Mass Proportion of Microaggregates and Bulk Density in a Brazilian Clayey Oxisol.

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ABSTRACT

The physical properties of Brazilian Oxisols are closely related to the development of their microstructure, which typically consists of stable microaggregates smaller than 1 mm. There is no model available to predict changes in microstructure in Oxisols. The objective of this work was to relate the proportion of microaggregates to the bulk density (D_b) in the soil studied. Five sites of a typic Haplustox under native vegetation (two sites) and pasture (three sites) were sampled. Soil bulk density, sand, silt, and clay content and aggregate size distribution were measured from the surface to 1.6 m deep in increments of 0.1 m. Thin sections were prepared from undisturbed samples collected in duplicate from 0-0.1 m, 0.3-0.4 m, 0.8-0.9 m and 1.5-1.6 m depth, and backscattered electron scanning images (BESI) were generated. Clay content ranged from 672 to 798 g kg^{-1} and bulk density between 0.87 and 1.18 g cm^{-3} among the 80 samples studied. D_b was poorly correlated with clay content (R^2 = 0.358) and at any depth was not significantly smaller under native vegetation than under pasture. Visual assessment of BESI revealed that soil material corresponded to either microaggregates (< 0.1 mm) in loose arrangement or to much larger aggregates. Quantification of BESI from the deepest sampling depth of all soils showed that 96.2 and 95.7 % of microaggregates were < 0.8 mm with 73.2 and 95.7 % between 0.1 and 0.5 mm under native vegetation and pasture, respectively. The mass proportion of microaggregates can be estimated using the < 0.84 mm soil material that is obtained by dry sieving ($\Phi_{<0.84}$). Finally, our results showed that $\Phi_{<0.84}$ varied with D_b. Linear regression coefficients were calculated for the relationship between $\Phi_{<0.84}$ and the reciprocal of bulk density (1/ D_b) ($\Phi_{<0.84}$ = 1.97 (1/ D_b) – 1.52, R^2 = 0.82), assuming no interaction between microaggregates and macroaggregates, the porosity of these two structural types was estimated as 0.71 and 0.51, respectively.

INTRODUCTION

Due to the lack or minimal development of macrostructure, the physical properties of most Oxisols in Brazil are closely related to their microstructure, which usually consists of very stable microaggregates 0.08 to 0.20 mm in size (e.g. Lima and Anderson, 1997; Furian et al., 1999; Neufeldt et al., 1999). Therefore and despite the small development of macrostructure, the bulk density (D_b) under native vegetation is usually lower than in many other Brazilian soils (Camargo et al., 1988; Brossard et al., 1997). Values of $D_b < 1$ g cm^{-3} are common in Oxisols with a strong microstructure (Bernoux et al., 1998; Neufeldt et al., 1999). When land is cleared for pasture or more intensive agricultural usage, the structure is usually altered and results in an increase in D_b (Stone and Da Silveira, 1978; Curmi et al., 1992; Tavares-Filho and Tessier, 1998; Kondo and Dias Junior, 1999). When the soil is cultivated, macropores that resulted from biological activity under native vegetation are the first to disappear, particularly in the topsoil (Borges et al., 1999). Tavares Filho (1995) studied tilled clayey Oxisols developed on basalts in southern Brazil and showed that macroaggregates development both in topsoil and subsoil was increased by management practices. This was also observed by Balbino et al. (2001 and 2004) as well as a decrease in microaggregates development in Brazilian clayey Oxisols on clearing for pasture. This was interpreted as resulting from a change in the faunal activity in the soil. Neufeldt (2001) showed that under a low productivity pasture, D_b was 1.2 g cm^{-3} at 0–0.1 m depth, compared with < 1.1 g cm^{-3} at the same depth under native vegetation. On the other hand, Lilienfein et al. (1999) compared D_b of Savana Oxisols in Brazil and did not record any significant difference at 0–0.1 m depth between the soil under native vegetation and under degraded pasture. Finally, Desjardins et al. (2004) studied the effect of forest conversion to pasture on soil carbon content in Brazilian Amazonia. They did not record any variation of D_b after 15 years of pasture in a clayey Oxisol, but an increase of about 0.2 g cm^{-3} in a sandy clayey Oxisol.

Numerous studies in the literature have related D_b to some combination of sand, silt, clay, organic matter content, water retention at -1500 kPa, including sometimes depth and $CaCO_3$ content (Alexander, 1980; Rawls, 1983; Manrique and Jones, 1991; Prevost, 2004). Bernoux et al. (1998) studied 62 Brazilian Oxisols and also found that D_b was closely related to clay and organic carbon content (R^2 = 0.71). Finally, Calhoun et al. (2001) developed pedotransfer functions for D_b using a data set of 987 horizons from Ohio soils. They showed that using a combination of continuous variables (laboratory data) and nominal variables (site/state factor and morphological class description) significantly improves prediction of D_b. This improvement can be explained by the residual variation of D_b within classes combining particle size distribution (sand, silt and clay content) and organic carbon content, particularly in topsoils because of variation related to soil use and its consequences on soil structure development (Neves et al., 2003). According to Calhoun et al. (2001), when soils developed in the same parent material and exhibit similar texture, D_b is mainly related to the development of the structure. The objective of this study was to relate the mass proportion of microaggregates to D_b for the soil studied.

MATERIALS AND METHODS

Site Characteristics

The study site is located in the Brazilian Savannah biome (Cerrado) on a farm (Fazenda Rio de Janeiro), 15 km north of Planaltina de Goiás (15°14'S, 47°42'W) in the state of Goiás. The native vegetation is a xeromorph forest (*Cerradão*) with most trees less than 20 m high. Most of the area was cleared in the last 20 years. The elevation at the site ranges from 780 to 810 m. The mean annual temperature is 22°C and the mean annual rainfall is 1100 mm with less than 100 mm over the period from May to September.

The soils are Typic Haplustox in the U.S. Soil Taxonomy (Soil Survey Staff, 1996) or Latossolo Vermelho according to the Brazilian classification (Embrapa, 1999). They developed in deeply weathered Meso-neoproterozoic metasedimentary rocks (Paranoá Group), which are conglomerates topped by quartzite and metasiltite (Freitas-Silva and Campos, 1998). Balbino et al. (2002a) studied Oxisols in the same area and found that the soils show little or no distinct horizonation. They also found that the macrostructure is weak to moderate and they have typically a strong microstructure with near spherical microaggregates from 0.05 to 0.50 mm in size. Balbino et al. (2002a) also found that the clay content ranges from 700 to 800 g kg^{-1}, the bulk density from 0.8 to 1.2 g cm^{-3}. They showed that the organic carbon content is < 30 g kg^{-1} in the surface horizons under native vegetation.

Two soils under native vegetation (NV1 and NV2) were selected at two locations along a 700 m long slope with a 5% gradient. The soils NV1 and NV2 were located approximately upslope and in the middle of the slope, respectively. Three soils under a pasture of *Brachiaria brizantha* cv. Marandú (BRA–000591, CIAT 6294) were selected: a 13 year-old pasture (PA1), a 10 year-old pasture (PA2) and a 2 year-old pasture (PA3). The soil PA2 on one hand and PA1 and PA3 on the other hand were at similar location along the slope than the soils NV1 and NV2, respectively. The five soils were located within a quadrilateral area of about 1 km^2.

Soil sampling and methods

We sampled five pits in April 2002. A single sample was collected every 0.1 m from the surface down to 1.6 m depth, air-dried and passed through a 2 mm sieve prior to organic carbon and particle size distribution analysis. Organic carbon contents are not discussed in this article. For the samples collected from 0 to 0.4 m depth, organic matter was removed with H_2O_2 prior to dispersion. The soil was dispersed by adding 10 g of < 2 mm soil to 100 ml of water with 10 ml of NaOH (40 g L^{-1}) and 10 ml of Na hexametaphosphate solution (50 g of hexametaphosphate with 7 g of Na_2CO_3 in 1 L of deionised water) (Camargo et al., 1986; Balbino et al., 2001). After resting 10 hours, the suspension was mechanically agitated overnight. Fractions smaller than 0.002 mm and from 0.002 to 0.02 mm were obtained by the pipette method. The sand fraction (> 0.05 mm) was separated by sieving. The 0.02–0.05 mm fraction was estimated as the difference between the sum of the different measured fractions expressed as g kg^{-1}.

Undisturbed samples were collected in duplicate using Kubiena boxes, at 0–0.1, 0.3–0.4, 0.8–0.9 and 1.5–1.6 m in each soil for thin section preparation. The undisturbed samples were impregnated under a suction of 5 kPa, with a polyester resin that was diluted with styrene monomer and left 4 weeks to ensure complete polymerisation. One thin section 45 mm × 60 mm was made with every impregnated sample following the method of FitzPatrick (1984). They were polished with diamond grains of decreasing size and coated with carbon (Bruand et al., 1996). Thin sections were examined in scanning electron microscopy (SEM, Cambridge 90B) using the emission of backscattered electrons. The size distribution of microaggregates was determined using backscattered electron scanning images (BESI) taken at a magnification of 20x of samples collected at 1.5–1.6 m depth in NV2 and PA2. A total of ten BESI were used and between 180 and 230 individual microaggregates were delineated manually on every BESI. The surface area of microaggregates was determined using Visilog image analysis software (NOESIS, Velizy, France). Equivalent diameters were computed by assuming circular microaggregates. The results are presented as a distribution of the surface area occupied by microaggregates according to their equivalent diameter on BESI with associated standard deviation.

Cylindrical soil cores 1300 cm^3 in volume were collected in triplicate from the 0–0.1, 0.1–0.2 and 0.2–0.3 m layers. Between 0.3 and 1.6 m depth, they were collected in duplicate every 0.1 m. The water content ranged from 0.18 to 0.26 g g^{-1} in the soils studied. The bulk density (D_b) was measured by weighing the soil within the 1300 cm^3 cylindrical soil cores after oven-drying at 105 °C for 60 hours. Then, the soil contained in every cylindrical soil core was sieved by dry sieving using a 0.84 mm meshed sieve, the smallest meshed sieve being able to separate the microaggregates. Because of great soil friability, the soil was sieved without any hand breaking prior sieving. Mechanical agitation with an horizontal movement was applied to the column of 5 sieves during 30 seconds (PRODUTEST, Brazil). For each depth, results are presented as the mean values of mass (g kg^{-1}) and its range. The SAS ANOVA procedure was used to find significant differences between D_b at the 95 % confidence level using a simple t test (SAS Institute, 1990).

RESULTS AND DISCUSSION

Visual assessment of BESI at low magnification showed areas with microaggregates in loose arrangement (Fig. 1a, c, d) and others where the aggregates were between 10 and 45 mm in size and included many multiconcave voids (Fig. 1b, c, d). Areas with aggregates 10 to 45 mm in size were numerous at the 0-0.4 m depth under native vegetation and pasture. Areas with microaggregates in loose arrangement were dominant in all horizons deeper than 0.5 m, except in PA1 where they started to be prominent after 0.9 m. In the first 0.1 m of PA1, the whole soil material corresponded to aggregates 10 to 45 mm in size in close arrangement.

Measurements on BESI from the deepest samples of soils NV2 and PA2 (1.5-1.6 m) revealed that 96.2 and 95.7 % of microaggregates were smaller than 0.8 mm, and 73.2 and 95.7 % were between 0.1 and 0.5 mm, respectively (Fig. 2). Thus, microaggregates were partly bigger than those described in other Brazilian Oxisols (e.g. Lima and Anderson, 1997; Furian et al., 1999; Neufeldt et al., 1999) and the sieved material < 0.84 mm can be used to estimate microaggregates proportion in the soil.

If we assume that before land clearing similar topographic locations have similar values of D_b at any depth, then NV1 can be compared with PA2, and NV2 with PA1 and PA3. There was no significant difference of D_b (P = 0.95) at any depth between NV1 and PA2 (Fig. 3a). Our results also showed a significant difference of D_b between NV2 and PA3 (P = 0.95) at 0.1 m depth and then no significant difference deeper in the soil. The small D_b recorded at 0.1 m depth in NV2 would be related to presence of numerous biological channels as earlier recorded by Balbino et al. (2004) under native vegetation. Values of D_b were significantly greater at PA1 than at NV2 (P = 0.95) at all depths from the surface to 1.3 m depth, and similar between 1.3 and 1.6 m depth. The lack of vertical variation in PA3 might be related to the youthfulness of the pasture (2 year-old pasture) compared to PA1 (13 year-old pasture). In this study, however, D_b was not systematically smaller under native vegetation than under pasture as suggested in earlier studies.

D_b was poorly correlated with clay content (R^2 = 0.36) and the texture was uniform across sites and with depth (Fig. 3c, d, e). The increase in D_b shown in PA1 was related to the increase in macroaggregates development recorded by Tavares Filho (1995) in Oxisols of Southern Brazil. The greater D_b values in PA1 are related to a decrease in the proportion of material < 0.84 mm ($\Phi_{<0.84}$) (Fig. 3b). Balbino et al. (2002b) discussed an increase in D_b in Oxisols of the same area as a decrease in microaggregates development when clearing the native vegetation for pasture.

Assuming no interaction between microaggregates and macroaggregates, the structure can be described as a combination of areas with microaggregates and those with macroaggregates at any depth. The volume of voids in the soil (V_v, in cm^3 per g of soil oven-dried at 105°C) can be written as follows:

$$V_v = \Phi_{<0.84} V_{v,magg} + \Phi_{>0.84} V_{v,Magg}, \quad (1)$$

where $V_{v,magg}$ and $V_{v,Magg}$, are volume of voids of areas with microagregates and macroaggregates, respectively, and $\Phi_{<0.84}$ and $\Phi_{>0.84}$, are mass proportion of microaggregates and macroaggregates, respectively with:

$$\Phi_{<0.84} + \Phi_{>0.84} = 1. \quad (2)$$

Combining equations (1) and (2), we obtain:

$$V_v = \Phi_{<0.84} V_{v,magg} + (1 - \Phi_{<0.84}) V_{v,Magg},$$

and thus:

$$V_v = \Phi_{<0.84} (V_{v,magg} - V_{v,Magg}) + V_{v,Magg},$$

$$\Phi_{<0.84} = \frac{(V_v - V_{v,Magg})}{(V_{v,magg} - V_{v,Magg})} \quad (3)$$

Bulk density (D_b) is related to V_v as follows:

$$V_v = \left(\frac{1}{D_b}\right) - V_s \quad (4)$$

Where V_s is specific volume of the solid phase in cm^3 of solid per g of soil. Combining equations (3) and (4), we obtain:

$$\Phi_{<0.84} = \left(\frac{1}{D_b}\right) \cdot \left(\frac{1}{(V_{v,magg} - V_{v,Magg})}\right) - \frac{(V_s + V_{v,Magg})}{(V_{v,magg} - V_{v,Magg})} \quad (5)$$

According to figure 2, $\Phi_{<0.84}$ and $\Phi_{>0.84}$ can be estimated using the proportion of soil material respectively smaller and greater than 0.84 mm.

Figure 4 shows that $(1/D_b)$ increased linearly with $\Phi_{<0.84}$ and the regression equation was:

$$\Phi_{<0.84} = 1.97 \cdot \left(\frac{1}{D_{\mathrm{b}}}\right) - 1.52 \tag{6}$$

Then, according to equations (5) and (6), we obtain:

$$\frac{1}{\left(V_{v,magg} - V_{v,Magg}\right)} = 1.97$$

and:

$$\frac{\left(V_{s} + V_{v,Magg}\right)}{\left(V_{v,magg} - V_{v,Magg}\right)} = 1.52$$

Assuming $V_{\mathrm{s}} = 0.38\ \mathrm{cm}^3\ \mathrm{g}^{-1}$, reciprocal of the average particle density 2.65 g cm^{-3} that was determined by Balbino et al. (2002b) on similar soils, we obtain:

$V_{\mathrm{v,Magg}} = 0.40\ \mathrm{cm}^3\ \mathrm{g}^{-1}$

$V_{\mathrm{v,magg}} = 0.90\ \mathrm{cm}^3\ \mathrm{g}^{-1}$.

The porosity of microaggregates arrangement (P_{magg}) and macroaggregates arrangement (P_{Magg}) can be computed using $V_{\mathrm{v,magg}}$ and $V_{\mathrm{v,Magg}}$, respectively with:

$$P_{\mathrm{magg}} = \frac{V_{\mathrm{v,magg}}}{\left(V_{\mathrm{v,magg}} + V_{\mathrm{s}}\right)} \tag{7}$$

and

$$P_{\mathrm{Magg}} = \frac{V_{\mathrm{v,Magg}}}{\left(V_{\mathrm{v,Magg}} + V_{\mathrm{s}}\right)}. \tag{8}$$

Thus, we obtain:

$P_{\mathrm{magg}} = 0.71$

$P_{\mathrm{Magg}} = 0.51$.

The porosity resulting from the arrangement of microaggregates was 39% greater than for the macroaggregates.

CONCLUSIONS

Our results showed that between 0 and 1.6 m depth in the Brazilian clayey Oxisols studied, the mass proportion of soil material < 0.84 mm was closely related to D_b. Assuming that soil material < 0.84 mm corresponded to microaggregates throughout the soils studied, we also showed that the porosity resulting from the arrangement of microaggregates was much greater than for the aggregates > 0.84 mm. Finally, our results showed that D_b at a given depth was not systematically greater under pasture than under native vegetation. As regards the latter point, the relationship recorded that uses D_b as easily accessible soil characteristic should enable a more accurate analysis of structural changes according to land use.

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Figure captions

Fig. 1. Examples of Backscattered Electron Scanning Images (BESI) illustrating soil structural features of soils sampled from native vegetation (NV2) and pasture (PA2, PA3) sites: a) microaggregates at 1.5-1.6 m (NV2), b) macroaggregates with multiconcave voids at 0.3-0.4 m (PA2), and macroaggregates associated with microaggregates at c) 1.5-1.6 m (NV2), and d) 0.3-0.4 m (PA3). Black areas are voids, light gray areas are quartz or oxide grains, and darker gray areas correspond to porous clay. Scale bar: 2mm.

Fig. 2. Microaggregate size distribution measured on Backscattered Electron Scanning Images (BESI) of soil sampled at 1.5-1.6 m depth from soil a) under native vegetation (NV2), and b) under pasture (PA2). Bars represent standard deviations.

Fig. 3. Soil properties as a function of depth: a) bulk density, b) proportion of mass fraction < 0.84 mm, and fraction of c) clay, d) silt, and e) sand content. Bars represent the largest and the smallest values.

Fig. 4. The inverse of bulk density ($1/D_b$) as a function of the mass proportion of soil material < 0.84 mm ($\Phi_{<0.84}$) for all the soils. The solid line is the linear regression of $\Phi_{<0.84}$ against ($1/D_b$).

Figure 1

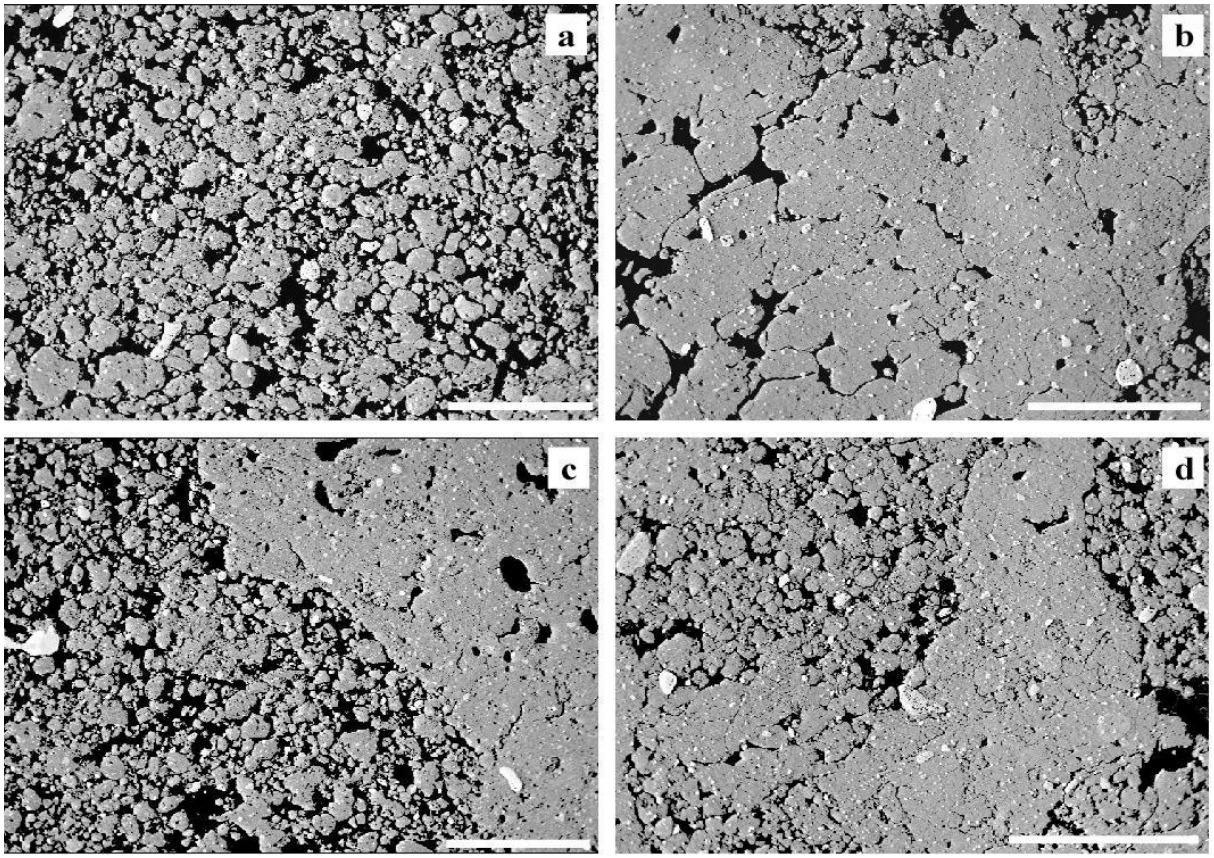
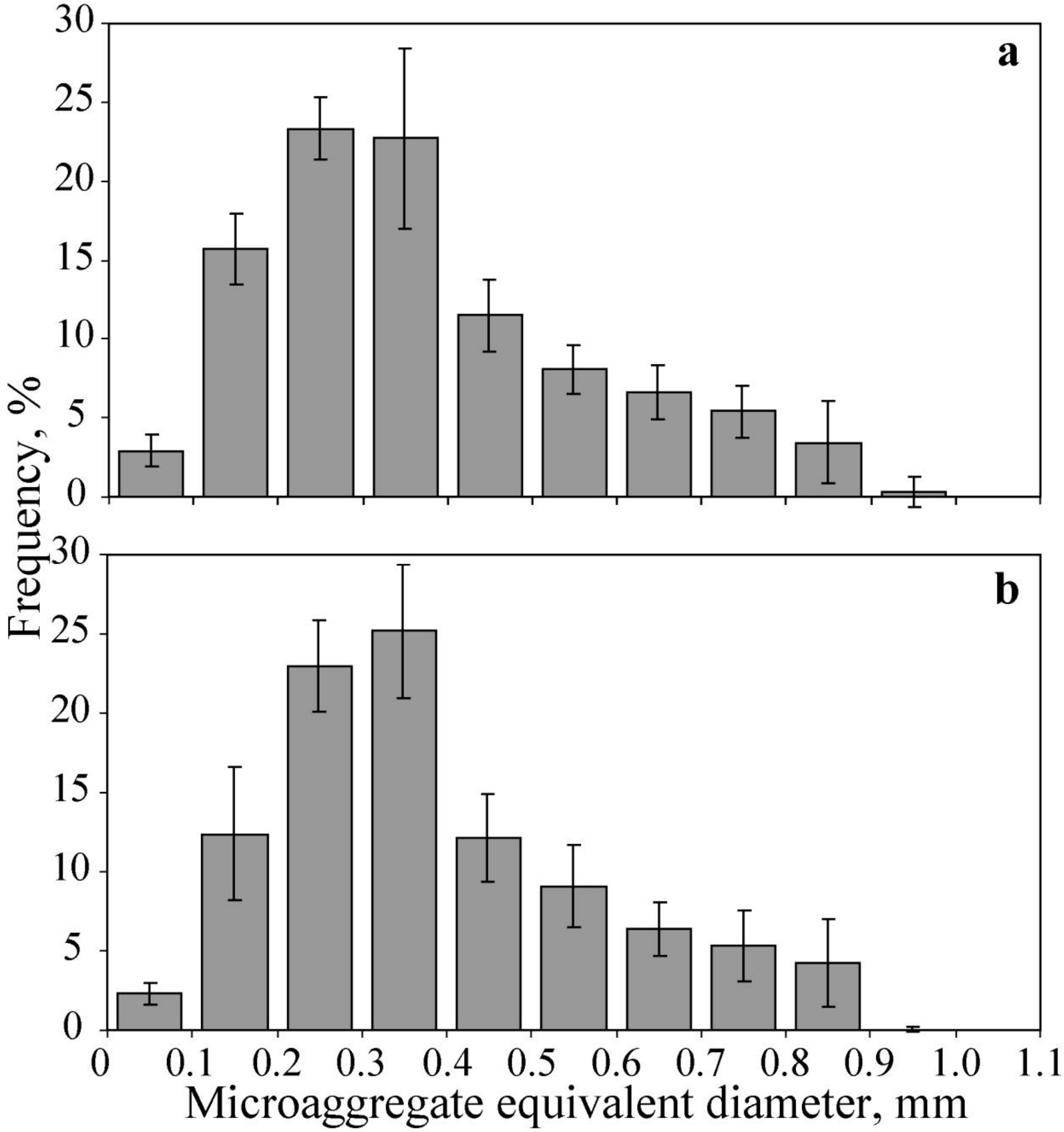
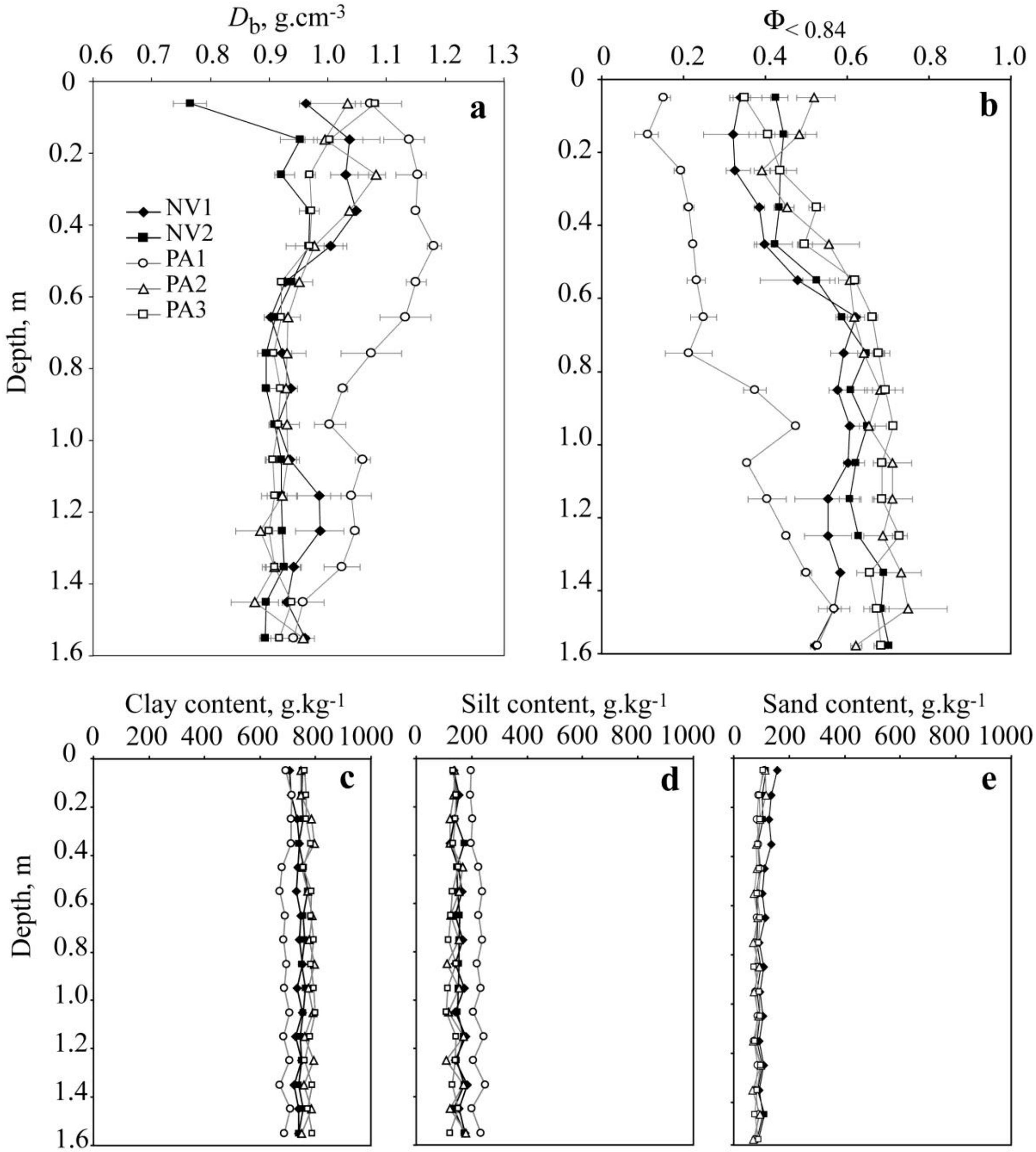


Figure 2



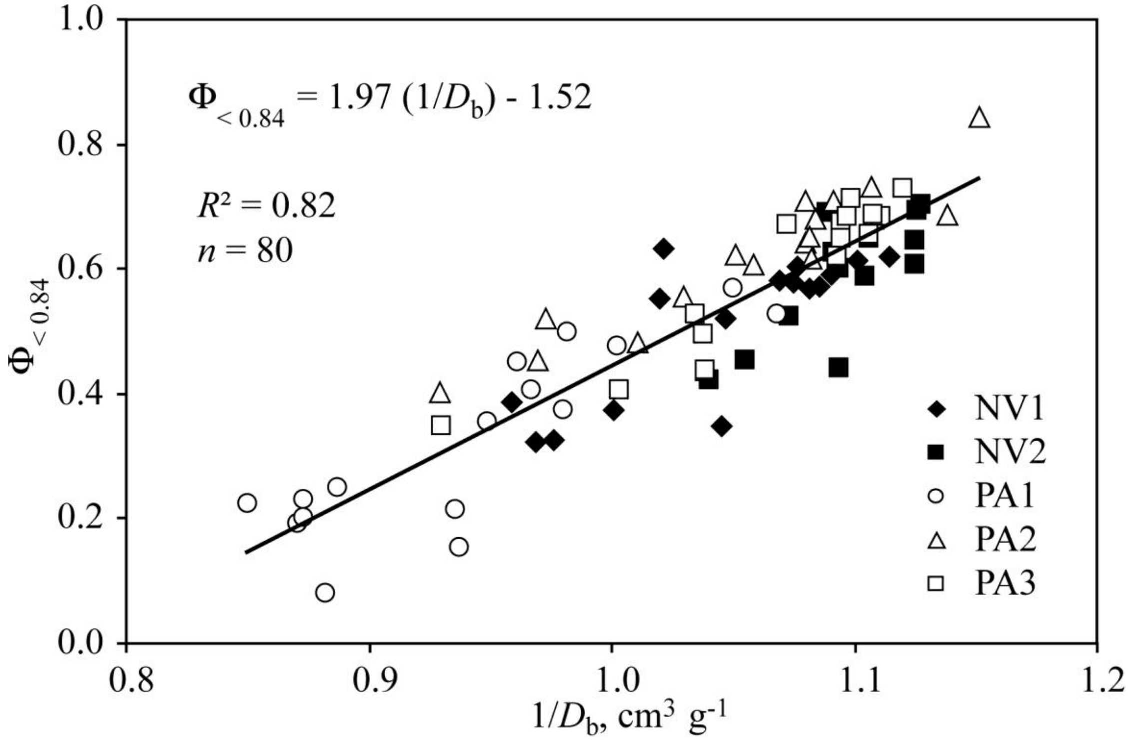
a
b
Frequency, %
30
25
20
15
10
5
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
Microaggregate equivalent diameter, mm

Figure 3



D_b, g.cm^{-3}
0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
a
NV1
NV2
PA1
PA2
PA3
Depth, m
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
$\Phi_{< 0.84}$
0 0.2 0.4 0.6 0.8 1.0
b
Clay content, g.kg^{-1}
0 200 400 600 800 1000
c
Silt content, g.kg^{-1}
0 200 400 600 800 1000
d
Sand content, g.kg^{-1}
0 200 400 600 800 1000
e

Figure 4



Φ< 0.84 = 1.97 (1/Db) - 1.52
R² = 0.82
n = 80
1.0
0.8
0.6
0.4
0.2
0.0
Φ< 0.84
0.8
0.9
1.0
1.1
1.2
1/Db, cm3 g-1
NV1
NV2
PA1
PA2
PA3