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Field-based soil-texture estimates could replace laboratory analysis

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ABSTRACT

Texture is one of the most important and most frequently measured parameters in soil science. It is common knowledge among field experienced soil scientists that soil texture can be well estimated in the field manually with so called "texture-by-feel". However, no systematic evaluation exists that assessed the precision and accuracy of field based texture estimates as compared to the common, but time consuming, standard laboratory methods. In the course of the German Agricultural Soil Inventory, the texture of 3896 soil samples from 728 soil pits was estimated manually in the field and measured in the laboratory using standard sedimentation techniques. The field based estimations of the sand, silt and clay content showed a relative deviation from the measurements of only 3.8, 11.5 and 15.5%, respectively. The absolute uncertainty of field texture was 23, 32 and 17 g kg^{-1} for sand, silt and clay, respectively. A large fraction (57–72%) of deviations between field and laboratory derived texture estimates was due to the laboratory measurement uncertainty, and due to the fact that only texture classes were estimated in the field and not mass fractions. Our findings indicate that for most purposes it is sufficient to estimate the soil texture manually "by feel" instead of conducting expensive particle size analyses in the laboratory.

1. Introduction

Soil texture influences nearly all soils processes, either directly or indirectly. The texture can be determined with common protocols in the laboratory by particle size analyses but also in the field: Trained soil scientists can do this by feel, assessing the granularity, the mealiness and the cohesiveness of the sample. This is done by testing the plasticity, shininess, detectability of sand grains visually and by deforming the sample between one's fingers (Sponagel et al., 2005) ('Fingerprobe'). The laboratory methods are standard methods to estimate soil particle size distribution. However, they are time-consuming and therefore more expensive than a soil texture-by-feel test; in particular due to pre-treatments of the samples to remove organic matter and salts. Even though there is traditional knowledge on the quality of field based texture estimates, a systematic evaluation of the magnitude of the uncertainty of field based texture estimates has never been conducted and published. In the course of the German Agricultural Soil Inventory 3896 soil samples were taken from 728 soil profiles and analyzed for their texture both in the field and in the laboratory, so that the accuracy of the field-based estimates could be assessed.

Earlier studies on the variability of field- and laboratory-based texture analyses focus on the percentage of samples for which both analyses yield the same texture class. Foss et al. (1975) for example, compared the results of field textures to those of laboratory analysis. For 598 samples taken from soils in the Coastal Plain of Maryland, USA, 50% were assigned the right texture class during the field texture rating according to the USDA textural classification (using 12 different classes). The accuracy was the highest for the texture classes sand, clay, sandy loam and silt loam, which the authors attribute to the larger portion of the textural triangle that is taken up by these classes. In cases where the texture class was not estimated correctly, high amounts of coarse fragments, free iron, organic matter or fine or coarse sands were often present in the sample. Other analyses of the accuracy of field based texture estimations of the USDA soil texture classes by Post et al. (1986); Rawls and Pachepsky (2002) and Pachepsky et al. (2006) showed that the overall texture class was correctly assigned in 46%, 39.8% and 28.4% of all cases in the three studies respectively. However, for most applications, such as soil models and ecological studies, texture classes are not required as input variable, but mass fraction of sand, silt and clay.

So far there are no published studies on the accuracy of field based texture class estimates to derive the texture mass fractions, thus the soil particle size distribution. Soil particle size distributions with the mass fractions of clay, silt and sand are basic parameters to characterize soils, and are used as input variables in most soil models. While earlier studies focus on the percentage of correctly assigned texture classes in the field, for modeling purposes the accuracy of the estimate is more important than the attribution of the correct texture class. Thus, the aim of this study is to assess the variance of the field based texture class

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estimates and their precision in determining a soil's particle size distribution.

2. Materials and methods

In the course of the German Agricultural Soil Inventory 3896 soil samples were taken at 728 sites throughout Germany in the Federal states Lower Saxony, Rhineland Palatinate, Mecklenburg Western Pomerania, Saarland, Bremen and Hamburg between 2011 and 2014 (Bach et al., 2011). These samples were taken by eight soil scientists in five to seven different depth increments between 0 cm and 200 cm depth from a soil pit. Only mineral soil samples with soil organic matter content below 30% were included in this study. In the field the soil texture was estimated using a soil-texture-by-feel ('Fingerprobe') according to the German Manual of Soil Mapping, 5th edition (Sponagel et al., 2005), so that each sample was assigned one of the 37 predefined soil texture classes. All eight soil scientists were well experienced in field soil surveys, which is the precondition for successful texture-by-feel estimates. Prior to conducting the soil survey, intercomparisons were conducted between the soil scientists but no calibrations were performed with reference samples and also no feedback with laboratory results during the time course of the inventory. The intercomparisons of the soil scientists were conducted before the official start of the sampling campaign. They were conducted to standardize the sample taking procedures. Therefore, all soil scientists analyzed numerous soil profiles together and compared their results. The laboratory based particle-size analysis was conducted after removal of salts and organic matter using hydrogen peroxide via wet sieving to determine the sand fractions and the pipette method to determine silt and clay fractions using a semi-automatic machine (Sedimat, UGT, Germany). All samples were measured in the same laboratory, using three of the Sedimat machines. A total of four laboratory workers were engaged in this task. To make sure that the measurements are not dependent on the laboratory workers some samples were measured by different workers. The differences between these measurements were generally <2% for sand content and <1% for silt and clay content. The absolute texture fractions are reported in g kg^{-1} throughout this paper in order to distinguish from relative deviations reported in %. In order to assess how well particle size distributions can be estimated by field based soil texture class estimates, each sample was assigned the arithmetic mean content of sand, silt and clay of the texture class that was determined with texture-by-feel. This causes a restriction in the precision of texture-by-feel as compared to the laboratory analysis that determined texture mass fractions directly. These texture-by-feel derived mass fractions were subtracted from the mass fractions of sand silt and clay that were determined in the laboratory to get the differences between field-based estimations and laboratory analyses. There are two different errors that need to be looked at separately: The precision (also referred to as random error) providing the measurement uncertainty and the bias (systematic error) that quantifies the deviation from the "truth", assuming that the laboratory measurement represents the unbiased truth. The root mean square deviation (RMSD, precision) and the bias were calculated for the differences in sand, silt and clay content.

The total methodological intrinsic error SD_m was estimated using Gaussian error propagation, with

$$SD_m = \sqrt{RMSD^2{}_{class} + RMSD^2{}_{lab} + 2\,\mathrm{cov}\left(Y_{\text{field based estimate}}, Y_{\text{laboratory measurement}}\right)},$$

where $RMSD_{class}$ is the root mean squared deviation that is only derived from the fact that texture classes were estimated in the field and not texture fraction. $RMSD_{lab}$ is the uncertainty of the laboratory texture analysis and cov is the covariance. This error (SD_m) thus represents the part of variance that is not caused by errors in estimating the mass fractions of sand silt and clay.

A linear mixed effect model was fitted for each type of difference (in sand, silt and clay content) using the 'nlme'-package (Pinheiro et al., 2014) in R (R Core Team, 2013). Such a statistical approach is required since it fulfills the following criteria:

- It is able to cope with unbalanced experimental designs (e.g., different numbers of soil samples were taken from different soil pits, depending on the depth of the layer of mineral soil. Not every soil scientist determined soil texture for every soil sample independently, but each soil sample was measured by one scientist only);
- it is able to account for a hierarchical data structure with not all samples being independent (several soil samples derived from one soil pit at one site and are thus not independent but hierarchically structured); and
- the regression parameters can be fixed as in normal regression analysis, but also random. This means that for each fixed effect the variance across the different levels of the random effects is estimated.

The variable "site" of the soil profiles was used as a random intercept, since samples from the same site are not independent. So the intercept term in the model is allowed to vary for the different soil profiles. The water content and the main texture class (main groups of texture classes as predetermined by Sponagel et al. (2005) sandy, loamy, silty or clayey soils,) were used as random slopes since the water content and texture class of a single sample from one soil profile are not independent of the water content and the texture class of the other samples from the same soil profile. Considered as possible fixed effects were main texture class (sandy, loamy, silty or clayey soils, see Fig. 1), sample depth, amount of soil organic carbon (SOC) and inorganic carbon in the sample, water content and the soil scientist who estimated the soil texture class (8 different soil scientists). In the final model the main texture class is used as a fixed as well as a random effect. The random part explains the variance that arises due to interdependence of the texture within a given soil profile, whereas the fixed effect part explains the variance that is due to differences in main texture class between the different soil profiles. The decision for the optimal fixed effect structure of the model was based on the Akaikes information criterion (AIC) of all possible models.

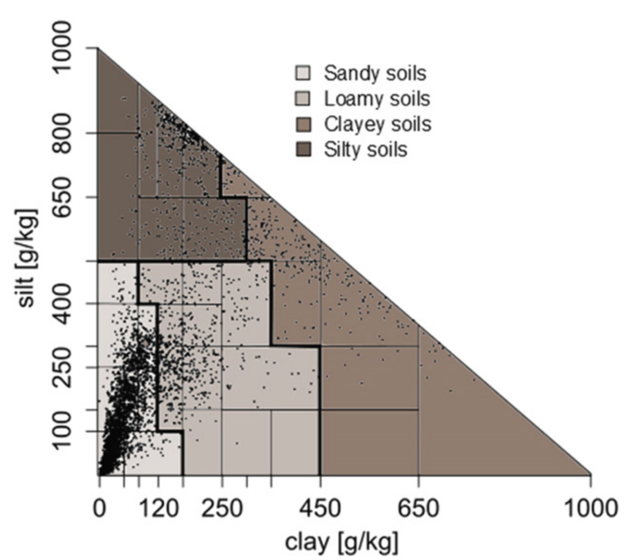

Fig. 1. Distribution of sand, silt and clay content as measured in the laboratory. The subdivision of the soil types is according to the KA5 (Sponagel et al., 2005). Thick lines indicate the subdivision of the main groups of texture classes (also according to Sponagel et al. (2005)).