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# **Hydraulic properties of the diagnostic horizon of Latosols of a regional toposéquence across the Brazilian Central Plateau**

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## **Abstract**

The Brazilian Central Plateau covers about 40% of the Cerrados Biome and represents 24% of the Brazilian territory. The Latosols that correspond to about 40 % of the surface area of the Central Plateau are characterized by a poor horizonation, a weak macrostructure and a strong development of the fine granular structure composed of sub-rounded microaggregates 50 to 300 µm in size. In this study, we analyzed the hydraulic properties of a set of Latosols varying according to their clay content and mineralogy with respect to their location along a regional toposéquence across the Brazilian Central Plateau. Ten Latosols (L) were selected on the South American Surface (L1 to L4) and Velhas Surface (L5 to L10) and we studied the properties of their diagnostic horizon

(Bw). We measured their bulk density and particle density, and the soil-water retention properties at -1, -6, -10, -33, -300, and -1500 kPa by using the centrifugation method. We also determined the saturated hydraulic conductivity in the field using the Guelph permeameter procedure. Results showed that the total pore volume ( $V_p$ ) ranged from 0.460 to 0.819 cm<sup>3</sup> g<sup>-1</sup> and 58.2 % of the variance was explained for by the clay content. According to Balbino et al. (2002),  $V_p$  was divided into a volume of intra-microaggregates pores ( $V_{intra}$ ) and inter-microaggregates pores ( $V_{inter}$ ). Results showed that  $V_{intra}$  ranged from 0.090 to 0.234 cm<sup>3</sup> g<sup>-1</sup> and  $V_{inter}$  from 0.305 to 0.585 cm<sup>3</sup> g<sup>-1</sup>. Results showed also that  $V_p$  explained a proportion of the variance of the water retained that decreased with the water potential. On the other hand, the clay content explained a proportion of that variance that increases when the water potential decreased. The great proportion of variance (90.7 %) explained for by the clay content alone at -1500 kPa showed that there is little variability that can be attributed to clay mineralogy variation. The saturated hydraulic conductivity ( $K_s$ ) was related to an effective porosity ( $\Phi_e$ ) defined as the volume proportion of pore with equivalent diameter > 300  $\mu$ m. Finally, our results showed that water retention properties and saturated hydraulic conductivity varied mainly according to the clay content and development of large pores without any close link with the mineralogy of the clay fraction.

**Keywords:** Structure; Oxisol; Ferralsol; Pedotransfer function, Water retention, Cerrado

## **1 – Introduction**

The Brazilian Central Plateau covers about 40% of the Cerrados Biome and 24% of the whole Brazilian territory (Adámoli et al., 1986). It can be divided into two main geomorphic surfaces: the South American Surface and the Velhas Surface (King, 1956; Lepsch and Buol, 1988; Motta et al., 2002; Marques et al., 2004). The South American Surface corresponds to a landscape that originated from a vast peneplain resulting from erosion between the lower Cretaceous and the middle Tertiary under humid climatic conditions favorable to deep weathering of rocks (Braun, 1971). Because of continent uplift, that peneplain was dissected, thus resulting in a landscape of tablelands 900 to 1,200 m high corresponding to remnants of the South American Surface (Radambrasil, 1984). On the other hand, the Velhas Surface has formed later and corresponds to surfaces connecting the South American Surface to lower portions of the landscape where the rivers flow. The Velhas Surface shows moderate and convex slopes and covers a much smaller surface areas of the Brazilian Central Plateau than the South American Surface.

The Latosols cover about 40% of the Central Plateau surface area (Silva et al., 2005). Most Latosols in the Brazilian Soil Taxonomy (Embrapa, 1999) correspond to Oxisols in the Soil Taxonomy (Soil Survey Staff, 1998) and to Ferralsols in the International Reference Base System (ISSS Working Group R.B., 1998; Reatto et al. 1998). In the Central Plateau, the Latosols can be Red Latosols (Acrustox, ~28%), Yellow Red Latosols (Acrustox, ~10%) and Yellow Latosols (Haplaquox, ~2%) (Silva et al., 2005). The main characteristics of Latosols are a poor differentiation of the horizons,

a weak macrostructure and a strong submillimetric granular structure (Embrapa, 1999) resulting in microaggregates 50 to 300  $\mu\text{m}$  in size (Balbino et al., 2001 and 2002; Volland-Tuduri et al., 2004 and 2005) and earlier described as “pseudosand”, “micropeds” and “granules” (Kubienna, 1950; Brewer and Sleeman 1960; Brewer, 1976) or primary particle fraction (Westerhof et al., 1999). The development of that granular structure in Brazilian Latosols was analyzed in numerous studies (e.g. Resende, 1976; Lima, 1988; Ker, 1995; Ferreira et al., 1999a; Schaefer, 2001; Gomes et al., 2004a; Cooper and Vidal-Torrado, 2005; Volland-Tuduri et al., 2004 and 2005). Kaolinite, gibbsite, goethite and hematite were recognized in different proportions in the clay fraction of Latosols. Curi and Franzmeier (1984) analyzed the mineralogy of the clay fraction in a topossequence of Latosols developed in the weathered basalt in Southern Goiás state. They showed that gibbsite was the main mineral in red Latosols located upslope when it was kaolinite and goethite in yellow Latosols located downslope. Ferreira et al. (1999a) studied seven diagnostic horizons (horizon Bw) of Latosols from the Minas Gerais and Espírito Santo states. They showed that kaolinite and goethite were the main minerals in the clay fraction of yellow Latosols when it was gibbsite, hematite and goethite in different proportions in the  $<2\mu\text{m}$  fraction of ferric red Latosols and red Latosols. They also concluded that kaolinite and gibbsite were the main minerals responsible for the structure development of the Latosols studied. Ker (1995) studied the clay fraction of 26 diagnostic horizons collected in Latosols located in several Brazilian states. He showed that ferric red Latosols were rich in kaolinite, gibbsite and hematite, the red Latosols in kaolinite and hematite, the yellow red Latosols in kaolinite and goethite, and the yellow Latosols in kaolinite, gibbsite and goethite. Reatto et al. (2000)

studied the diagnostic horizon of 124 Latosols located in the Brazilian Cerrado area and showed that other mineralogical compositions than those recorded by earlier authors were associated to the different types of Latosols. Gomes et al. (2004a) analyzed the clay fraction of 36 diagnostic horizons of Latosols located in the Eastern Goiás and Minas Gerais states. These authors grouped the Latosols studied according to their clay and  $\text{Fe}_2\text{O}_3$  content and showed a large range of clay mineralogy.

The hydraulic properties of Latosols have been studied by several authors. Macedo and Bryant (1987) studied a hydrosequence of Latosols developed in weathered Tertiary sediments in the Federal District. They showed that the Red Latosols were located on the South American Surface in the well drained central part of the plateau. On the other hand they showed also that the Yellow Red Latosols were located downslope in poorly drained position. Pachepsky et al. (2001) found relationships between the soil water retention and topographic variables and showed that more than 60% of the variation in soil water content at  $-10$  and  $-33\text{kPa}$  were explained by these relationships. Van den Berg et al. (1997) studied the water retention properties of Latosols in different regions and showed that water release occurs between  $-5$  and  $-10$  kPa such as in sandy soils. Cichota & van Lier (2004) discussed the spatial variability of the water retention properties of loamy Yellow Red Latosols. The water retained at every different potential ranging from  $-1$  to  $-100$  kPa was not closely related to the clay content. Ferreira et al. (1999b) showed that the saturated hydraulic conductivity ( $K_s$ ) of Latosols increased with the clay content but they did not discuss the variability within every class of Latosols. However they showed for the diagnostic horizon that  $3.9 \cdot 10^{-6} < K_s < 2.2 \cdot 10^{-5} \text{ m.s}^{-1}$  for kaolinitic Latosols except for on diagnostic horizon ( $K_s = 1.7 \cdot 10^{-4} \text{ m.s}^{-1}$ ) and  $5.5 \cdot 10^{-5} < K_s < 8.4 \cdot 10^{-5} \text{ m.s}^{-1}$  for

gibbsitic Latosols. Thus, according to these authors, the kaolinitic Latosols would have smaller  $K_s$  than gibbsitic. They recorded also that kaolinitic Latosols had a greater bulk density, a smaller aggregate stability and macroporosity than gibbsitic Latosols. Marques et al. (2002) studied the water retention properties and  $K_s$  of the different horizons of clay Yellow Latosol and Red Latosol. They recorded no difference between these two Latosols whatever the horizon studied. Gomes et al. (2004b) showed that the water retention properties in the surface horizons of large range of type of Latosols located in the Eastern Goiás and Minas Gerais states were closely correlated with the clay and organic carbon content. Balbino et al. (2004) studied a clayey Latosol and showed a variation of the water retention properties and unsaturated hydraulic conductivity between native vegetation and pasture. Cooper and Vidal-Torrado (2005) studied a Nitisol and a Latosol in Southeast of Brazil. They showed that the diagnostic horizon of the Nitisol had a strong to moderate subangular blocky structure and smaller  $K_s$  than the diagnostic horizon of the Latosol.

Although there is a large range of composition among Brazilian Latosols, the earlier studies did not show any close relationship between the Latosol composition and their hydraulic properties. In this study, we analyzed the hydraulic properties of set of Latosols varying in their particle size distribution and mineralogical composition according to their location in a regional topossequence across the Brazilian Central Plateau. We showed that water retention properties and saturated hydraulic conductivity varied mainly according to the development of the microaggregation with no clear link to the mineralogy of the clay fraction.

## **2 – Material and Methods**

### *2.1 – Site conditions*

According to the Köppen classification, the most representative climate of the Central Plateau is Megatermic or Humid Tropical (Aw) with the subtype savanna. It is characterized by a dry winter (medium temperature of the coldest month  $> 18^{\circ}\text{C}$ ) and maximum rains in summer. The mean annual rainfall ranges from 1,500 to 2,000 mm, with the highest rainfall in January and the smallest in June, July and August ( $< 50$  mm/month). The relative humidity of the air is about 75% between January and April, when it is about 30% during the dry winter (Assad et al., 1993).

### *2.2 - Soil selection*

The Latosols studied were selected according to Reatto et al. (2000) who studied the mineralogical composition of Latosols in the Cerrados Biome. By using a semi-quantitative method based on a sulfuric acid extraction and the soil color (Resende et al., 1987, Resende and Santana, 1988). Reatto et al. (2000) showed that for the data of mineral oxides from sulfuric acid extraction, was used to estimate the values of kaolinite, gibbsite, goethite and hematite, and the two last clay minerals with the integration of the color (hue, value and chrome), according Santana (1984). Besides of the mineralogical variability was realized an arrangement between: class of Latosols, according Brazilian Soil Taxonomy (Embrapa, 1999) and topography surface, and textural class, and parent material.

Ten Latosols (L) were selected along an approximately 350 km long regional toposequence across the South American Surface (L1 to L4) and Velhas Surface (L5 to



L10) (Table 1). The Latosols L5 and L6 were located on the upper Velhas Surface, L7 and L8 on the intermediate Velhas Surface, and L9 and L10 on the lower Velhas Surface. According to Reatto et al. (2000) who studied the mineralogical composition of a large range of Latosols in the Cerrados Biome by using semi-quantitative methods based on sulfuric acid extraction and soil color (Resende et al., 1987; Resende and Santana, 1988), the selected Latosols showed a large range of mineralogical composition (Table 1).

### *2.3 - Soil characterization*

Soils were described according to the field manual of Lemos and Santos (1996) and the Brazilian Soil Taxonomy (Embrapa, 1999). A pit 2-m depth was dug and the top horizon (A), transitional horizons (AB and BA) and diagnostic horizon (Bw) were described. Disturbed samples were collected in every horizon as well as undisturbed samples in triplicate using copper cylinders 100 cm<sup>3</sup> in volume ( $\varnothing = 5.1$  cm, h = 5 cm).

Basic soil characterization was performed on the air-dried <2-mm material according to the Brazilian standard procedures as described by Embrapa (1997). Thus, the particle size distribution was determined using the pipette method after dispersion with NaOH 1N. The particle density was determined by using 95% hydrated alcohol with 20 g of air-dried soil material in a 50-ml pycnometer. The soil pH was measured in distilled water and 1N KCl using 1:1 mass soil to solution ratio. The cation exchange capacity (CEC) was determined as being the sum of the electric charges of Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Al<sup>3+</sup> extracted with 1N KCl, of K<sup>+</sup> and Na<sup>+</sup> extracted with 0,05N HCl, and of H<sup>+</sup> and Al<sup>3+</sup> extracted with a tampon solution of Ca(CH<sub>3</sub>COO)<sub>2</sub> and CH<sub>3</sub>COOH at pH 7.0. The organic carbon content was determined by wet oxidation with 0.4N K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>.

The water retention properties of the horizon Bw were determined for every soil by using the undisturbed samples collected in triplicate. These samples were saturated for 24 h prior the determination of their water retention properties by using the centrifugation method (Freitas Junior and Silva, 1984). A 120-min centrifugation long was used as recommended by Silva and Azevedo (2002). The water content was determined at -1, -6, -10, -33, -300, and -1500 kPa. The sample mass was measured at every water potential and the final water content was determined at -1500 kPa after oven-drying the soil at 105°C. The water content at every potential was then calculated. The bulk density ( $\text{g}\cdot\text{cm}^{-3}$ ) was calculated using the oven-dry mass of the soil material contained in the 100  $\text{cm}^3$  cylinders. The saturated hydraulic conductivity was determined in the field using the Guelph permeameter procedure (Reynolds and Elrick, 1985). The water infiltration measurements were taken from three bore holes, applying two different constant water heads for each hole. The field saturated hydraulic conductivity was thus measured in the horizon Bw at a depth ranging from 110 to 140 cm according to the soil description.

### **3 - Results**

#### *3.1 – Structure*

Field observations revealed a decrease in the development of the sub-angular blocky structure with depth and a strong increase in the development of the very fine granular structure. Dense centimetric nodules with similar composition to the surrounding soil material were recorded in different proportion in the Latosols studied. Nodules were about 20% of the soil volume between 30 and 70 cm depth in L1, L2, L3, L5, L6 and L10, 10% in L8, 5% in L9 and 2% in L4 and L7. Spherical iron concretions <2 mm in

diameter were also recorded in L1 and their proportion roughly increased with depth. Most roots were located within the 0-5 cm top layer and their size decreased with depth, roots several centimeters in diameter being very rare below 20 cm depth. Channels a few millimeters in diameter and cavities a few centimeters in size that are related to termite and ant activity were found in the Latosols studied. They were particularly numerous in L7, moderately numerous in L1, L6 and L8 and a few in the other Latosols studied.

The diagnostic horizons (Bw) of the Latosols studied showed a compound weak to moderate medium subangular blocky structure and a strong fine to very fine granular structure (Table 2). Dense nodules were not recorded in the diagnostic horizons (Bw) of L2, L4, L6, L7 and L7. They were between 30 and 40% of the soil volume in L1, about 20% in L5, 10% in L7 and 5% in L3 and L8. Cavities and channels were several millimeters in diameters and few in L1, L4 and L5 when they were numerous in L7. They were very rare in the other diagnostic horizons.

### *3.2 – Physico-chemical characteristics of the diagnostic horizon Bw*

The  $\text{pH}_w$  ranged from 4.8 to 5.3 and  $\text{pH}_{\text{KCl}}$  from 4.0 to 6.2. The horizons Bw of the Latosols of the South American Surface were more electropositive than the Latosols of the Velhas Surface (Table 3). The organic carbon content of the horizon Bw was close to  $0.6 \text{ g.kg}^{-1}$  in L2, L5, L7 and L8, close to  $0.3 \text{ g.kg}^{-1}$  in L1 and L4, and close to  $0.02 \text{ g.kg}^{-1}$  in L3, L6, L9, and L10. The sum of exchangeable bases (SB) ranged from 0.16 to 0.27  $\text{cmol}_c \text{ kg}^{-1}$ , except in L10 where it was much greater ( $0.93 \text{ cmol}_c \text{ Kg}^{-1}$ ). The cation exchange capacity (CEC) ranged from 1.72 to  $10.60 \text{ cmol}_c \text{ kg}^{-1}$ . The high values of CEC appeared to be related to the high  $\text{H}^+ + \text{Al}^{3+}$  content as observed in L2, L6 and L8.

The horizon Bw studied showed high clay content that ranged from 520 to 780 g.kg<sup>-1</sup>, except for L4 where it was 300 g.kg<sup>-1</sup>. The particle density ( $D_p$ ) and bulk density ( $D_b$ ) ranged from 2.64 to 2.88 g.cm<sup>-3</sup> and from 0.84 to 1.21 g.cm<sup>-3</sup>, respectively and there is no distinction between the horizons Bw collected in Latosols located on the South American Surface and those located on the Velhas Surface (Table 4). The saturated gravimetric water content ( $W_0$ ) ranged from 0.378 to 0.748 g.g<sup>-1</sup> and the gravimetric water content at -1500 kPa ( $W_{1500}$ ) ranged from 0.099 to 0.281 g.g<sup>-1</sup>. The field saturated hydraulic conductivity ( $K_s$ ) of the diagnostic horizons Bw ranged from 8.64 10<sup>-6</sup> to 4.18 10<sup>-5</sup> m.s<sup>-1</sup> (Table 4).

## 4 – Discussion

### 4.1 – Total pore volume and elementary pore volumes

We computed the total pore volume ( $V_p$  in cm<sup>3</sup> g<sup>-1</sup>) by using both the bulk density ( $D_b$ ) and particle density ( $D_p$ ) as following:

$$V_p = 1/D_b - 1/D_p$$

Results showed that  $V_p$  ranged from 0.460 to 0.819 cm<sup>3</sup> g<sup>-1</sup> (Tables 4 & 5) and 58.2 % of the variance was explained for by the clay content (Fig. 1). Earlier studies (Balbino et al., 2002; Volland-Tuduri et al., 2004 and 2005; Cooper and Vidal-Torrado, 2005) showed that the total pore volume of microaggregates of the Latosols resulted from the contribution of the pores related to the assemblage of elementary particles inside the microaggregates (intra-microaggregate pores,  $V_{intra}$  in cm<sup>3</sup> g<sup>-1</sup>) and of the pores between the microaggregates (inter-microaggregate pores,  $V_{inter}$  in cm<sup>3</sup> g<sup>-1</sup>). The volume of inter-microaggregates pores resulted from the contribution of the pores related to the

assemblage of the microaggregates and of those related to biological activity that are usually greater in these soils than the former (Schaefer, 2001; Barros et al., 2001; Volland-Tuduri et al., 2004 and 2005). Balbino et al. (2002) studied the variation of  $V_{\text{intra}}$  for a large range of Latosols and showed that it was closely related to the clay content ( $C$ ) as following:

$$V_{\text{intra}} = 0.0003 C - 0.0004$$

with  $C$ , the clay content ( $\text{g.kg}^{-1}$ ). According to that relationship,  $V_{\text{intra}}$  ranged from 0.090 to  $0.234 \text{ cm}^3 \text{ g}^{-1}$  for the Latosols studied (Table 5). Then we computed  $V_{\text{inter}}$  using the following relationship:

$$V_{\text{inter}} = V_{\text{p}} - V_{\text{intra}}$$

The recorded  $V_{\text{inter}}$  ranged from 0.305 to  $0.585 \text{ cm}^3 \text{ g}^{-1}$  (Table 5). That variation of  $V_{\text{inter}}$  cannot be related to the structure development of the diagnostic horizons Bw studied as described in Table 2. However, the smallest  $V_{\text{inter}}$  was recorded in L1 where the horizon Bw<sub>2</sub> showed the greatest proportion of dense nodules (Tables 2 & 5).

#### *4.2 – Water retention properties*

Our results showed that the percentage of variance of the gravimetric water content explained for by  $V_{\text{p}}$  decreased with the water potential (Fig. 2). That percentage gradually decreased from 97.9 to 63.6 % when the water potential decreased from  $-1$  to  $-300 \text{ kPa}$ , the percentage of variance explained being a little greater at  $-1500 \text{ kPa}$  (65.1 %) than at  $-300 \text{ kPa}$ . Such a decrease of the closeness of the relationship with the water potential was earlier recorded for other soils (Bruand et al., 1988; Dexter, 2004) and it is related to the decrease in the proportion of  $V_{\text{p}}$  that retains water when the water potential decreases.

On the other hand, our results showed also that the percentage of variance of the gravimetric water content explained for by the  $< 2 \mu\text{m}$  content increased with the absolute value of the water potential (Fig. 3). Indeed, that percentage gradually increased from 56.7 to 90.7 % when the water potential decreased from  $-1$  to  $-1500$  kPa. That increase is related to the decrease in the size of the pores retaining the water when the water potential decreases, the more their pore size being small, the more the pore volume to which they correspond to being closely related to the  $< 2 \mu\text{m}$  content (Bruand and Prost, 1987; Bruand et al., 1988).

The proportion of variance remaining unexplained for by the  $< 2 \mu\text{m}$  content and its increase with the water potential would result from the contribution to water retention of a volume of pores that increased with the water potential and that was not related to the  $< 2 \mu\text{m}$  content but to aggregation development. On the basis of the Jurin's law, water is retained at  $-1500$  kPa in pores with equivalent pore diameter ( $D_e$ )  $\leq 0.2 \mu\text{m}$  thus indicating that at this water potential water was retained in pores resulting from the assemblage of the  $< 2 \mu\text{m}$  particles and explaining the great percentage of variance explained for by the  $< 2 \mu\text{m}$  content at  $-1500$  kPa (90.7%) (Fig. 3f).

#### 4.3 – Saturated hydraulic conductivity

The smallest and greatest averaged  $K_s$  and  $V_{\text{inter}}$  were recorded for L1, respectively  $8.64 \times 10^{-6} \text{m.s}^{-1}$  and  $0.305 \text{cm}^3 \text{g}^{-1}$ , and L6, respectively  $4.18 \times 10^{-5} \text{m.s}^{-1}$  and  $0.585 \text{cm}^3 \text{g}^{-1}$  (Tables 4 & 5). However, comparison of  $K_s$  and  $V_{\text{inter}}$  led to poor correlation between them probably because  $V_{\text{inter}}$  includes a large proportion of small pores that only participate marginally to water transfer when the soil is saturated. Ahuja et al. (1989)

related  $K_s$  to the effective porosity ( $\Phi_e$ ) defined as the porosity occupied by air at -33 kPa as following:

$$K_s = a(\Phi_e)^b$$

where a and b are constants. That relationship was used by Franzmeier (1991) and Tomasella and Hodnett (1997) for a large range of soils. We computed the porosity occupied by air ( $\Phi_a$ ) at different potentials as following:

$$\Phi_a = (V_p - W_h/\rho_w) \times D_b$$

with  $\rho_w$ , the specific mass of water taken as equaled to  $1 \text{ g cm}^{-3}$ , and h, successively equaled to -1, -6, -10 and -33 kPa. Then we correlated  $K_s$  to the different values of  $\Phi_a$  and showed that the closest correlation was recorded with  $\Phi_a$  computed for h = -1 kPa ( $R^2 = 0.558$ ) (Fig. 4). The correlation recorded with  $\Phi_a$  computed for h = -33 kPa as earlier proposed by Ahuja et al. (1989) was the loosest ( $R^2 = 0.362$ ). Thus, unlike  $\Phi_e$  defined by Ahuja et al. (1989) as the porosity occupied by air at -33 kPa ( $D_e = 10 \text{ }\mu\text{m}$ ), the effective porosity should be defined as the porosity corresponding to larger pores ( $D_e \geq 300 \text{ }\mu\text{m}$  since occupied by air at -1kPa) for the diagnostic horizons (Bw) of Latosols.

## 5 – Conclusion

Our results showed that for the diagnostic horizons studied the total pore volume ( $V_p$ ) ranged from  $0.460$  to  $0.819 \text{ cm}^3 \text{ g}^{-1}$ . They showed also that 58.2 % of the variance of  $V_p$  was explained for by the clay content alone although there was a large range of clay mineralogy within the set of diagnostic horizons (Bw) studied.

According to Balbino et al. (2002),  $V_p$  was divided into a volume of intra-microaggregates pores ( $V_{intra}$ ) and inter-microaggregates pores ( $V_{inter}$ ). Results showed that  $V_{intra}$  ranged from 0.090 to 0.234 cm<sup>3</sup> g<sup>-1</sup> and  $V_{inter}$  from 0.305 to 0.585 cm<sup>3</sup> g<sup>-1</sup>.

Results showed also that  $V_p$  explained a proportion of the variance of the water retained that decreased with the water potential. On the other hand, the clay content explained a proportion of that variance that increases when the water potential decreased. The great proportion of variance (90.7 %) explained for by the clay content alone at -1500 kPa showed that there is little variability that can be attributed to clay mineralogy variation. The saturated hydraulic conductivity ( $K_s$ ) was related to an effective porosity ( $\Phi_e$ ) defined as the volume proportion of pore with equivalent diameter > 300  $\mu$ m.

Thus, our results showed that water retention properties and saturated hydraulic conductivity varied mainly according to the clay content and development of large pores without any close link with the mineralogy of the clay fraction.

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Table 1  
General characteristics of the Latosols (L) studied

Latosols	Geographical Coordinates	Geomorphic Surface	Soil type	Altitude	Geology	Lithology	Parent Material	<2 µm mineralogy	Vegetation
L1	S066°60'77'' W81°60'187''	South America	Red Latosol (Rhodic Acrustox)	1,050 m	Metamorphic Rocks- Complex Goiano – (Anápolis - Itauçu) and metaclastic rocks – Group Araxá - Superior Precambrian	Granulite	Mafic granulite	gibbsite/hematite	Subcaducifolic Tropical Florest (Floresta Tropical Subcaducifólia)
L2	S15°37'127'' W47°45'576'	South America	Red Latosol (Typic Acrustox)	1,200 m	Clastic rocks - Paranoá Group - Superior Precambrian	Sandy Metaritimite	Lateritic crusts and saprolite Sandy Metaritimite	gibbsite/hematite	Typical Savannas (Cerrado Típico)
L3	S15°36'919'' W47°45'78''	South America	Yellow Latosol (Xanthic Acrustox)	1,190 m	Clastic rocks - Paranoá Group - Superior Precambrian	Sandy Metaritimite	Lateritic crusts and saprolite Sandy Metaritimite	gibbsite/goethite	Typical Savannas (Cerrado Típico)
L4	S15°36'320'' W47°44'148'	South America	Plinthic Yellow Latosol (Plinthic Acrustox)	1,180 m	Clastic rocks - Paranoá Group - Superior Precambrian	Quartzite	Lateritic crusts and saprolite Quartzite	gibbsite/goethite	Typical Savannas (Cerrado Típico)
L5	S15°36'502'' W47°42'813''	Velhas, superior level	Red Latosol (Typic Acrustox)	920 m	Clastic rocks - Paranoá Group - Superior Precambrian	Clayed Metaritimite	Colluvial Sediment Lateritic crusts and	kaolinite/hematite	Xeromorphic Tropical Florest (Cerradão)
L6	S15°31'450'' W47°41'903	Velhas, superior level	Red Latosol (Rhodic Acrustox)	880 m	Pelitic rocks - Paranoá Group - Superior Precambrian	Metapelite	saprolite Metapelite	kaolinite/hematite	Subcaducifolic Tropical Florest (Floresta Tropical Subcaducifólia)
L7	S15°13'24,2'' W47°42'14,7''	Velhas, intermediate level	Red-Yellow Latosol (Typic Acrustox)	820 m	Pelitic rocks - Paranoá Group - Superior Precambrian	Metapelite	Colluvial Sediment	kaolinite/goethite	Dense Savannas (Cerrado Denso)
L8	S15°13'23,3'' W47°42'5,2''	Velhas, intermediate level	Red Latosol (Rhodic Acrustox)	805 m	Pelitic rocks - Paranoá Group Superior Precambrian	Metapelite	Colluvial Sediment Saprolite	kaolinite/hematite	Dense Savannas (Cerrado Denso)
L9	S15°11'183'' W47°43'680''	Velhas, inferior level	Red Latosol (Rhodic Acrustox)	785 m	Pelitic rocks and limestone - Paranoá Group Superior Precambrian	Metapelite and limestone	Colluvial Sediment Metapelite and limestone	kaolinite/hematite	Dense Savannas (Cerrado Denso)
L10	S15°14'080'' W47°46'372'	Velhas, inferior level	Red Latosol (Rhodic Acrustox)	760 m	Limestone and lacustrine sediment of Terciary	Lacustrine limestone	Colluvial Sediment	kaolinite/hematite	Dense Savannas (Cerrado Denso)

Geographical Coordinates: measured with a Global Positioning System (GPS); Altitude: measured with an altimeter, vegetation classified according to Ribeiro and Walter (1998).

Table 2

## Morphological characteristics of the diagnostic horizons (Bw) selected in the Latosols (L) studied

Latosol	Horizon	Depth cm	Matrix Munsell Color		Compound Structure	Nodules	Root channels	Insects channels and cavities
			dry	wet				
L1	Bw <sub>2</sub>	100 - 160	2,5YR 4/8	2,5YR 3/6	1mSBK and 2fSBK and 1f-mGR and 3f-vfGR	(+++)-vf-fDN	(+)fCH	no
L2	Bw <sub>2</sub>	115/120 - 200+	5YR 5/6	2,5 YR 4/8	1cSBK and 3f-vfGR	no	no	no
L3	Bw <sub>2</sub>	130 - 180	10YR 6/6	10YR 6/6	2-1cSBK and 3f-vfGR	(+)-fCN	no	no
L4	Bw <sub>1</sub>	60 - 110	10YR7/8	10YR 5/8	1cSBK and 1f-mSBK and 2f-vfGR	no	(+)-fCH	no
L5	Bw <sub>1</sub>	57/90 - 90/120	5YR 5/8	2,5YR 3/6	2mSBK and 3-2fSBK and 3-2fGR	(++)fDN	(+)fCH	(+)f-mCV
L6	Bw <sub>2</sub>	140 - 200+	2,5YR 4/8	10R 3/6	1mSBK and 3f-vfGR	no	no	no
L7	Bw <sub>2</sub>	96/110 - 200+	5YR 5/6	5YR 5/9	2-1m-fSBK and 3f-vfGR	(+)vfDN	no	(++++)-vf-f CHCV
L8	Bw <sub>2</sub>	95 - 200+	2,5YR 4/8	2,5YR 3/6	2-1m-fSBK and 3f-vfGR	(+)-vfDN	no	(+)vf-f CHCV
L9	Bw <sub>2</sub>	100/110 - 180	2,5YR 4/6	2,5YR 3/6	1mSBK and 3f-vfGR	no	no	no
L10	Bw <sub>2</sub>	100 - 140	2,5YR 4/6	10R 4/8	2-1c-mSBK and 2c-mGR and 3f-vfGR	no	no	no

Structure description: (grade – size – type). Grade: 1 – weak; 2 – moderate; 3 – strong. Size of granular structure: vf – very fine (< 1mm); f = fine (1-2mm); m = medium (2-5mm); c = coarse (5-10mm); vc = very coarse (>10mm). Size of subangular blocky: vf – very fine (< 5mm); f = fine (5-10mm); m = medium (10-20mm); c = coarse (20-50mm); vc = very coarse (>50mm). Type: GR = granular; SBK = subangular blocky. Nodules description: (grade – size – type). Grade: (++++) = very strong; (+++) = strong; (++) = moderate; (+) = weak; (+-) = very weak; no = not observed. Size similar of subangular blocky. Type: DN = dispersed nodules; CN = concentrated nodules. Biological Activity description: (grade – size – type). Grade and size similar of nodules. Type: CH = channels; CV = cavities

Table 3  
Chemical characteristics of the diagnostic horizons (Bw) of the Latosols (L) studied

Latosol	Horizon	pH <sub>w</sub>	pH <sub>KCl</sub>	OC (g Kg <sup>-1</sup> )	————— (cmol <sub>c</sub> kg <sup>-1</sup> ) —————							SB	CEC
					Ca <sup>2+</sup> + Mg <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	Al <sup>3+</sup>	H <sup>+</sup> + Al <sup>3+</sup>				
L1	Bw <sub>2</sub>	5.3	6.2	0.34	0.25	0.01	0.00	0.00	1.74	0.26	2.00		
L2	Bw <sub>2</sub>	5.3	6.2	0.61	0.16	0.00	0.00	0.00	10.44	0.16	10.60		
L3	Bw <sub>2</sub>	5.2	5.8	0.02	0.17	0.00	0.00	0.00	1.58	0.17	1.75		
L4	Bw <sub>1</sub>	5.2	5.7	0.34	0.24	0.00	0.00	0.00	1.48	0.24	1.72		
L5	Bw <sub>1</sub>	4.8	4.0	0.62	0.23	0.04	0.00	0.29	2.92	0.27	3.19		
L6	Bw <sub>2</sub>	4.8	5.5	0.02	0.18	0.01	0.00	0.00	9.80	0.19	9.99		
L7	Bw <sub>2</sub>	4.8	4.9	0.59	0.21	0.01	0.00	0.01	2.84	0.22	3.06		
L8	Bw <sub>2</sub>	4.9	4.2	0.61	0.20	0.01	0.00	0.18	8.84	0.21	9.05		
L9	Bw <sub>2</sub>	5.0	4.0	0.01	0.23	0.02	0.00	0.32	2.86	0.25	3.11		
L10	Bw <sub>2</sub>	5.2	4.3	0.02	0.91	0.02	0.00	0.09	4.66	0.93	5.59		

OC = Organic carbon. SB = Sum of exchange bases (Ca<sup>2+</sup> + Mg<sup>2+</sup> + K<sup>+</sup> + Na<sup>+</sup>). CEC = Cation exchange capacity (SB + H<sup>+</sup> + Al<sup>3+</sup>). BS = Bases saturation (SB/CEC) x 100.

Table 4  
Physical characteristics of the diagnostic horizons (Bw) of the Latosols (L) studied

Latosol	Horizon	Particle size distribution ( $\mu\text{m}$ )			Density		Gravimetric water content							$K_s$ ( $\text{m.s}^{-1}$ )
		50-2000 ( $\text{g.kg}^{-1}$ )	2-50	< 2	$D_p$	$D_b$ ( $\text{g.cm}^{-3}$ )	$W_0$	$W_1$	$W_6$	$W_{10}$	$W_{33}$	$W_{300}$	$W_{1500}$	
L1	Bw <sub>2</sub>	440	40	520	2.73	1.21	0.392	0.384	0.290	0.267	0.221	0.188	0.169	$8.64 \times 10^{-6}$
L2	Bw <sub>2</sub>	250	140	610	2.76	0.90	0.664	0.621	0.395	0.341	0.292	0.251	0.231	$3.36 \times 10^{-5}$
L3	Bw <sub>2</sub>	160	90	750	2.72	0.88	0.640	0.609	0.422	0.367	0.301	0.264	0.245	$3.53 \times 10^{-5}$
L4	Bw <sub>1</sub>	690	10	300	2.64	1.18	0.378	0.349	0.227	0.194	0.144	0.112	0.099	$3.98 \times 10^{-5}$
L5	Bw <sub>1</sub>	300	150	550	2.76	1.02	0.531	0.516	0.377	0.325	0.272	0.228	0.202	$1.52 \times 10^{-5}$
L6	Bw <sub>2</sub>	130	90	780	2.65	0.83	0.748	0.678	0.418	0.382	0.326	0.291	0.272	$4.18 \times 10^{-5}$
L7	Bw <sub>2</sub>	160	140	700	2.76	0.96	0.615	0.569	0.391	0.364	0.327	0.302	0.281	$2.65 \times 10^{-5}$
L8	Bw <sub>2</sub>	170	70	760	2.88	0.98	0.638	0.582	0.375	0.341	0.296	0.268	0.246	$2.56 \times 10^{-5}$
L9	Bw <sub>2</sub>	170	80	750	2.80	1.06	0.487	0.459	0.381	0.340	0.298	0.268	0.248	$2.97 \times 10^{-5}$
L10	Bw <sub>2</sub>	180	70	750	2.76	0.88	0.680	0.649	0.456	0.391	0.323	0.277	0.252	$1.69 \times 10^{-5}$

$D_p$  = Particle density.  $D_b$  = Bulk density.  $W_h$  = water content in  $\text{g.g}^{-1}$  at a potential of  $-h$  in kPa.  $K_s$  = saturated hydraulic conductivity.

Table 5  
 Total pore volume and elementary  
 pore volumes of the diagnostic  
 horizons (Bw) of the Latosols (L)  
 studied

Latosol	Horizon	$V_p$	$V_{intra}$	$V_{inter}$
		(cm <sup>3</sup> g <sup>-1</sup> )		
L1	Bw <sub>2</sub>	0.460	0.156	0.305
L2	Bw <sub>2</sub>	0.739	0.183	0.556
L3	Bw <sub>2</sub>	0.771	0.225	0.547
L4	Bw <sub>1</sub>	0.463	0.090	0.373
L5	Bw <sub>1</sub>	0.618	0.165	0.453
L6	Bw <sub>2</sub>	0.819	0.234	0.585
L7	Bw <sub>2</sub>	0.682	0.210	0.472
L8	Bw <sub>2</sub>	0.667	0.228	0.439
L9	Bw <sub>2</sub>	0.584	0.225	0.359
L10	Bw <sub>2</sub>	0.765	0.225	0.540

$V_p$ , total volume of pores;  $V_{intra}$ , volume of intra-microaggregate pores,  $V_{inter}$ , volume of inter-microaggregates pores.

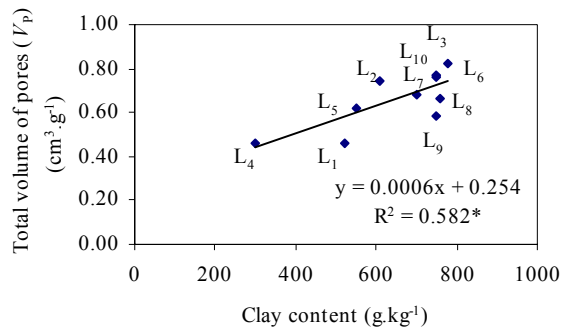


Fig.1. Volume of Total Pores ( $V_p$ ) according to the clay content of the diagnostic horizons (Bw) for the Latosols (L) studied. (\*:  $P = 0.05$ , significant at  $p > 0.05$  level of probability).

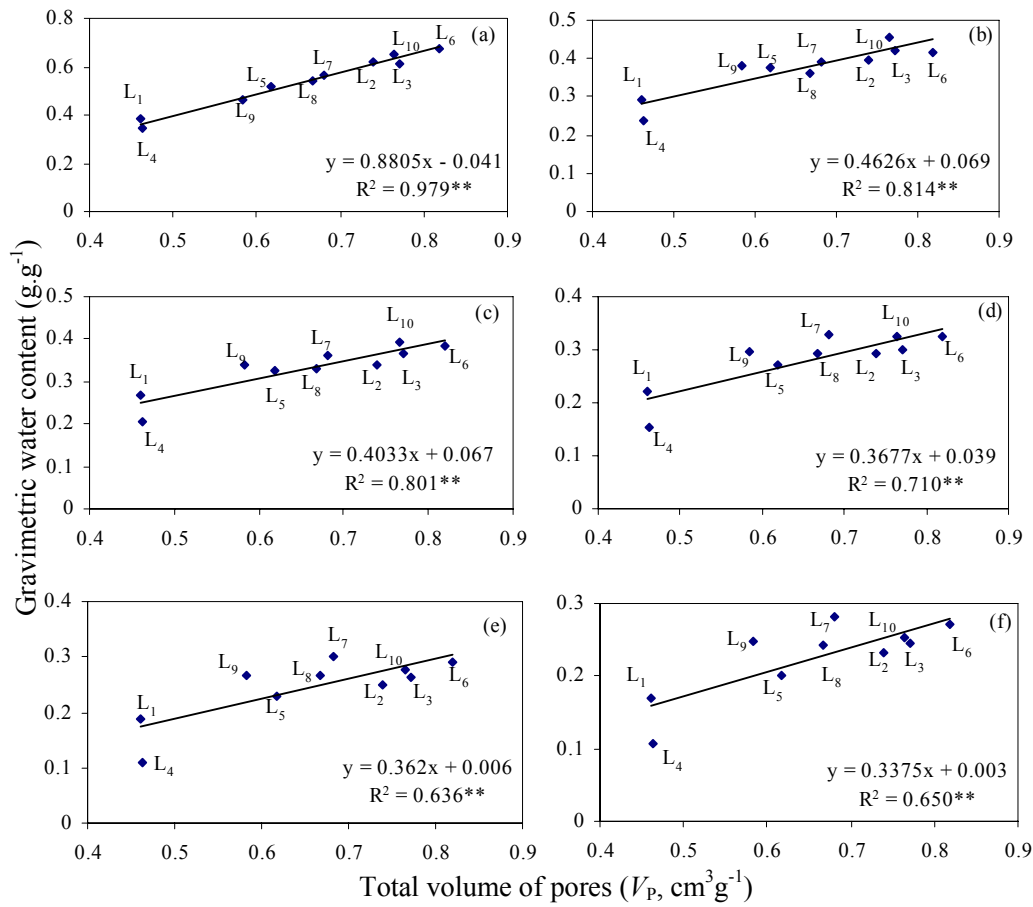


Fig.2 - Gravimetric water content at (a) -1kPa, (b) -6kPa, (c) -10kPa, (d) -33kPa, (e) -300kPa, (f) -1500kPa according to the total volume of pores ( $V_p$ ) of the diagnostic horizons (Bw) for the Latosols (L) studied. (\*\*:  $P = 0.01$ , significant at  $p > 0.01$  level of probability).



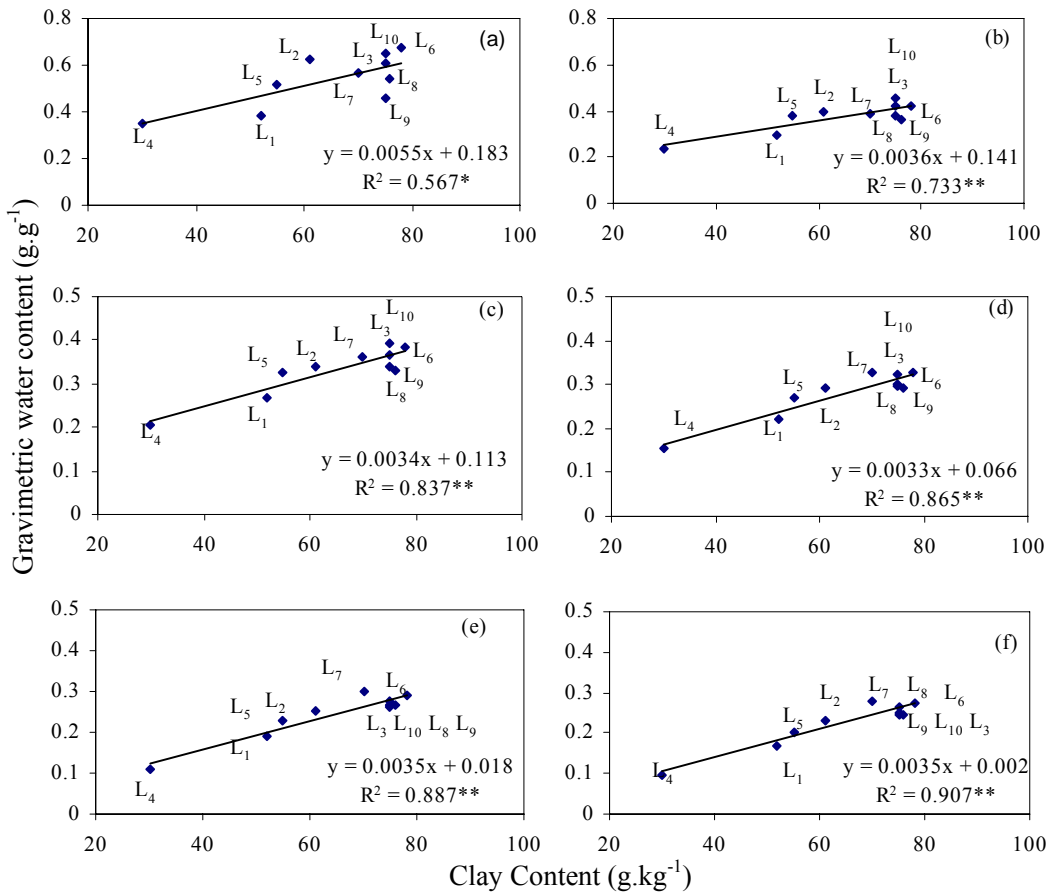


Fig.3. Gravimetric water content at (a) -1kPa, (b) -6kPa, (c) -10kPa, (d) -33kPa, (e) -300kPa, (f) .1500kPa according to the clay content of the diagnostic horizons (Bw) for the Latosols (L) studied. (\*\*: P = 0.01, significant at p > 0.01 level of probability), (\*: P = 0.05, significant at p > 0.05 level of probability).

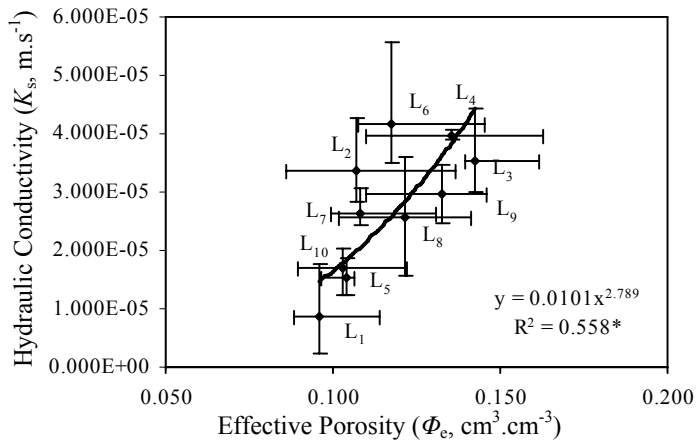


Fig.4. Saturated hydraulic conductivity ( $K_s$ ) according to the effective porosity ( $\Phi_e$ ) of the diagnostic horizons (Bw) for the Latosols (L) studied. (\*:  $P = 0.05$ , significant at  $p > 0.05$  level of probability).