COMMUN. SOIL SCI. PLANT ANAL., 28(19&20), 1871–1887 (1997)

A New Approach to Determining Water Stable Aggregation

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ABSTRACT

A new method is introduced to measure water stability of soil aggregates. The wrist-action shaker is a simple, inexpensive tool that provides highly accurate data for the assessment of soil erodibility. Three soils from Hawaii (two Oxisols and one Vertisol) with different mineralogies, management histories, and potassium (K)-factors were examined in this study. Six indices of water stable aggregation were determined after rapid immersion of air-dry aggregates, followed by gentle wet-sieving. Single-sieve indices of percent water stable aggregates (WSA) < 0.063 mm, > 0.25 mm, and > 1.00 mm, were highly correlated. Additionally, these indices were highly correlated with three multiple sieve indices, namely geometric mean aggregate diameter (GMAD), arithmetic mean aggregate mass diameter (MAMD), and the coarse-to-fine index (CFI = % WSA > 1.00 mm / % WSA < 0.063 mm). Analysis of WSA data indicated that the relative soil erodibility ranking, from high to low, would be: Lualualei Vertisol > Molokai Oxisol > Kanelôa Oxisol. Discriminant analysis using GMAD and % WSA > 1.00 mm correctly classified 55 of 56 soil samples into their respective soil series.

INTRODUCTION

Soil erodibility is a complex concept, generally related to the susceptibility of a soil system to erosional sub-processes (c.f., Bryan et al., 1989). Susceptibility to erosion is an integrated response between inherent soil properties, properties of the eroding fluid, and their interaction with climate (Lal, 1990). A soil's erodibility is a major consideration in developing sound management practices for agricultural lands (Young and Mutchler, 1977). Four approaches have traditionally been used to assess the water erodibility of agricultural soils: (1) the long-term measurement of soil loss from plots under natural rainfall conditions (Hudson, 1993), (2) the short-term field measurement of soil loss under standardized conditions using rainfall simulation (Elliot et al., 1989), (3) the measurement of interrill or rill erosion under controlled laboratory conditions (Bryan and Poesen, 1989; Sutherland et al., 1996), and (4) the statistical isolation of certain soil properties as indices of erodibility (Bryan, 1968, 1971, 1974). The latter two approaches have received significant attention over the last two decades because, as Truman and Bradford (1995) note, field studies are laborious and costly, and soil loss/ erodibility determination under laboratory conditions allows better control of test conditions, can provide more accurate baseline results for comparison between soils, and is more reproducible compared with measurements made under field conditions. To this, we add that laboratory testing is more rapid and often less expensive.

Aggregate breakdown mechanisms are vital in soil seal and soil crust formation, reduction in infiltration, initiation of overland flow, alteration of surface sediment characteristics, hard setting, compaction, and hence, interrill and rill erosion processes (Farres and Cousen, 1985; Angers and Mehuys, 1993). Therefore, soil erodibility generally increases as the stability of aggregates in water decreases. Lavee et al. (1996) found that aggregate stability has the potential to serve as a sensitive indicator of the effect of climate and/or environmental change on soil degradation.

Several techniques have been used to assess the stability of aggregates in water. The most commonly used method, first introduced by Yoder (1936), is based on the mechanical wet-sieving of soil in a column of water. Other approaches to measuring the water stability of aggregates include single water drop tests (Bruce-Okine and Lal, 1975; Farres and Cousen, 1985; Lavee et al., 1996), multiple water drop tests (Young, 1984), end-over-end shaking (Williams et al., 1966; Pojasok and Kay, 1990), a volumeter test (Srzednicki and Keller, 1984), and a high-energy moisture characteristic method (Pierson and Mulla, 1990).

Results of aggregate stability analyses are used to develop indices of water stable aggregation. Schaller and Stockinger (1953) stated that the difficulty with aggregate analyses has been finding a suitable method of expressing the results of the analysis. Numerous values cited in the literature have been based on combining aggregate mass percent from a set of sieves, including the arithmetic mean aggregate mass diameter (MAMD; Van Bavel, 1949), and the geometric mean aggregate diameter (GMAD; Mazurak, 1950; Gardner, 1956).

From an analysis of 200 aggregate-size distributions, Gardner (1956) found most were log-normal or very nearly so; therefore, he concluded that the GMAD would be the best index for describing the central tendency of water stable aggregates. Others have used MAMD because it was found to be highly correlated with corn yield (Van Bavel and Schaller, 1950 ($r = + 0.713$)). El-Swaify and Dangler (1977) found that MAMD was strongly correlated with field measured K-factor values ($r = - 0.768$) for 10 soil series in Hawaii—where the K-factor represents the soil erodibility in the Universal Soil Loss Equation (USLE). Loch and Foley (1994) found a strong positive correlation between MAMD and GMAD ($r = +0.95$, $P < 0.001$), as did Schaller and Stockinger (1953) ($r = +0.891$). The Schaller and Stockinger study favored GMAD over MAMD or other indices of WSA because there was less variability, and thus, better replication using GMAD. Some researchers have suggested that the extra time required to analyze data from a set of sieves is not warranted, as indices derived from single sieves are highly correlated with MAMD and GMAD (c.f., Kemper and Koch, 1966). Thus, it is common to see results of aggregate analyses summarized as % WSA > 0.25 mm, > 0.50 mm, > 1.00 mm, > 2.00 mm, and > 3.00 mm (e.g., Bryan, 1968).

This study focuses on laboratory-defined soil erodibility indices based on the stability of soil aggregates to breakdown in water. As discussed, soil aggregate stability is one of the main soil characteristics related to soil erodibility; therefore, an index estimating soil aggregate stability can be useful in assessing soil erodibility (Rousseva, 1989). Indices of water stable aggregation are most commonly found to be highly correlated with erosion potential and laboratory soil loss (c.f., Bryan, 1971, 1974; Luk, 1979). Although several WSA methods have been proposed, new approaches are welcome should they provide highly accurate data and if they are inexpensive and/or labor efficient. Thus, the objectives of this study are to: (1) evaluate a new, inexpensive, simple approach to measuring water stable aggregation, (2) determine the correlation structure between WSA indices, and (3) determine the indices most efficient in discriminating between soils of different erodibility.

MATERIAL AND METHODS

Soil Selection

Three soils from Hawaii differing in mineralogy, structural stability, erodibility, erosion history, and management practices were used in the WSA experiments. These soils represent three distinct soil series and two soil orders. The upper 10 cm of the A-horizon of the Lualualei Vertisol (Typic Chromustert) from western O'ahu was sampled. This soil was under grassland vegetation at the time of

TABLE 1. Chemical and physical characteristics of three soil series from Hawaii.

Soil Characteristics	Units	Kaneloa Oxisol†	Molokai Oxisol‡	Lualualei Vertisol§
Soil texture	-	Silty clay loam	Clay	Clay
pH in water (1:1)	-	7.4	6.4 - 7.6	7.2
Organic carbon	$g\ kg^{-1}$	5.0 - 10.0	10.0 - 24.0	5.0
Total nitrogen	$g\ kg^{-1}$	-	-	1.8
CEC	$cmol\ (+)\ kg^{-1}$	-	14.8 - 19.2	47.5
Exchangeable Ca^{2+}	$cmol\ (+)\ kg^{-1}$	5.79	3.20 - 4.80	34.4
Exchangeable Mg^{2+}	$cmol\ (+)\ kg^{-1}$	3.46	-	18.4
Exchangeable K^{+}	$cmol\ (+)\ kg^{-1}$	0.82	0.54 - 1.30	0.6
Smectite	$g\ kg^{-1}$	-	-	175
Kaolinite / Halloysite	$g\ kg^{-1}$	Moderate	730	110
Surface area (< 2.0 mm)	$m^2\ g^{-1}$	-	92 - 98	743
Particle density	$Mg\ m^{-3}$	-	2.92	3.19
Field bulk density	$Mg\ m^{-3}$	1.10 - 1.30	1.05 - 1.15	1.08 - 1.22
Liquid limit	%	45	47	62 - 73
Plastic limit	%	30	30	36

†Data from Nakamura and Smith (1995).

‡Data from J. Jackman (personal communication), Reichert and Norton (1994), and Kawano and Holmes (1958).

§Data from Ziegler et al. (1997), and Kawano and Holmes (1958).

sampling, and has not been used for sugar cane production since the 1940s. The mean annual rainfall in this area is approximately 660 mm. The physical and chemical properties are summarized in Table 1. In general, Vertisols are highly erodible because they have very slow infiltration rates and tend to form surface seals and crusts that favor runoff (Van Wambeke, 1992). From field rainfall simulations Dangler and El-Swaify (1976) found the Lualualei soil to be one of the most erodible on the island of O'ahu, having a mean weighted K-factor of 0.30 (US customary units).

The upper 10 cm of the Ap-horizon of the Molokai Oxisol (Typic Eutrotorrox) from central O'ahu was also sampled (Table 1). This area has a mean annual rainfall of approximately 800 mm. This Oxisol is an important soil series in Hawaii as it is widely used for pineapple, sugar cane, and most recently, diversified agriculture. This soil was also selected because it has been previously studied by Dangler and El-Swaify (1976), and Reichert and Norton (1994). Dangler and El-Swaify (1976) found that the mean weighted K-factor (0.15) was significantly lower than that of the Lualualei soil.

Finally, the 10 cm layer of the Bw-horizon of the Kaneloa Oxisol from the Island of Kaho'olawe (Table 1) was sampled. Mean annual rainfall in this area is approximately 560 mm (Nakamura and Smith, 1995). Kaho'olawe is unique among the main Hawaiian islands because it has undergone significant environmental degradation resulting primarily from overgrazing by goats and military bombing from 1941-1990 (c.f., Loague et al., 1996). This soil series is critical to the future island rehabilitation and reclamation that is planned over the next decade. This research is the first in which WSA properties of any Kaho'olawe soil have been quantified. Nakamura and Smith (1995) have estimated the K-factor$_{nom}$ of the Kaneloa soil from the USLE nomograph to be approximately 0.17. It should be remembered, however, that K-values estimated from the soil erodibility nomograph are very crude. For example, Young and Mutchler (1977) found that the K-factor$_{nom}$ significantly underestimated the erodibility of six, and overestimated the erodibility of three of 13 soils from Minnesota. In addition, El-Swaify (1977) found serious discrepancies between K-factor$_{nom}$ and field measured K-factors from rainfall simulation for various Hawaiian soils.

Soil Aggregate Preparation

Bulk samples were collected and air-dried in the laboratory for at least 30 days. Following dry-sieving, aggregates between 2.00-4.00 mm were selected and visible pieces of organic material and gravel were removed. A limited size fraction was used because aggregate stability analyses are more reproducible (Kemper and Rosenau, 1986). The selected size range is the most commonly used fraction in experimental WSA studies (e.g., Molope et al., 1985; Haynes and Swift, 1990). Air-dry aggregate samples of 10 g were placed in aluminum (Al)-tins, where 7.5 mL of tap water was added carefully along the tin edges with a pipette. Water was added to allow comparisons between bare aggregates and aggregates treated with various solution concentrations of an anionic soil conditioner, see our companion paper (Ziegler and Sutherland, 1998). Aggregates were allowed to cure for 48 h, then were transferred to 250 mL Ehrlemeyer flasks. A volume of 100 mL of tap water (< 400 μS cm^{-1} @ 25°C) was rapidly added to cause slaking. Rapid immersion wetting was used because slaking is the primary mechanism responsible for soil aggregate breakdown (Farres, 1980). The flasks were stoppered and shaken using a eight sample wrist-action shaker (Burrell Corp., Pittsburg, PA) at a setting of 2.0 for a 10 min period. Each flask was then wet-sieved through a nest of sieves with dimensions of 2.00, 1.00, 0.25, and 0.063 mm using a gentle water jet. Aggregate mass retained on each sieve was determined to ± 0.001 g after oven drying at 105°C for 24 h. The mass of material passing the 0.063-mm sieve was calculated by residual after correcting for air-dry moisture content and tap water salinity.

The mass of aggregates in each grain size fraction were used to determine the following indices of water stable aggregation: (1) GMAD, (2) MAMD, (3) % WSA > 0.25 mm, (4) % WSA > 1.00 mm, (5) % WSA < 0.063 mm, and (6) coarse-to-fine WSA index (CFI = % WSA > 1.00 mm / % WSA < 0.063 mm). The assumption behind indices (1) and (2) is that the greater the average WSA size, the greater the resistance of the soil to water erosion; for indices (3) and (4), the greater the percent of WSAs in each size fraction, the greater the soil resistance. Higher proportions of WSAs in the fractions < 0.25 mm and < 0.063 mm reflect a system that is highly susceptible to splash detachment and subsequent erosion, as these are the fractions most easily moved by fluids (Savat, 1982).

Statistical Design

All WSA indices were determined from 16 replicates of the Molokai and Kaneloa Oxisols, and 24 of the Lualualei Vertisol. Samples to be shaken from the three soils were randomly selected using a pseudo-random number generator; additionally the position (1 to 8) within the shaker was randomly assigned. Differences between soils for given indices were assessed using one-way analysis of variance (ANOVA) followed by multiple comparison testing using Fisher's Protected Least Significant Difference test at α=0.05 (Gagnon et al., 1989). The nonparametric Spearman Rank Order correlation coefficient was used to determine whether monotonic relationships between WSA indices were statistically significant.

Stepwise discriminant analysis was applied to the data using MacStatistica™ 4.0 (StatSoft™, Inc., 1994). Discriminant analysis is a statistical technique that allows the researcher to study the difference between two or more groups of objects with respect to several variables simultaneously (Klecka, 1980). Some of the WSA indices were found to be non-normal, based on skewness testing; therefore, a single transformation was not applicable to all data. Thus, untransformed data were used. The error rates resulting from violating normality assumptions using this technique are very small, i.e., ± 5% (c.f., Sutherland and Lee, 1994). The most parsimonious model using two variables was selected based on two criteria: (1) the partial Wilk's lambda—a value of 0.0 denotes perfect discriminatory power, and thus, the greater is the unique discriminant power of the respective variable (StatSoft™, Inc., 1994), and (2) the percent of correctly classified cases. Since there were three soils with two variables compared, two canonical discriminant functions (roots) were calculated; and these functions will be uncorrelated.

RESULTS AND DISCUSSION

Aggregate Size Distributions

The dry-sieved aggregate size distribution of each of the three soils is shown in Figure 1. The distributions for the Lualualei and Kaneloa soils appear to be log-normal, while the Molokai Oxisol is neither normal or log-normal. Only 2.00-4.00 mm aggregates were used for WSA analyses; the contributions of these fractions to the overall distributions are highlighted in Figure 1. In brief, the 2.00-4.00 mm aggregates comprise approximately 9.6% of the total aggregates for the Lualualei Vertisol; 11.7% for the Molokai Oxisol; and 21.5% for the Kaneloa Oxisol.

Correlation of WSA Indices

Table 2 shows the Spearman correlation coefficient (r_s) matrices for six WSA indices of the three soils. Correlation between indices for the method reported herein are similar to data reported for the wet-sieving technique (e.g., Schaller and Stockinger, 1953; El-Swaify and Dangler, 1977; Loch and Foley, 1994). Approximately 84% of the correlation coefficients in Table 2 are significant at α=0.05; 73% at α=0.01; and 53% at α=0.001. The average values for MAMD and GMAD for each of the three soils are shown in Table 3. The MAMD for the Lualualei is significantly smaller (0.34 mm) than both the Molokai Oxisol (1.32 mm) and the Kaneloa Oxisol (1.40 mm). The MAMD calculated using this new procedure for the Molokai Oxisol (1.32 mm) is comparable to the value of 1.20 mm determined using a Yoder-type wet-sieving device with air-dried 4.75-8.00 mm aggregates (Reichert and Norton, 1994). The larger MAMD and GMAD, and the greater percentages of WSA > 0.25 mm and > 1.00 mm for the Oxisols relative to the Vertisol supports the erodibility ranking discussed earlier based on K-factor values (i.e., the greater the WSA, the lower the erodibility). Thus, the Vertisol is expected to be more erodible than the Oxisols. The erodibility differences between the Oxisols is more subtle. Given a coarser average aggregate size (both GMAD and MAMD), significantly greater % WSA > 0.25 mm, and a higher CFI value, it would be expected that the Kaneloa Oxisol would be less erodible than the Molokai Oxisol. Thus, the K-factor$_{nom}$ (0.17) determined by

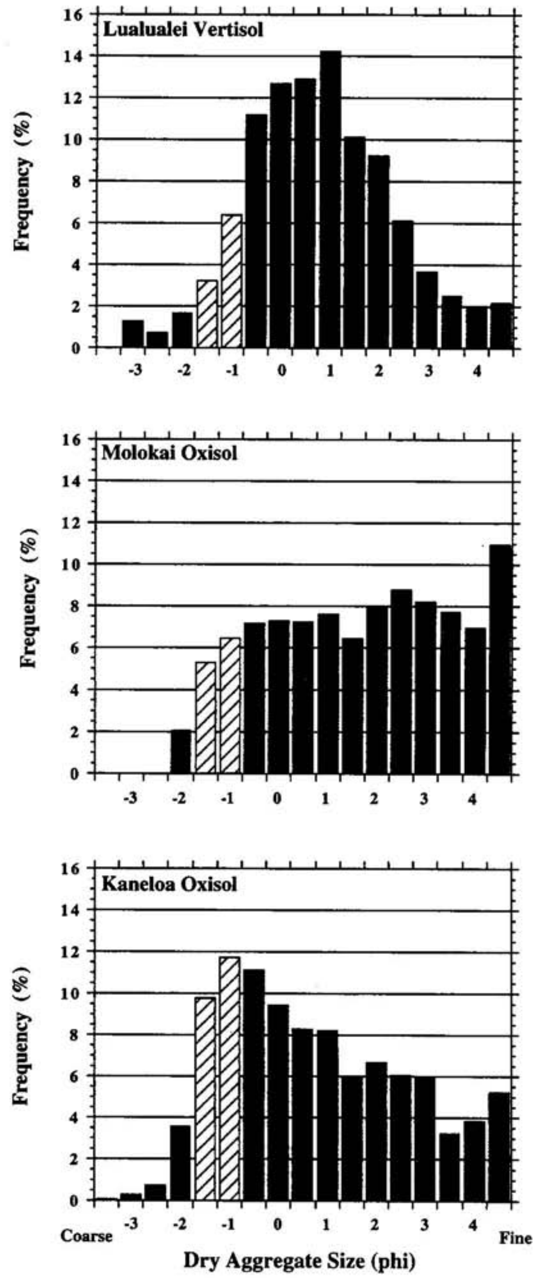

FIGURE 1. Dry-aggregate size distributions for three Hawaiian soils. Note the phi-scale is used for ease of plotting [phi = $-\log_2 (d/d_o)$, where d_o is the standard diameter of 1 mm]. The 2.00-4.00 mm aggregate fraction is highlighted separately.

TABLE 2. Spearman rank order correlation matrices for WSA indices for three Hawaiian soils.

Kaneloa Oxisol	GMAD†	MAMD†	< 0.063†	> 0.25†	> 1.00†
GMAD	1.00				
MAMD	0.85***	1.00			
< 0.063	-0.91***	-0.62*	1.00		
> 0.25	0.93***	0.64**	-0.97***	1.00	
> 1.00	0.88***	0.93***	-0.68**	0.71**	1.00
CFI	0.95***	0.70**	-0.98***	0.99***	0.75**

Molokai Oxisol	GMAD	MAMD	< 0.063	> 0.25	> 1.00
GMAD	1.00				
MAMD	0.80***	1.00			
< 0.063	-0.75**	-0.30	1.00		
> 0.25	0.89***	0.52*	-0.93***	1.00	
> 1.00	0.90***	0.92***	-0.46	0.71**	1.00
CFI	0.85***	0.45	-0.96***	0.97***	0.62*

Lualualei Vertisol	GMAD	MAMD	< 0.063	> 0.25	> 1.00
GMAD	1.00				
MAMD	0.83***	1.00			
< 0.063	-0.81***	-0.51*	1.00		
> 0.25	0.89***	0.86***	-0.56**	1.00	
> 1.00	0.32	0.69***	-0.07	0.32	1.00
CFI	0.56**	0.75***	-0.39	0.42	0.91***

†GMAD=geometric mean aggregate diameter (mm); MAMD=mean aggregate mass diameter (mm); < 0.063 = percent water stable aggregates (WSAs) <0.063 mm; > 0.25= WSAs > 0.25 mm; > 1.00 = WSAs > 1.00 mm; CFI = coarse-to-fine WSA index (% WSA > 1.00 mm / % WSA < 0.063 mm).

*Correlation coefficients are statistically significant at α=0.05.

**Correlation coefficients are statistically significant at α=0.01.

***Correlation coefficients are statistically significant at α=0.001.

TABLE 3. Summary of mean values and results of multiple comparison testing between three Hawaiian soils for six WSA indices.

WSA Indice	Lualualei Vertisol	Molokai Oxisol	Kaneloa Oxisol
GMAD (mm)	0.48 ± 0.004[a]†	0.85 ± 0.007[b]	0.90 ± 0.013[c]
MAMD (mm)	0.34 ± 0.006[a]	1.32 ± 0.015[b]	1.40 ± 0.033[c]
WSA < 0.063 mm (%)	21.35 ± 0.38[c]	12.26 ± 0.54[b]	9.06 ± 0.38[a]
WSA > 0.25 mm (%)	33.75 ± 0.93[a]	75.59 ± 0.45[b]	80.80 ± 0.77[c]
WSA > 1.00 mm (%)	3.04 ± 0.17[a]	52.19 ± 0.59[b]	51.03 ± 1.31[b]
CFI	0.14 ± 0.01[a]	4.46 ± 0.33[b]	5.84 ± 0.33[c]

†Plus / minus values represent one standard error about the mean. Row-wise values with the same letter are not significantly different at α=0.05.

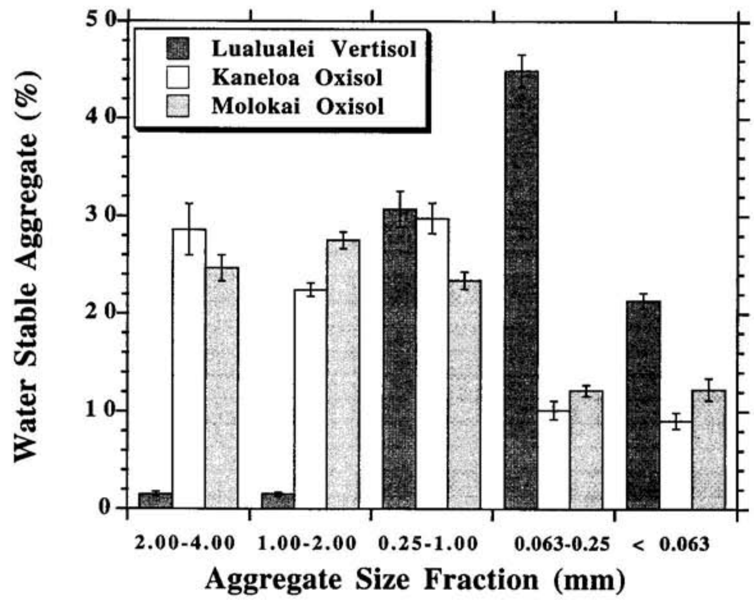

FIGURE 2. The percentage of water stable aggregates in various size fractions for three Hawaiian soils subjected to wrist-action shaking and gentle wet-sieving. Note error bars represent 95% confidence bands about the mean.

Nakamura and Smith (1995) is probably an overestimate, and should be reduced to a value less that 0.15, i.e., lower than the value for the Molokai soil.

WSA Indices and Analysis of Variance

Figure 2 shows the mean percent and 95% confidence bands for the five WSA fractions isolated for the three soil series. The Oxisols are most alike; and they differ significantly from the Vertisol. The WSA fractions 2.00-4.00, 1.00-2.00, and 0.25-0.063 mm are particularly distinctive between the two soil orders. Less pronounced differences exist between the two Oxisols in the aggregate fractions 1.00-2.00, 0.25-1.00, and < 0.063 mm.

Multiple comparison testing indicated that mean values of five of the six WSA indices were significantly different for all pair-wise comparisons of the three soil series—the exception was WSA > 1.00 mm (Table 3). Therefore, any of these indices can adequately characterize the average status of water aggregation in the three soils examined using the new procedure.

Kemper and Koch (1966) argued that a single sieve index would suffice for characterizing the WSA status of a soil. They used the % WSA > 0.25 mm as

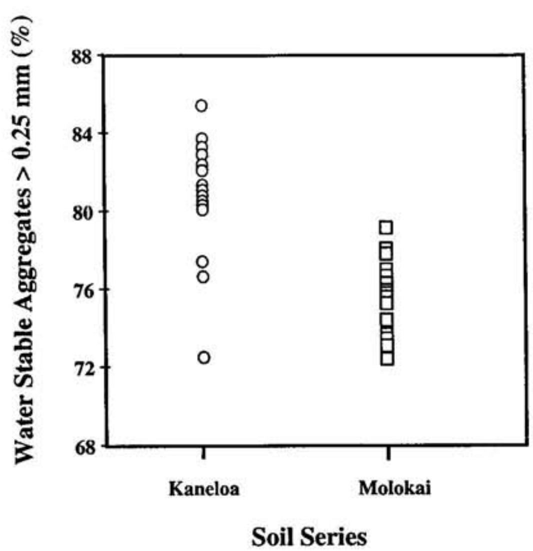

FIGURE 3. A dot-plot for two Hawaiian Oxisols exhibiting overlap in water stable aggregates greater than 0.25 mm for 16 replicates of each soil.

their preferred variable. This index would also be useful in the present study as it was highly correlated ($r_s \geq 0.89$, $P<0.001$) with GMAD for all soils (Table 2), and because multiple comparison testing indicated significant differences between the three soils (Table 3). The coefficient of variation (CV = [standard deviation / arithmetic mean] x 100) for the Lualualei soil, however, was 13.5% indicating that more replications would be required to characterize the mean with suitable confidence, compared to the GMAD. Despite increased replications, however, the work involved in wet-sieving would still be substantially reduced (i.e., single sieve vs. multiple sieve). The CFI is an attractive index because it has physical meaning and because multiple comparison testing indicated it differed significantly between the three soils (Table 3). Nevertheless, its reliance on more than one sieve and its high CV values (22.8 to 29.5%) suggest it may not be the most efficient index to effectively characterize WSA status of the three soils.

Discriminant Analysis and Use of Multi-WSA Indices

The above discussion focused on selecting a single index to characterize the average aggregation status of a soil, and thus, characterize its erodibility. Although the % WSA > 0.25 mm was found to be a useful single sieve variable, a dot-plot of actual values for each of the 16 replicates for the two Oxisols indicates significant overlap (Figure 3). Therefore, it was examined combining the WSA indices in

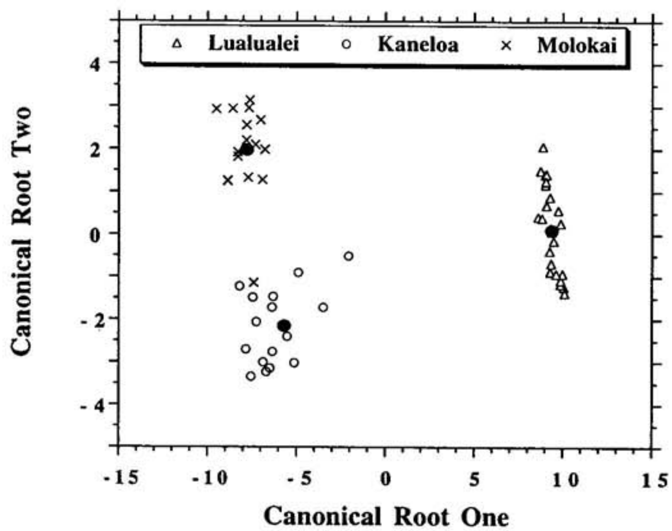

FIGURE 4. A discriminant analysis plot, with canonical roots based on geometric mean aggregate diameter and percent WSA > 1.00 mm. Note separation between the three soils except for one Molokai replicate that was classified as a Kaneloa soil. The solid circles represent group centroids.

Table 3 to develop a parsimonious model that would account for the highest classification percent of all replications per soil series.

Pair-wise combinations of WSA indices were investigated using discriminant analysis. The most successful model combined GMAD and % WSA > 1.0 mm. Partial Wilk's lambda values were 0.15 for % WSA > 1.00 mm and 0.25 for GMAD (both were significant at P-values < 0.0001). The two canonical roots were found to be statistically significant, with root one more heavily weighted by % WSA > 1.00 mm; root two by GMAD. The canonical plot (Figure 4) reflects the significant discrimination between the three soils series for all replications. Canonical root one provides the separation between the two Oxisols and the Vertisol, while canonical root two provides the separation between the Oxisols. It should be noted that only one (a Molokai Oxisol) of 56 samples was misclassified using these two WSA indices. Such a multi variate statistical approach may prove to be a useful tool in future soil classification studies.

CONCLUSIONS

A new procedure for estimating the water stability of soil aggregates was introduced. The water stable aggregate results from the wrist-action shaker, followed by gentle wet-sieving were encouraging. Six indices of water stable aggregation were highly correlated for the three Hawaiian soils investigated (two Oxisols and one Vertisol). Coefficients of variation were lowest for the GMAD; therefore, this index is the most efficient from a statistical perspective. It is additionally beneficial because erosion models are most likely to incorporate an average size parameter in the calculation of erosion susceptibility. Based on high correlations of GMAD with other WSA indices, the least time-consuming measurement index is % WSA>0.25 mm. Soil erosion models that have exclusively focused on this size range for prediction purposes are not known. Discriminant analysis was used to select GMAD and % WSA>1.00 mm as the most useful pair of indices in separating the three soil series investigated. Approximately 98% (55 of 56) aggregate samples were correctly classified using these two variables.

Finally, average aggregate size and percent of water stable aggregates indicates that the relative erodibility ranking of the three soils would be Lualualei Vertisol > Molokai Oxisol > Kaneloa Oxisol. The corresponding field measured K-factors reported in the literature indicate the same order for the Lualualei and Molokai soils (K=0.30 and 0.15, respectively). No comparable field data are available for the Kaneloa Oxisol; a USLE nomograph value, however, 0.17 has been estimated. This estimate seems too high, and should be lowered to a value less than 0.15 (United States customary units).

In conclusion, the wrist-action shaker, commonly available in soil science and geomorphology laboratories, appears to provide a simple, inexpensive tool, that is highly accurate for estimating the stability of aggregates in water. Future studies are required to investigate the correlation between this new approach with other methods, such as Yoder-type wet-sieving and water drop tests. Additionally, correlations need to be established between laboratory or field measurements of erosion on a variety of soils and WSA indices estimated from the wrist-action shaker.

ACKNOWLEDGMENTS

We thank the following for their contribution to the project: the Department of Geography University of Hawaii at Manoa (supplies and equipment); U.S. Naval Magazine Lualualei, Oahu (soil collection site); and Alexis Lee (laboratory assistance). Alan Ziegler is supported by an Environmental Protection Agency Graduate Fellowship.

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