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Sieving duration and sieve loading impacts on dry soil fragment size distributions

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Abstract

Measurement of the soil fragment size distribution has been found to be related to erosion processes, water retention, temperature, porosity and other soil properties that can affect crop growth and productivity. However, there is little agreement about the procedure to follow to determine dry soil fragment size distributions using flat sieves. Our objective was to determine the effects of dry-sieving duration and loading on the resulting fragment size distributions of 2 soils [Maury silt loam (Typic Paleudalf) and McAfee clay loam (Typic Hapludalf)] under contrasting management practices (undisturbed sod and recently roto-tilled). After air drying, the samples were dry-sieved with a vertical vibratory sieve shaker and the mass of soil retained on each sieve in a nest of 13 sieves, with aperture sizes ranging from 16.00 to 0.85 mm, was determined. The ability to discriminate between undisturbed and tilled soil samples varied with the mass fraction of fragments examined. In general, there was a greater probability of discriminating between sod and tilled soils, with a lower coefficient of variation, when the sieving duration was at least 30 s. Loading the uppermost sieve up to 30% of its volume did not significantly affect the results, and allowed for processing, in a single operation, composite samples taken with a probe of 5.4 cm diameter and 10.0 cm length.

Keywords: Soil structure; Aggregation; Laboratory procedure; Tillage; Soil physics

1. Introduction

The arrangement of soil particles into coherent units (soil structure) is an important factor related to many soil processes (e.g. wind and water erosion, infiltration and aeration) crop establishment and productivity (Skidmore et al., 1994). The soil structure, as it exists in the field, is difficult to evaluate and indirect procedures based on the dry or wet separation of soil fragments, after the partial breakdown of hierarchical units by applying a mechanical stress, are generally used. Because the median size of the broken pieces of soil is inversely related to the amount of applied energy, and does not necessarily reflect the size of aggregates as they exist in the field, we consider the term ''fragments'' when referring to the soil units resulting from mechanical disruption.

Early methods of dry sieving were done by hand with a nest of flat sieves. Significant variation in the results was caused by inconsistency during manual operations. To overcome some of the difficulties with the flat sieve

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method, Chepil and Bisal (1943) invented a rotary sieve that was not subject to operator error and this technique is generally accepted as the standard procedure for determining dry fragment size distributions when assessing wind erosion potential (Zobeck, 1991; Skidmore et al., 1994). However, based on a survey of articles published in the Soil Science Society of America Journal between 1996 and 2000, most studies using dry sieving procedures for soil fragment size distribution analysis were performed using flat sieves. Furthermore, there are no standardized procedures for fragmentation-based methods of assessing soil structure (Díaz-Zorita et al., 2002).

The duration of sieving is a major factor in obtaining accurate results. With the rotary machine, sieving continues until no more material remains on the screen. Thus, different treatments may receive different total energy inputs. The use of other sieving systems presents a problem in that there are few guidelines as to how long to continue the sieving operation (White, 1993). A wide range of sieving durations (from 5 to 6000 s), when reported, have been used in soil fragmentation studies (Cole, 1939; Hall et al., 1981). The size distribution resulting from the sieving operation also depends on the sieve-loading rate. Allen (1997) showed that greater discrepancies between different loading rates occur when small sieve apertures are used for sieving sand mixtures. This author also reported no sieve loading differences when sieving coal dust. To our knowledge, there are no published studies on the effects of sieve loading rates for soil samples.

Our objective was to determine the effects of flat sieve loading and sieving duration on the description of dry fragment size distributions for two soils under contrasting soil management practices. These effects were investigated on the individual fractions as well as on the geometric mean diameter (GMD) and the log of the geometric standard deviation (logGSD) parameters from the log–normal distribution model.

2. Materials and methods

The study was performed on a Maury silt loam (Typic Paleudalf) and a McAfee clay loam (Typic Hapludalf) at the University of Kentucky's ''Spindletop'' Research Farm near Lexington, Kentucky, USA (Table 1). On each soil, eight 1-m wide by 6-m long plots were established in a long-term fescue (*Festuca arundinacea* L.) sod. Half of the plots were tilled to a depth of 12 cm with a Gravely front mounted roto-tiller and immediately after tillage, all of the plots were flood irrigated until ponding was achieved. Seven days after ponding (DAP), when the gravimetric soil water content (SWC) averaged 191 ± 24 g kg^{-1} and 214 ± 27 g kg^{-1} for the Maury and the McAfee, respectively, 12 soil samples per treatment from the 0–10 cm layer were taken with a 5.4 cm diameter cylinder. Each sample was placed in a plastic bag and dropped from a height of 1.6 m over an aluminum tray to induce fragmentation with a mean specific energy of 0.017 J g^{-1}. The fragmented samples were carefully transferred to paper bags, individually or composited in duplicates, and air-dried for 11 days before sieving. For both soils, the average SWC after air-drying was 13.2 g kg^{-1}.

Dry-sieving was performed with Fritsch vertical vibratory sieve shaker (model Analysett-3, Idar-Oberstein, Germany) for 15, 30, 60 or 120 s using an oscillation amplitude of 2 mm and a frequency of approximately 50 Hz. Two loading rates, corresponding to 15 and 30% of the upper sieve volume, were used at each sieving time.

The dry fragment size distribution was determined using a nest of sieves that consisted of 13 aperture sizes: 16.00, 8.00, 4.75, 4.00, 3.35, 2.80, 2.36, 2.00, 1.70, 1.40, 1.00 and 0.85 mm. The mass of fragments remaining on each sieve after sieving was used to calculate the distribution of fragments, which was then normalized with respect to the total mass. The fragment size

Table 1
Selected physicochemical properties for the 0-10 cm layer of the 2 soils

Soil	Texture	Clay <2 μm (g kg^{-1})	Silt 2–50 μm (g kg^{-1})	Sand		TOC (g kg^{-1})	BD (mg m^{-3})
				50–850 μm (g kg^{-1})	850–2000 μm (g kg^{-1})		
Maury	Silt loam	243	599	135	23	31.4	1.06
McAfee	Clay loam	286	472	200	42	35.4	1.08

Average of samples from undisturbed sod and recently roto-tilled treatments. Clay, silt and sand contents determined using the pipette method (Gee and Bauder, 1986), total organic carbon (TOC) measured by dry combustion using a LECO CN-2000 (Leco Corp., St. Joseph, MI) carbon analyzer (Tabatabai and Bremner, 1970) and bulk density (BD) from samples taken with a 5.4 cm diameter and 137.4 cm^3 cylinder volume (Blake and Hartge, 1986).

distribution was characterized using the GMD and the logGSD parameters from the cumulative log–normal distribution equation fitted using the NLIN procedure of PC-SAS (SAS Institute Inc., 1997),

$$P(x<X) = \frac{1}{\log \mathrm{GSD}\sqrt{2\pi}} \exp\left[-\frac{(\log(x) - \mathrm{GMD})^2}{2(\log\mathrm{GSD})^2}\right] \quad (1)$$

where $P(x < X)$ is the fraction of soil fragments smaller than sieve size X. The upper size of fragments was estimated as the maximum length of the sampled soil (i.e. 100 mm).

For each soil, the management treatments (sod and roto-tilled) were imposed within four randomized blocks split by a complete factorial combination of sieving duration and sieve loading rate. The validity of assumptions regarding variance homogeneity and normal distribution of error were evaluated for the individual mass fractions of fragments among sieve sizes and for the GMD and logGSD parameters using the procedure UNIVARIATE of PC-SAS (SAS Institute Inc., 1997). In the majority of cases these assumptions were not violated and consequently analysis of the data was performed using untransformed values. In the few cases that violated assumptions of variance homogeneity or normal distribution of error, log transformation of the mass fraction values was employed. However, no relevant differences in results, as compared with the untransformed data, were observed. Thus, for simplicity, we present the results of the analysis performed using untransformed values. ANOVA and the LSD test were used in interpreting the results (SAS Institute Inc., 1997).

3. Results and discusion

Analysis of variance of the mass fractions of dry fragments retained on each sieve and the parameters from the log–normal distribution (GMD and logGSD) did not reveal any significant 2 or 3 factor interactions. In both soils, averaged over the two sieved volumes and the four durations of sieving, the mass fraction of dry fragments greater than 16.00 mm was significantly greater in sod than roto-tilled treatments (data not shown). With sieves smaller than 1.10 and 2.36 mm, for the McAfee and Maury soils, respectively, the mass fractions from the tilled treatment were greater than those from the sod. In both soils, the GMD of soil fragments from the sod treatment was greater than that from the roto-tilled treatment (Fig. 1). The distribution of mass fractions, evaluated using the logGSD parameter, was more uniform (smaller logGSD) under roto-tilled conditions than under sod, but this difference was significant only in the Maury silt loam (Fig. 1). This implies that, independent of the soil type, the sampling and handling procedures we used were able to capture differences in field aggregation conditions. Because roto-tilling decreases soil cohesion and aggregate stability (Bullock et al., 1988) and breaks up the root network, we expected smaller-sized fragments in the roto-tilled treatment.

In the Maury soil, a greater mass fraction of soil fragments was retained within the 2.36–8.00 mm size range when the loading rate was 30%, rather than 15%,

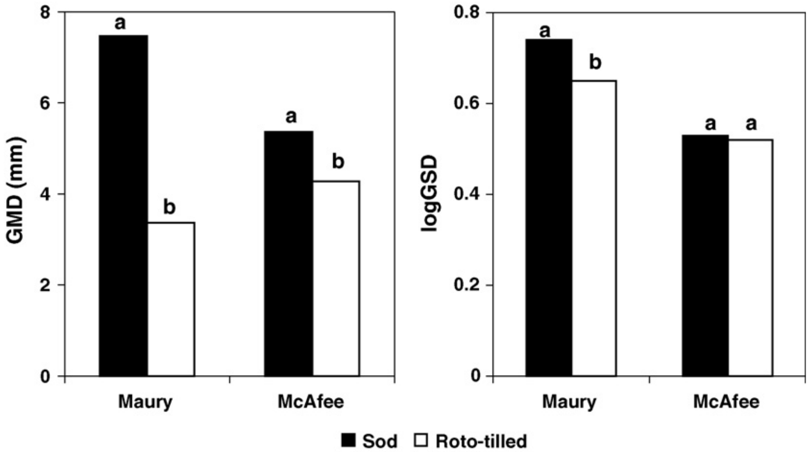

Fig. 1. Effect of the two soil management practices on the GMD and logGSD parameters derived from the distribution of dry soil fragments for the two soils. Average of four durations of sieving and two loading rates. Solid and open bars are for the sod and rototilled treatments, respectively. Different letters at the top of each column indicate a significant difference in soil management at the 95% level of confidence.

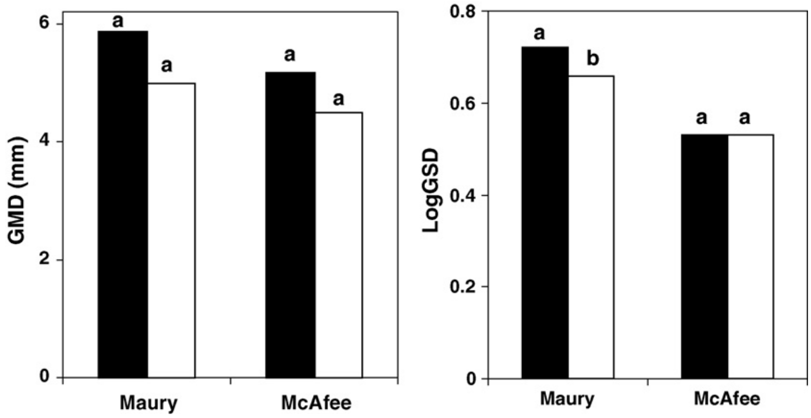

Fig. 2. Effect of sieve loading rate on the GMD and logGSD parameters derived from the mass-size distribution of dry fragments. Average of four durations of sieving and two soil management practices. Solid and open bars are for the 15 and 30% sieve loading rates, respectively. Different letters at the top of each column indicate a significant difference due to loading rate at the 95% level of confidence.

of the upper sieve volume (data not shown). Because of this difference in the distribution of fragments among sieves, the sieve-loading rate also affected the logGSD parameter for this soil. The GMD for the Maury soil was not significantly affected by the loading rate treatment (Fig. 2). In the McAfee soil, the mass fraction of fragments retained among sieves and the parameters from the log–normal equation were not affected by sieve loading rate (Fig. 2).

Statistically discriminating between the management treatments using the parameters of the log–normal equation (GMD and logGSD), averaged over the four sieving durations, was most likely with the greater sieve-loading rate. The capability to simultaneously sieve subsamples occupying a total of 30% of the upper sieve volume may help to reduce variation without introducing errors due to multiple subsample sieving operations. For the several size ranges, there were different sensitivities in their ability to discriminate between the soil management practices, depending on the sieve loading rate and the soil type. These results suggest that where analysis of soil aggregation is to be based on a single fragment size range, it is important to perform preliminary experiments in order to identify an appropriate loading rate for the size range of fragments and soil type under investigation.

The duration of sieving, averaged over the soil management and sieve loading rate treatments, had a

Table 2
Effect of duration of sieving on the soil mass fraction distribution averaged over two loading rates and two soil management treatments

Size (mm)	Maury silt loam				McAfee clay loam			
	15 s	30 s	60 s	120 s	15 s	30 s	60 s	120 s
0.85–1.00	0.014c	0.017bc	0.018ab	0.020a	0.014b	0.016b	0.018a	0.019a
1.00–1.18	0.025c	0.026bc	0.029ab	0.032a	0.024b	0.028a	0.029a	0.030a
1.18–1.40	0.026b	0.027b	0.031a	0.033a	0.025c	0.030b	0.034a	0.036a
1.40–1.70	0.033b	0.035b	0.040a	0.044a	0.034b	0.044a	0.047a	0.048a
1.70-2.00	0.026b	0.028b	0.033a	0.036a	0.030c	0.038b	0.041ab	0.044a
2.00-2.36	0.037b	0.038b	0.044a	0.046a	0.042b	0.052a	0.056a	0.056a
2.36-2.80	0.033c	0.036bc	0.041ab	0.044a	0.041c	0.052b	0.056ab	0.059a
2.80-3.35	0.041c	0.043bc	0.049ab	0.053a	0.050b	0.064a	0.068a	0.071a
3.35-4.00	0.042b	0.044b	0.047ab	0.051a	0.054b	0.065a	0.065a	0.069a
4.00-4.75	0.038c	0.042bc	0.049ab	0.050a	0.049b	0.061a	0.065a	0.067a
4.75-8.00	0.099a	0.108a	0.117a	0.120a	0.126a	0.143a	0.146a	0.147a
8.00–16.00	0.083a	0.085a	0.092a	0.096a	0.133a	0.124a	0.112a	0.110a
16.00–100.00	0.352a	0.288ab	0.224bc	0.158c	0.285a	0.168b	0.131b	0.110b
GMD	7.29a	5.94ab	4.93bc	3.48c	7.46a	4.42b	3.85b	3.57b
logGSD	0.75a	0.73ab	0.67bc	0.64c	0.58a	0.54ab	0.52b	0.49b

GMD: geometric mean diameter, logGSD: log of the geometric standard deviation. Different letters within a fragment size range, for a particular soil, indicate a significant difference due to sieving duration at the 95 % level of confidence.

significant effect on the mass fraction of dry fragments found in most of the size ranges. Many researchers have described the effect of sieving duration on dry fragments (e.g., Chepil, 1952) and it has been proposed as a basis for dry structural stability calculations (Kemper and Rosenau, 1986; Buschiazzo et al., 1994). In our study, the 4.75–16.00 mm size range of fragment size was not sensitive to the different sieving durations in either soil. In general, the differences in the mass of several fragments sizes during sieving were greater than the changes in observed in the parameters from the log–normal distribution equation. This observation emphasizes the importance of selecting an appropriate size range if the results are to be used for structural stability calculations based on single or selected sizes.

As sieving duration increased, the proportion of sample mass found on sieves from 0.85 to 4.75 mm in size increased. The GMD and logGSD parameters and the mass fraction of fragments greater than 16.00 mm decreased as the sieving duration increased (Table 2). The reduction in GMD between 30 and 120 s of sieving was somewhat greater in the silt loam than in the clay loam, implying a lower structural stability in the former. From the particle size distributions of both soils (Table 1), we can assume that the contribution of primary particles greater than 0.85 mm was not relevant to this GMD decline. Thus, the differences in mass fractions observed after sieving can basically be explained by the fragmentation of large soil units into lower hierarchical states as related to their stability prior to fragmentation.

Although the greatest change in mean fragment size was detected between 15 and 30 s of sieving (data not shown), the differences in the Maury were not significant because of the high variability between samples (Fig. 3). A relatively constant coefficient of variation in GMD values was achieved with at least 30 s of sieving. Increasing the duration of sieving resulted in a narrowing of the distribution of fragment sizes (lower logGSD values) in both soils. However, no large changes in the coefficient of variation due to sieving duration were observed for this parameter (Fig. 3).

Statistically discriminating between the two management treatments, using either a single fragment size range, the GMD, or the logGSD, was somewhat more likely with 30 s of sieving (data not shown). In both soils, sieving for 30 s appeared to be adequate for the separation of soil fragments without excessive abrasion. Braunack and McPhee (1991), Eghball et al. (1993) and Aubertot et al. (1999) also concluded that 30 s was an adequate duration for soil fragmentation, without much abrasion, using flat sieves.

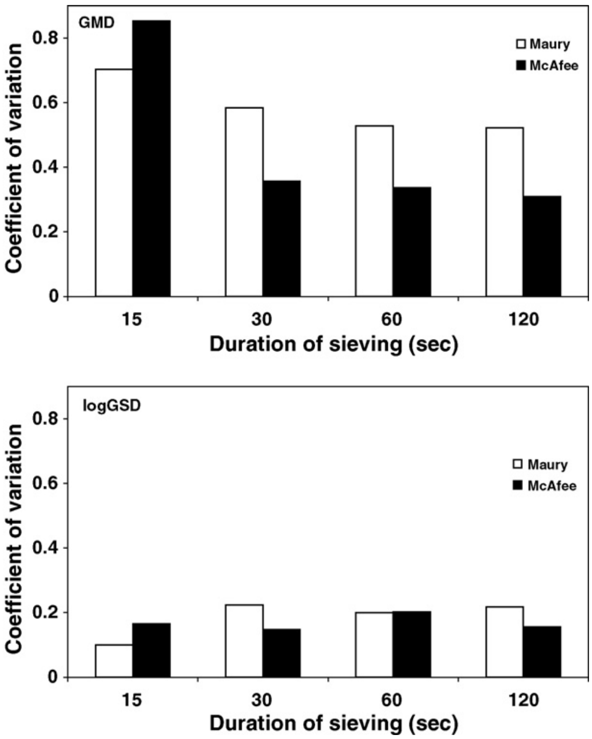

Fig. 3. Effect of sieving duration on the variability of GMD and logGSD values for the two soils. Average of two management and two sieve loading rate treatments.

4. Conclusions

Differences in field aggregation between undisturbed sod and recently roto-tilled soils were adequately characterized by dry sieving soil samples initially fragmented by applying a low energy impact when they were moist.

When the parameters of the log–normal equation were used to characterize soil aggregation, loading flat sieves up to 30% of the upper sieve's volume did not interfere with the fragmentation of air dry soil samples using vertical vibratory sieving.

Increasing the duration of sieving from 30 to 120 s resulted in greater fragmentation of the soils without much reduction in the variability between samples. A higher probability of separating the sod and roto-tilled treatments was found when sieving the samples for at least 30 s. The maximum sensitivity to the duration of sieving treatment was found in fragment sizes larger than 16.00 mm or smaller than 4.75 mm.

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