Int. Agrophysics, 1992, 6, 27-32

A COMPARISON OF THREE MICROAGGREGATION INDICES WITH OTHER TESTS OF STRUCTURAL STABILITY

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Abstract. Six structural indices at three micro and three macro levels were used to measure the stability of 15 natural aggregates to water. Of the micro tests (the percent water-stable aggregates WSA < 0.25 mm) index reflected differences in organic carbon (O.C.) levels more than the aggregated silt+clay (ASC) and the aggregated clay (AC) indices. Similarly among the macro (WSA > 0.25 mm) tests the single sieve percent water stable aggregates (S%) reflected such differences more than the water stability index (WSI) and the mean-weight diameter of water-stable aggregates (MWD). The WSA < 0.25 mm and S% indices were also the easiest to determine and the most reproducible.

The ASC index correlated positively whereas the WSA < 0.25 mm negatively with all the macro indices. Differences in the plasticity index (PI) and the (sand+silt)/clay ratios (K) of these soils were most clearly reflected by the AC index. This suggests that these physical parameters are closely related to structural stability at this micro level.

INTRODUCTION

The stability of aggregates of agricultural soils to water influences many physicochemical and biological processes such as the ease of compaction, gaseous exchange and root penetration. Dębicki [7] and De Boodt *et al.* [6] reported a positive correlation between crop yield and higher percentages of water stable aggregates in soils.

Many methods of assessing aggregate stability exist [3,19] and techniques for their determination are fairly standardized. Matkin and Smart [12] compared six tests of stability used in geotechnical studies and found that each emphasized a different aspect of stability. Bazzoffi and Mbagwu [1] also reported that in none of the fifteen soils they studied did all the seventeen structural indices agree on its relative order of stability. Molope *et al.* [14] on the other hand observed that a turbidimetric test of stability reflected differences in cropping history of 5 soils more than the wet-sieving technique.

According to Tisdall and Oades [17] the mechanisms controlling the stability of aggregates operate at both the macro (>0.25 mm) and the micro (<0.25 mm) levels. Techniques for measuring these aspects of stability vary in complexity. Most reported tests of stability dealt with macro aggregation, yet to the extent that microaggregation influences crusting, surface sealing, soil permeability and infiltration characteristics [8,13] it is important in evaluating the productive potential of soils.

In this study three microaggregation tests of stability are compared with three macro aggregation indices obtained by the wet-sieving method. The efficiency of these indices in reflecting observed differences in the organic carbon levels of the soils is evaluated. Also the indices are related to the particle fractions and plasticity index of the soils.

MATERIALS AND METHODS

The fifteen soil samples used for this study were collected from different parts of north central Italy and air-dried at room temperature (about 20°C). The 4-2 mm aggregates used for all determinations of structural stability were obtained by dry-sieving. Some physical properties of the soils are given in Table 1.

Table 1. Properties of the soils

Soils [1]	Particle size fractions (%)			Texture [2]	Organic carbon (%)	Plasticity index (%)
	Clay (<0.002 mm)	Silt (0.002-0.02 mm)	Sand (0.02-2.0 mm)			
1	12.2	41.4	46.4	C	1.31	31.0
2	13.1	40.1	46.8	C	1.55	29.9
3	56.8	25.1	18.1	SL	1.14	16.8
4	54.2	21.7	24.1	SL	1.53	15.4
5	51.6	28.7	19.7	SCL	1.71	12.8
6	54.1	28.1	17.8	SCL	1.51	11.9
7	26.0	36.6	37.4	CL	1.35	27.3
8	28.9	34.1	37.0	CL	0.92	27.4
9	22.2	34.0	43.8	C	0.88	28.5
10	52.0	28.3	19.7	SL	0.54	15.5
11	59.1	24.9	16.0	SL	1.14	14.7
12	66.1	19.3	14.6	SL	0.53	10.4
13	64.6	22.1	13.3	SL	1.62	16.0
14	49.2	29.9	20.9	SCL	1.49	15.4
15	46.4	36.0	17.6	SCL	1.71	15.3

1. With the exception of soil No. 8 which is from the 20-40 cm depth the rest are from the 0-20 cm horizon;
2. C = clay, SL = sandy loam, SCL = sandy clay loam.

Determination of the microaggregation indices

Aggregated silt+clay (ASC)

This was computed as the difference between the percent silt+clay obtained in sodium hexametaphosphate (calgon)-dispersed aggregates and that obtained when distilled water alone was used as the dispersant.

Aggregated clay (AC)

This is the difference between the clay content in samples dispersed with calgon and that in distilled water-dispersed samples.

Percent water-stable aggregates less than 0.25 mm diameter (WSA < 0.25 mm)

Twenty five grams of the aggregates were placed on the top of a nest of 4 sieves of diameters 2, 1, 0.5 and 0.25 mm and presoaked for 10 min in water. The nest of sieves was then oscillated vertically in water for 20 times at the rate of 1 oscillation per second. The resistant aggregates were recovered from the sieves, oven-dried at 105°C for 24 h and weighed. The mass of the < 0.25 mm aggregates was obtained by difference and expressed as a percentage of the initial mass sieved.

Determination of the macroaggregation indices

Mean-weight diameter of water-stable aggregates (MWD)

The method of Kemper [11] was adopted by using the masses of the resistant aggregates in the respective sieves indicated above.

Water-stability index (WSI)

5 g of the aggregates were placed on a 0.2 mm sieve and moistened for 10 min over a layer of wet blotter. They were then immersed in a beaker of distilled water and shaken at the rate of 60 rpm. After 5 min and again after 60 min the aggregates which resisted breakdown were oven-dried at 105°C for 24 h, cooled and then weighed. The WSI was computed as 100(1-A/B), where A is the percentage of aggregates which passed through the sieve in 5 min and B is the percentage which passed after 60 min [10].

Single sieve water stability index (S%)

The 4-2 mm dry aggregates were placed on a 0.2 mm sieve and soaked for 10 min, then heliocoidally oscillated 20 times in water at 1 oscillation per sec and an amplitude of 4 cm. After oven-drying the resistant aggregates for 24 h, their masses were recorded [5].

Other determinations

Organic carbon was determined by the dichromate oxidation method [18] and plasticity index as the difference between the liquid and plastic limits. These consistency limits were obtained by the method described by Sowers [15]. Particle size analysis was by the pipette method of Day [4]. All determinations were in triplicates.

RESULTS AND DISCUSSION

Of the six indices compared it is only in the WSA < 0.25 mm that higher values indicate lower stabilities. In others higher values reflect relatively higher structural stability. Table 2 is a correlation matrix between pairs of the variables measured. Comparing the microaggregation with the macroaggregation tests, the ASC correlated positively and significantly with the MWD, WSI and S indices with respective coefficients of 0.69, 0.80 and 0.78. The AC index also correlated positively with these macro indices but the coefficients were not statistically significant at $P \leq 0.05$. The WSA < 0.25 on the other hand correlated negatively but significantly with all the macro tests with respective coefficients of -0.83, -0.89 and -0.94 for the MWD, WSI and S indices. It is therefore obvious that the AC index is not closely related to any of the macroaggregation tests whereas the ASC and WSA < 0.25 mm are.

Table 2. A correlation matrix of indices of structural stability and other soil properties

	ASC	AC	WSA < 0.25mm	MWD	WSI	S %	O.C.	PI
AC	0.66**							
WSA < 0.25	-0.80***	-0.47NS						
MWD	0.69**	0.46NS	-0.83***					
WSI	0.80***	0.45NS	-0.89***	0.77***				
S %	0.78***	0.37NS	-0.94***	0.70**	0.78***			
O.C.	0.48NS	0.03NS	-0.70***	0.28NS	0.51*	0.73***		
PI	0.63**	0.92***	-0.49NS	0.62**	0.53*	0.33NS	0.03NS	
K	-0.72**	-0.93***	0.56*	-0.64**	-0.60**	-0.44NS	0.02NS	-0.89**

* Significant at 5% level; ** significant at 1% level; *** significant at 0.1% level; NS - not significant.

Of interest also is the relationship between the ASC and WSA<0.25 mm indices which is negative as expected. Aggregation of particles at the micro level involves linkages between organic matter, clay domains and polyvalent cations. The stability of aggregates thus formed depends on the nature of these linkages and the internal cohesive forces they produce within the aggregates. The individual linkages are held together by

Van der Waal's forces, H-bonding and Coulomb attraction [9]. Higher values of ASC or AC indicate stronger cohesive forces within the linkages which are capable of resisting dispersion by water molecules. Consequently the corresponding values of WSA < 0.25 mm will be smaller as observed in this study.

Only one microaggregation index (WSA<0.25 mm) and two macroaggregation indices (WSI and S%) were capable of reflecting differences in organic carbon levels of the soils. The negative correlation coefficient (-0.70) obtained between percent organic carbon and WSA<0.25 mm is again expected. The implication is that most of the organic carbon present is involved in binding the smaller aggregates into larger structural units. The S% index which, is more or less the reciprocal of the WSA<0.25 mm confirms this assertion. Here percent organic carbon is positively correlated with the S% index (r=0.73) implying that more of the organic carbon is involved in stabilizing more than 0.2 mm water-stable aggregates.

The fact that the correlation between the ASC or AC and percent organic carbon is low, albeit positive, can be explained by the fact that at the most fundamental level of aggregation the organic carbon can act as either an aggregating or a disaggregating agent depending on the relative contributions of the other aggregating agents (clay and divalent cations). Hence, when aggregate stability at this fundamental level is compared across different textural classes the influence of organic carbon will appear to be diminished [16].

The higher the value of the plasticity index (PI) of a soil, the less the force required to mold it. The PI is the amount of water that needs to be added to the soil system to increase the distance between its constituent particles from a film thickness at which maximum tension occurs to a thickness that produces flow. The high correlation coefficient of 0.92 between AC and PI indicates that both indices are closely related and that in fact PI can be estimated from the more easily determined AC index (Fig. 1A). The significant positive correlations between PI on the one hand and ASC, MWD, and WSI on the other hand also implies that the PI index can be used as a measure of the stability of aggregates to water.

The ratio of the sand + silt to clay contents (K) was proposed as a stability index for soils in which the main aggregating agent are the clay particles [2]. Higher ratios indicate smaller values of clay and therefore lower stability. Hence the negative correlations between this K ratio and ASC, AC, MWD, WSI and S indices and positive correlation with WSA<0.25 mm imply that all the indices are measuring the same aspect of stability even though at varying degrees. The highly significant negative correlation (-0.93) between AC and K in

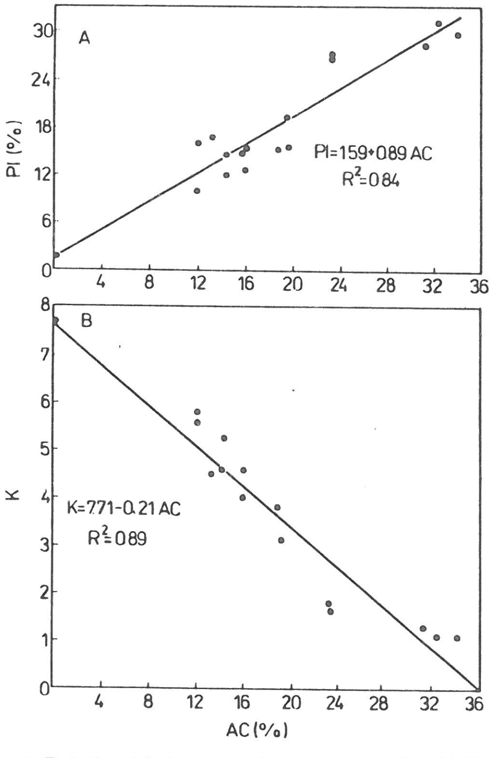

Fig. 1. Relationship between: A - aggregated clay (AC) and plasticity index (PI); B - aggregated clay (AC) and sand + silt/clay ratio (K).

particular emphasizes again the close relationship between the two indices and the possibility of predicting one from the other (Fig. 1B).

Evaluation of the stability tests

Three important criteria for evaluating structural tests of stability are reproducibility, ease of determination and ability to reflect differences in land use history. Variation in organic carbon contents of soils is one of the measures od differences in land use history. Only two indices (WSA<0.25 mm and S%) were consistent in reflecting this.

These two indices were also the easiest to determine, each requiring only two weighings for computation. This contrasts with the ASC and AC indices which require the use of two different dispersants for particle size fractionation, evaporation of the liquid in the pipetted soil suspensions and the use of precision balance (at least up to four decimal places). The MWD index also involves repeated weighings each of which is associated with a scale sensitivity error.

A measure of reproducibility of results is the coefficient of variability (CV) among replicate determinations. These were 14.5%, 15.9%, 10.2%, 29.6%, 20.6% and 7.9% for the ASC, AC, WSA<0.25 mm, MWD, WSI and S% indices, respectively. Again the WSA<0.25 mm and the S% indices have the lowest CV values and hence indicate better reproducibility.

CONCLUSIONS

The studies carried out allow us to draw the following conclusions:

1. Of the six structural indices used to measure the stability of 15 soils, those representing micro tests can be arranged as follows: the percent water stable aggregates (WSA<0.25 mm) index reflected differences in organic carbon levels more than the aggregated silt+clay (ASC) and the aggregated clay (AC) indices. Similarly among the macro (WSA>0.25 mm) tests the single sieve percent water stable aggregates (S%) reflected such differences more than the water stability index (WSI) and the mean-weight diameter of water-stable aggregates (MWD). The WSA<0.25 mm and S% indices were also the easiest to determine and the most reproducible.

2. The ASC index correlated positively whereas the WSA<0.25 mm negatively with all the macro indices. Differences in the plasticity index (PI) and the (sand+silt)/clay ratios (K) of these soils were most clearly reflected by the AC index. This suggests that these physical parameters are closely related to structural stability at this micro level.

ACKNOWLEDGEMENTS

This study was partially financed by the International Centre for Theoretical Physics, Trieste, Italy, under its programme of “Training and Research in Italian Laboratories”.

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