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ASSESSMENT METHODS FOR SOIL CARBON

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CHAPTER 19

Fractionating Soil in Stable Aggregates Using a Rainfall Simulator

G.C. Starr, R. Lal and J.M. Kimble

I. Introduction

Methods of fractionating soil into aggregate size fractions usually involve some variation of the wet sieve method (Yoder, 1936). This method is cumbersome and laborious (Kemper and Rosenau, 1986), and unable to accurately simulate the physical energies imparted to aggregates in rainfall and runoff events (Bruce-Okine and Lal, 1975; De Vleeschauwer et al., 1978; Mbagwu, 1986). Hence, the wet sieving alone cannot supply a very accurate measure of the size pools of stable soil aggregates and associated soil organic carbon (SOC) and nutrients available for transport by water erosion. A raindrop impact method for testing aggregate stability (Bruce-Okine and Lal, 1975) represents a better simulation of erosion-induced aggregate breakdown. The purpose of this chapter is to report on testing of a realistic method to fractionate raindrop-stable soil aggregates into size pools using a rainfall simulator.

The traditional wet sieve method (Yoder, 1936) involves gently raising and lowering a nest of sieves in water to assess the stability of aggregates to rapid wetting. Typically, intact macro-aggregates in some known size range are placed on the top sieve. The action of the water infiltration into the aggregates (slaking) and the movement of water around the aggregates cause disintegration and the water stable aggregates (WSA) settle to the appropriately sized sieve. Variations of the method (Kemper and Rosenau, 1986) include: type of pretreatment (e.g. air dry, capillary wetting, vacuum wetting, equilibration at 100% relative humidity, etc.), selected sieve sizes (usually >0.1 mm), the initial size range of macro-aggregates (commonly 5 to 8 mm), and the time of wet sieving.

In addition to establishing the wet sieve method of fractionation, Yoder (1936) showed that the majority of soil transported from runoff plots in Ohio was in the form of WSA and hypothesized that size distributions of aggregates would be closely related to vulnerability to soil erosion. However, the wet sieve approach to fractionation does not involve raindrop impact to disintegrate the soil structure as occurs in natural rainstorms. Also, the wet sieve method is laborious (Kemper and Rosenau, 1986), particularly when analyzing the finest material remaining in a dilute mixture of [illegible] micro-aggregates, and clay domain sizes. The amount of water used (about 9 L) for the Yoder method makes filtering, drying, and centrifuging the smallest WSA material very cumbersome. The quantity of fine material can be estimated by subtracting the amount retained on the sieves from the total but the fine material itself is difficult to analyze.

Soil organic carbon (SOC), a stabilizing agent for aggregates (Tisdall and Oades, 1982; Feller and Beare, 1997; Kay, 1998), reduces soil susceptibility to erosion (Le Bissonnias et al., 1997; Piccolo et al., 1997; Singer and Le Bissonnias, 1997). The soil and SOC movement from the landscape in erosion events is probably much greater for the fine fraction because of preferential transport by runoff into inland waterways and aquatic ecosystems (Lal, 1995; Starr et al., 2000). It was expected that the transport and fate of soil moved by erosion would depend on the WSA pool size. Therefore, the objective of this study was to develop and describe a realistic technique for assessing the WSA size fraction pools available for transport by water erosion.

II. Materials and Methods

The approach and methodology described in this chapter involved the use of a rainfall simulator to rain on aggregates placed on a nest of sieves. When raindrops fall on soil at the top of a nest of sieves much of the energy is absorbed in an initial impact on the top sieve or largest aggregates. Water droplets and WSA are accelerated between sieves by gravity and strike the smaller sieve sizes with a somewhat lower energy. As the WSA pass through the nest of sieves, some impact and disintegration take place and the soil is fractionated into WSA that can withstand raindrop impact.

A schematic of the essential components of the system (Figure 1) shows the nest of five 12.6-cm inside diameter sieves (0.25-, 0.50-, 1.0-, 2.0-, and 5.0-mm mesh sizes), a cylindrical splash-guard, and a cylindrical collection trough (12 cm diameter × 10 cm height). The splash-guard (12 cm diameter × 15 cm height) effectively contained all WSA within the system. The collection trough holds about 8 cm of rain before overflowing through the spout and could withstand over 110 °C if oven drying were desired. The splash-guard and collection trough were built using galvanized steel. In these fractionations, the rainfall simulator (Choudhary et al., 1997) produced 50 mm/hr of rain for 30 min with a sprayer raining at 340 KPa pressure from 2 m above the top sieve with about 2 mm mean drop diameter.

The soil (Rayne series – 2 to 6% slopes, fine loamy mixed mesic typic Hapludult) for this study was taken from plateaus of the USDA – North Appalachian Experimental Watersheds (Kelley et al., 1975). Samples were taken under moist conditions from the near surface (0 to 5 cm) of four management systems: hardwood forest (>100 yr old), conventional tillage continuous corn (*Zea mays*), no-till continuous corn, and pasture. Coarse (>8 mm) litter, plants, and roots were removed, samples from several random locations were composited, and the soil was air-dried. Soil samples were then sieved to obtain 5 to 8 mm macro-aggregates and equilibrated 3 days at 100% relative humidity under a slight vacuum in a chamber containing 1 *N* sulfuric acid (Collis-George and Lal, 1971).

Fifty grams of prepared macro-aggregates were placed on the top (5-mm) sieve and treated with the rainfall simulator with the settings described above. Six sieve sets were placed directly beneath the rainfall simulator in a circular pattern (radius of about 30 cm) and rotated 120° around the circle every 10 min for a total of 30 min and 360° of rotation. The rotations were done so that all sieves would be treated about equally by raindrop impact. The splash guards were then removed and WSA on them were rinsed onto the top sieve, taking care to use the minimum amount of de-ionized water from a water bottle. To complete the fractionation, two or more minutes of settling allowed the coarser micro-aggregates to settle to the bottom of the collection trough and about 250 ml of supernatant was decanted through the spout into a beaker. The supernatant was subsequently poured back through the nest of sieves to break up any conglomerations of aggregates. The sieves were then separated, starting with the top (5 mm) and working down through the nest, while using the de-ionized water and supernatant sparingly to break up conglomerations and rinse the sides.

Material on each sieve was rinsed into a pan where the macro-aggregates were allowed to settle to the bottom quickly. The floatable organic matter (FOM) and water were decanted through a 0.25-mm sieve. The FOM from all sieve sizes were combined in a single sieve and transferred to a drying container. The WSA were transferred to drying containers and all pools fractionated in this fashion

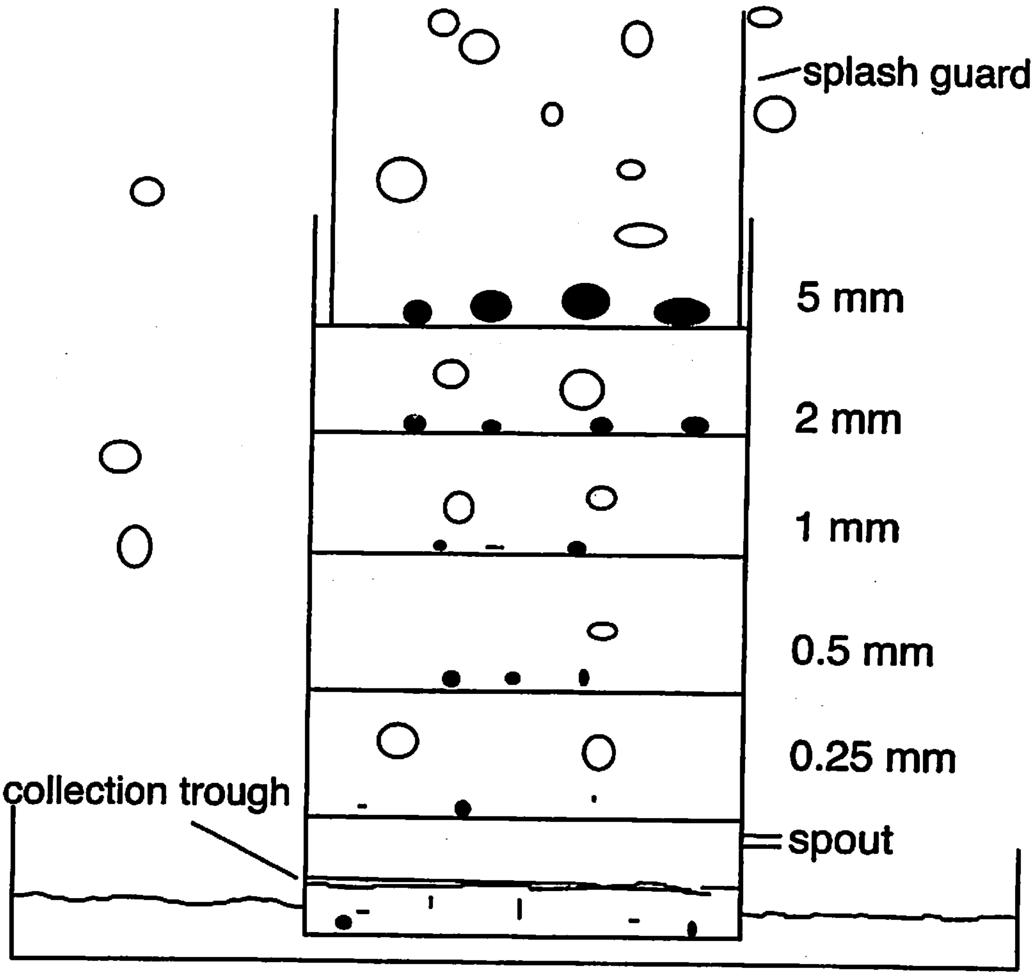

Figure 1. Schematic of the rainfall fractionator showing aggregates (solid) and water.

were allowed to air dry on a warm surface atop of an oven (~35 °C surface temperature). The pools were then weighed, a sub-sample was taken for gravimetric water content analysis, and another sub-sample was analyzed for total organic C (USDA-NRCS, 1995).

Three 50-g sub-samples were prepared from the soil of each management system. Each sub-sample repetition was fractionated into seven pools (>5, 2 to 5, 1 to 2, 0.5 to 1, 0.25 to 0.5, <0.25 mm WSA, and > 0.25 mm FOM). The same sieve sets were used to obtain the mass distribution of primary particles (Gee and Bauder, 1986) and water stable aggregates (Kemper and Rosenau, 1986). The relevant statistical means represented a best estimate of the WSA size distributions. Standard deviations and coefficient of variability were used to assess the repeatability of the method. Grapher software (Golden Software Inc., Golden, CO) was used to calculate and display the linear regressions between SOC and MWD for the comparison of various wet sieve fractionation methods.

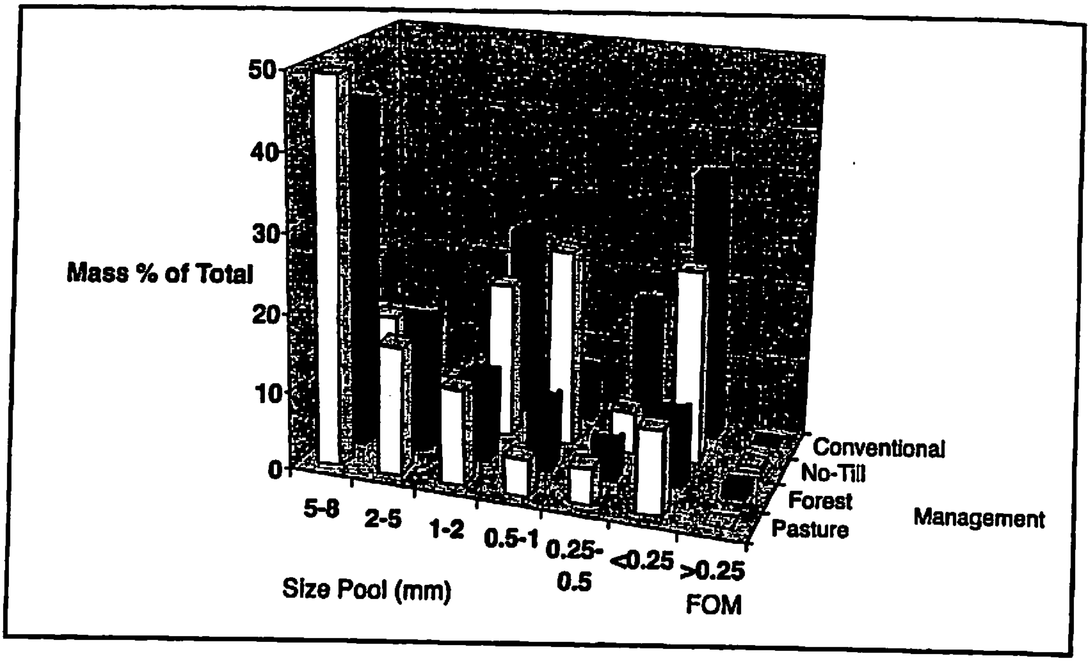

Figure 2. Mass of aggregate pools obtained using the rain fractionator.

III. Results and Discussion

Initial feasibility studies showed efficient use of water with only 400 ml of concentrated micro-aggregates and good repeatability so the system capabilities were expanded to fractionate six sieve sets simultaneously. The system was further tested on the same soil under four management systems that were expected to have very different aggregate stability. The relatively stable size distributions and lower micro-aggregate pool (<0.25 mm) of forest and pasture soils (Figure 2) were assessed using the rainfall simulator and compared with the no-till and conventional-till continuous corn. The management system with the least stable aggregates and most transportable micro-aggregates (35%) was conventional till continuous corn showing more than three times as much transportable micro-aggregates as pasture and forest. No-till was intermediate in its stability under raindrop impact and had a surprisingly high transportable micro-aggregate pool (25%). This would suggest that low erosion from no-till agriculture is more dependent on factors such as high infiltration rates, low runoff, and the protection of surface aggregates from raindrop impact by litter, rather than inherent stability of large aggregates to raindrop impact. The FOM was a small fraction (ranging from 0.2 to 2%) of total mass.

Expressed as a percent of total mass (50 g) there was an average standard error of 2.5% (1.3 g) for a single sample estimation of a pool using the rainfall fractionator. This standard error compares favorably with 5.3% for the Yoder method (Table 1) and is comparable to but slightly more than 0.94% for primary particles. The repeatability of the calculated MWD was good with a coefficient of variability averaging 6.8% compared with 14% for primary particles and 19% for the Yoder method. The percent mass recovery, calculated for each trial then averaged, was 98.5% for the rainfall fractionator. Mass recovery was not attempted on the microaggregates (Yoder method) and primary particles (0.25 mm).

Table 1. Four measures for assessing repeatability of the various fractionation methods

Aggregate fractionation method	Standard deviation (% of total soil mass) for individual pool assessment	Average coefficient of variability for individual pool assessment (%)	Standard deviation (mm) for calculation of mean weight diameter (MWD)	Average coefficient of variability for MWD (%)
Rain fractionator	2.5	24	0.15	6.8
Yoder fractionator	5.3	48	0.56	19
Primary particles	0.94	23	0.14	14

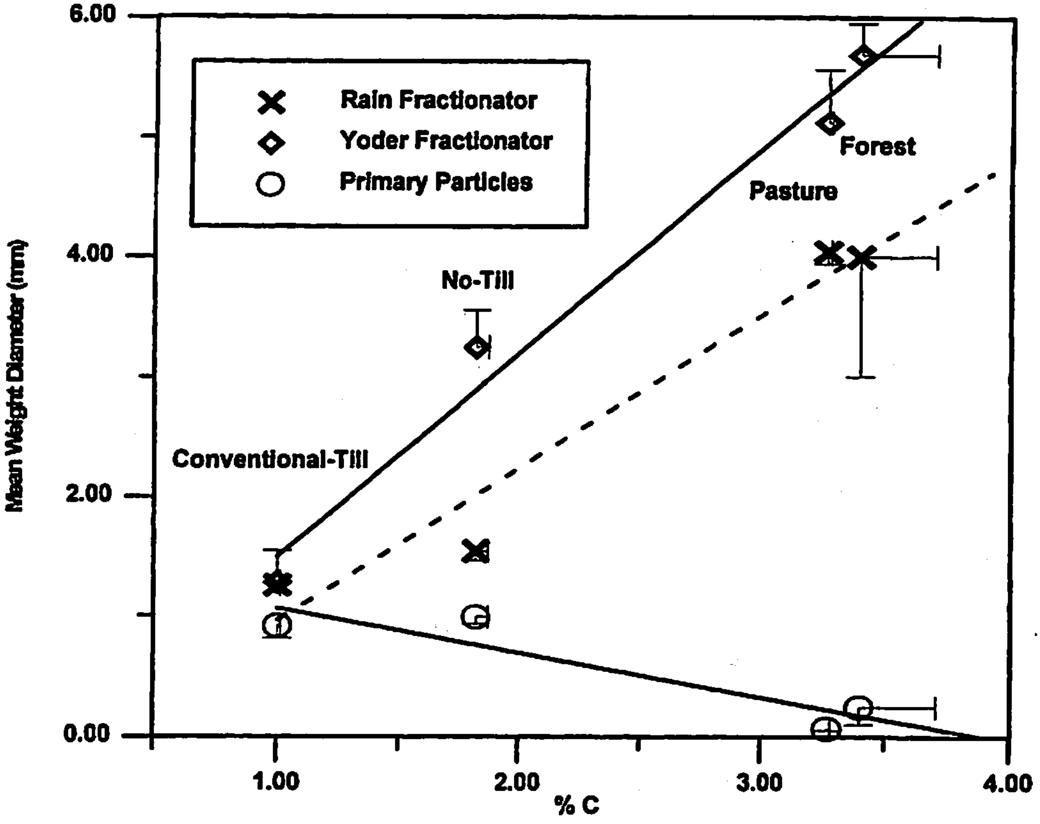

Figure 3. Relationship between aggregation and C percent; bars are standard error for three replications.

Four measures of repeatability (shown in the four data columns of Table 1) were considered: standard deviation (% of total soil mass) for individual pool assessment, average coefficient of variability for individual pool assessment (%), standard deviation (mm) for calculation of MWD, and average coefficient of variability for MWD (%). The Yoder method had the lowest repeatability in all four categories. Although the rainfall simulator had more than two times the repeatability of the

Table 2. Regression parameters expressing the correlation between mean weight diameter (MWD) and soil organic carbon content (SOC)

Aggregate fractionation method	Regression equation	Number of points used	Average mean weight diameter (MWD, mm)	Average soil organic carbon (SOC, %)	Coefficient of determination
Rain fractionator	MWD = 1.28×SOC -0.31	4	2.72	2.37	0.95
Yoder fractionator	MWD = 1.70×SOC -0.20	4	3.83	2.37	0.95
Primary particles	MWD = -0.37×SOC +1.43	4	0.56	2.37	0.84

Yoder method in all four categories, it was comparable to or slightly less repeatable than primary particle fractionation in three of four categories.

A positive, approximately linear relationship between aggregation (expressed as mean weight diameter) and C% (Figure 3) was observed for both the aggregate fractionation methods; however, the correlation was negative for primary particles. Aggregation was consistently greater when assessed using the Yoder method, intermediate for the rain fractionator, and least for primary particles, as would be expected considering the increased physical energies imparted to the large aggregates by raindrop impact. The statistics of the regression analysis (Table 2) showed coefficients of determination of 0.84, 0.95, and 0.98 for primary particles, rain fractionator, and Yoder method, respectively.

IV. Conclusions

Testing of the rain fractionator system of aggregate fractionation and comparison with traditional wet sieving was conducted and results presented in this study suggest the following inferences may be conclusively drawn:

1. The rainfall fractionation procedure is easy to use.
2. The variability of the new method is good when compared with the Yoder method and is comparable to the variability obtained in primary particle fractionation.
3. The rainfall frationator is consistently more destructive than the Yoder method because of the energies imparted by rainfall impact and this simulates natural rainfall conditions.
4. The method is sensitive enough to detect treatment-induced differences in aggregation and structural attributes.
5. Differences in aggregation (expressed as mean weight diameter) are mostly explained by treatment-induced differences in SOC content. This is evidenced by the linear correlations between MWD and SOC (coefficients of determination ranged from 0.84 to 0.98).

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