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RESEARCH NOTE

Soil texture analyses using a hydrometer: modification of the Bouyoucos method

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Abstract

A.N. Beretta, A.V. Silbermann, L. Paladino, D. Torres, D. Bassahun, R. Musselli, and A. García-Lamohte. 2014. Soil texture analyses by hydrometer: modifications of the Bouyoucos method. Cien. Inv. Agr. 41(2): 263-271. The Robinson pipette method (Pipette) is accurate and precise but time consuming. Bouyoucos (1936) proposed a more rapid and simpler procedure called the hydrometer method. Both analytical techniques are sedimentation procedures accepted as standard techniques for particle-size analysis. The sand, silt, and clay contents of several soil samples were determined using the Pipette method as a control and compared with the Bouyoucus, the Bouyoucos Modified (Bouyoucos_M) and the Bouyoucos Modified with gravimetric determination of the sand content (Bouyoucos_M-T) methods. Data obtained from these procedures was used to assess soil textural class, the soil erodibility coefficient (K), the water retained at field capacity (FC) and the permanent wilting point (PWP). In the Bouyoucos_M method, the soil organic matter (SOM) was destroyed and the dispersingagent concentration was increased. In the Bouyoucos_M-T method, the sand was quantified gravimetrically by sieving samples through a 53 µm mesh. The hydrometer and Pipette methods measurements correlated well. The Bouyoucos and the Bouyoucus-M methods overestimated the sand content. The performance of the Bouyoucos_M-T method did not differ from that of the Pipette method. Compared with the Pipette method, the Bouyoucus method underestimated the clay content, and the Bouyoucos_M method did not differ from the Pipette method. The values obtained with the Bouyoucos_M and the Bouyoucos methods underestimated the FC and the PWP, and Bouyoucos_M-T method did not differ from estimations based on the Pipette method data. The assessed K value was underestimated with the Bouyoucos_M method. The Bouyoucos and the Bouyoucos_M-T methods estimated the K values similar to the Pipette method. The Bouyucus_M-T method is suitable for determining the soil texture and inferring soil properties but is unacceptable for assessing the class texture for soil taxonomic classification.

Key words: particle sedimentation,particle size distribution, Pipette method.

Introduction

There are several methods for determining soil texture. The Robinson's pipette method (Pipette) is considered to be an exact and precise method; however, it is time consuming and not very suitable for routine analyses (Gee and Or, 2002).

Bouyoucos (1936) proposed the hydrometer, which is less accurate than the Pipette method but also simpler and quicker to use, as an alternative analytical method. Both methods are based on Stokes' law (Jury and Horton, 2004), which establishes a relationship between particle size

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and the rate of sedimentation. Thus, particles are assessed by their settling velocities from suspension in a water solution that can be used to *quantify particle* size.

In the Pipette method, the particles in the suspension are measured as they move through the maze of solids of a known volume. In the methodology proposed by Bouyoucos, the size of the solids in the suspension is estimated from the density of the solution measured using the hydrometer. The Pipette method and the method proposed by Bouyoucos differ in the treatment of the samples before sedimentation.The Pipette methodrecommends the destruction of the soil organic matter (SOM) in the sample, whereas the Bouyoucos method does not recommend this pretreatment (Bouyoucos, 1962).Another important difference between these two techniques is that the clay fraction determination is performed following two hours of sedimentation using the Bouyoucos method (Gee and Or, 2002), whereas in the Pipette method, the length of the clay fraction determination is dependent on the temperature of the solution and frequently exceeds two hours.

There are also differences in the analytical results obtained from the Pipette and Bouyoucos methods. These differences may have varying degrees of importance, depending on the purpose of the analysis. In Uruguay, soil texture has been used to estimatethe gravimetric content of water under field capacity (FC) and under permanent wilting point (PWP) (Molfino and Califra, 2001). Another important use of the soil particle size distribution has been for estimating the soil erodibility, K factor, used in the Universal Soil Loss Equation (USLE/RUSLE, Revised Universal Soil Loss Equation; Puentes and Szogi, 1983). The impact of using different methods to determine soil texture based on inferred soil properties has not been evaluated. Bouyoucos' method is easier to use, quicker and convenient for routine analyses but is less precise than the Pipette method. However, depending on thesoil type, Bouyoucos's method can be improved by destroying SOM and dispersing the colloids before the sedimentation process (Beverwijk, 1967). Moreover, the sand fraction may be quantified by sieving the soil sample through a 53 µm mesh as suggested by Gee and Bauder (1986).

The objective of this study was to compare the silt, clay and sand contents measured using the Pipette method, Bouyoucos method or a modification of the Bouyoucos method. The differences were evaluated to assess the soil textural class and the impact of the soil textural class on estimates of FC, PWP and K.

Materials and methods

Samples from the A horizons of different soil types were analyzed to determine the size distribution of the mineral particles (texture). The set of analyzed samples were chosen to cover varyingrepresentative values of sand, silt, clay and organic carbon from the A horizons of Uruguay according to the Ministerio de Agricultura y Pesca/ Direccion de Suelos y Fertilizantes (MAP/DSF, 1976). The chemical composition of the samples is summarized in Table 1.The percentages of sand, silt and clay were determined using the following four methods: (1) 21 samples were analyzed using the Pipette method (modified of Day, 1965); (2) 13 samples were analyzed usingthe Bouyoucos method; (3) 21 samples were analyzed using the-Bouyoucos Modified method (Bouyoucos_M) and (4) 21 samples were analyzed using the Bouyoucos_Mmethod with the determination of the sand fraction by sieving (Bouyoucos_M-T). In all the methods, the soil samples were dried at 40 °C for 48 h and further ground and sieved to eliminate particles larger than 2 mm in diameter. The same clay content was assumed for the Bouyoucous_M and the Bouyoucus_M-T methods. Because differences between the Bouyoucus method and the Pipette method have been reported by other researchers, fewer samples were compared using these methods. The samples that were examined

Table 1. Summary of the sand, silt, clay and C organic content of the samples analyzed.

	Sand[1]	Silt	Clay	C.org
		%		g 100 g^{-1}
Average	36	33	31	2.34
Standard deviation	19.12	13.56	8.89	0.85
Minimum	13	7	13	0.50
Maximum	81	54	43	3.96

[1]Values analyzed using the Pipette method.
[3]It was considered equal for both procedures.

with these methods were used to reinforce the previous results.

The Bouyoucos_M method consisted of the destruction of the SOM with hydrogen peroxide and its further dispersion with an increased concentration of sodium hexametaphosphate (Calgon, Bioquim, Montevideo, Uruguay). The SOM was destroyed in a 70 g soil sample by applying successive aliquots (approximately three times) of 40 mL of hydrogen peroxide (H_2O_2, 130 volumes) until the effervescence of the reaction was minimal (Secretaría de Medio Ambiente y RecursosNaturales (México), 2002). The procedure was performed on an 80 ºC hotplate. The oxidized samples were placed in a forced-air oven and allowed to dry-off at 80 ºC. Dispersion was obtained by shaking 50 g of dry soil sample with 100 mL of 25% sodium hexametaphosphate (technical Calgon, Bioquim, Montevideo, Uruguay) for 16 hours in a reciprocating shaker. The mixture was then placed in a Bouyoucos' blender cup and stirred for two minutes with an electrical mixer. The contents of each cup were transferred to a 2 L sedimentation cylinder, and the cylinder was filledwith deionized water to the 2000 mL mark. The mixture was then homogenized using manual agitation.

The solids in the suspension were measured with a hydrometer following 40 seconds of decantationwitha second lecture taken after two hours. The measurement was made when the suspension was between 20 and 22 °C and then corrected due to the temperature. The first reading was for estimating the sand content [1], whereas the second one at two hours was to estimate the clay content [2]. The silt fraction was calculated as the difference between those two measurements [3]. In the Bouyoucos_M-T method,following the destruction of SOM and dispersion of the sample, the sand was separated from the sample by sieving it through a 53 µm mesh and quantified gravimetrically. Before the hydrometer was used,a blank lecture was performed. This consisted of hydrometer readings at 40 seconds and two hours in the same cylinder with dispersant samples and then water without the soil samples.

Sand%=100–(Lecture 40 s x 2 – blank Lecture) x 100/oven-dry wt. [1]

Clay%= (Lectureat 2 hours x 2 – blank Lecture) x 100 / oven-dry wt. [2]

Silt % = 100 – sand % - clay % [3]

The Pipette method was performed at the laboratory of the National Soil Survey Department (MGAP, Ministerio de GanaderíaAgricultura y Pesca, Mexico). The Bouyoucos' and Bouyoucos' modified methods were performed at the Soil, Plant and Water Laboratory in the soils department of the National Institute of Agricultural Research (INIA- La Estanzuela, Uruguay).

The soil organic carbon content was determined by exposing the samples to dry combustion at 900 °C and then using infrared detection with the LECO TruSpec (Wright and Bailey, 2001).

The texture data obtained with the different techniques was used to determine the FC, the

PWP and the K coefficient (USLE/RUSLE) and to identify which methods were the most accurate at describing the soil texture in comparison with other soil characteristics. The equations applied by Molfino and Califra(2001) were used to estimate the FC and the PWP. The formula proposed by Puentes and Szogi (1983) was used to calculate the K coefficient with the following assumptions: (1) a code of structure 2; (2) a code of permeability 3; and (3) a content of very fine sand equal to 1/3 the amount of total sand. The determination of the texture class was completed using the soil textural triangle proposed by the USDA (Gee and Or, 2002).

The differences between the measurements made using the hydrometer and Pipette methods were compared using regression analysis and the comparison of the paired averages with the InfoStat statistical software (Di Rienzo*et al.,* 2012). The data obtained using the Pipette method was chosen as the independent variable. The error was considered to be the differences in the measurements obtained using the hydrometer and the Pipette method because the later method is often used as the standard for which other methods are compared, due to its increased precision.

Results and discussion

The assessment of the sand fraction using the hydrometer methods (Bouyoucos and Bouyoucos_M) had a good correlation with the values obtained using the Pipette method (Table 2).However, the

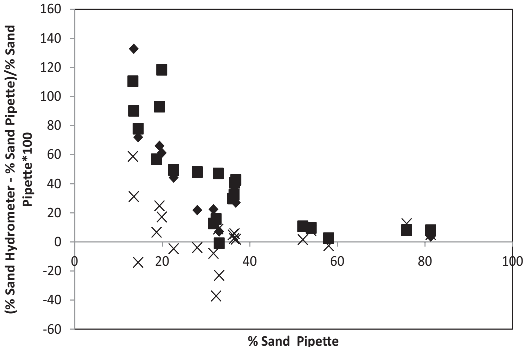

Figure 1. Differences between the sand fraction contents measured using the hydrometer methods and the Pipette method as a function of the sand content determined using the Pipette method. Thediamonds represent the Bouyoucus method; squares represent the Bouyoucus_M method, with the destruction of the organic matter and an increased concentration of dispersant agent; and the crosses represent the Bouyoucus_M-T method (with the destruction of the organic matter and an increased concentration of the dispersant agent), where sand fraction was also measured using sieve separation.

Table 2. The soil texture fraction measured using the hydrometer method in comparison to thePipette method determination function.

Hydrometer Method	N	Regression	R^2	μ Pipette - μ Hydrometer[1]
Sand				
Bouyoucos	13	14.07+0.85*Sand Pipette	0.94	-9.35*
Bouyoucos_M	21	15.91+0.84*Sand Pipette	0.91	-10.35*
Bouyoucos_M-T[2]	21	-0.66+1.04*Sand Pipette	0.94	-0.92 ns
Silt				
Bouyoucos	13	2.39+0.73*Silt Pipette	0.95	7.03*
Bouyoucos_M	21	-3.19+0.81*Silt Pipette	0.85	9.60*
Bouyoucos_M-T	21	-0.85+1.02*Silt Pipette	0.92	0.31 ns
Clay				
Bouyoucos	13	-9.58+1.21*Clay Pipette	0.97	2.52*
Bouyoucos_Mand M-T[3]	21	-5.94+1.16*Clay Pipette	0.80	1.00 ns

[1]paired means comparison: *significant difference (P≤0.05) between the Pipette or hydrometer measurement; ns indicates non-significant difference.
[2]Bouyoucos_M: proposed technique of the Bouyoucos_Modified, the dispersant agent (Calgon) was increased, and the organic matter was destroyed; Bouyoucos_M-T: Same as above, but the sand content was measured using sieve separation.
[3]It was considered equal for both procedures.

error tended to increase as the sand content in the samples decreased (Figure 1). The sand measurements made using the hydrometer overestimated the sand fraction in the soil samples.

The sand measurement made using the Bouyoucos_M-T method, where this fraction was determined gravimetrically after sieving, improved the accuracy of the measurement because the average error became less significant and statistically equal to zero. The magnitude of the error was not associated with the quantity of sand present in the sample when the Pipette method was used (Figure 1). Because the differences in the procedures for destroying the SOM and the dispersion of the samples between the Pipette and the Bouyoucos_M-T methods are not expected to significantly affect the quantity of sand, the observed differences could be attributed to the differences in the variability between the soil samples. The magnitude of error for the sand measurements using the hydrometer lectures was consistent with the data reported by Gee and Or (2002). Norambuenaet *al.* (2002) reported a9.69% sand overestimation when assessing this fraction in 29 soil samples from the Andean region using the Bouyoucos method. According to the Pipette method results, the absolute value of the measured errors increased when the samples had smaller amounts of sand present.

The hydrometer measurements of the clay fraction also had a significant correlation with the measurements obtained with the Pipette method (Table 2). However, the Bouyoucos method underestimated the clay fraction in 13 of the analyzed samples. This underestimation was more pronounced when the true clay content of the samples was less (Figure 2).The magnitude of the error, however, was lower than what was reported by Gee andBauder (1986).

There was no difference in the average clay content (P=0.16) when using the Bouyoucos or the Bouyoucos_M methods.The destruction of the SOM and the increased concentration of the dispersing solution did not significantly effect this measurement. Although the average clay content of the 13 samples analyzed with the Bouyoucus methodincrease slightly (2.05%), the results obtained with the Bouyoucos_M method did not significantly differ in average clay content(P=0.38) from the measurements obtained with the Pipette method. The underestimation of the clay fraction decreased as the soil sample had a progressively higher clay concentration according to the Pipette method (Figure 2).That correlation was lower than when the SOM in the sample was not destroyed. Norambuena*et al.* (2002) reported that the Bouyoucos method did not differ from the Pipette method, even without the destruction of the SOM in the samples. Those results can be attributed to a very low SOM concentration in the samples analyzed by the researchers. Day (1965) determined a minor difference in clay content obtained using the hydrometer in comparison to that obtained using the Pipette method when the soil samples were pre-treated to destroy the SOM. Because the SOM acts as a “cementing” agent and can bind clay particles together, groups of particles wouldprecipitate more rapidly than individual particles and could thus be quantified as silt (Gee and Or, 2002).

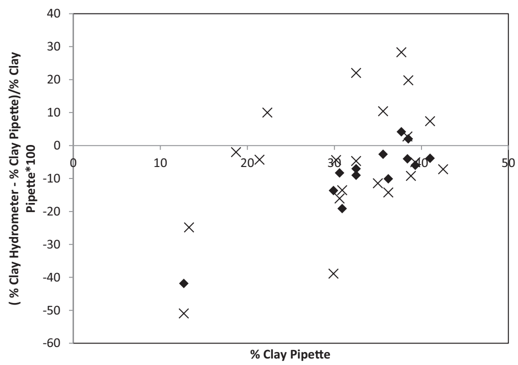

Figure 2. Differences between clay fractions content measured using a hydrometer method or the Pipette method as a function of the clay fraction contents measured using the Pipette method. The diamonds represent the Bouyoucus method, and the crosses represent the Bouyoucos_M method, with the destruction of the organic matter and an increased concentration of the dispersant agent.

All of the methods evaluated in this study estimated the silt concentration of the sample as the difference between 100 and the percentage of sand and clay (equation 3). Therefore, the analytical errors will impact the estimation of the silt content when determining these two fractions. The average silt content determined using the Bouyoucus method was7% less than that determined using the Pipette method ($P \leq 0.05$) in the 13 samples measured. The Bouyoucos_M method underestimated the average silt content by 9.58% ($P \leq 0.05$) in the 23 samples measured, whereas the Bouyoucos_M-T method only underestimated the average silt fraction by 0.21%,which is not significantly different from zero ($P=0.72$).

When adding theabsolute values of the differences between the sand and the clay contents from the hydrometer method to those from the standard Pipette method, the results for the Bouyoucos, Bouyoucos_M and Bouyoucos_M-T methods were 12.09%, 14.57% and 7.82%, respectively. Therefore, the Bouyoucos M-T method is the method that would present the smallest analytical error when compared to the particle size distribution obtained using the Pipette method. Beverwijk (1967) suggested that the hydrometer can be used instead of the Pipette method only in cases where the pre-treatment of the sample completely destroys the SOM and a total dispersion of the sample is achieved.

Differential estimations of soil properties based on soil texture data

Because a soil's texture may affect its other properties, the differences in the measurements obtained from the technology used to assess the texture will likely impact information about the soil properties that is inferred from the data.

The estimations of the FC and the PWP derived from the hydrometer particle size distribution measurements correlated significantly with the estimations derived from the Pipette method (Table 3). However, the average calculation of the FC and the PWP were underestimated ($P \leq 0.05$) when the soil texture was determined using the-Bouyoucos and Bouyoucos_M methods in relation to estimations based on the Pipette method results. The differences disappeared when using the Bouyoucos_M-T method; the results were not significantly different from the estimations derived from the Pipette method results.

When the K value (USLE/RUSLE) was estimated using the hydrometer data only, the Bouyoucos_M method significantly differed from the average estimations that used values derived from the Pipette method (Table 3).Additionally, the former method also markedly underestimated theaverage K values. However, it is possible to assume that the estimations of K using the particle size distribution obtained usingthe Bouyoucos or Bouyoucos_M-T methods can be successfully used because the K values were equal to those obtained when the Pipette method measurements were used for this calculation.

None of the analytical procedures for determining texture with the hydrometer has the required accuracy to classify the soil in textural classes according to USDA classification (Gee and Or, 2002) (Table 4). In samples where the particle size was obtained using the Bouyoucos method, only 19% of the samples had the same textural class defined when using the results obtained using the Pipette method. In contrast, comparison of the samples analyzed with the Bouyoucos_M and Bouyoucos_M-T methods had a coincidence of 31% and 52%, respectively. The accuracy of the three methods is unacceptable for taxonomical objectives.Miller *et al*. (1988) suggested that the determination of the texture must be performed using the Pipette or Bouyoucos– Days methods when the texture is going to be used for taxonomic purposes.

The Boyoucus M-T method is suitable for determining soil texture when this property is intended to be used for inferring other soil-related properties such as FC, PWP and K.

Table 3. Estimation of the water content of soil and the erodibility coefficient (K) from the sand, silt and clay fractions determined using different methods.

Hydrometer method	n	Regression	R^2	y= 1* x	µ Pipette - µ Hydrometer[1]
Field capacity water content (FC)					
Bouyoucos[2]	13	0.6+0.93*FC-Pipette	0.98	ns	1.74*
Bouyoucos_M	21	0.01+0.94* FC-Pipette	0.95	ns	1.73*
Bouyoucos_M-T	21	-1.53+1.04* FC-Pipette	0.97	*	0.16 ns
Permanent wilting point water content (PWP)					
Bouyoucos	13	-3.48+1.12*PWP-Pipette	0.96	ns	1.49*
Bouyoucos_M	21	-2.28+1.08* PWP-Pipette	0.85	*	1.03*
Bouyoucos_M-T	21	-2.68+1.15* PWP-Pipette	0.88	*	0.35 ns
K					
Bouyoucos	13	-0.01+1.02*K-Pipette	0.91	ns	0.01 ns
Bouyoucos_M	21	-0.06+1.19* K-Pipette	0.92	*	0.02*
Bouyoucos_M-T	21	-0.03+1.21* K-Pipette	0.85	ns	-0.01 ns

[1]Paired means comparison: * significant difference ($P \leq 0.05$) between the pipette or hydrometer measurement; ns indicates non-significant differences.
[2]Pipette: International Pipette method; Bouyoucos_M: modification of the technique proposed by Bouyoucos, with destruction of the organic matter and an increased concentration of the dispersant agent (Calgon); Bouyoucos_M-T: same as above, but the sand content was measured using sieve separation.

Table 4. Soil textural class classification according to the measurements of the sand, silt and clay fractions.

	Pipette[1]	Bouyoucos	Bouyoucos_M	Bouyoucos_M - T
Sample	Textural classes			
1	Clay		Sandy Clay	Clay Loam
2	Clay Loam		Sandy Clay	Clay Loam
3	Clay Loam	Clay Loam	Sandy Clay	Clay Loam
4	Clay Loam	Clay Loam	Silty Clay Loam	Clay Loam
5	Silty Clay Loam	Clay Loam	Clay Loam	Silty Clay Loam
6	Clay Loam	Clay Loam	Clay Loam	Clay Loam
7	Clay Loam	Clay Loam	Clay	Clay
8	Clay Loam	Clay Loam	Clay Loam	Clay Loam
9	Clay	Clay Loam	Clay	Clay
10	Clay Loam	Clay Loam	Clay	Clay
11	Clay Loam	Clay Loam	Clay Loam	Silty Clay Loam
12	Clay Loam		Loamy Sand	Sandy Loam
13	Clay Loam		Clay Loam	Clay Loam
14	Loam		Silty Clay Loam	Sandy Clay Loam
15	Silty Clay Loam		Silty Clay Loam	Sandy Clay Loam
16	Loam		Sandy Loam	Sandy Loam
17	Clay Loam	Loam	Silty Clay Loam	Clay Loam
18	Clay Loam	Clay Loam	Clay Loam	Clay Loam
19	Clay Loam	Clay Loam	Loam	Silty Loam
20	Clay Loam		Clay Loam	Silty Clay Loam
21	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam

[1]**Pipette:** International Pipette method; Bouyoucos_M: modification of the technique proposed by Bouyoucos, with the destruction of the organic matter and an increased concentration of the dispersant agent (Calgon); Bouyoucos_M-T: same as above, but the sand content was measured using sieve separation.

Resumen

A.N. Beretta, A.V. Silbermann, L. Paladino, D. Torres, D. Bassahun, R. Musselli y A. García-Lamohte. 2014.Análisis de textura del suelo con hidrómetro: modificaciones al método de Bouyoucus.Cien. Inv. Agr. 41(2): 263-271. El método de la Pipeta de Robinson (Pipeta) es exacto y preciso, pero insume mucho tiempo. Bouyoucos (1936) propuso el método del hidrómetro como más rápido y simple. Ambos métodos de sedimentación se aceptan para el análisis textural del suelo. Se comparó el contenido de arena, limo y arcilla de varias muestras de suelo. Se asumió el método de la Pipeta como control y se comparó con: Bouyoucus; una modificación de Bouyoucos, con destrucción de materia orgánica y mayor concentración de dispersante (Bouyoucos_M); y Bouyoucos_M con determinación gravimétrica de arena previo tamizado de las muestras con malla de 53 µm (Bouyoucos_M-T). Los datos se emplearon para evaluar: clase textural; coeficiente de erodabilidad (K); agua retenida a capacidad de campo (CC); y el punto de marchitez permanente (PMP). Hubo buena correlación entre las mediciones con hidrómetro y la Pipeta. El método Bouyoucos o Bouyoucus-M sobreestimó el contenido de arena, pero Bouyoucos_M-T no difirió. Bouyoucus subestimó el contenido de arcilla y Bouyoucos_M no difirió. Con los datos de Bouyoucos_M y Bouyoucos se subestimaron FC y PWP; con Bouyoucos_M-T no hubo diferencias de las estimaciones al comparar con la Pipeta. Se subestimó el coeficiente K al utilizar los datos de Bouyoucos_M. Con Bouyoucos o Bouyoucos_M-T, los valores estimados de K no difirieron de los estimados a partir de la Pipeta. Bouyucus_M-T fue adecuado para inferir las propiedades del suelo, pero inaceptable para adjudicar la clase textural con el fin de clasificar suelo con fines taxonómicos.

Palabras clave: Distribución de tamaño de partículas, método de la Pipeta, sedimentación de partículas.

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