Soil & Tillage Research 141 (2014) 19–24

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

A novel soil wetting technique for measuring wet stable aggregates

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ARTICLE INFO

Article history:
Received 2 December 2013
Received in revised form 19 March 2014
Accepted 20 March 2014

Keywords:
Soil wet stable aggregates
Measurement
Soil organic matter
Tillage system
Stability

ABSTRACT

The measurement of aggregate size distribution and stability has been widely used to evaluate soil quality, yet there exists large variation in measured values from various pre-wetting methods. The most widely used technique, the high vacuum slow wetting (HVSW) method, could minimize the variability in wet aggregate stability (WAS) of samples, but is laborious and time consuming. In this paper, we introduced a novel soil wetting method and compared its performance with three other widely used pre-wetting techniques on a group of soil samples with organic matter content ranging from 21.0 to 61.0 g kg^{-1} and from two tillage systems. The new method combined the advantages of existing wetting procedures; soil samples and dispersing agents are de-aerated synchronously over a short duration. Statistical analysis showed that the new wetting method significantly diminished the breakdown of large aggregates (0.5–10 mm), had the lowest coefficient of variation and variance of WAS, which assured the reliability and reproducibility of aggregate stability measurements.

1. Introduction

Soil structure plays a crucial role in sustaining agricultural productivity and preserving environmental quality (Hamblin, 1985; Amézketa, 1999). Soil aggregation influences water runoff, infiltration, and redistribution, as well as aeration and root growth (Nimmo and Perkins, 2002). Soil aggregate stability has been considered one of the most important indicators of soil quality; good soil structure relies on the presence of stable aggregates (Anderson et al., 1997). Thus, the quantification and interpretation of soil aggregate stability are of great importance in a variety of applications. Considering this importance, it is critical that techniques used to evaluate aggregate stability do not artificially influence or bias outcomes of this test.

Many different methods have been used to measure soil aggregate stability (Jastrow and Miller, 1991; Amézketa et al., 1996). Yoder (1936) applied the wet sieving and no vacuum fast wetting (NVFW) techniques to obtain his information on soil aggregate stability. At present the wet sieving apparatus has been used as the standard instrument for characterizing wet aggregate stability (WAS) (Kemper and Rosenau, 1986; Dickson et al., 1991; Nimmo and Perkins, 2002). However, it has been found that the NVFW associated with this practice has several disadvantages: rapid wetting causes the disruption of aggregates due to pressure buildup of entrapped air in the inter-particle spaces of the aggregate (Levy et al., 1997), wetting a dry soil by immersion at atmospheric pressure increases the disrupting force by allowing entrapment of air within the aggregates (Kemper and Rosenau, 1986), and the release of nonpolar molecules (primarily O_2 and N_2) adsorbed on the surfaces of soil components also influence aggregate stability (Kemper and Rosenau, 1986). Various modified processes have been introduced with the goal of giving an accurate, reliable and reproducible measure of aggregate resistance to breakdown due to moving water (Amézketa, 1999). For example, modified pre-wetting (i.e., slow wetting, high vacuum and dispersing liquid) procedures were applied in determining WAS of wet soil samples at low water tensions to minimize the slaking of the aggregates (Bullock et al., 1988), application of high vacuum at the time of wetting to reduce the amount of entrapped air within soil aggregates was used by Dickson et al. (1991), and use of de-aired water (distilled and deionized water) and an organic solvent (ethanol, methanol) was used to modify surface tension, viscosity, and contact angle, which reduces aggregate disintegration and

Abbreviations: BA, Beian; BX, Binxian; CV, coefficient of variation; HL, Hailun; nHVSW, new high vacuum slow wetting; NVFW, no vacuum fast wetting; SOM, soil organic matter; WAS, wet aggregate stability.

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http://dx.doi.org/10.1016/j.still.2014.03.009
0167-1987/

maintains aggregate structure (Le Bissonnais, 1996). The high vacuum slow wetting (HVSW) method has been regarded as effective in maintaining the structure of a specific soil and therefore minimizing the variations of aggregate stability measurements (Dickson et al., 1991; Nimmo and Perkins, 2002). Nonetheless, when using the HVSW method, it usually takes 45–75 min for air evacuation and water equilibration, which is laborious and time consuming (Dickson et al., 1991). Furthermore, the relatively high cost of organic solvents as the dispersing agent limits the application the HVSW method. In this study, we propose a novel pre-wetting technique that combines the advantages of slow wetting, high vacuum, and wetting with distilled water and is completed in about 10 min. The objective of this study are to (i) propose a new soil aggregate pre-wetting technique, and (ii) to evaluate the effect of this new technique on WAS by comparing results of this method with that of three widely used methods on three soils of different organic matter (OM) content and subjected to two different tillage systems.

2. Materials and methods

2.1. Soil sampling

There have been numerous positive correlations between soil organic matter, tillage systems and water stable aggregates. To test the applicability of this new method, aggregates from soils with different organic matter content and tillage system treatments were evaluated for their water stability. Soils with different organic matter content are respectively denoted S_I, S_{II} and S_{III}. They were collected respectively from three sites (Binxian county, Hailun county, and Beian county of Heilongjiang Province, China) with a 2-year soybean-corn rotation. The soil is a typical Mollisols (Udolls) with silty clay loam texture, high clay content, and high organic matter content (Table 1). Soil samples of two tillage systems were collected from the Hailun Agroecology Experimental Station, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences. The two tillage systems tested are no-till (NT) and convention tillage (CT). The tillage trials started in 2004 on flat farmland. For NT only the crop seed was harvested and all biomass (approximate 4 t ha^{-1} for soybean and 10 t ha^{-1} for corn) except harvested seeds was evenly distributed across the plot to cover the surface. Corn or soybean was planted with a no-till planter on May 1 of the following year. There were no other soil tillage practices used. For CT all above-ground biomass was removed manually and moldboard plowing was conducted annually to a 20 cm depth and ridged by rotary tillage in the autumn. Corn or soybean was planted on the top of ridges in these plots with a conventional planter on May 1. The field was ridged twice at 15-day time intervals after planting. For soil properties and field management of tillage systems see our previous study (Chen et al., 2011). The experiment used a randomized block design with 3 replicates. From each plot (site), soil samples were collected from the cultivated layer (0–20 cm) with a flat, square-cornered spade in May 2011 for different OM content and in June 2013 for tillage system treatments. The samples were air-dried at room temperature, crushed and sieved through a 10-mm mesh, and stored at a temperature of 4 °C prior to WAS determination.

2.2. Methods of analysis of soil aggregate stability

Four different pre-wetting methods, NVFW (no vacuum fast wetting), NVSW (no vacuum slow wetting), no vacuum fast distilled water wetting (NVFW-dw), and nHVSW (new high vacuum slow wetting, the new method), were applied prior to determining soil aggregate stability. For the NVFW, 50 g (air-dried soil that passed through a 10 mm sieve) soil samples were placed on the top of a nest of five sieves with 5, 2, 1, 0.5 and 0.25 mm openings and submerged in tap water for 10 min. The wet sieve apparatus (Model: DIK-2001, Daiki Rika Kogyo Co. Ltd., Japan) was then set in oscillating motion 3-cm up and down, with a rate of 30 cycles per minute for 2 min. Then the resistant soil materials on top of each sieve and the unstable (<0.25 mm) aggregates were transferred into beakers and dried in an oven at 50 °C for 48 h. The stable soil aggregates that stayed above the sieve were weighed after oven-drying to calculate WAS.

$$\text{WAS} = \frac{\text{weight of aggregates on sieves}}{50\,\text{g}} \times 100\%$$

For the NVSW technique, soil samples were wetted with tap water by a wick arrangement constructed in circular aluminum weighing boats for 45–65 min (Dickson et al., 1991). Water-equilibrated aggregates were then transferred to the sieving apparatus and subjected to wet sieving for 2 min as described for NVFW above. The procedure thereafter was similar to that of the NVFW. The device and procedures of the NVFW-dw technique were the same as the NVFW except the dispersing agent was distilled water.

The new method introduced in this study uses a high vacuum slow wetting approach. Fig. 1 shows a schematic diagram of the device. The aggregate wetting device is composed of three primary components: (i) a vacuum desiccator; (ii) a removable tray, with 0.5-cm vertical walls, resting at a 0.5% angle upon which the aggregate sample is placed for wetting within the desiccator; and (iii) a small cylindrical water reservoir assembly also placed on the aggregate tray within the desiccator and from which water is slowly released to contact the aggregates once a vacuum is established (Figs. 2–4). The cylindrical reservoir is designed with an on/off valve mechanism controlling water flow onto the tray through a 0.5-mm diameter orifice in the reservoir base. Multiple designs (including those with a remotely controlled electrical switch) could be used to control this valve. For this study a lever was attached to the top of the reservoir as shown in Fig. 4. A string was tied to one end of the lever and the opposite end of the string was tied to a rubber plug (valve) in the reservoir orifice. On the side of the lever opposite the string tied to the plug, an iron counter balance in the shape of a doughnut was slid onto the lever. With the counter balance positioned close to the rod pivot pin, i.e., close to the middle of the lever, the plug end of the rod was in the down position and the reservoir plug was in the 0.5-mm reservoir orifice retaining water in the reservoir. When the counter balance was

Table 1
Texture, organic matter content and bulk density of soil.

	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Texture	SOM (g kg^{-1})	Bulk density (g cm^{-3})
S_I	257	275	468	Clay	21.0	1.23
S_{II}	255	337	408	Loam clay	44.1	1.12
S_{III}	315	327	358	Loam clay	61.3	1.18
NT	295	298	407	Loam caly	40.6	1.20
CT	306	286	408	Loam caly	40.1	1.08