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Simple method for measuring soil sand content by nylon mesh sieving

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Abstract

A rapid and reagent-free method for measuring soil sand content is presented. In this method, a 20 µm-opening nylon mesh cloth was used for wet-sieving of the sand fraction, and the difference of the soil weight before and after sieving was measured with an electric balance. Once air-dried, 2-mm sieved samples are prepared, the analysis can be completed within 2 days and 50 samples can be handled together by one person. The accuracy of this method was evaluated by using five agricultural surface soils with various textural classes. The sand content obtained from the proposed method agreed well with that from the conventional method. Repeatability and reproducibility of the proposed method were high for sandy soils and were moderate for a clayey soil. The sensitivity of the method was further evaluated by analyzing hundred surface soils collected from a single paddy field having a similar textural class. The regression analysis of data between the proposed and conventional methods brought the R^2 value of 0.83 and a slope of 1.04. The slight overestimation by the proposed method suggested a systematic error originated probably from the lack of pretreatment to remove organic matter. Limited to agricultural soils containing total C at less than 5%, the proposed method would be useful not only for scientific investigation but also for educational purposes.

Key words: Agricultural soils, nylon mesh cloth, reagent-free, sand content, sieving.

INTRODUCTION

Soil texture is determined by the percentage of sand, silt and clay. Although the definition of the soil particle size and textural class differs among countries and/or associations (Murano et al., 2015), it is widely accepted that soil texture is one of the most important properties controlling the nature and function of soils such as accumulation of organic matter, retention of water and fertilizer elements and ease of tillage by agricultural machinery.

The conventional methods for measuring soil texture are divided into field-based hand texturing or laboratory-based sieving and sedimentation. The former method depends on our hand feeling. The results obtained are qualitative, and substantial errors are involved. On the other hand, the latter method can produce quantitative results. A 2-mm sieved sample is treated with hydrogen peroxide for removal of organic matter, and subjected to ultrasonic and/or chemical treatments for dispersion.

Then, the sand fraction is collected by sieving and the silt and clay fractions are separated by sedimentation rates based on Stokes' law. The analysis requires a long time for pretreatments and cost for special equipment. Most of the equipment for texture is used for dispersion and sedimentation procedures to separate silt and clay fractions, so many scientists have attempted to simplify the procedures.

The sedimentation method was simplified and miniaturized to use a 50 mL centrifuge tube for soil particle settling and a Gilson micropipette for sampling of clay particles (Miller and Miller, 1987). A rapid method was also proposed by Kettler et al. (2001) who eliminated the use of the pipette method and a high quality balance. The sedimentation method was also simplified by LaMotte Company to provide a soil texture test kit (LaMotte Soil Texture Test), by which the percentage of sand, silt and clay fractions in a soil can be measured roughly by their volumes after sedimentation. In the hydrometer method, the density of a soil suspension after various times of settlings is measured non-destructively. The particle size distribution of a soil can be evaluated without any pretreatments except for dispersion with a sodium hexametaphosphate solution (Day, 1965). A simplified version of Day (1965) was described by Kroetsch and Wang (2008), which can be applied to soils except for calcareous or saline soils or soils with greater than 2% organic C.

In contrast to continuous efforts to simplify the dispersion and sedimentation procedures, sieving of sand is usually carried out with a stainless sieve, and its simplification has not been attempted. As mentioned above, however, most of the equipment and reagent is used to separate silt and clay fractions. If we focus on the analysis of sand content alone, many pretreatments for dispersion can be omitted. From the content of sand, it is possible to calculate the content of clay plus silt. The content of clay plus silt was a good predictor for compaction susceptibility of forest soils (Smith et al., 1997). It was also one of the main factors affecting the capacity of a soil to accumulate organic matter in both uncultivated grassland soils (Hassink, 1997) and cultivated upland soils (Zhao et al., 2006).

In this paper, therefore, we propose a rapid and reagent-free method for measuring soil sand content. Instead of using a stainless sieve, a nylon mesh cloth was used as a sieve. The accuracy of the proposed method was evaluated by using two sets of soils collected from agricultural fields in Japan.

MATERIALS AND METHODS

Procedures of the proposed method

The proposed method is referred to as nylon mesh method hereafter. A nylon mesh cloth with an opening of 20 µm (NY20-HC, NYTAL, Sefar Inc., Ruschlikon, Switzerland) was used as a material for soil sieving. This opening size is the lower limit of the sand fraction according to the International Society of Soil Science (ISSS) classification (Gee and Or, 2002). The original cloth was cut into pieces with a size of about 15×15 cm. The weight of each cloth was measured with an electric balance to the second decimal place (weight A). The weight A was around 0.79 g.

Then, a pre-weighed 10.00 g sample, which had been air-dried and 2-mm sieved beforehand, was placed on the center of the cloth. The sample was packed in the cloth by picking up four corners of the cloth and tying it up with a rubber band, as shown in Figure 1. This soil bag was soaked in tap water for about a minute, and the fine particles in the bag were washed away by destroying soil aggregates between the thumb and forefinger in running tap water until the water squeezed from the bag became transparent. The period of washing was usually shorter than 5 minutes per sample for our case. After washing, the rubber band was removed from the soil bag, and the nylon mesh bag containing coarse particles was dried overnight in a forced-air dryer (DNF 810, Yamato Scientific Co., Ltd., Tokyo, Japan) maintained at 40ºC. The forced-air dryer was used to save time for drying.

On the following day, the weight of the bag was measured with an electric balance to the second decimal place (weight B). The difference between the weights A and B was regarded as the weight of the sand fraction present in the original sample. The sand content was calculated based on the percentage of its weight to the original sample weight (10.00 g).

Evaluation of nylon mesh method

To evaluate the accuracy of the proposed method, soil samples with various textural classes were subjected to the analysis by the proposed method and a conventional sieving method. The error due to the lack of accuracy was evaluated from a random error originated from the lack of precision (repeatability and reproducibility) and a systematic error originated from the lack of trueness (Menditto et al., 2007). Trueness is defined as the closeness of agreement between the average value obtained from a large series of test results and an accepted reference value.

In the conventional method, the sand fraction was collected by sieving with a 20-µm mesh sieve after removal of organic matter and soluble salts, and the percentage to the sum of mineral fractions (sand, silt and clay) was calculated (Gee and Or, 2002). In the same way as the nylon mesh method, 10.00 g of an air-dried, 2-mm sieved sample was used for the analysis.

Table 1 indicates two sets of samples used in this study. All samples were collected from agricultural fields in Japan. The first sample set was composed of five soils with separate sampling sites and various soil types. The second sample set was composed of hundred soils collected from the surface layer in the same experimental paddy field of Kyoto University with an area of 0.5 ha.

For the first sample set, two operators analyzed the samples by the nylon mesh method with three replicates. Analyses of the sand content by the conventional method for the first and second sample set and by the nylon mesh method for the second sample set were performed by one operator without replication. Repeatability and within-laboratory reproducibility of the proposed method were evaluated by the coefficient of variation (CV) calculated from the three measurements by each person and by the similarity of measurements between two persons, respectively. Trueness of the proposed method was estimated from the slope and the coefficient of determination (R^2) of the regression line of sand contents between conventional and proposed methods, assuming that the conventional method can produce accurate sand contents.

For the second sample set, the content of total C in air-dried, 2-mm sieved samples (Moritsuka et al. 2004) and the content of adsorbed water in air-dried, 2-mm sieved samples and sand fraction samples after nylon mesh sieving were measured to suggest the presence of a systematic error in the nylon mesh method. The content of adsorbed water was measured by gravimetric method after drying the samples overnight in a forced-air dryer maintained at 105^{o}C.

RESULTS AND DISCUSSION

Table 2 shows the sand content of the first sample set measured by nylon mesh method and conventional sieving method. The CV values of three measurements of the same sample by the nylon mesh method ranged from 0.2 to 8.1%. Except for the Acrisol with a clayey texture, the CV values were less than 4%. The average data obtained by the operator #1 were similar to or slightly higher than those obtained by the operator #2. The relative difference, expressed as the percentage of the difference of two averages to the fully averaged data, was largest for the clayey Acrisol (11%), which may be due to incomplete removal of fine particles by the operator #1. For other soils, the relative difference was less than 5%. The correlation coefficient of the average data obtained by two persons was higher than 0.99. When the average data obtained from the nylon mesh method by two persons was plotted against the data obtained from the conventional method, the linear regression line, whose y-intercept term was forced to 0, became $y = 1.00x$ ($R^2 = 0.99$).

These results suggest that the nylon mesh method has high repeatability for soils containing sand at greater than 50% and moderate but acceptable repeatability for clayey soils. Within-laboratory reproducibility of the method is also high for sandy soils and is moderate for clayey soils. The data obtained from the nylon mesh method will agree well with those from the conventional method, when the sample set contains soils with a wide range of textural classes.

In this study, we did not measure the repeatability of the sand analysis by the conventional sieving method. In a paper by Miller and Miller (1987), the CV values of three measurements of the same sample ranged from 0.1 to 5.4%, when the sand content of 12 soils with various textural classes was analyzed at the sample weight of 20 or 30 g. The CV values tended to be higher at lower sand contents, which agreed with our results from the nylon mesh method.

The extent to which the nylon mesh method is sensitive to measure within-field variations of sand content was further evaluated by using the second sample set. The sand content of hundred samples measured by the conventional method ranged from 31 to 54% with the CV value of 8.5%.

Figure 2 shows a relationship between the sand contents by the nylon mesh method and those by the conventional method. The linear regression line, whose y-intercept term was forced to 0, became

$y = 1.04x$ ($R^2 = 0.83$). More than 80% of the within-field variations in the sand content measured by the conventional method could be explained by the nylon mesh method. The sample with the lowest sand content measured by the conventional method (31%) seems to be due to an experimental error based on an exceptionally low recovery percentage of mineral fractions to the original sample weight (83%). Removal of this sample from the plot increased the R^2 value to 0.85. The slope of the regression line (1.04) indicated that the nylon mesh method tended to give slightly higher values than the conventional method. The sand contents measured by the nylon mesh method ranged from 94 to 124% of those by the conventional method when all samples were included, and from 94 to 113% when the above sample was excluded.

These results indicate that the nylon mesh method could detect a small within-field variation of the sand content as sensitively as the conventional method. The slight overestimation by the nylon mesh method suggests the presence of a systematic error. This is probably originated from the lack of pretreatment for removal of organic matter and the high content of fragmented rice straw in the samples analyzed, because the magnitude of overestimation calculated from the difference of the sand content between two methods (Figure 2) was correlated positively with the content of total C in 2-mm sieved samples ($r = 0.31$, $p < 0.01$). The slight overestimation of the sand content by a simplified method without removal of organic matter was also reported by Kettler et al. (2001), when six soils with organic C at less than 2% were analyzed.

Another possible source of the systematic error is the presence of adsorbed water in the samples analyzed by the nylon mesh method. This is because air-dried samples are used by the nylon mesh method and 105°C dried samples are used by the conventional method. The content of adsorbed water in air-dried samples ranged from 1.6 to 5.2% for 2-mm sieved samples and from 0.77 to 2.1% for sand fraction samples, both of which were correlated positively ($r = 0.41$, $p < 0.01$). When this water content was considered in the calculation of the sand content by the nylon mesh method, the average sand content increased from 48.2 to 48.9%. The difference of the sand content between two methods became larger, suggesting that the difference was originated from the presence of organic matter in the samples analyzed by the nylon mesh method.

In conclusion, the main advantage of the nylon mesh method over the conventional method lies in the simplicity without use of any reagents. The proposed method would be useful for researchers who must analyze many samples for a screening purpose or who do not have necessary equipment for soil texture as well as for non-specialists such as farmers, gardeners, citizens and students. In the case of our second sample set, 50 samples could be handled together by one person and the data could be obtained within two days when a forced-air dryer was used. A forced-air dryer would not be necessary if samples are dried at room temperature for several days. In this case, the analysis could be performed in a remote area without supply of electricity. Indispensable items are a nylon mesh cloth and an electric balance accurate to 0.01 g in addition to a mortar, a pestle and a 2-mm mesh sieve for sample preparation. All items can be purchased by individuals. Except for the nylon mesh cloth, they would be already available in a soil laboratory. The nylon mesh cloth with the opening of 20 µm costs about US$5 per sample. It could be recycled at least 10 times, when paddy soils (Fluvisols) were analyzed. In the case of reddish and clayey soils like soil no. 3 in our case, however, the nylon mesh cloth will become reddish even after washing with water and more frequent renewal may be desirable.

On the other hand, the main disadvantage of the nylon mesh method lies in the fact that available data is the sand content alone. This method must be used in parallel with the sedimentation method in order to obtain the relative percentage of sand, silt and clay in a soil sample and determine its textural class. Another drawback of the proposed method is the lack of pretreatment for removal of organic matter. The sand fraction evaluated by this method includes sand-size organic matter, which can be referred to as particulate organic matter according to the similar analytical procedures described by Kettler et al. (2001). The sand content was calculated based on its proportion to the original soil containing organic matter. Accordingly, the definition of the sand fraction evaluated by this method is different from that by the conventional method, which may cause a large systematic error in the results when soils rich in organic matter are analyzed. Our samples were collected from agricultural fields with the content of total C ranging from 0.4 to 4.5%. This implies that the nylon mesh method can be used safely to bring the results comparable to the conventional method for soils containing total C at less than 5%. So it may not be suitable for surface soils on grassland, orchard and forest where a humus-rich layer is formed in the surface. As far as upland and paddy soils in Japan are concerned, surface soils classified as all soil types except Peat soils, Wet Andosols, Non-allophanic Andosols, Andosols usually contain total C at less than 5% (Yanai et al., 2012), and the proposed method can be useful for such agricultural soils.

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Caption of Figures and Tables

Figure 1: A picture showing a soil sample packed in the nylon mesh cloth. The sample is already washed with tap water.

Figure 2: A relationship between the sand contents by the nylon mesh method and those by the conventional method. A broken line in the figure shows a 1:1 line. A filled symbol in the figure shows the sample with the lowest sand content measured by the conventional method.

Table 1: Two sets of soil samples used in this paper.

Table 2: Sand content of the first sample set measured by nylon mesh method and conventional method.

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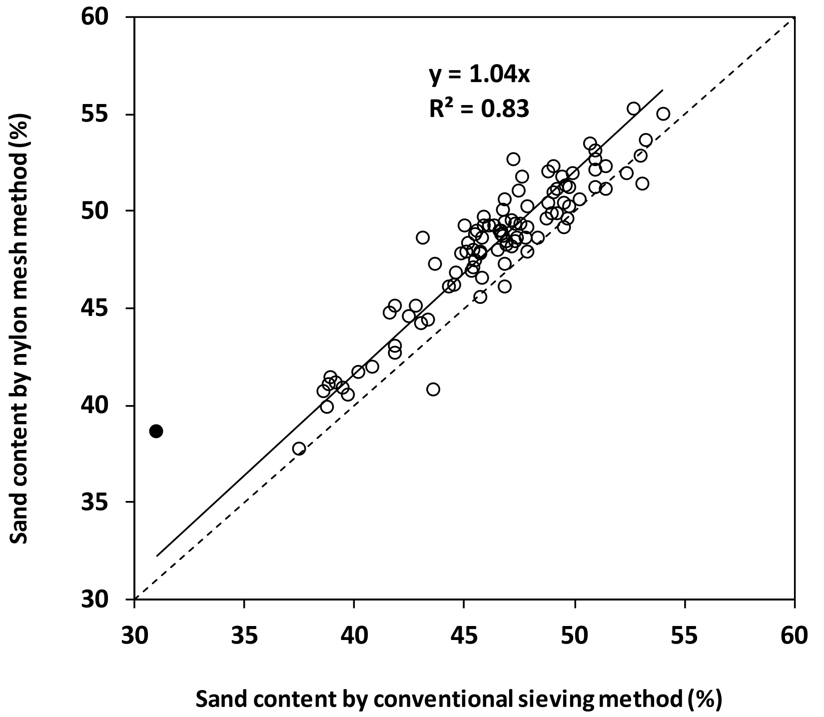

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Table 1. Two sets of soil samples used in this paper.

	Soil no.	Location	Soil type	Sample depth	Sand (%)	Silt (%)	Clay (%)	Total C (%)	Reference
1st set	1	Kyoto	Fluvisol	Surface layer	72.9	14.8	12.3	1.39	Matsuoka et al. (2006)
	2	Shimane	Arenosol	Surface layer	98.4	0.62	1.03	0.37	Matsuoka et al. (2006)
	3	Shimane	Acrisol	Surface layer	13.4	37.1	49.5	1.63	Matsuoka et al. (2006)
	4	Osaka	Fluvisol	0-12 cm	62.3	21.6	16.1	1.79	
	5	Osaka	Fluvisol	48-60 cm	53.4	19.9	26.7	0.36	
2nd set		Osaka	Fluvisol	0-15 cm	46.3	31.8	21.9	3.48	Moritsuka et al. (2004)

Average data of hundred samples are indicated for the second sample set.

Table 2. Sand content of the first sample set measured by nylon mesh method and conventional method.

Soil no.	Sand-N[a] (average %)	Sand-N[b] (average %)	Sand-N[a] (CV %)	Sand-N[b] (CV %)	Sand-C (%)
1	74.5	73.2	0.8	0.3	72.9
2	97.4	97.1	0.2	0.3	98.4
3	13.9	12.4	8.1	4.4	13.4
4	63.2	61.9	0.9	0.6	62.3
5	53.8	51.3	1.8	3.7	53.4

Sand-N (nylon mesh method), Sand-C (conventional method).

[a] Data obtained by an operator #1.

[b] Data obtained by an operator #2.