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Particle size distribution of Oxisols in Brazil

Tairone Paiva Leão

Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, Campus Universitário Darcy Ribeiro, Asa Norte, Brasília 70910-900, Brazil

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ABSTRACT

Soil texture or particle size distribution is of fundamental importance not only for understanding soil chemical and physical functioning but also for soil classification within a given taxonomic system. The objective of this study was to collect and analyze particle size data of Brazilian "Latossolos" (Oxisols) published in the Brazilian Journal of Soil Science from 2003 to 2012. It is expected that the data collected and analyzed here can be used for evaluating the quality of soil particle size analysis, as well as to aid in the characterization of Brazilian soils. The dataset could also be used to evaluate pedotransfer functions that use particle size as estimators. Overall 737 data points with values of clay, silt and sand were tabulated. None of the three fractions were normally distributed. The clay fraction presented trimodal distribution, while the silt distribution was found to be right skewed asymmetric with a high frequency of lower values. The logratio analysis using sand as the divisor showed a strong linear relationship between silt and clay fractions. The dataset collected is available upon request by email.

1. Introduction

The quantitative concept of soil particle size distribution, in contrast to the often qualitative concept of soil texture, is used to determine the proportions on a weight basis of the inorganic soil mineral fractions: clay, with particle sizes ≤0.002 mm, silt, with particle sizes >0.002 and ≤0.053 mm, and sand with particle sizes >0.053 and ≤2.00 mm in a given soil or sedimentary material (Hillel, 1998; Schaetzl and Anderson, 2005; Ker et al., 2012). Grain size distribution is a fundamental property of the soil, used to define soil use and management classes and as criteria for distinguishing soil classes in several taxonomic systems, including the US Soil Taxonomy (Soil Survey Staff, 1999) and the Brazilian SiBCS (Embrapa, 2013). Knowledge of particle size distribution is also useful in studies for evaluation of soil quality and it is fundamental for quantification of soil processes and properties that directly affect plant growth and crop production, such as the transport of heat, gases and solutes, including contaminants that can affect groundwater. Soil thermal and hydraulic conductivities, gas diffusion, mechanical resistance, cation and anion exchange and storage capacity, specific surface area, water retention and available water content are examples of important soil properties directly affected by particle size distribution. An incorrect determination of soil particle size distribution can lead to errors in soil management, and or its contamination and increased susceptibility to degradation any of which can be a burden on society. Ultimately, the global community has to account directly or indirectly for loss of crop productivity, scarcity of food supplies, increase of the price of food to the end consumer, and reclaiming of degraded or contaminated areas.

Problems in the determination of particle size distribution have been often observed samples from Brazilian Savannah (Cerrado) soils, especially in the order "Latossolos" from the Brazilian taxonomic system (Embrapa, 2013). The "Latossolo" class is mostly equivalent to the Oxisol and Ferralsol classes from the Soil Taxonomy and WRB (IUSS Working Group WRB, 2015) systems, respectively. The major difference from the Soil Taxonomy Oxisol class is that the Brazilian system considers highly weathered oxidic soils with kandic horizon ("Bt" in both Soil Taxonomy and SiBCS) as "Argissolos" or "Nitossolos". The Brazilian "Latossolos" correspond thus to the Oxisols strictly with oxic horizons ("Bo" in Soil Taxonomy and "Bw" in SiBCS). In these soils, especially where the clay content is higher, the dispersion of the silt sized clay microaggregates has been problematic due to the strong interaction forces caused by the binding of aluminum and iron oxides and organic matter domains (Donagemma et al., 2003; Azevedo and Bonumá, 2004). Often in these cases the silt fraction is overestimated while the clay fraction is underestimated due to the incomplete dispersion of silt sized clay aggregates (often called pseudo-silt in Brazilian literature) that remain chemically and physically stable throughout dispersion treatments (Donagemma et al., 2003; Mauri, 2008). The objective of this research is to create a database of published data of soil particle size values of the "Latossolo" soil order with the purpose of increasing the understanding of the nature of these soils and that can be used in further studies of pedotransfer functions and in the definition of the Brazilian "Latossolo" taxonomic class. For simplicity the term "Latossolo" will be employed without quotations from now on.

E-mail address: tleao@unb.br.

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2. Data collection and analysis

The data were collected by surveying the digital database of the Revista Brasileira de Ciência do Solo (RBCS, Brazilian Journal of Soil Science) available at: www.scielo.br/rbcs. The RBCS is the official publication of the Brazilian Soil Science Society and has been the primary vehicle for publications in soil science in Brazil for several decades. The search procedure was performed using the keyword Latossolo for the period between the years of 2003 and 2012. All the manuscripts containing the term were inspected and in the cases where there was the occurrence of quantitative values of clay, silt and sand contents, these values were stored in an electronic spreadsheet. The file also contained the qualitative variables: soil class (including the taxonomic class on the SiBCS in effect during the period), laboratory method used (represented by the citation), city, state, lithology, current use, and resumed citation of each article, including digital object identifier (doi). Data analysis and processing was performed in R statistical analysis and graphing software. The figure with the number of points for location considered only the location of the main city of the municipality where the study was located and thus no special georeferencing tools were necessary other than R standard procedures over a Google® South America base map.

3. Results and discussion

Overall, 763 occurrences of particle size data in 251 published articles were observed (references on supplementary data files), an occurrence of particle size data within this context meaning a triad of values of sand, silt and clay corresponding to a single sample analyzed in laboratory. In most of the articles consulted, the sampling depth was reported as an interval (e.g. 0–0.20 m) and only a few reported the soil horizons sampled (<30 studies). To provide an idea of the sampling depth, the midpoint of the reported layer was calculated as the difference between the lower limit and the upper limit divided by two and the result was considered the sampling depth. When the depth was reported as a single value, this value was used. A frequency analysis showed that the vast majority of the sampling depths was between 0 and 0.10 m ($n = 553$), followed by sampling depths between 0.10–0.20 m ($n = 70$), 0.20–0.30 m ($n = 25$), 0.30–0.40 m ($n = 16$) and 0.40–0.50 m ($n = 14$). All other intervals up to 2.00 m had a number of samples of <5 each. In 49 studies the depth was not reported or was ambiguously reported and these were not used in the assessment above. The data indicates that most of the samples might be representative of surface horizon, or “A”, followed by transitional horizons such as “AB” or “BA”. As the definition of the Latossolo class does not allow significant textural gradient in the profile, these values are likely a good representation of the subsurface horizon of these soils as well.

Before analyzing the clay, sand and silt data, a filtering procedure was established to try to avoid data with gross experimental or tabulation errors. Any sample with the sum of clay, silt and sand >1001 or <999 was discarded. After filtering the values outside those limits and removing one occurrence of a kandic (Bt) horizon listed above an oxic horizon, the remaining dataset had 737 observations. The arithmetic average, minimum, maximum, standard deviation and normality tests for the granulometric fractions analyzed are presented in Table 1. None of the variables were normally distributed when subjected to the Kolmogorov-Smirnov and Shapiro-Wilk normality tests (Shapiro and Wilk, 1965; Razali and Wah, 2011). In both cases the probability values calculated using the tests were much lower than the critical value of $p = 0.05$ adopted in this research, indicating that the null hypothesis that the data is from a normally distributed population must be rejected. The Shapiro-Wilk test results will be considered in this study since there is empirical evidence that it is more robust than the Kolmogorov-Smirnov test (Razali and Wah, 2011). When considering any of the available normality testes, normality was not achieved by logarithm transformation of the raw data. The departure from normality on the frequency distributions is not surprising in this study where different datasets are pooled together to composed the meta-data. As no hypothesis testing using parametric statistics was further explored here, the lack of normality did not influence the analysis and discussion of the results.

Table 1
Descriptive statistics for the values of clay, silt and sand for the data set gathered for this study. The number of observation is 737 and the values are in g kg^{-1}.

Parameter	Clay	Silt	Sand
Mean (arithmetic average)	490.9	130.0	379.2
Median	518.4	108.0	344.0
Mode	540.0	40.0	140.0
Standard deviation	211.1	87.5	256.7
Minimum	33.0	8.9	3.0
Maximum	910.0	582.0	900.1
Skewness	−0.2	1.1	0.3
Kurtosis	−1.0	−1.6	−1.2
Shapiro-Wilk (W)	0.96^{***}	0.92^{***}	0.93^{***}
Kolmogorov-Smirnov (D)	0.08^{**}	0.12^{**}	0.11^{**}

** Significant $p > D < 0.0100$.
*** Significant $p < W < 0.0001$.

Another striking feature of the data set is that a large fraction of the points corresponds to the areas close to or at institutions of research and education in soil science, mainly in Brazil's South and Southeast regions (Fig. 1). This is likely due to the fact that the development of the North and Northeast has been slow when compared to areas that were colonized first and that have long standing agricultural tradition. Another possibility is that large areas in the North and Northeast were or still are arid lands or areas subjected to preservation laws were the agricultural expansion has been intensified only in the last two or three decades. Fig. 1 also indicates that the samples are more representative of the Latossolos of the South and Southeast located on or near the Paraná Basin and formations located over central Brazil largely metamorphic Brasilia Belt. A small number of samples correspond to the Latossolos formed over sediments and sedimentary rocks on the Amazon Basin and those of the Barreiras Formation in the Northeast. However, the number of studies that presented the lithology over which the soil was formed was very small ($n < 30$), and thus a comparative analysis with relation to the parent material of the soils was not possible.

Confirming the lack of normality detected by quantitative tests, visual inspection of the frequency distribution plots shows that the clay distribution is trimodal with peaks occurring around the clay content values of 200, 550, and 700 g kg^{-1} (Fig. 2). For the silt distribution, the graph shows an asymmetric distribution, corresponding to a few high values causing it to be right skewed (Fig. 2). The higher value of the skewness coefficient also confirms the asymmetry on the silt distribution (Table 1). As it is expected for highly weathered soils, the frequency distribution of silt fraction peaks at a low value, around 100 g kg^{-1}. The intense dessilification process in tropical conditions tends to eliminate easily weatherable primary minerals with concentration of clay sized secondary minerals of the kaolinite group, and iron and aluminum oxides, thus explaining the lower silt content, a fraction which is often originally composed of less resistant primary minerals (Schaetzl and Anderson, 2005). Other than titanium and zircon oxides, the most resistant primary mineral in total hydrolysis conditions is quartz in the sand fraction (Schaetzl and Anderson, 2005; Ker et al., 2012). Since quartz is much more abundant than other resistant oxides in the sand fraction it is observed that this fraction is fairly abundant in Brazilian Latossolos (Fig. 2). Overall, the data shows that Brazilian Latossolos are on average of “Clay” composition according to the USDA textural triangle (Table 1). The modal and median values also indicate “Clay” texture.

The insertion of the data on the textural triangle by using the package “soiltexture” (available at http://soiltexture.r-forge.r-project.org/) developed for R statistical software confirms the trend discussed above (Fig. 3). A concentration of points close to the left axis can be