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SHORT COMMUNICATION

Quantitative and qualitative comparison of three wet aggregate stability methods using a long-term tillage system and crop rotation experiment

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Abstract: Automated wet-sieving is preferred for this clay loam soil due to better sensitivity and savings (time and disposables) despite a larger capital investment. Rotations with greater frequency of winter wheat and no-till compared with conventional plow system had greater wet aggregate stability values, indicating better surface soil quality.

Key words: soil sampling methods, soil quality, soil health, winter wheat, soybean, no-till, plow tillage.

Résumé : Pour ce type de loam argileux, les auteurs privilégient la filtration humide automatisée en raison de la plus grande sensibilité de la méthode et des économies réalisées (temps, pertes), malgré le plus grand investissement initial que cela suppose. Les assolements incluant la culture plus fréquente de blé d'hiver et le non-travail du sol présentent des agrégats humides plus stables que les assolements classiques avec travail du sol, signe que leur sol est de meilleure qualité. [Traduit par la Rédaction]

Mots-clés : méthodes d'échantillonnage du sol, qualité du sol, état du sol, blé d'hiver, soja, non-travail du sol, labours.

Introduction

The desire to increase agricultural productivity and resilience has led to a focus on best management practices that improve soil quality. The ability to identify changes in soil quality requires sensitive and feasible soil indicators (Karlen et al. 2013). Aggregate stability is one suitable soil quality indicator, as it is affected by several interacting factors, such as microbial activity, organic matter content, content of clay and clay mineralogy, and the presence of calcium carbonate. Therefore, further development of aggregate stability as an indicator may provide insights into soil quality and influential agricultural management practices.

There is no consistent measurement of aggregate stability. There are several methods to characterize aggregate stability through the measurements of water stable aggregates, mean weight diameter, and geometric mean diameter (e.g., Saygin et al. 2012). For instance, an automated wet-sieving (AWS) method by Kemper and Rosenau (1986) is widely used and emulates natural destructive forces by submerging aggregates repeatedly in liquid using a single-sieve apparatus. Pojasok and Kay (1990) modified a hand wet-sieving (HWS) aggregate stability method. More recently, a rainfall simulator (RFS) method emulated the force of a heavy rainfall after surface drying (Idowu et al. 2008). All three methods estimate wet aggregate stability (WAS) with various soil sampling and pre-treatment requirements.

Single sieve, multiple sieve, and rainfall simulator methods each have corresponding advantages and disadvantages. Moreover, method accuracies have been found to fluctuate with soil texture (Lado et al. 2004). Therefore, determining which method may be the most sensitive for detecting real differences in aggregate

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Abbreviations: **AWS**, automated wet-sieving; **CSW**, corn–soybean–winter wheat rotation; **HWS**, hand wet-sieving; **RFS**, rainfall simulator; **SOY**, continuous soybean; **SW**, soybean–winter wheat rotation; **WAS**, wet aggregate stability.

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stability is important. Furthermore, little information is available on the effect of differing soil sampling methods on aggregate stability estimates. Determining which method is the least laborious and the most sensitive for detecting differences in WAS across agricultural management systems may help to improve soil aggregate testing techniques in the future. Thus, we evaluated three wet-sieving methods and two soil sampling methods in terms of resource efficiency (e.g., time and costs) and sensitivity to detect changes in aggregate stability due to agricultural management using a 18 yr long-term experiment at Ridgetown, ON.

Materials and Methods

The long-term tillage system and crop rotation experiment (est. 1995) at Ridgetown, ON (latitude 42°26′26″N; longitude 81°53′3″W), was utilized because previous research identified differences in various soil quality attributes including WAS (Van Eerd et al. 2014; Congreves et al. 2015). Field treatments were arranged in a split-plot design with four replicates. Main effects were no-till [zone-till for grain corn (*Zea mays* L.)] and conventional tillage (fall plow with spring secondary tillage), and three crop rotations were sampled in the soybean (*Glycine max* L.) phase: corn–soybean–winter wheat (*Triticum aestivum* L.) [CSW], soybean–winter wheat [SW], and continuous soybean [SOY]. Soil samples were collected in 24 experimental units from the fertilizer nitrogen treatment subplots of 100 kg N ha^{-1} applied to the winter wheat crop and 120 kg N ha^{-1} to the grain corn crop. For crop production details see Van Eerd et al. (2014).

Soil sampling

Soil (clay loam, Orthic Humic Gleysol) was collected on 26 June 2013 at a 0–15 cm depth using two methods. For the probe method, one composite soil sample per experimental unit consisted of 15 cores per experimental unit was taken using a 3.5 cm diameter soil probe. Similarly, for the ring method, one composite sample was taken per experimental unit but consisted of three 7.5-cm-diameter ring cores typically used for bulk density measurements. In the field, soil was homogenized by hand; plant debris and stones were removed and partitioned into three subsamples — one for each aggregate stability method.

Aggregate stability methods

Automated wet-sieving method

According to Kemper and Rosenau (1986), field-moist soil was hand sieved (4 mm) and air-dried for 1 wk at room temperature (22.5 °C). Using an automatic sieving apparatus (Eijkelkamp Agrisearch Equipment 08.13. Giesbeek, Netherlands), 4 g of soil was placed in sieve (0.25 mm) cups and lightly re-wetted for 1 min with 1 mL of distilled water spray. Soil was subjected to 3 min of repetitive submersion into 100 mL of distilled water, then sieved two more times in 100 mL of NaOH for 10 min each. Soil slaked into solutions were filtered (Whatman 42), oven-dried (105 °C) for at least 12 h, and weighed. Data were expressed as mean weight diameter.

Hand wet-sieving method

This method was according to Pojasok and Kay (1990). Briefly, field-moist soil was passed through a 4 mm sieve. Soil (5 g) was placed on filter paper (Whatman 42, 3 cm by 5 cm) and wetted for 90 min on a Mariotte bottle wetting table. Soil in distilled water (40 mL) was agitated at 25 r min^{-1} for 10 min on an Eberbach shaker. Soil was sieved (0.25 mm) and rinsed with an additional 40 mL of distilled water. Slaked soil left on sieves was oven-dried (105 °C) for 24 h, weighed, and subjected to 5 mL of sodium hexametaphosphate $(NaPO_3)_6$ at 5% concentration for 4 h prior to sieving and weighing the resulting fractions. Data were expressed as the percent weight of stable aggregates relative to total weight and corrected for sand (>250 μm) content. Additional dispersible clay readings suggested by Pojasok and Kay (1990) were not completed.

Rainfall simulator method

Soil was oven-dried at 40 °C for 72 h (constant weight), and 40 g of soil was shaken for 10 min over 8, 2, and 0.25 mm sieves. The resulting 0.25–2 mm fraction was subjected to 5 min of rainfall (500 mm; individual drops approximately 4 mm in diameter with an estimated total impact of 0.74 J) using a RFS apparatus (source: Cornell University) according to Idowu et al. (2008). For RFS, data were expressed as the percent weight of stable aggregate of the total weight (0.25–2 mm fraction).

Qualitative analysis of soil sampling and aggregate stability methods

To assess sensitivity, laboriousness, and costs, each method was evaluated using seven criteria (Table 1) on a relative indexing score of low, intermediate, and high. Sensitivity was based on data variability (coefficient of variability and sample standard deviation) and statistical differences among treatments. Laboriousness was assessed according to (*i*) complexity of set up and the number of steps required, (*ii*) time required to process samples expressed as the number of samples processed per run, and (*iii*) storage requirements. Costs include equipment and disposables but not labour costs.

Statistical analysis

All analyses were conducted in SAS (SAS Institute Inc., version 9.2, Cary, NC, USA). Data met all analysis of variance (ANOVA) assumptions; no transformations were required. Initial four-way ANOVA of soil sampling method, aggregate stability method, tillage system, and crop rotation revealed no impact of soil sampling method ($P = 0.2866$) nor interactions containing soil sampling method ($P \geq 0.2041$); therefore, a three-way analysis was conducted without soil sampling method effect. Using a mixed model (PROC MIXED), fixed effects

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Table 1. Qualitative analysis of soil sampling and aggregate stability method.

Procedure	Method	Sensitivity[b]	Complexity: preparation	Complexity: procedures	Storage: Ease + space required	Time required (samples/day)[c]	Cost: equipment	Cost: disposables
Sampling	Probe[a]	High	Low	Low	High	Low	Low	None
	Ring[a]	High	Intermediate	Intermediate	Intermediate	High	Low	None
Aggregate stability	AWS	High	Low	Intermediate	High	Low (32 in 2 d)	High	Low
	HWS	Intermediate	High	High	Low	High (16 in 2.5 d)	Intermediate	Intermediate
	RFS	Low	Intermediate	Intermediate	High	High (24 in 4.5 d)	Intermediate	High

Note: AWS, automated wet-sieving; HWS, hand wet-sieving; RFS, rainfall simulator.
[a]Probe: 15 cores of 3.5 cm diameter; Ring: three cores of 7.5 cm diameter.
[b]Includes variability in data and ability to detect agricultural management differences.
[c]Includes set up and clean up time assuming equipment was assembled.

included aggregate stability method, tillage, crop rotation, and their respective interactions. Random effects were block and block by tillage to account for the split-plot design with tillage as the main effect and crop rotation as the subplot effect. Treatment differences were separated by a Tukey–Kramer least significant difference test with an alpha value of 0.05. To determine relationships among WAS methods, linear correlations were conducted (PROC CORR).

Results and Discussion

Mean WAS values (± standard error) were not influenced by soil sampling method (probe 49.8% ± 1.74%; ring 51.1% ± 1.77%). The WAS measurements from the two soil sampling methods were highly correlated ($r = 0.851$; $P < 0.0001$). The lack of interactions of sampling method with all other effects ($P > 0.2041$) and similar variability in the data (probe CV = 29.4%; ring CV=29.6%), suggests that either method would be appropriate on this soil. Based on these results, the probe method may be preferred because it is less laborious (Table 1), unless bulk density measurements via ring-core samples are needed.

Despite a higher initial capital investment, AWS was less costly (time and disposable) and less laborious than the other two WAS methods (Table 1). In addition, AWS requires less bench-top space and can be completed at any time after soil was dried. The HWS method takes more time per sample and must be completed on field moist soil, thus should be processed in a timely manner. The constraining factors of the RFS method were the large space requirement and the ability to contain/remove large volumes of water (e.g., a floor drain). All methods require minimal training, but the AWS minimizes human error due to its simple procedure and automated nature. Thus, based on effort, the AWS is preferred.

For all three WAS methods, surface soil WAS was greater in the no-till (avg. 54.3% ± 1.08%) than conventional fall plow system (avg. 46.7% ± 1.08%) (Fig. 1), which agreed with previous WAS results at Ridgetown (Van Eerd et al. 2014) and other long-term trials in Ontario (Congreves et al. 2015). This indicates better surface soil quality with no-till than fall plow conventional systems. The magnitude of differences in WAS between tillage systems was smallest with HWS (no-till avg. 51.0% ± 1.70%, plow tillage avg. 45.6% ± 1.70%), suggesting lesser sensitivity (Fig. 1).

Only the RFS method detected a tillage system by crop rotation interaction ($P = 0.0151$). The interaction was due to a lack of difference between tillage systems in the SW rotation (42.2% and 42.8% ± 3.37%) but greater WAS values with no-till than conventional systems in the other two rotations. With RFS method, the smallest WAS values were in SOY under conventional tillage (27.2% ± 3.37%), which was not different from CSW under conventional tillage (33.2% ± 3.37%). These results were consistent with other soil quality indicators (Van Eerd et al. 2014;

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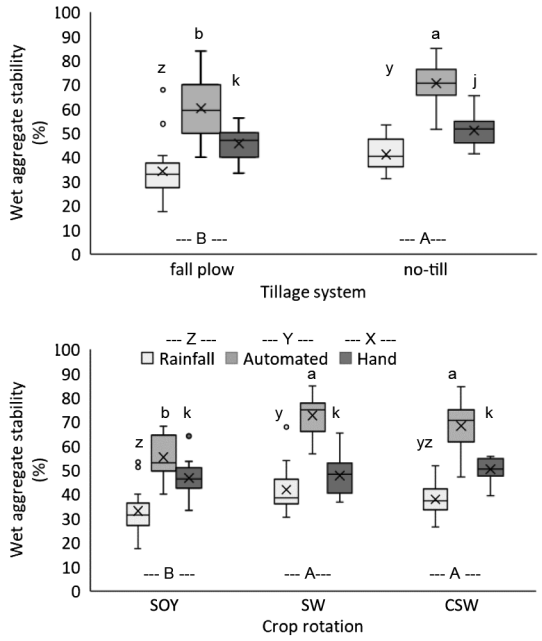
Fig. 1. Wet aggregate stability (WAS; %) as influenced by rainfall, automated, and hand measurement methods and affected by tillage system (top) and crop rotation (bottom). Boxplots show 25th, 50th, and 75th percentiles, whiskers indicate 10th and 90th percentiles, circles are outliers and "x" depicts average. Different uppercase letters indicate statistical differences ($P < 0.05$) of mean WAS values among crop rotations or between tillage systems (above the *x*-axes) and among WAS measurement methods (above the legend). For each panel, different lowercase letters within each method indicate significant differences among tillage system ($n = 24$) or crop rotation ($n = 16$) treatments. SOY, continuous soybean; SW, soybean–winter wheat; CSW, corn–soybean–winter wheat. Note: there was a tillage system by crop rotation interaction for the rainfall simulator method only.



Congreves et al. 2017) as well as corn and soybean productivity and resiliency with winter wheat in the rotation (Gaudin et al. 2015).

The WAS method by crop rotation interaction ($P = 0.0003$) was attributed to the lack of rotation effect in HWS but differences among crop rotations with the other two methods (Fig. 1). Thus, the ability to detect crop rotation differences in WAS depended on the method used. Trends among crop rotations were consistent with all methods; WAS values were greatest in SW and smallest in SOY rotations. This result agreed with other locations and other soil quality indicators (Van Eerd et al. 2014; Congreves et al. 2015) and demonstrates the positive influence of winter wheat on soil quality.

The RFS method had the greatest variability followed by AWS and HWS (e.g., CV = 24.7%, 18.0%, and 13.7%, respectively). Although RFS and HWS were not correlated ($r = 0.00971$; $P > 0.05$), the AWS method was correlated with RFS ($r = 0.492$; $P < 0.001$) and HWS ($r = 0.325$; $P < 0.05$). The relatively weak correlations among methods were surprising but likely reflect the observed differences in quantifying WAS among methods.

The most significant outcome of this research was that interpretation of the impact of agricultural management practices on soil structure depended on the WAS measurement method employed. The AWS method had the lowest variability and the greatest sensitivity in detecting differences among agricultural management practices and greater correlations with the other two methods. Influencing factors of AWS method may include the automation of the wet-sieving process that reduces human error, the air-dried pre-treatment that may mimic field drying conditions, and pre-misting to moisten aggregates that would prevent bursting upon contact with water. Moreover, compared with the other two methods, AWS was simple to conduct and time efficient with minimal disposable costs after initial investment. Overall, the AWS method by Kemper and Rosenau (1986) was the preferred method to quantify WAS on this clay loam soil of contrasting soil quality.

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