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Lauren Williams-Caudle
University of Arkansas, Fayetteville

Kristofor Brye
University of Arkansas, Fayetteville

E. Moye Rutledge
University of Arkansas, Fayetteville

Soil particle-size analysis: A comparison of two methods

Lauren A. Williams-Caudle, Kristofor R. Brye†, and E. Moye Rutledge§*

ABSTRACT

Knowing the proportion of particle sizes in soil is important to soil scientists and agronomists. The mixture of sand, silt, and clay influences water movement, solute transport, nutrient retention, and many other properties and processes in soil. The standard method for particle size determination is a somewhat time-consuming process. An equally accurate but shorter method would be appealing for many reasons. The objective of this study was to compare a standard method of particle-size analysis using a hydrometer to an abbreviated hydrometer method, which, instead of 12 h for the standard method, requires about 3 h to complete. Twenty-four soil samples of varying textural classes determined by the standard method were reprocessed for particle-size and textural-class determination using an abbreviated hydrometer method. Results of the methods comparison showed that the textural class from the abbreviated method matched that of the standard method in only 10 of 24 samples and that the abbreviated method over-estimated the amount of total sand in the soil sample. The abbreviated method was reasonably accurate in comparison to the standard method with respect to percentages of clay and silt. Based on this comparison, the time savings gained with the abbreviated method do not outweigh the lack of accuracy of particle-size determination with coarse-textured soils, but may be justifiable for fine-textured soils without a large fraction of sand-sized material.

* Lauren Williams-Caudle graduated in May 2003 with a degree in environmental, soil, and water sciences.

† Kristofor Brye, faculty mentor, is an assistant professor in the Department of Crop, Soil, and Environmental Sciences.

§ E. Moye Rutledge is a professor in the Department of Crop, Soil, and Environmental Sciences.

MEET THE STUDENT-AUTHOR

Lauren A. Williams-Caudle

I was born at Fitzsimmons Army Medical Center in Denver, Colo., to a career Army Officer. Since then I have lived all over the United States and abroad. I came to the University of Arkansas from Georgetown High School in Georgetown, Tex. on an Army ROTC scholarship. Two years into the program I broke my back and had to choose another career path. I decided to major in environmental, soil, and water sciences offered in the Department of Crop, Soil, and Environmental Sciences (CSES) after taking Dr. Wolf's Introduction to Environmental Science course. Dr. Wolf made the major sound interesting and this area of study was what I had been looking for since I have always loved the outdoors. I have participated in soil judging and the departmental student club. I also studied in Israel with Dr. Bacon and at the Scottish Agricultural College during Spring Break 2000.

Dr. Rutledge, pedologist in CSES, originally devised this project and the laboratory work was conducted under the supervision of Michelle Steele. The development of this research paper came under the direction of Dr. Brye, whom I got to know through the Soil Judging Team. I could not have completed this project without Dr. Brye's assistance. Dr. Brye has been a great mentor through the difficult scientific writing process. I graduated in May 2003 and I intend to stay in the area while my husband completes his degree.

INTRODUCTION

In soil science it is important to know the particle-size distribution when classifying a soil. The textural class is important in many aspects of soil science sub-disciplines. Textural analysis can help to determine several soil properties. For example, to determine whether or not a septic system can be installed, the soil texture must be known in order to classify the soil so that drainage capability can be identified. Textural class is also used by the Extension Service to aid farmers and gardeners in determining soil fertility requirements for commercial farms or gardens.

There are several methods that can be used to determine particle size. The two most common and inexpensive methods are the pipet and hydrometer methods (Gee and Bauder, 1986). Both of these methods are based on Stoke's Law, which relates a particle's diameter and mass to the time required to fall out of suspension. In general, for the pipet method, a suspension is created by plunging soil mixed with a dilute dispersing agent. After a specified time after cessation of plunging, an aliquot of the suspension is removed from a certain depth in the suspension using a pipet. The aliquot is washed into a container, oven dried, and weighed to determine the mass of particles remaining in suspension at the specified sampling time.

The initial steps involved in the hydrometer method are similar to those in the pipet method. A suspension is created by plunging a mixture of soil with dilute dispersing agent, but, in contrast to the pipet method, after a specified time a hydrometer is lowered into the suspension and the density of the suspension is determined. The density measurement from the hydrometer is used to calculate the mass fraction of particulates remaining in suspension at the specified sampling time.

A method for soil particle-size analysis that required less time to accomplish than the standard methods, which require over 12 h to complete, would allow particle-size analysis and textural class determination to be made in a more timely manner. In addition, a similarly accurate but shorter method would allow more samples and/or more replicates to be processed in less time compared to the standard method. Therefore, the objective of this study was to evaluate the accuracy of an abbreviated hydrometer method for determining soil particle size compared to a standard hydrometer method. We hypothesized that the abbreviated method would be reasonably accurate compared to the standard method in determining soil textural class and sand, silt, and clay fractions.

MATERIALS AND METHODS

Particle-Size Analysis

Twenty-four soil samples of varying textural class determined by the standard hydrometer method (Day et al., 1955) were chosen for repeat particle-size analysis by an abbreviated hydrometer method. The soil samples had previously been air dried, crushed, and sieved through a 2-mm mesh screen.

For the standard method, 40 g of oven-dried, sieved soil were mixed with 50 mL of Calgon solution (i.e., 10% sodium hexametaphosphate), diluted to 500 mL with distilled water and then allowed to soak for at least 10 min. After soaking, the solution was mixed with a motorized mixer for 5 min, added to a 1-L sedimentation cylinder, and further diluted with distilled water to the 1000-mL final volume. Once this process was completed, the samples were left overnight to equilibrate to a constant temperature. Once the solution reached constant temperature, the solution was mixed thoroughly with a plunger. A hydrometer was inserted into the suspension and the density was recorded at 4.5 min after plunging ceased. The hydrometer was removed, rinsed, and the density of the suspension was recorded again at 6 and 90 min and at 6 and 12 h after plunging ceased. Once all readings had been recorded, the suspension was passed through a 300-mesh sieve to retain the sand fraction. Once the sample was free of silt and clay, the remaining soil material was washed into a 500-mL beaker to decant off the organic matter. Once only the sand fraction remained, the sample was oven dried at 105°C overnight. The sample was then placed in a mechanical shaker and sieved for 5 min through a series of sieves with 50-, 100-, 250-, 500-, and 1000-μm diameter openings, which represent the very-fine sand, fine-sand, medium-sand, coarse-sand, and very-coarse sand classes, respectively. After sieving, the mass of the sand fraction retained on each sieve and that which passed through the finest-mesh sieve was recorded.

The percentages of sand in each class and the total sand in the original soil sample were determined from Equation [1],

$$\% \text{ Sand} = [(\text{mass of sand fraction} / \text{mass of soil sample})*\text{moisture factor}]*100, \quad [1]$$

where the moisture factor was determined by oven-drying a separate 10 g of the initial air-dry soil so that the sand fraction could be expressed on an oven-dried basis. Before the silt and clay fractions could be determined, all hydrometer readings had to be corrected with a hydrometer reading in a soil-less blank. To calibrate the hydrometer in a soil-less blank, 50 mL of Calgon were added to a 1-L sedimentation cylinder and diluted to the 1-L mark with distilled water, and the cylinder was allowed to equilibrate overnight. The solution was plunged in the same manner as for the actual soil measurement and a hydrometer reading was recorded to represent a soil-less blank value. The percentages of clay were then determined from the density measurement at the 12-h mark after plunging ceased. The silt fraction was determined by difference from the total sand and clay fractions.

For the abbreviated method, the procedure outlined by Arshad et al. (1996) was followed. Fifty grams of oven-dried, sieved soil were added to an Erlenmeyer flask along with 50 mL of Calgon solution and the mixture was placed on a magnetic stirrer for 5 min. After stirring, the mixture was added to a 1-L sedimentation cylinder, filled with distilled water to the 1-L mark, and allowed to equilibrate to a constant temperature overnight. The following day, samples were plunged by hand. Hydrometer readings were recorded at 40 s and 2 h after plunging ceased. The hydrometer readings were corrected based on readings from a soil-less blank as was previously described for the standard method. The following equations were used to determine percentages of total sand and clay from the abbreviated method,

$$\% \text{ Silt} + \% \text{ Clay} = (R_{40\text{ sec}} - R_{\text{Blank}}) / (\text{oven-dried soil weight in g})*100 \quad [2]$$

$$\% \text{ Clay} = (R_{2\text{ hr}} - R_{\text{Blank}}) / (\text{oven-dried soil weight in g})*100 \quad [3]$$

$$\% \text{ Sand} = 100 - (\% \text{ Silt} + \% \text{ Clay}). \quad [4]$$

The percentages of silt were determined by difference using the results from Equations [2] and [3].

Textural-Class Determination

The soil textural class for each of the 24 samples was determined using an electronic version of the textural triangle accessed through a computer program (MSU, 2003). The program uses the values for total sand and silt as input variables, calculates the clay fraction by difference, and outputs the textural class.

Statistical Analysis

Linear-regression analysis was used to compare the percentages of total sand, silt, and clay from the abbreviated method (dependent variable) to those from the standard method (independent variable) (Minitab 13.31, Minitab Inc., State College, Penn.). If the percentages of total sand, silt, and clay from the abbreviated method matched exactly those from the standard method, we would expect the slope of the resulting regression line to be 1 with an R^2-value of 1.

RESULTS AND DISCUSSION

Comparison of Particle-Size Analysis

For the total-sand comparison, the relationship between the abbreviated method and the standard method was significant ($P \leq 0.001$). The resulting regression equation fit the total-sand data well ($R^2 = 0.95$). However, due to a slope of 0.71 and an intercept of 26.6, the abbreviated method resulted in an over-estimation of the total-sand fraction compared to the standard method, where the over-estimation was greatest at small sand fractions (Fig. 1). The accuracy of the abbreviated method could be improved if multiple 40-s readings were conducted on each soil sample before allowing the samples to sit for the remaining 2 h.

Although not measured directly in either procedure, the relationship between the abbreviated and standard methods for silt was also significant ($P \leq 0.001$). The resulting regression equation also fit the silt data well ($R^2 = 0.92$). The slope of the regression line was the smallest, 0.63, of the three particle-size comparisons, which indicated that the abbreviated method underestimated the silt fraction, but the y-intercept was also the smallest of the three comparisons, 1.4 (Fig. 2).

The methodological comparison of the clay fraction yielded the best results. The linear relationship between the methods was significant ($P \leq 0.001$) as it was with the total-sand and silt comparison (Fig. 3). The regression line fit the clay data the best of the three particle-size comparisons ($R^2 = 0.97$). The slope of the regression equation was closest to 1 (i.e., 0.84) and the y-intercept was reasonably small at 4.3.

Comparison of Textural Class

In contrast to the particle-size comparisons, the abbreviated method was not sufficiently accurate compared to the standard method for determining soil textural class. Aside from the sub-classes of sand, the resulting textural class (from the percentages of sand, silt, and clay determined by the abbreviated method) matched the textural class from the standard method for only 10 of 24 soil samples; in other words, a matching efficiency of only 42% (Table 1). This result does not support the original hypothesis that the abbreviated method can be used in place of the standard method for determination of soil textural class.

Although the standard method is more accurate, the abbreviated method can be used in time-constraint situations or in situations where the coarse-soil fractions are either unimportant or do not need to be identified. Based on the resulting over-estimation of the sand fraction by the abbreviated method, it is recommended that several trials be conducted on each sample and that an average be used to increase accuracy for the total-sand fraction when the abbreviated method is used. In addition, multiple trials could be conducted to reduce the slight under estimation of the silt and clay fractions. This experiment also demonstrated that the abbreviated method was less than 50% accurate for identifying the soil textural class. With this study, it was shown that the abbreviated hydrometer method for particle-size determination could be a reasonably accurate and time-saving procedure for determining the fine-textured soil particles (i.e., silt and clay), but it is less accurate for determining the fraction of coarser soil particles (i.e., total sand) and the resulting textural class.

ACKNOWLEDGMENTS

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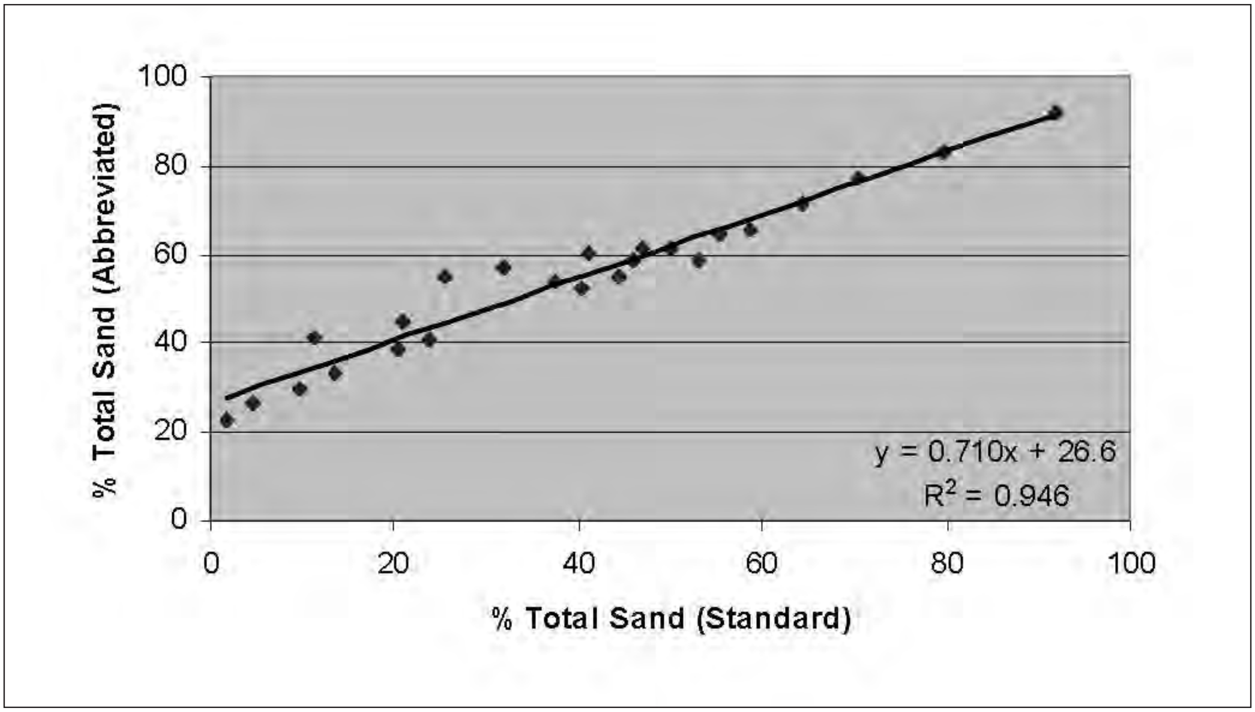

Fig. 1. Relationship between the percentage of total sand from the abbreviated and standard hydrometer methods for particle-size determination.

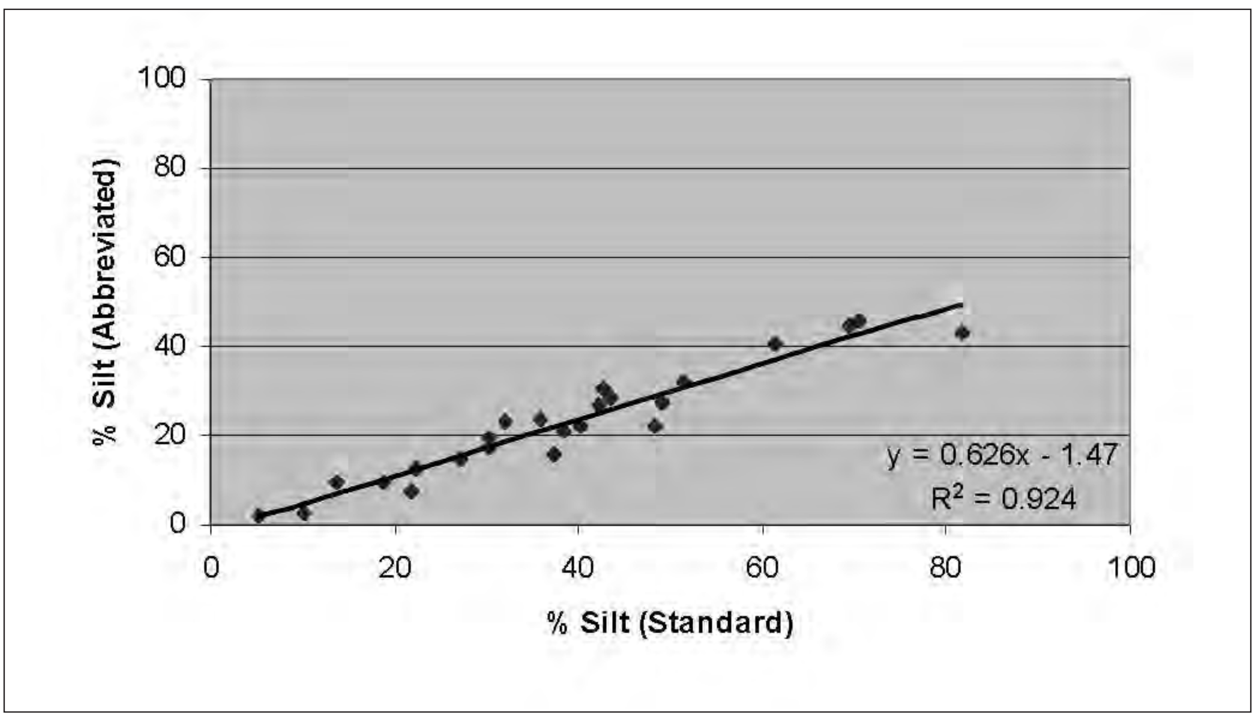

Fig. 2. Relationship between the percentage of silt from the abbreviated and standard hydrometer methods for particle-size determination.

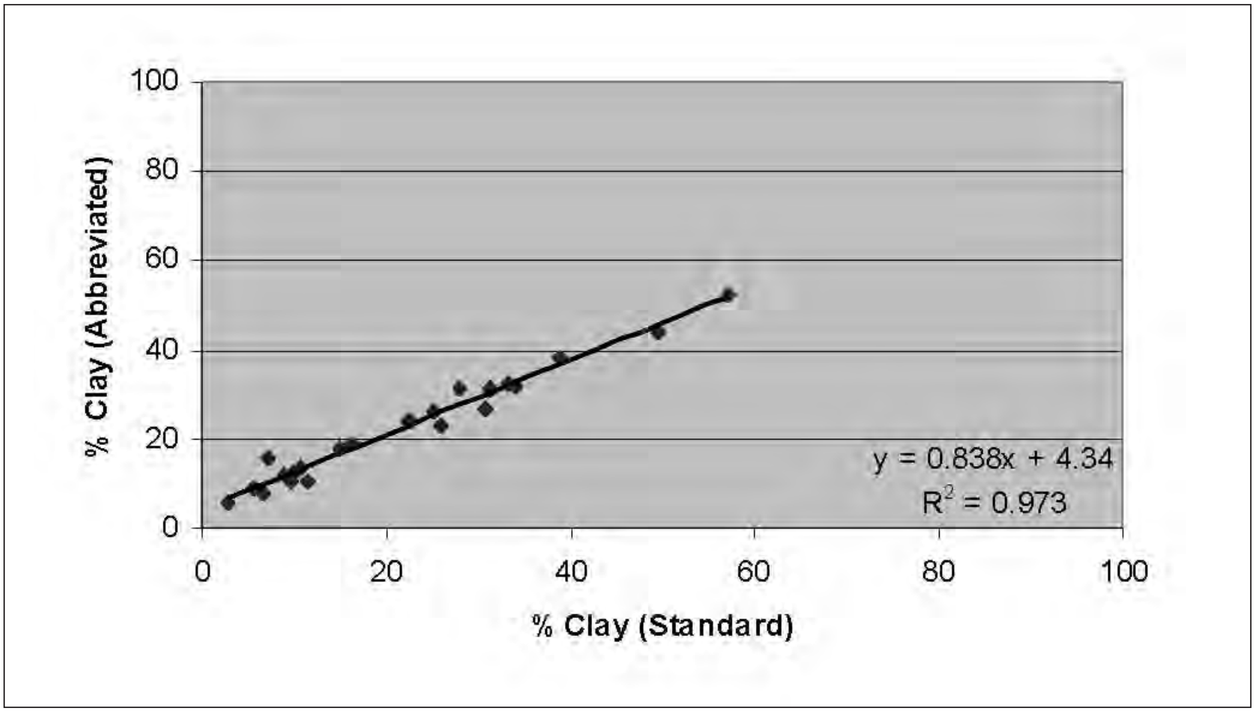

Fig. 3. Relationship between the percentage of clay from the abbreviated and standard hydrometer methods for particle-size determination.

Table 1. Soil textural classes from the standard and abbreviated methods.

	Textural class	
Sample ID	Standard method	Abbreviated method
10431	Loam	Sandy loam
10434	Clay	Clay
10442	Loam	Loam
10443	Loam	Sandy clay loam
10446	Very fine sandy loam	Sandy loam
10455	Clay loam	Sandy clay loam
10465	Silty clay loam	Clay loam
10473	Silt loam	Loam
10484	Silt loam	Loam
10488	Clay loam	Clay loam
10489	Clay loam	Sandy clay loam
10532	Fine sandy loam	Sandy loam
10535	Fine sandy loam	Sandy loam
10541	Silty clay loam	Clay loam
10548	Clay loam	Clay
10559	Silt	Silt
10563	Loam	Sandy clay loam
10570	Sandy clay	Sandy clay loam
10575	Sandy loam	Sandy loam
10576	Coarse sand	Sand
10581	Sandy clay	Sandy clay loam
10586	Sandy clay	Sandy clay loam
10620	Loam	Sandy loam
10667	Loamy fine sand	Loamy sand