Comparison of four measurement schedules for determination of soil particle-size distribution by the hydrometer method

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Karkanis, P.G., Au, K. and Schaalje, G.B. 1991. **Comparison of four measurement schedules for determination of soil particle-size distribution by the hydrometer method.** Can. Agric. Eng. 33:211-215. Four schedules of measurement by the hydrometer method were examined for determining the particle-size distribution of soils in southern Alberta. All methods utilized the same sample pretreatment procedures and differed only in the time at which hydrometer readings were taken. Linear and quadratic regression analyses were used to describe the relationship between estimates for sand and clay content determined by the different methods. Comparisons among the methods were made by testing the hypothesis that the relationship between any two methods was linear and had a slope of one. Clay content was significantly overestimated with the Bouyoucos (1962) method when compared with the other three methods. Regression equations were developed for conversion of sand and clay content, as determined by the Bouyoucos (1962) method, to the more theoretically sound methods of Day (1965), USDI (1982), and Gee and Bauder (1986).

Key Words: Particle-size distribution, hydrometer method, soil texture, soil analysis.

Quatre séries de mesures hydrométriques ont été examinées afin de déterminer la distribution granulométrique de sols dans le sud de l'Alberta. Toutes les méthodes utilisaient les mêmes procédures de prétraitement d'échantillons et ne différaient que par le moment où les mesures avaient été prises. Par des analyses de régression linéaire et quadratique, on a pu déterminer les relations entre les estimations de teneur en sable et en argile établies par les différentes méthodes. Des comparaisons ont été faites en se fondant sur l'hypothèse que les relations entre deux méthodes, quelles qu'elles soient, étaient linéaires et fondées sur une pente de un. La teneur en argile était considérablement surestimée par la méthode Bouyoucos (1962), comparativement aux trois autres. Des équations de régression furent établies pour convertir la teneur en sable et en argile déterminée par la méthode Bouyoucos (1962), suivant les méthodes théoriquement plus sûres de Day (1965), d'USDI (1982), et de Gee et Bauder (1986).

INTRODUCTION

Particle-size distribution (PSD) of the fine earth (less than 2 mm diameter) fraction is an important measurement for characterization of soils for irrigation and drainage purposes. Soil texture is used in evaluating irrigation suitability, assessing land drainability, predicting hydraulic conductivity and estimating moisture-retention characteristics (Alberta Agriculture 1983).

Several methods are available for measurement of PSD, but sieving and sedimentation techniques are generally used for agricultural soils. Sieving methods are only suitable for separation of the sand fraction of soils, i.e. particles larger than 0.05 mm diameter (Baver et al. 1972). The pipette and hydrometer methods represent two approaches to the determination of PSD by the sedimentation method. The pipette method is generally considered more accurate than the hydrometer method (Day 1965), however, comparable results can be obtained provided similar pretreatment techniques are employed (Gee and Bauder 1986).

Sedimentation methods are based on the relationship between the settling velocity and diameter of a spherical particle in a fluid at constant temperature, described by Stokes' law (Baver et al. 1972). The strict applicability of Stokes' law to PSD determinations has been the subject of much debate due to variations in the shape and density of clay-sized particles, however, for most practical purposes a reasonable estimate of particle size can be obtained (Baver et al. 1972). Particle size may also be defined in different ways on the basis of several arbitrary criteria that apply to spherical particles but do not necessarily hold true for the anisometric particles occurring in the soil (Day 1965).

The Bouyoucos (1962) hydrometer method is commonly used for determination of PSD in agricultural soils in Alberta. This method uses a 40 s hydrometer reading to estimate the sand content and a 2 h hydrometer reading to approximate the clay fraction. The 2 h hydrometer reading yields an estimate of the less than 0.005 mm silt and clay fraction rather than the less than 0.002 mm clay fraction. When more accurate differentiation between silt and clay is required, the Bouyoucos method is not recommended (Gee and Bauder 1986).

Day (1965), USDI (1982), and Gee and Bauder (1986) describe alternative approaches that overcome the major criticism of the Bouyoucos method. The Day (1965) method involves hydrometer readings at 0.5, 1, 3, 10, 30, 90, 270 and 720 min that are plotted against calculated particle diameters to obtain estimates of PSD through graphical interpolation. Sand content is estimated from a 40 s hydrometer reading and clay content from a 8 h reading in the USDI (1982) method. Hydrometer readings are obtained at 30 and 60 s for determination of sand content and at 1.5 and 24 h for calculation of clay content in the simplified Gee and Bauder (1986) method.

The purpose of this study was to evaluate four hydrometer methods for determining the PSD of southern Alberta soils from a wide range of textural classes. Relationships between estimates of PSD determined at specific settling times in the different methods were also described.

MATERIALS AND METHODS

A total of 177 samples from mineral horizons of soils from the Brown and Dark Brown soil zones in southern Alberta were used for this study. These soils were generally low in organic matter (less than 1%) and represented a wide range of textural classes from sand to heavy clay (Fig. 1). Sand content ranged from 6 to 95 percent and clay content varied from 3 to 82 percent.

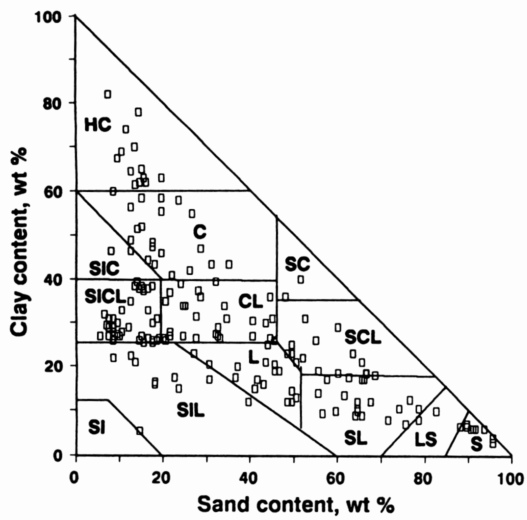

Fig. 1. Texture of soil samples used according to the Day (1965) method.

All soil samples were subjected to the same pretreatment and dispersion procedures. A 50 g sample of the fine earth (less than 2 mm diameter) fraction of the soils was soaked overnight in a beaker containing 50 $g \cdot L^{-1}$ of sodium-hexametaphosphate dissolved in distilled water to enhance dispersion (Gee and Bauder 1986). Other pretreatment procedures such as removal of carbonates, soluble salts, organic matter or iron oxides were not undertaken.

Each sample was subsequently dispersed mechanically by transferring the soil suspension from the beaker to a 1 L mixing cup and was stirred with an electric mixer at 1500 rpm for 10 min. The mixed suspension was then transferred to a 1130 mL hydrometer cylinder (Bouyoucos 1962) and made up to volume by adding distilled water with the density hydrometer in suspension. The density hydrometer was then removed and the suspension was left overnight to equilibrate to room temperature. Prior to commencing the tests the next day, the hydrometer was again placed in the suspension and the volume was remade up to 1130 mL. An ASTM No. 152H density hydrometer was used for all measurements.

Particle-size distribution tests were started by removing the hydrometer from the glass cylinder and mixing the soil suspension by turning the cylinder upside-down twenty times. The cylinder containing the soil suspension was then placed on a level surface in a room having a constant temperature of 22°C. A stop watch was used for timing measurements of the soil suspension at sedimentation times of 30, 40, 50 and 60 s and at 1.5, 2, 4, 6, 8 and 24 h. The hydrometer was immersed in the suspension 10 s before each reading and was removed immediately following each reading, except for the first four measurements. Density measurements were also obtained at the same time intervals on a blank solution of sodium-hexametaphosphate made up to the same 1130 mL volume. A corrected hydrometer reading was obtained at each settling time as:

$$C = R_1 - R_2 \quad (1)$$

where:

C = mass of soil in suspension at time hydrometer reading was taken ($g \cdot L^{-1}$),

R_1 = density of soil suspension ($g \cdot L^{-1}$), and

R_2 = density of blank solution ($g \cdot L^{-1}$).

Sand, silt, and clay contents were then calculated for all samples according to the settling times used in the Bouyoucos (1962), Day (1965), USDI (1982) and simplified Gee and Bauder (1986) methods. Calculations were based on air-dry weight of soil to conform with procedures used in routine PSD analysis in most agricultural soil laboratories in Alberta.

Linear and quadratic regression analyses were used to examine relationships among the methods. Nonlinearity of the relationships was examined by testing the hypothesis that the coefficient of the second degree term was equal to zero. When a relationship between two methods was linear, agreement of the methods was examined by testing the hypothesis that the intercept was equal to zero and the slope was equal to one. In all cases the coefficient of determination (R^2) was used as a measure of the goodness of fit between two methods.

RESULTS AND DISCUSSION

A significant linear relationship was observed between any two of the methods for measuring sand content (Table I). In all cases the slopes were significantly different from one. All of the methods were thus systematically different from each other, but the results from any one method would be very accurately predicted from the results of any other method using the regression equations (Table I).

In spite of a non-zero intercept and a slope significantly different from one, it can be seen that the relationship between sand content determined according to Gee and Bauder (1986) and Bouyoucos (1962) or USDI (1982) was close to 1:1 in all textural classes (Fig. 2). In contrast, the relationship between sand content determined according to Day (1965) and that determined by both other methods (Gee and Bauder 1986, Bouyoucos 1962, USDI 1982) was close to 1:1 only for soils with less than 40% sand. For soils with more than 40% sand, the Day (1965) method gave a higher estimate of sand content than the other methods. This may be due to the use of graphical values in determining results in the Day (1965) method, rather than the use of a formula in determining results, as in the other methods.

Gee and Bauder (1979) found that the difference between

Table I. **Comparison of percent sand content measured by four hydrometer methods.**

Method	Regression equation	SE of intercept	SE of 1st deg. coefficient	R^2	SE of prediction
††Gee & Bauder vs Bouyoucos Gee & Bauder vs USDI	$Y_2 = 0.666 + 0.995\ (Y_1)$	0.081†	0.002*	0.999	0.60
Day vs Bouyoucos Day vs USDI	$Y_2 = -0.184 + 1.039\ (Y_1)$	0.174	0.004*	0.997	1.30
Day us Gee & Bauder	$Y_2 = -0.870 + 1.044\ (Y_1)$	0.171	0.004*	0.997	1.27

† y-intercept significantly different from zero, $p \leq 0.05$.

* 1° coefficient significantly different from one, $p \leq 0.05$.

††Bouyoucos and USDI were the same.

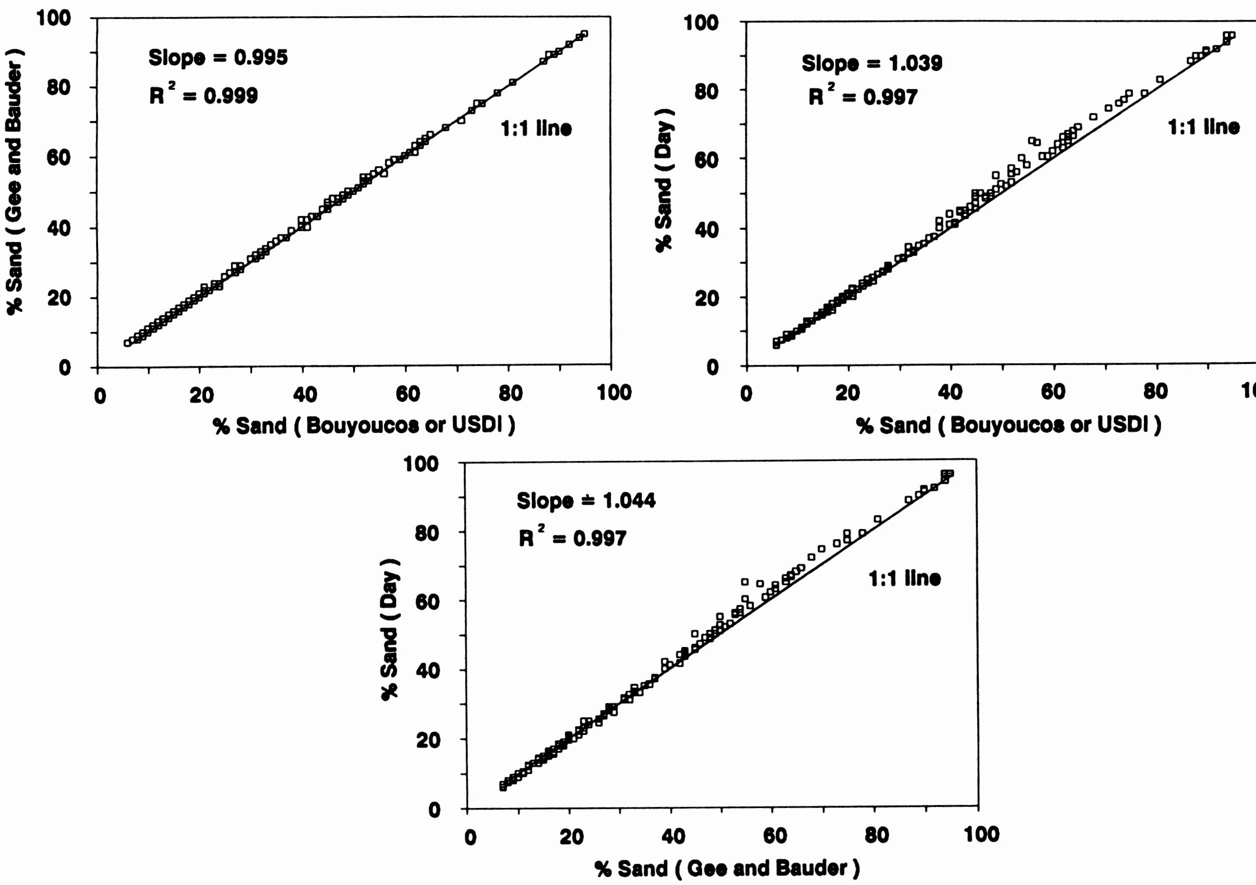

Fig. 2. Relationship between % sand measured by four methods.

sand content determined from hydrometer readings at 30 and 60 s, and readings at 40 s according to Bouyoucos (1962), was within 0.5% by mass. They also found that the difference between sand, as determined by sieve and hydrometer methods often exceeded 5% by mass. Recently, Bohn and Gebhardt (1989) stated that hydrometer readings anywhere between 30 and 60 s should reasonably estimate the sand content.

Relationships among the four methods of measuring clay content were all significant (Table II), but some of the relationships were quadratic instead of linear and no pair of methods gave identical results. As with sand content, this means that each of the methods gave systematically different results from the others, but the results from any method could be combined with the regression equations to accurately predict the results from any other method.

The relationship between Bouyoucos (1962) and any of the

Table II. Comparison of percent clay content measured by four hydrometer methods.

Method	Regression equation	SE of intercept	SE of 1st deg coefficient	SE of 2nd deg. coefficient	R^2	SE of prediction
Gee and Bauder vs Bouyoucos	$Y_2 = 1.079 + 0.735\ (Y_1) + 0.001\ (Y_1)^2$	0.393†	0.021*	0.002#	0.992	1.39
Day vs Bouyoucos	$Y_2 = 1.362 + 0.654\ (Y_1) + 0.003\ (Y_1)^2$	0.671†	0.035*	0.004#	0.980	2.37
USDI vs Bouyoucos	$Y_2 = 1.098 + 0.712\ (Y_1) + 0.002\ (Y_1)^2$	0.628†	0.033*	0.003#	0.982	1.39
Day vs Gee and Bauder	$Y_2 = -1.818 + 1.056\ (Y_1)$	0.257†	0.008*		0.991	1.59
USDI vs Gee & Bauder	$Y_2 = -0.845 + 1.035\ (Y_1)$	0.219†	0.007*		0.993	1.36
USDI vs Day	$Y_2 = 1.004 + 0.977\ (Y_1)$	0.125†	0.004*		0.998	0.81

† y-intercept significantly different from zero, $p \leq 0.05$.
* 1° coefficient significantly different from one, $p \leq 0.05$.
# 2° coefficient significantly different from zero, $p \leq 0.05$.

other methods was quadratic (Fig. 3), and clay content determined by the Bouyoucos (1962) method was always higher than that determined by other methods. The other three methods, (Day 1965), Gee and Bauder (1986), and USDI (1982) gave comparable results. The 2 h reading in the Bouyoucos (1962) method provided a mean estimate of particles about 0.0044 mm in diameter and less according to Stokes' law and did not yield a correct estimate of the less than 0.002 mm clay fraction.

Bohn and Gebhardt (1989) noted that clay content estimated from 2 h readings was significantly different from an average estimate of the 6 and 12 h readings, and no statistical difference was found between the 6 and 12 h methods. They concluded that 6 h of settling should be adequate. Gee and Bauder (1979) compared clay content determined on the basis of graphical values (Day 1965) to clay content determined from a formula calculation (Gee and Bauder 1979) and noted no significant difference in the results.

CONCLUSIONS

Examination of four schedules of measurement by the hydrometer method, for determination of PSD in soils from southern Alberta, revealed statistically significant differences in estimates for sand and clay content between methods. These differences were most pronounced in soils having high clay content. Conversion of sand and clay contents between methods may be accurately completed using regression equations presented in this study. Specification of the method used for PSD measurements is essential because of the statistically significant differences found between any of the four methods compared.

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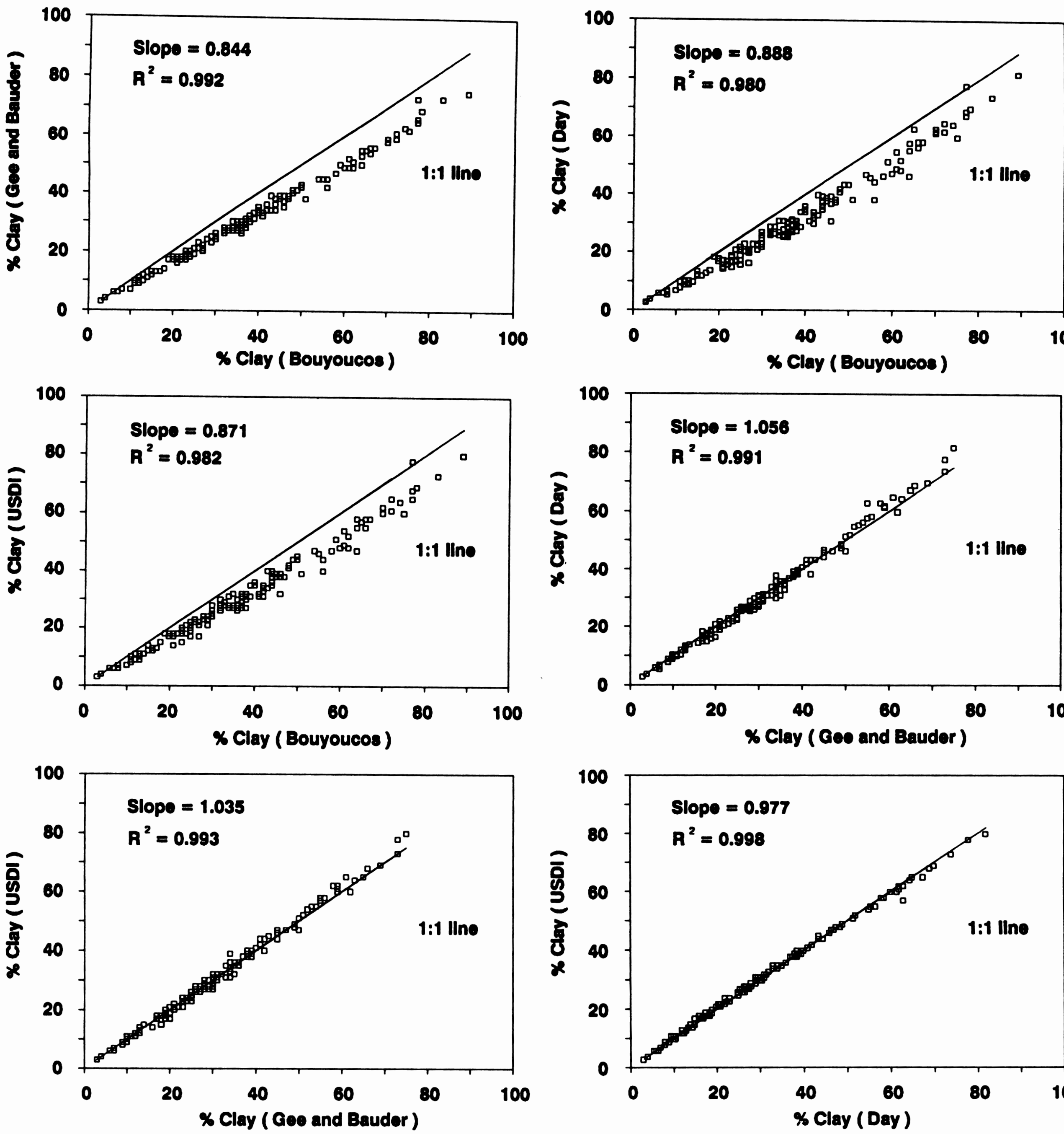

Fig. 3. Relationship between % clay measured by four methods.

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