the organic matter which was in its interior becomes unprotected, accelerating its decomposition process, reducing both resistance of these aggregates and the soil quality [10].

As such, due to the importance of the physical attributes for the soil quality maintenance, the objective of the present study was to analyze and characterize the physical attributes indicative of the quality of the Latosols in native, agricultural, pasture and planted forest environments, in the Cerrado biome.

2. Location, climate, soil and management systems

In order to conduct this study, it was constructed a physical attribute database of the Latosols located in areas under Cerrado. The database in question was prepared through the selection of information and data contained in the files of the Soil and Water Conservation Sector, Soil Science Department, Federal University of Lavras, gathering information from [11- 16]. The studied physical attributes indicators of soil quality were the soil density, total pore volume, macroporosity, microporosity, average geometric diameter, hydraulic conductivity of the saturated soil and soil resistance to penetration.

3. Study areas

The study was conducted in several areas of the Brazilian Cerrado, with samplings in the State of Minas Gerais (Campos das Vertentes, Vale do Rio Doce - Guanhães, Noroeste, Vale do Rio Doce - Belo Oriente, Central) and the State of Goiás (South). Figure 1 presents the location of the environments under study.

3.1. Campos das Vertentes, MG

Campos das Vertentes is located in the Alto Rio Grande basin (20° 21'-21° 42' S; 43° 16'-44° 42' WGr), in the South-Central of Minas Gerais State. According to the Köppen climatic classification, the predominant climate in the area is the Cwa type (mild-temperate mesothermal), that is characterized by having an average temperature of the coldest month under 18°C and

the average of the hottest month over 22°C , with rainy summers and dry winters. The average annual precipitation is 1435 mm, concentrated between December and April.

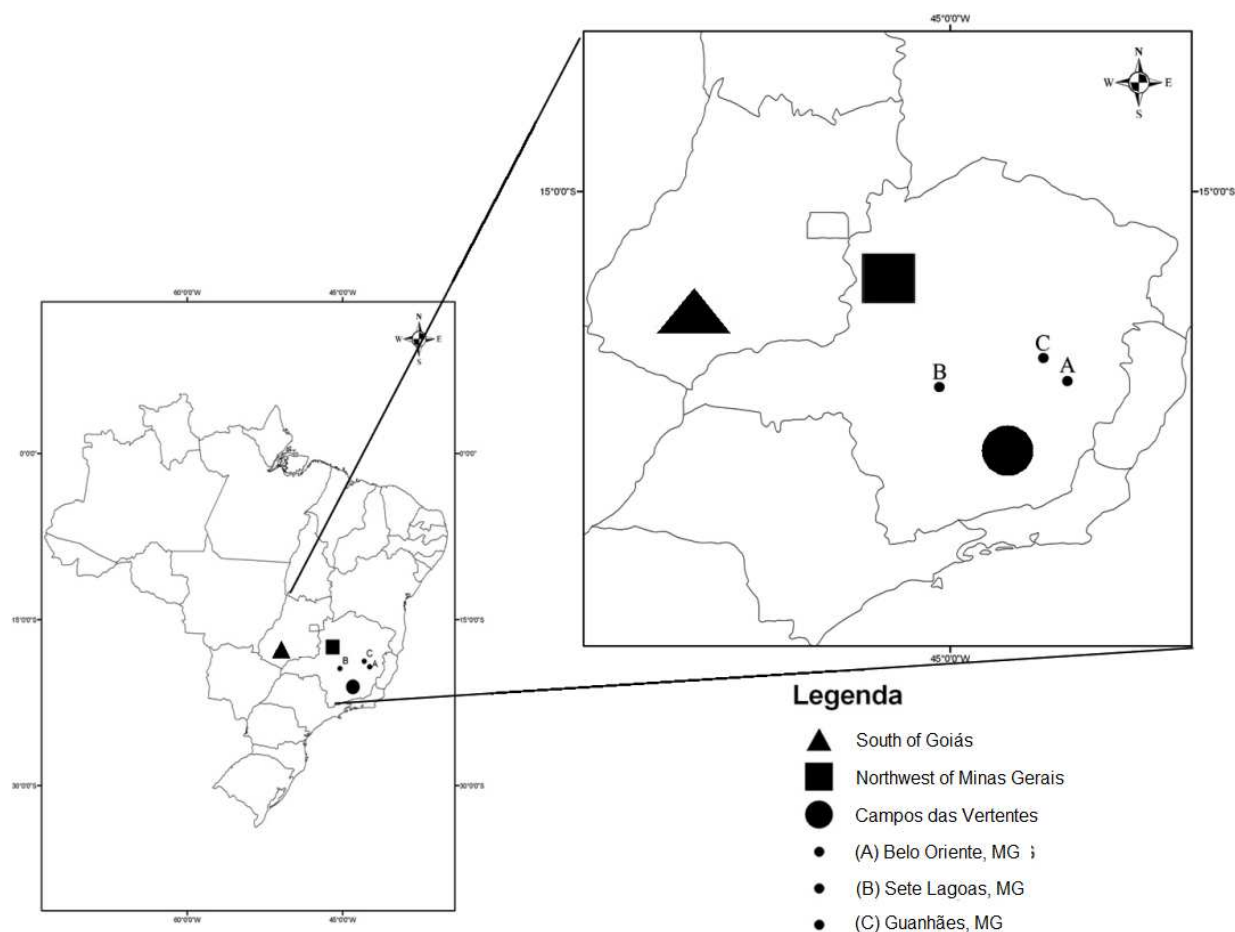


Figure 1. Location of the studied areas.

The soil of the mentioned area is classified as typical acric Red-Yellow Latosol (LVA_1) of clayey texture (EMBRAPA, 2006), developed over a geological substratum corresponding to poor metapelitic rocks of the São João del Rei (phyllite) and Andrelândia (micaschist) groups. The selection of the studied management systems was conducted attempting to reach a better representativeness of the area over that soil class, as shown in Table 1.

3.2. Vale do Rio Doce, Guanhães, MG

The Vale do Rio Doce region, municipal district of Guanhães ($18^{\circ} 46' \text{ S}$; $42^{\circ} 55' \text{ WGr}$), State of Minas Gerais, presents the Cwa climate (dry winter and rainy summer) with temperature of the coldest month under 18°C and the one of the hottest month passing 22°C , according to the Köppen climatic classification. The dry season occurs between the months of April and September, the average annual precipitation of the area being 1,180.8mm and an average altitude of 850m.

Systems	Symbol	Characteristic of the systems
Native Cerrado	NC1	Primary vegetation represented by the sub deciduous tropical Cerrado and Savanna woodland.
Conventional cultivation with potato	CCP	Conventional cultivation with potato, sampled postharvest.
Conventional cultivation with potato and oat	CCPO	Conventional cultivation with potato, followed by oat, after a postharvest subsoiling of potato and rotated with corn, sampled 15 days after the corn planting.
Conventional cultivation with corn	CCC	Conventional cultivation with corn
No-till with corn	DPC	No-till with corn after the conventional cultivation with potato in the harvest, rice and conventional corn, sampled 52 days after planting.
Conventional eucalyptus	CE1	Conventional eucalyptus cultivation, without application of subsequent management practices.

Source: [16] modified.

Table 1. Characterization of the management systems in typical acric Red-Yellow Latosol in the Campos das Vertentes - MG region.

The soil of the area under studies is classified as typical dystrophic Red Latosol (LV₁), very clayey texture, prominent A horizon, alic, kaolinitic-oxidic, mesoferric, wavy relief, gneiss and granite-gneiss substrate. The selected study areas are presented in Table 2.

Systems	Symbol	Characteristic of the systems
Native savanna	NC2	Original condition
Native pasture	NP	Degraded native pasture of long duration.
Uncovered soil	UCS1	System where the soil does not possess plant covering.
Eucalyptus planted following the slope, with burning of crop debris	ESq	Eucalyptus planted in line accompanying the slope of the land, burning of crop debris being carried out.
Eucalyptus planted following the slope, without burning of crop debris	ES	Eucalyptus planted in line accompanying the slope of the land, the crop debris being left on the surface.
Eucalyptus planted cross slope	ECS1	Eucalyptus planting line is perpendicular to the slope direction.

Source: [12] modified.

Table 2. Characterization of the management systems in typical dystrophic Red Latosol (LV₁) Vale do Rio Doce region, town of Guanhões – MG.

3.3. Northwest Minas Gerais

The Northwest region of the State of Minas Gerais is located between latitudes 16° 10' and 18° 42' S, and longitudes 44° 24' and 47° 44' WGr, the climate of the area being the Cwa type, characterized by the temperature of the coldest month under 18° C, and the precipitation of the driest month less than 60 mm with annual averages varying from 1,300 to 1,400 mm. The soil is classified as typical dystrophic Red Latosol (LV₂) [17]. Seven production systems were studied in this area, according to Table 3.

Systems	Symbol	Characteristic of the systems
Native Cerrado	NC3	Typical Cerrado vegetation, without reports of human interference and agricultural use.
Eucalyptus + rice	ER	Eucalyptus intercropped with rice, eucalyptus being 4 months of age.
Eucalyptus + soybeans	ESy	Eucalyptus intercropped with soybeans. On the date of the sampling, the eucalyptus was 1 year and 4 months old.
Eucalyptus + pasture	EP	Eucalyptus intercropped with planted pasture. On the date of the sampling, the eucalyptus was 3 years and 4 months old.
Eucalyptus + pasture + cattle	EPC	Eucalyptus intercropped with planted pasture. On the date of the sampling, the eucalyptus was 7 years and 4 months old.
Conventional pasture	CP	Conventional pasture
Conventional eucalyptus	CE2	Conventional eucalyptus (3x2 spacing)

Source: [14] modified.

Table 3. Characterization of the management systems in a typical dystrophic Red Latosol (LV₂), Northwestern Minas Gerais region.

3.4. Vale do Rio Doce, Belo Oriente, MG

In the municipal district of Belo Oriente (19° 17' S; 42° 23' WGr), in the Rio Doce region, State of Minas Gerais, the predominant climate is the Aw type, in other words, tropical, with dry winters and rainy season in the summer, according to the Köppen classification, presenting an average annual temperature varying between 22° and 27°C, the maximum temperature being 32° C and the lowest, 18° C with an average annual precipitation varying from 701 to 1500 mm at an altitude of 233m. The dry season occurs between the months of May to September.

The soil of this area was classified as typical dystrophic Red-Yellow Latosol (LVA₂), very clayey texture. The geological formation is granite-gneisse bedrock of the Pre-Cambrian period, and the material of origin are gnaisse alterations. The study areas were made up of six soil use systems, as presented in Table 4.

Systems	Symbol	Characteristic of the systems
Native Cerrado	NC4	Reference system in equilibrium
Planted pasture	PP1	Pasture of <i>Brachiaria sp.</i> Soil use reference in the study area.
Eucalyptus planted cross slope	ECS2	Planting line of the eucalyptus is perpendicular to the slope direction.
Conventional eucalyptus with burning of crop debris	ECq	Eucalyptus planted in line accompanying the slope of the land, burning of crop debris being carried out.
Conventional eucalyptus	CE3	Eucalyptus planted in line accompanying the slope of the land, the crop debris being left on the surface.
Uncovered soil	UCS2	System Referencial in degradation process.

Source: [15] modified.

Table 4. Characterization of the management systems in a dystrophic Red-Yellow Latosol (LVA₂) in the Vale do Rio Doce region, town of Belo Oriente – MG.

3.5. Central region of Minas Gerais

The samples were collected in the city of Sete Lagoas, MG, located at 19° 25' south and 44°15' west at an altitude of 732m. The average annual temperature in the area is 22.1°C and the average annual precipitation is 1340 mm. According to the Köppen climatic classification, the climate is Aw (seasonal tropical savanna).

The soil is an alic Red Latosol (LV₃), with moderate A horizon, very clayey texture, Cerrado tropical semideciduous phase and gentle undulated relief, derived from pelitic rocks of the Late Proterozoic Bambuí group. For the Sete Lagoas area, five production systems and a reference environment were studied, according to Table 5.

Systems	Symbol	Characteristic of the systems
Native Cerrado	NC5	Environment without anthropic interference
Disk harrow and corn cultivation	DHCC	Conventional preparation with disk harrow and continuous cultivation with corn
Disk plow and cultivation with corn	DPICC	Conventional preparation with disk plow and continuous cultivation with corn
Disk plow and cultivation in rotation with corn and beans	DPIRCB	Conventional preparation with disk plow and cultivation in rotation with corn and beans.
No-till and corn	DPCntC	No-till and continuous cultivation with corn
No-till and cultivation with rotation with corn and beans	DPRCB	No-till and cultivation with rotation with corn and beans

Source: [11] modified.

Table 5. Characterization of the management systems in an alic Red Latosol (LV₃) in the Sete Lagoas region.

3.6. Southern region of Goiás

The work was developed in agricultural properties in the municipal districts of Morrinhos and Caldas Novas in the Southern area of the State of Goiás, located in the Central Goiano Plateau geomorphological unit, Lowered Goiânia Plateau sub-unit.

The soil was classified as typical dystrophic Red Latosol (LV₄), according to [17]. Being this soil developed from Pleistocenic lateritic-residues covering on micaxists of the group Araxá of Proterozóico Inferior. The studied areas were constituted of eight systems of use of the soil as presented in Table 6.

System	Symbol	Characteristic of the systems
Native Cerrado	NC6	Environment without anthropic interference
Pasture	PP2	Planted pasture of long use, without fertility management in the last 10 years and under continuous cattle grazing.
Irrigated No-till	IDP 1	System under central pivot in the last 5 years, with corn cultivation in rotation with beans, with subsoiling to 15 cm of depth 2 years before the harvest.
Irrigated No-till	IDP 2	No-till under central pivot in the previous 5 years, with corn, beans and rice cultivation and a harvest of industrial tomato with surface harrowing from 0 to 1 cm depth, 2 years before.
Dryland No-till	DDP	No-till planting with soybean cultivation over millet straw in the previous 7 years, after conventional system (soybeans).
Irrigated conventional planting	ICP 1	Conventional system, with use of heavy harrowing, irrigated under central pivot in the previous 2 years, with corn after more than 15 years of dryland soybeans-corn succession.
Irrigated conventional planting	ICP 2	Recently irrigated conventional system, with use of heavy harrowing, under central pivot in the previous 2 years, with squash/beans/sweet corn rotation, after more than 10 years as pasture.
Dryland conventional planting	DCP	Conventional dryland system, with use of heavy harrowing for the soil preparation and soybeans-corn succession for more than 15 years.

Source: [13] modified.

Table 6. Characterization of the management systems in a typical dystrophic Red Latosol (LV₄) in the South of State of Goiás.

4. Determination in the field

Samples with undisturbed structures were collected with the use of the Uhland sampler, in cylinders with average dimensions of 8.25 cm of height by 6.90 cm of internal diameter. The

samples with deformed structure were collected in the depth of 0-20 cm, being air-dried and sieved in a 2 mm mesh sieve (fine soil) for analyses.

The soil resistance to penetration was determined in the field using an impact penetrometer (IAA/PLANALSUCAR STOLF model), according to the methodology of [18]. The values obtained in Kgf cm^{-2} were multiplied by a factor of 0.098 to be expressed in MPa.

5. Laboratory determinations

The textural analysis was conducted by the pipette method [19], using $\text{NaOH } 1 \text{ mol L}^{-1}$ as chemical dispersant and fast agitation (12,000 rpm), for 10 minutes. The soil density was determined according to [20]. The total pore volume was determined according to the expression recommended by [21]. The pore size distribution was determined using a porous filter plate funnel in the suction unit with 60 cm of water column height for macro and microporosity separation in samples previously saturated for 48 hours. In this situation, the water volume retained in the samples after the equilibrium corresponds to the microporosity, the macroporosity being obtained by difference between the total pore volume and the microporosity [22].

The aggregates with diameter from 4.76 to 7.93 mm were obtained by soil sieving, and the aggregate stability determined through sieving in water after slow pre-wetting of the aggregates by capillarity for 24 hours [23-24]. Sieves with 2.00; 1.00; 0.50; 0.25 and 0.105 mm meshes were used for separation of the aggregate size classes [25]. Concerning the aggregate stability and size distribution, the procedure involves a known weight of soil mass which is submitted to slow wetting and sieving, so the average geometric diameter could be used as an index of the aggregate size distribution [25].

The soil water permeability was evaluated in laboratory, from samples previously saturated by capillarity and using a constant-head permeameter, adapted for elimination of the percolated water close to the cylinder walls, following methodology described by [26].

6. Granulometric characterization of soil

The granulometric characteristics and the particle density (PD) of the studied Latosols are presented in Table 7.

In relation to the relative particle size proportion, we verified high clay fraction and low of silt content and a silt/clay ratio lower than 0.7. The particle density values of presented variations from 2.29 to 2.65 kg dm^{-3} , and the particle density is not influenced by mechanical alterations, but by the organic matter content in the soils.

Local	Soil	Silt	Clay	Sand	Silt / Clay	PD kg dm ⁻³
		----- g kg ⁻¹ -----				
Campos das Vertentes – MG	LVA1	155	627	218	0.25	2.43
Guanhães – MG	LV1	71	598	331	0.12	2.56
Northwest – MG	LV2	141	681	178	0.21	2.29
Belo Oriente – MG	LVA2	109	425	466	0.26	2.50
Central – MG	LV3	234	582	184	0.40	2.65
South – Goiás	LV4	198	335	467	0.59	2.52

Table 7. Silt, clay, sand content and particle density for the Latosols under Cerrado [27].

7. Mineralogical properties

The tropical soils present high degree of weathering, with the clay fraction mineralogy dominated by silicate minerals of the 1:1 type and iron and aluminum oxides [28]. Latosols are what best represents the pedogenetic tendencies of the tropical soils, being defined as those that present a latosolic mineral subsurface B horizon, that evidences an advanced of weathering stage, as shown by the complete or almost total alteration and decomposition of easily weathered minerals, the high depth and by the low cationic exchange capacity [29].

Latosols present clay fraction mineralogy basically dominated by kaolinite, gibbsite, goethite and hematite, besides poorly crystallized iron and aluminum oxides. Although the predominant mineralogical composition in the tropical soils can be considered simple, variations that can occur within and among the mineral groups as to particle size and specific surface, exposed faces, degrees of isomorphic substitution and crystallinity can provide high soil behavior variability within a same class [30].

The mineralogical properties of the studied Latosols are presented in Table 8

Local	Symbol	Gb	Kt	Gb/ Gb+Kt	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	ki	kr
		mg kg ⁻¹			-----g kg ⁻¹ -----					
Campos das Vertentes - MG	LVA ₁	290	350	0.45	161	260	145	10.8	1.05	0.78
Guanhães - MG	LV ₁	162	364	0.31	177	235	69	13.6	1.28	1.08
Northwest - MG	LV ₂	480	260	0.65	175	252	72	6.3	1.18	1.00
Belo Oriente - MG	LVA ₂	117	380	0.24	116	173	77	16.6	1.14	0.89
Central - MG	LV ₃	160	310	0.34	234	319	120	5	1.24	1.08
South - Goiás	LV ₄	335	188	0.64	123	174	140	1.96	1.2	0.8

Gb = gibbsite; Kt = kaolinite; Ki = SiO₂/Al₂O₃ molecular ratio; Kr = SiO₂/(Al₂O₃ + Fe₂O₃) molecular ratio.

Table 8. Mineralogical characteristics of Latosols under Cerrado [27].

8. Soil density

The soil density (SD) increased in the management systems that underwent anthropic interference, three lowest values being the found in natural environments, represented by the native Cerrado (NC5) of the Central Minas Gerais region and native Cerrado (NC2 and NC4), both from Vale do Rio Doce, MG, with values of 0.83, 0.87 and 0.93 kg dm⁻³, respectively (Table 9).

The highest soil density values were observed for the use systems installed in the South of Goiás, the three highest values being for the irrigated conventional planting, conventional dryland and direct dryland planting (ICP2, DCP and DDP), with values of 1.36, 1.35 and 1.31 kg dm⁻³, respectively. The maintenance of the soil in the uncovered forms (UCS1 and UCS2) caused increases of 41 and 39% in the soil density in relation to the native environment of the same area, because in these areas the direct impact of the rain drops occurs, which provides elevation of the soils density. The density results found for Latosols under study were below the value of 1.40 kg dm⁻³, a value that, according to [31], is restrictive to the plants root growth in clayey soils.

Alterations in the cultivated soil density values in relation to the natural condition have been reported by several references [5, 32]. The soil density in non-cultivated environments is a physical property that depends on pedogenetic factors and processes. The lowest soil density value for native areas and that did not undergo anthropic interference results from a higher accumulation of plant residues incorporated into the soil, associated to the non-disturbance of the structure by the machines and agricultural implements traffic, animal trampling, intensive cultivation and inadequate management systems [33].

According to [34], it becomes difficult to affirm under which use systems the soil density increase would tend to be harmful to other functions and the soil quality in reason of the differences in the granulometric composition, the chemical and mineralogical nature of the soil, the time of use of the management systems and the resilience and resistance inherent to each soil class, among other factors.

Land use	Ds	Pt	Macro	Micro	Ks	AGD
	Kg dm ⁻³		----- m ³ m ⁻³ -----		mm h ⁻¹	mm
Campos das Vertentes – MG - LVA ₁						
CCP	1.17	0.52	0.09	0.43	42.6	4.67
CCPO	1.22	0.51	0.10	0.41	29.8	4.85
CCC	1.05	0.56	0.10	0.46	49.4	4.68
DPC	1.18	0.52	0.05	0.47	13.8	4.64
CE1	1.15	0.53	0.07	0.46	41.3	4.77
NC1	1.11	0.55	0.18	0.37	38.0	4.87

Land use	Ds	Pt	Macro	Micro	Ks	AGD
	Kg dm ⁻³		----- m ³ m ⁻³ -----		mm h ⁻¹	mm
Vale do Rio Doce – Guanhães – MG - LV ₁						
NC2	0.87	0.65	0.33	0.32	230.0	4.90
NP	1.08	0.56	0.19	0.38	90.0	4.71
UCS1	1.23	0.49	0.10	0.40	183.0	4.79
ESq	1.14	0.54	0.17	0.37	174.0	4.92
ES	1.13	0.55	0.18	0.37	160.0	4.92
ECS1	1.18	0.54	0.17	0.37	75.0	4.89
Northwest – MG – LV ₂						
NC3	1.07	0.54	0.24	0.30	733.7	4.39
ER	1.06	0.54	0.23	0.31	136.4	4.05
ESy	1.01	0.55	0.19	0.36	348.6	4.17
EP	1.15	0.54	0.23	0.31	74.95	3.92
EPC	1.13	0.56	0.27	0.29	128.6	4.00
CP	0.99	0.60	0.21	0.39	240.9	4.03
CE2	1.14	0.52	0.28	0.24	214.5	4.33
Vale do Rio Doce – Belo Oriente – MG – LVA ₂						
NC4	0.93	0.60	0.30	0.30	191.0	4.55
PP1	1.20	0.50	0.15	0.35	81.8	4.36
ECS2	1.13	0.55	0.26	0.29	180.0	4.57
ECq	1.21	0.51	0.19	0.32	161.0	4.46
CE3	1.19	0.52	0.21	0.3	152.0	4.35
UCS2	1.29	0.47	0.11	0.36	70.0	1.95
Central – MG – LV ₃						
DHCC	1.11	0.58	0.16	0.42	6.1	2.44
DPICC	1.10	0.59	0.16	0.43	13.5	1.93
DPIRCB	0.98	0.62	0.21	0.41	14.2	3.87
DPCntC	1.11	0.58	0.17	0.41	6.7	3.87
DPRCB	0.97	0.63	0.21	0.42	6.7	2.71
NC5	0.83	0.68	0.29	0.39	95.0	4.42
South – Goiás – LV ₄						
NC6	1.27	0.52	0.19	0.35	174.5	4.62
PP2	1.14	0.56	0.21	0.35	340.8	4.42

Land use	Ds	Pt	Macro	Micro	Ks	AGD
	Kg dm ⁻³		----- m ³ m ⁻³ -----		mm h ⁻¹	mm
IDP1	1.21	0.51	0.17	0.34	65.1	4.38
IDP2	1.18	0.56	0.21	0.35	145.1	4.38
DDP	1.31	0.49	0.17	0.32	76.3	3.67
ICP1	1.19	0.56	0.23	0.33	253.6	3.15
ICP2	1.36	0.50	0.13	0.37	114.8	4.56
DCP	1.35	0.50	0.23	0.27	159.9	2.63
Descriptive statistics						
Minimum	0.83	0.47	0.05	0.24	6.1	1.93
Lower quartile	1.08	0.52	0.16	0.32	46.0	3.96
Average	1.13	0.56	0.21	0.38	136.2	4.07
Median	1.14	0.54	0.19	0.36	114.8	4.39
Upper quartile	1.20	0.56	0.23	0.40	177.2	4.68
Maximum	1.36	0.68	0.33	0.47	733.7	4.92

Table 9. Soil density (Ds), total porosity (Pt), macroporosity, microporosity, hydraulic conductivity (Ks) and average geometric diameter (AGD) for land use systems in the Cerrado [27].

8.1. Total porosity and pore distribution per size

Considering all of the management systems, the values of total porosity varied between 0.47 and 0.68 m³m⁻³ (Table 9). Among the soil use systems without anthropic interference, two systems presented the largest total porosity values, the native Cerrado of the Central area (NC5) being the system that presented the highest value, followed by the native Cerrado (NC2) of Guanhões, respectively 0.68 and 0.65 m³m⁻³, whereas No-till plus crop rotation with corn and beans (DPRCB) and planting with conventional preparation with disk plow plus crop rotation with corn and beans (DPIRCB), both in the Vale do Rio Doce of Minas Gerais, presented total porosity values of 0.63 and 0.62 m³m⁻³, respectively.

The reduction in the total porosity in areas under agricultural management in relation to the native areas is in agreement with the observations of [9, 35] and the latter verified a reduction of up to 24% in the total porosity, when compared with areas that did not undergo anthropic action. The trampling by animals, agricultural machines and inadequate management lead to interferences in the soil structure, promoting reduction in the total porosity. According to [36], crop rotation systems can increase the total porosity of the soil when implanted in agricultural areas, an effect being confirmed in this study.

The lowest total porosity values were found in the uncovered soils (UCS2 and UCS1), followed by the dryland No-till (DDP), irrigated conventional planting (ICP2) and dryland conventional planting (DCP), presenting values of 0.47, 0.49, 0.49, 0.50 and 0.50 m³m⁻³, respectively. The fact that the area with uncovered soil presented the lowest total porosity values can be related to

the absence of the crop root systems, because after the decomposition of the roots, a soil pore increase occurs, and in these areas old pores can be obstructed due to reorganization of the surface after the removal of the plant covering.

The highest macroporosity values were found for areas without anthropic interference (Table 9), and the native Cerrado (NC2) in Guanhães, MG, the native Cerrado (NC4) in Belo Oriente and the native Cerrado (NC5) in the Central area of MG, presented macroporosity values equal to 0.32; 0.30 and 0.29 $\text{m}^3 \text{m}^{-3}$, respectively. These data show that a soil macropore reduction tendency exists when native areas are transformed into agricultural or forest areas.

The lowest macroporosity values were found in the systems installed in Campos das Vertentes (MG). According to [37], the low macropore presence tends to occur in the same area, because this attribute is related to the soil texture. In the Campos das Vertentes area the macropores presented low values, on the order of 0.05; 0.07; 0.09; 0.10 and 0.10 $\text{m}^3 \text{m}^{-3}$ for the DPC; CE1; CCP; CCPO and CCC systems, respectively. For this area, the native Cerrado (NC1) presented a macroporosity value above that of the agricultural systems, 0.18 $\text{m}^3 \text{m}^{-3}$, which demonstrates the sensitivity of this attribute in the detection of the alterations imposed by the different management systems under natural conditions.

The highest microporosity values were found in the area of Campos das Vertentes, in Minas Gerais (Table 9). This occurs by the same explanation given to the macroporosity in the area, because, for the same total porosity, an increase in the macroporosity causes the reduction of the microporosity.

The Northwest area of MG uses an agrosilvopastoral system and it presented the lowest microporosity values, among them the conventional eucalyptus system (CE2) and eucalyptus + pasture + cattle (EPC) stand out with values of 0.24 and 0.29 $\text{m}^3 \text{m}^{-3}$, respectively.

9. Permeability of the soil to water

The permeability of the soil to water, appraised through the hydraulic conductivity of the saturated soil, presented accentuated difference among the management systems used in Latosols (Table 9). The lowest soil permeability values were found in the Central area of Minas Gerais, and the systems of agricultural management underwent reductions between 85 and 93.3% of its permeability when compared to the native Cerrado of the same area. In the other environments, the system that uses No-till with corn (DPC) in the Campo das Vertentes, MG, presented the lowest permeability value, 13.8 mm h^{-1} . This value is justified since this system presented the lowest macroporosity value found in the studied soils, according to Table 9.

The highest permeability values were found in the native Cerrado (NC3) and eucalyptus + soybeans (ESy) systems of the Northwest area, MG, followed by the pasture (PP2) and irrigated conventional planting (ICP 1) of the South of Goiás and pasture of the Northwest area, MG, that presented values of 733.77; 348.6; 340.8; 253.6 and 240.92 mm h^{-1} .

According to the permeability classes adapted from the [38] and presented in Table 10, 71.8% of the soils were classified with the permeability varying between the moderate and fast classes, being this high permeability one of the characteristics of Latosols.

Class	Permeability (mm h ⁻¹)
Fast	> 254.00
Moderate to fast	254.00 – 127.00
Moderate	127.00 – 63.50
Slow to moderate	63.50 – 20.00
Slow	20.00 – 5.00
Very slow	< 5.00

Table 10. Classes of soil permeability to water [38].

9.1. Aggregate stability

The Average Geometric Diameter (AGD) represents an estimate of the most frequent aggregate size and demonstrates the stability of the structure facing the disaggregation action of the water, and may indicate the susceptibility degree of soil to hydric erosion [39].

As such, the native systems inside each area and the systems that possess eucalyptus in the area of Guanhães and Belo Oriente, MG, by not presenting constant tillage of the soil, low machine traffic and animal trampling, are the systems that possess the largest size of aggregates (Table 9).

Among the five lowest AGD values, three were found in soil use systems installed in the Central region of MG, they being conventional soil preparation with disk plow for corn planting (DPICC), conventional preparation with disk harrow for corn planting (DHCC), and no-till with corn and beans rotation with (DPRCB), that present AGD values of 1.93, 2.44 and 2.71 mm, respectively. The other two systems are the uncovered soil (UCS2) of Belo Oriente, MG, and the dryland conventional planting (DCP) in the South area of the State of Goiás. A characteristic of these systems, except for DPRCB, was the high soil tillage operations for the soil preparation that fractioned the larger aggregates into smaller ones. For DPRCB, a possible explanation for the low AGD indexes presented would be the short transformation time from the conventional planting to no-till, thus the system still maintains AGD indexes from when the soil was tilled.

In general, a very high aggregate stability was verified for Latosols of the Cerrado area, since most of the aggregates diameter was superior to 4 mm, as suggested in Table 11. This high aggregate stability is a characteristic of Latosols, which enables the installation of intensive farming without even greater damage to the environment [40].

Class	Average geometric diameter - mm
Very high	> 4
High	4 – 3
Moderate	3 – 2
Low	2 – 1
Very low	< 1

Source: Summary of bibliographic research – DCS/ UFLA

Table 11. Aggregate stability classes.

10. Soil resistance to penetration

The penetration resistance until the depth of 60 cm for the management systems studied in Cerrado Latosols are presented in FIGURES 2 to 7.

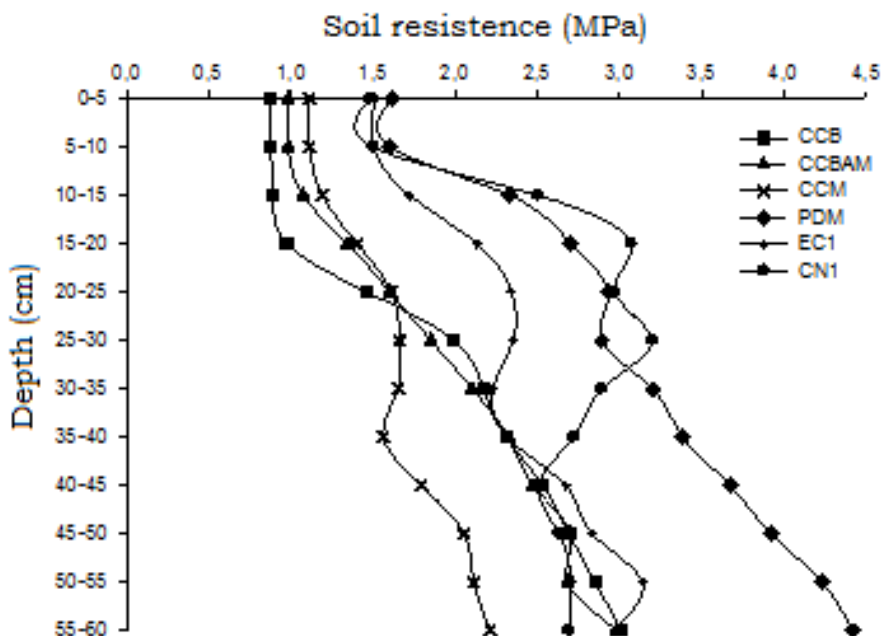


Figure 2. Penetration resistance for LVA₁, located in Campos das Vertentes, MG [27].

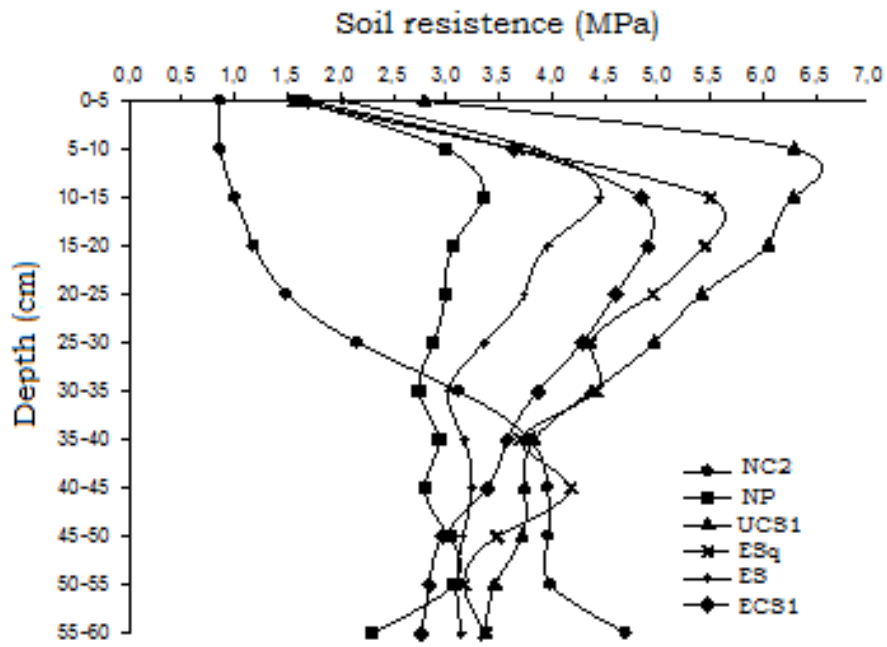


Figure 3. Soil penetration resistance for LV₁, located in Vale do Rio Doce, Guanhães, MG [27].

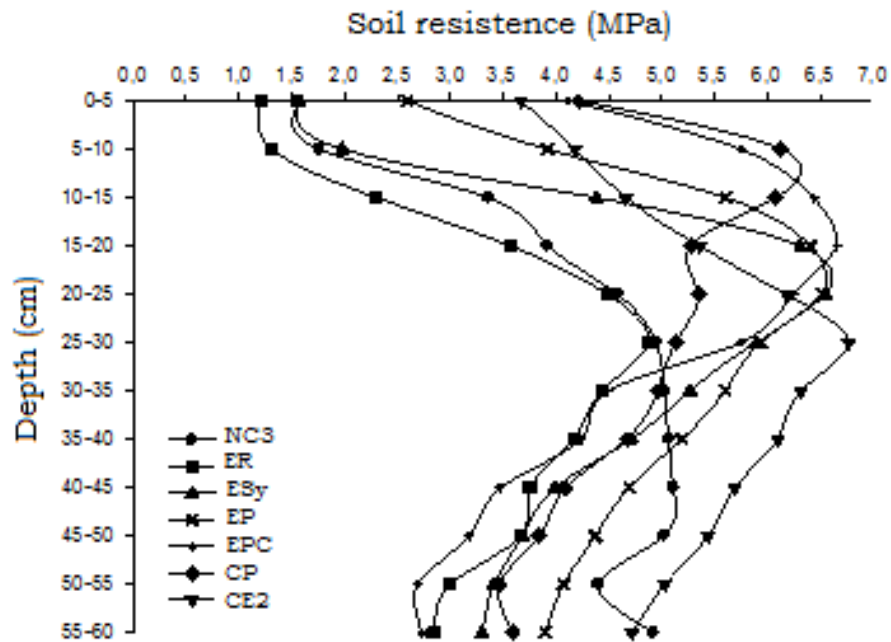


Figure 4. Penetration resistance of LV₂, Northwest region, MG [27].

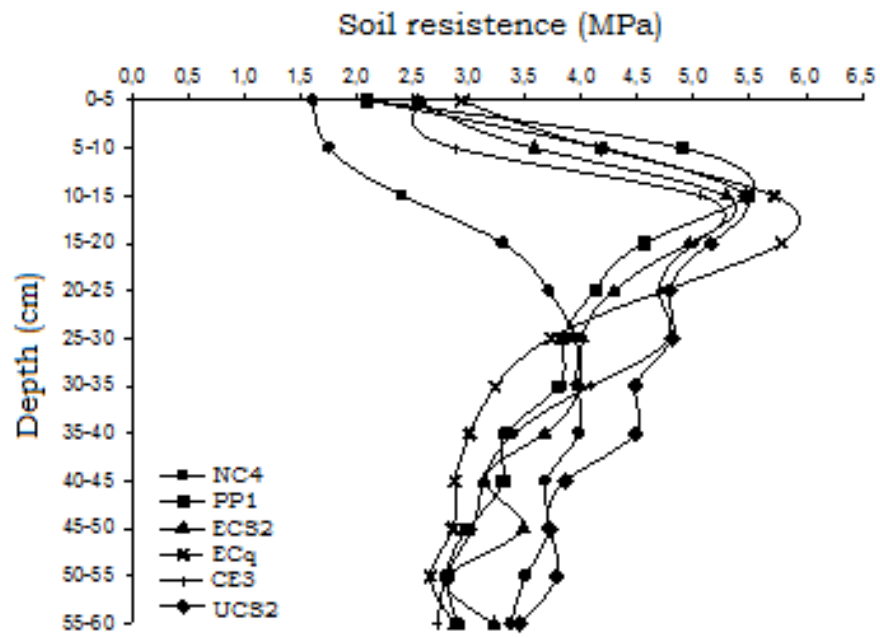


Figure 5. Soil penetration resistance for LVA₂, Vale do Rio Doce, Belo Oriente, MG [27].

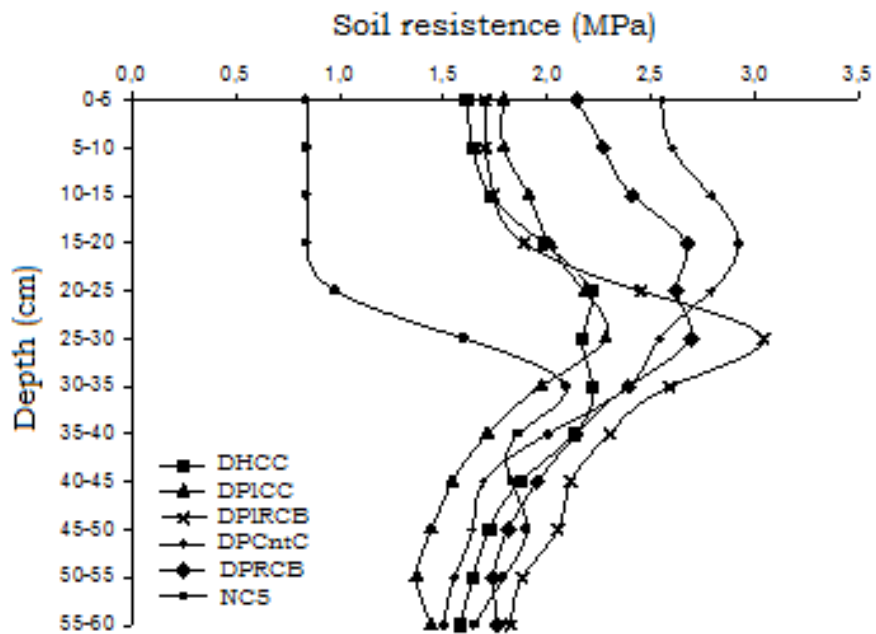


Figure 6. Soil penetration resistance for LV₃, Central MG region [27].

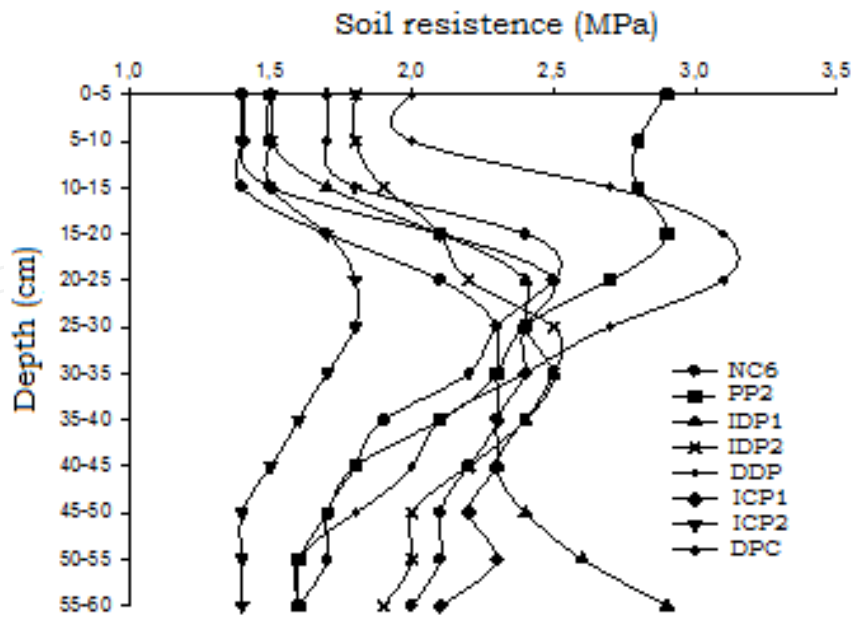


Figure 7. Soil penetration resistance for LV_{4r}, South Goiás region [27].

The penetration resistance values varied from 0.84 MPa to 6.77 MPa (Table 12). In the native systems, except for the native Cerrado (NC2) of Guanhões, the average soil penetration resistance increases considerably in the sublayers, reaching values of 5.11 MPa in the native Cerrado of the Northwest area of Minas Gerais in the 40-45 cm depth. As such, a natural densification tendency is verified in Latosols located under the Cerrado biome, that can reach the average to high penetration resistance classes according to the classification contained in Table 13.

Depth	Soil penetration resistance, MPa					
	Lowest	Lower Quartile	Average	Median	Upper Quartile	Highest
0-10	0.84	1.50	2.24	1.75	2.80	6.30
10-20	0.84	1.82	3.27	2.79	5.00	6.66
20-30	0.98	2.31	3.41	2.93	4.68	6.77
30-40	1.56	2.30	3.15	2.89	3.98	6.32
40-50	1.40	2.01	2.88	2.83	3.68	5.69
50-60	1.37	1.89	2.73	2.79	3.35	5.03
0-60	0.84	1.90	2.96	2.7	3.83	6.77

Table 12. Descriptive statistics for the soil penetration resistance in the Cerrado.

Class	Penetration resistance (MPa)	Root growth limitation
Very low	< 1.1	Without limitations
Low	1.1 – 2.5	Few limitations
Moderate	2.6 – 5.0	Some limitations
High	5.1 – 10.0	Serious limitations
Very high	10.1 – 15.0	Roots practically do not grow
Extremely high	" /> 15.0	Roots do not grow

Source: Camargo & Alleoni (1997).

Table 13. Classes of soil mechanical penetration resistance and degree of root growth limitation [41].

The 0-10 cm depth was the one which presented the lowest average soil penetration resistance, and the lowest values were found in environments without anthropic interference, as in the native Cerrado of the Central area of Minas (NC5) and native Cerrado of Guanhões (NC2), that presented values of 0.84 and 0.86 MPa, respectively. In this depth the uncovered soil of Guanhões (UCS1) and of Belo Oriente (UCS2) presented high penetration resistance, with values of 6.30 and 4.18 MPa, respectively, a characteristic that can hinder the plant growth due to these values being classified in the average to high penetration resistance classes (Table 13). Even at this depth, the conventional pasture (CP) and eucalyptus + pasture + cattle (EPC) systems, both from the Northwest area of Minas Gerais, and planted pasture of Belo Oriente (PP1) presented values of 6.13; 5.75 and 4.9 MPa, that can be due to the animal trampling that can cause compaction, mainly in the first centimeters of the soil, proven for higher increases in the 0-10 cm depth [42].

In the 10-20 cm depth the tendency is continued for the layer above this, and the native Cerrado of the Central of Minas Gerais region (NC5) and the native Cerrado of Guanhões (NC2) systems present the lowest penetration resistance values. In this depth the systems that use potato planting (CCP and CCPO) in the Campo das Vertentes, MG, present low penetration resistance, due to the potatoes harvest process that provokes a high tillage of the soil.

The depths over 20 cm presented high soil penetration resistance values, which cannot only be demonstrated by the animal trampling in the pasture systems, because this effect is only limited to the surface layer of the soil. According to [43], the compaction and higher soil penetration resistance can also be the result of particle settling, a consequence of the pore blockage by the finer particles, as well as the wetting and drying cycles of the soil.

For [31] the root growth of annual cultures undergoes restriction in penetration resistance values over 2.0 MPa, and according to Table 12, above 2.6 MPa there are some restrictions to the root growth, and with this, for the depths over 20 cm, the development of roots in the studied areas can be compromised, because most of the soils presented penetration resistance over 2.5 MPa.

11. General overview on the variations among the physical indicators

Analyzing the soil physical attributes as indicators of soil quality in native and anthropic systems, it is verified that the land use for agricultural purposes provokes soil physical attributes quality reduction. This degradation varies according to the geographical region, soil types and soil use and management practices. However, the use of conservationist systems coupled with little soil revolving tends to improve the soil physical attributes.

The systems that provoke soil revolving are more likely to compact the soil and increase water erosion, being this the main cause for the Brazilian soils degradation. Systems with reduced revolving or even the ones with no revolving (no-till) maintain the soil structure. Thus, those systems allow rapid water infiltration in the soil and, hence, reduce the water erosion.

12. Conclusions

The physical attributes analyzed in Latosols of Cerrado were sensitive to the reduction of the soil quality due to the substitution of native areas by agricultural areas, mainly in the planting systems that highly upturn the soil.

In most cases, the exploitation of the native soil caused an increase of the soil density and soil penetration resistance and it reduced the total porosity, macroporosity, hydraulic conductivity of the saturated soil and the average geometric diameter of the aggregates.

Systems that use direct planting and eucalyptus reforestation without burning present higher organic matter content, total organic carbon and carbon storage than agricultural systems.

The impact of the findings presented from this research is high considering the geographical extension of the Brazilian Cerrado region (one of the latest world agricultural frontiers) and their potential for developing land use and management policies is highly significant.

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