TWO SUGGESTIONS FOR QUANTIFICATION OF FIELD MORPHOLOGY[1]

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Abstract. It should be useful for evaluation of the physical condition of mine soils to have field tests that (1) could be made at a narrow range of water suction and (2) stand largely independent of soil survey descriptive approaches. We would improve control of the water state by use of a Mariotte Container to add water. We further propose use of the so called Modified Singleton Blade test to evaluate resistance of the soil to failure against a stress. The test involves insertion of a blade, an established depth into the soil followed by rotation using a Pocket Penetrometer to measure the force required. The width of the blade selected is decreased as the strength of the soil fabric increases.

Additional Key Words: Singleton Blade, Soil Morphology Index, Mariotte Container.

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Introduction

Formation of mine soils in the process of reclamation is an engineering exercise. It would seem plausible that personnel of mining companies would prefer an empirical test for soil physical condition rather than the application of soil survey descriptive approaches which require much experience to master and are not highly quantitative. It also would be highly preferable to have a procedure to moisten the soil in a controlled fashion. We propose to use a Mariotte container to moisten the soil and a Modified Singleton Blade test to make measurements of soil physical condition. In this test a blade of variable width is inserted into the soil a standard depth and the force determined to rotate the blade using a Pocket Penetrometer to apply and measure the force applied.

Penetration resistance using a 30° cone, referred to as the Cone Index (Lowery and Morrison, 2002), is widely used in agronomy. One may inquire why use the Modified Singleton Blade test instead of the Cone Index. The Cone Index inherently does not reflect structural expression and size, which is part of the information needed to evaluate physical condition. It is a useful measurement if the soil material is massive or has weak structure, or the structure units are fine, perhaps less than about 2 mm across horizontally. But the mechanical process of moving and redepositing most soil materials in mine spoil reclamation, unless coarse textured, produces a soil fabric with planes of weakness exceeding perhaps 10 mm in the longest dimension and commonly exceeding 50 mm. These dimensions are of the order or exceed the base diameter of the larger of the two most common tips used in agronomy which is 19 mm.

Methods

Water State

For many conditions the soil should be moistened before the Singleton Blade test. Heretofore, in our practice, moistening has been accomplished by insertion of rings 30 cm diameter and 15 cm high to the minimum depth that avoids large scale lateral leakage. For the tests used 10 to 20 cm of water is added. The objective is to bring about 30 cm depth to field capacity. In the process of moistening the uppermost part of the soil may be modified, particularly if initially dry, despite the use of an energy breaker.

We have the alternative of slowly prewetting from a Mariotte container (Fig. 1) that is placed over the point to be subsequently excavated for measurements of physical organization. Water is applied at a rate below that to produce ponding at the ground surface. Hence, the soil beneath the Mariotte container should be under at least very low suction (assuming absence of a water table) and so less subject to alteration.

Mariotte containers may be of variable size. Current emphasis is on 19ℓ (5 gallon) plastic containers with a rather large hole in the top, such as are commonly used for liquids in commerce. A large rubber stopper with a vertical hole is mounted in the hole. Plastic or aluminum pipe about 1.5 cm ID is inserted through the hole in the stopper; the length should permit adjusting the height above the bottom of the container by hand. Holes at the bottom are made with a 1.6 mm (1/16 inch) drill bit. A piece of duct tape is placed over the hole. A coincident hole, smaller than 1.6 mm, is made in the duct tape using a suitable diameter needle. Alternatively, an 11 mm (7/16 inch) hole is made in the bottom of the Mariotte container and a serum stopper inserted through which is pushed a large hypodermic needle. Multiple holes may be made.

An energy breaker is needed. Absorbent material may be placed on the ground surface or a small hole dug and plugged with absorbent material over which the hole or holes in the Mariotte containers are placed. For the latter kitchen toweling rolls minus the central cardboard work well. It is necessary to know the position of the water outlet in the mounted Mariotte container relative to where it is desired that the water be delivered. One approach is to place an annulus of about 8 mil plastic over the soil. The annulus of plastic should have an outside diameter 10 to 15 cm larger than that of the Mariotte container and an inside diameter that readily encampasses the position of the holes in the Mariotte container. The plastic is so marked that in mounting the Mariotte container on the soil the position of the water outlet is known relative to the point(s) to be wetted.

For insertion of the Singleton Blade successfully into a horizontal plane the excavation must be at least 1 m long. It may be necessary to use two adjacent 19ℓ Mariotte containers each with two holes along their diameters. For sloping sites the wetting tends to be offset to the downhill side. To counteract, the water delivery can be placed somewhat above where the wetting is desired.

Prior wetting of a point could be made quite quantitative. A test observation point can be established and from the information a strategy developed to produce an acceptable suction profile by addition of more water or draining while covered for a longer time. The tension may be specified at a depth related to the objective. If near-surface physical condition is desired, the depth of measured tension could be from 10 to 20 cm. A porous cup tensiometer with a Bourdon gauge would seem adaptable. If 10 kPa were the upper limit several of the models listed in Table 3.2.-2 of Young and Sisson (2002) should be satisfactory. For the example to be discussed (Tables 1 and 2), it should be possible to calculate the suction from the field water content and standard soil survey laboratory data applied to the measurement point. Simple, accurate procedures for gravimetric water content are available. For some situations use of deionized water brought to 0.01 M $CaC1_2$ may be preferable.

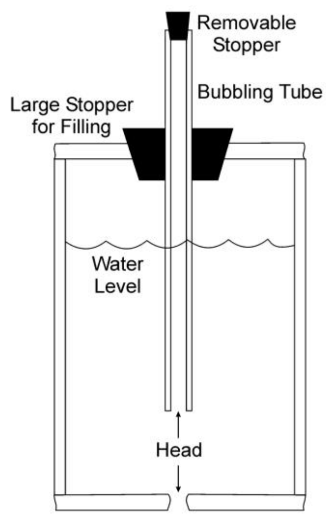

Figure 1. Schematic of a Mariotte Container. (Modified from Ogden et al., 1992).

Modified Singleton Blade.

We will first describe the original device and present information from the original publication (Griffiths, 1985). We refer to the test using the original design of the blade as the Singleton Blade test and to the test proposed as the Modified Singleton Blade test.

Fig. 2 shows the dimensions of the original Singleton Blade. The blade is 3.0 mm thick. The circle represents recess made on either side, within which the tip of a Pocket Penetrometer is

Table 1. Morphology Index and Strength by the Modified Singleton Blade for the uppermost 30 cm of a pedon of Aksarben located in Lancaster County, NE. Measurements were made on December 19, 2003, Julian Date: 2452993. Elevation is above sea level 1214 ft.; GPS coordinates :N40º 59.206'; W96° 33.790.

Depth cm	Water State gravimetric pct	Water State suction[1/] kPa	Morphology Index[2/]	Depth cm	Modified Singleton Blade Test[3/] $N\ cm^{-1}$
0-3	34.6[4/]		83	0-3	1.0
				3-6	3.2
3-7	27.4	0.2	20	6-9	5.1
				9-12	7.9
7-15	23.4	0.3	50	12-15	8.2
				15-18	6.4
15-20	24.3	0.3	58	18-21	7.3
				21-24	4.8
20-30	26.9	0.3	75	24-27	4.8
				27-30	6.7
0-10			48		
10-20			55		
20-30			80		
0-30			55		

1/ Baumer 1992, which is based on a van Genuchten-type power function (Kosugi et al, 2002.) Particle size, bulk density, water retention at 33 1500 kPa, and cation exchange capacity by NH_4Ac are inputs.

2/ Based on structure and rupture resistance only. Consult Appendix A.

3/ 3cm insertion.

4/ Two days prior to the measurements, the soil was frozen 0-3 cm. The gravimetric water content was 60.1% and the mode of failure after thaw was moderately fluid (Soil Survey Div. Staff, 1993).

Table 2. Properties of the pedon of Aksarben that appear in table 1.[1/]

Depth	Sand 2-0.05	Silt 0.05-0.002	Clay <0.002	Weight Water Retention l/3 bar	15 bar	Bulk Density 1/3 bar
cm		Pct		Pct		g cm^{-3}
0-3	7.1	63.6	29.3	-	13.1	1.00
3-7	5.5	64.7	29.8	24.5	12.6	1.42
7-15	4.5	64.2	31.3	23.9	13.1	1.46
15-20	3.2	63.4	33.4	24.6	14.2	1.40
20-30	2.4	61.0	36.6	27.5	15.6	1.32

1/ Sand, silt, and clay by 3A1d, 1/3 bar by 4B1c, and 15 bar by 4B2a, and bulk density except for 0-3 cm by 4A1d in Soil Survey Laboratory Staff (1996). The bulk density 0-3 cm was by the ring-excavation method (Grossman and Reinsch, 2002). For calculation of CEC by NH_4Ac the clay percentage was multiplied by 0.60.

placed. The handle is a solid cylinder of resistant plastic, 2.5 cm diameter and 3 cm long with a 3 mm wide groove cut inward 1 cm. The blade is inserted into the groove and glued. The end with the notch is beveled. The blade is held normal to the face of the exposure in a vertical plane with the notch upward. Alternatively, the insertion may be in a horizontal plane. Insertion of the blade is to where the notch just touches the soil. The tip of the pocket penetrometer is placed in the recess in the blade. The force is applied 5 cm from the mid plane of the insertion depth over 3-5s. The median of at least 5 determinations should be reported. Obviously, the Singleton Blade test may be inapplicable if the volume of rock fragments in excess of about 5 mm (No. 4 sieve) is appreciable.

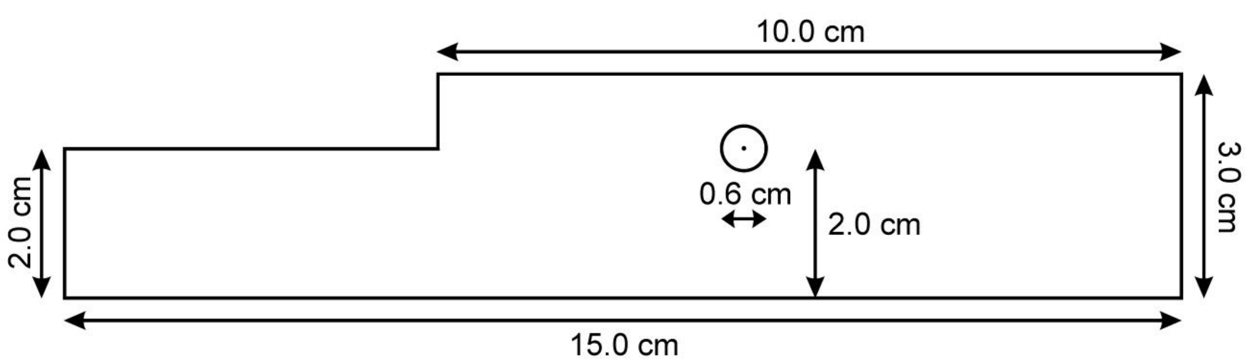

Figure 2. The dimensions of the original Singleton Blade.

The discussion to follow is from Griffiths (1985):

> *Permeability and packing: Permeability is related to the consistence of the soil, a property usually determined from unconfined samples. In assessing the permeability of soils for agricultural purposes, however, the characteristics of undisturbed (i.e., confined) horizons are relevant. A new term is required which reflects the condition of particles or peds in undisturbed soil. Packing is proposed as a general term and degree of packing as an indication of how closely or densely the particles or peds are packed together. Closely packed units leave smaller spaces between them that loosely packed ones, leading to decreased porosity. At present it is proposed that these terms will apply in all moisture states.*
>
> *The degree of packing is defined in terms of the ease with which particles or peds may be removed from the horizon. This procedure has worked relatively well but much depends on the skill and experience of the pedologist. Penetration resistance as a measure of packing is not satisfactory because results are greatly affected by soil moisture content and the presence of gravels of stones.*
>
> *A more objective method that gives greater uniformity of assessments is introduced here. A single-vane tester or Singleton Blade is inserted vertically into the soil and the force required to push it sideways is measured with a penetrometer. Difference parameters are being measured in different situations: in pedal soils the degree of interped packing is being measured; in non-coherent apedal soils, the degree of interparticle packing; in coherent apedal soils, the cohesive force.*
>
> *Moisture content as well as pedality, or the lack of it, affects the force required to move the blade. This force is greater for dry soils that for moist, but about the same force is required for wet and moist coherent soils. This contrasts with the case of penetration resistance, where significantly different readings are obtained from wet and moist soils.*

Griffiths refers to “degree of packing.” The use of the term “packing density,” which would seem very close in concept to “degree of packing,” is discussed by McKeague et al., (1984). The term “packing density” is applied in Europe but not in the U. S. soil survey. The analogues concept in the U. S. soil survey involves structural expression, size and rupture resistance.

Rationalization of "packing density" to bulk density, structural expression, and rupture resistance is needed.

The blade for the original test may be too narrow for there to be sufficient soil resistance to measure readily and is probably too thick for fragile fabric. To make a blade for the Modified Singleton Blade test commercial blades are selected that have an edge normal to the axis of force exertion, the lowest thicknesses possible which avoid flexure for the range in force to be applied, and a blade depth not less than about 5 cm. Paint scrappers and putty knives are possible commercial tools. Fig. 3 contains a commercial blade, the original blade, and a Pocket Penetrometer. A point is selected 5 cm above the mid plane of the depth of blade insertion and alone the longitudinal axis of the tool. This point is where the force is applied with the Pocket Penetrometer (Lowery and Morrison, 2002). Commonly a washer with an inside diameter slightly larger than the 6 mm diameter of the tip of the Pocket Penetrometer is glued onto the blade as a guide to where the force is applied; alternatively the blade can simply be marked with a pen or scribed.

Figure 3. The Modified Singleton Blade and the original blade at the site for the data are in Tables 1 and 2. The measuring tape is extended to 5 cm.

The blade is inserted vertically a predetermined distance into the soil. Force is applied with the Pocket Penetrometer until the blade has been rotated a minimum of 45°. The pressure is converted to force by dividing by the area of the flat-end tip of the Pocket Penetrometer which is 0.317 cm^2. Insertion depth is constant. Griffiths (1985) used 5 cm. We suggest 3 cm for the near surface. We report the strength in kilograms per centimeter of width of the blade. We do not use units of pressure because the pivot depth in the rotation is not fixed as it is for a vane sheet test. Scale of the Modified Singleton Blade would be dependent on objectives. A possible appropriate approach for mine spoil would be to increase the scale of the tool with depth. A machine probably could replace hand operation. Commonly, the ground surface is scored 1-2 cm deep with a sharp knife and the blade is inserted first at a corner and then rotated to be horizontal with the ground surface at the completion of insertion.

A few remarks are in order about the Pocket Penetrometer. We use the devise sold by Soil Test[a]; other vendors have essentially the same product. For the Soil Test instrument and perhaps others the scale is in bars but it is not the pressure exerted at the scale mark. Rather, it is an estimate of what the unconfined compressive strength expressed in bars would be at that scale mark. It is necessary to calibrate the spring to the marks using a top loading balance. We use four springs: the original, Lee LCO 38G13SS from Lee Spring Co., 1452 62nd St., Brooklyn, New York 11219, and Jones 11 and Jones 323 from Jones Spring Co., 5509 Fairlane Drive, Cincinnati, Ohio 45227. Tables are prepared relating the marks on the barrel to <u>force</u>.

Discussion

Table 1 contains the Morphology Index and the Modified Singleton Blade test for a pedon of Aksarben (Typic Arguidoll fine, smectitic, mesic) located in Lancaster County in Southeast Nebraska. Table 2 contains relevant laboratory characterization data. The site is in Map Unit Sharpsburg silty clay loam, 2 to 5% slopes (Brown et al. 1980). Soybeans were grown in 2003 in a no-till corn-soybean rotation. Suction is calculated for the gravimetric field water content of the delineated zones for the Morphology Index (Appendix A) from standard characterization data. In practice the suction estimates would be made from soil characterization data applied to the point measurement. There are 20,000 or so such records. Consult http://www.soils.usda.gov and select “Soil Lab Data” for the records. Such calculated suction values could be used for rationalization of strength tests. The measured water retention at 1/3 bar and the field water content are similar for nearly the same suction, which is supportive evidence for the model-based calculation of the suction. Pre-wetting was not attempted because temperatures were below freezing during part of the day. In practice, measurements by the Modified Singleton Blade test need not be made continuously through the study depth. However, if the test is made by non-pedologists, the interval between the measurements must be small because presumably sensitivity to morphology change with depth would be low.

We do not have enough data to construct an index using data by the Modified Singleton Blade test. Presumably very low values in the uppermost few centimeters coupled with weak structure or massive conditions would be suggestive of susceptibility to wind and water erosion. Such an inference has been made for the Morphology Index (Grossman et al., 2001). We can construct indexes that reflect weighting with depth as has been done for the Morphology Index to apply to guidelines of tilth. For water movement at low suction or satiated conditions, the depth to specified high values of N cm^{-1} would come into play.

Conclusions

We have provided approaches to control water state and to make empirical measurement of strength. The former uses Mariotte Containers and the latter the Modified Singleton Blade test. The twin approaches if developed and applied to mine soils should provide opportunities to increase the reproducibility of morphological evaluation, and in particular by people not conversant with standard soil survey descriptive protocol. Aside from the Modified Singleton Blade test the proposals on water state control should be helpful for the Cone Index.

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Dr. Allen Hewett, Landcare Research, Lincoln, New Zealand, introduced the senior author to the Original Singleton Blade in 1989.

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[a] Information provided on commercial products does not imply endorsement.

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Appendix A

The Morphology Index (Grossman, et al. 2001) uses descriptors from the Soil Survey Manual (Soil Survey Div. Staff, 1993), principally structure and rupture resistance, and optionally crust and surface connected macropores, to construct a numerical statement about the physical state of the soil, usually 0-30 cm, in respect to root growth and water transmission. It is used in Seybold, et al., (In Press) in this volume. In the discussion to follow we exclude crust and surface-connected macropores.

All layers except the crust must be *moderately moist* or wetter. Layers within the 30 cm depth zone should be recognized wherever there is a change in the quality class of a feature. In order for a freshly tilled zone to be considered, at least 50 mm of water must have passed through it after tillage, and all parts must have alternated at least once between *wet* or *very moist* and *slightly moist or dry*. Five quality classes are provided for each of the morphological properties. The class sets are ranked with 5 being the best and 1 the worst. The class sets are combined following rules to be discussed later to produce a 2-digit index number between 1 and 5 (e.g., 4.2). Index numbers may be expressed to a 100 base: $\text{Index}_{100} = 100 - ((5\text{-Index}_5) \times 25)$.

Four classes of particle size designated A through D are defined: (A) Sand, Loamy sand; (B) Not A and Clay <18%; (C) Clay 18-40%' and (D) ≥40%. Skeletal is the same as non-skeletal; fragmental is not considered. Structure and rupture resistance are combined to obtain the placement. Relative weight for structure is decreased as texture becomes coarser because maximum structural expression decreases and is less diagnostic of soil quality:

Textural Class	Rule
A	Use rupture resistance only
B	Use whichever gives the higher class placement of the two properties
C	Weight structure twice rupture resistance except, if *very friable*, then use rupture resistance alone.
D	Use structure class alone.

An overall index is computed from the constituent layers 0 to 30 cm (Table A3). Weighted averages are calculated for the three 10 cm intervals or for the total thickness divided by 3 if there is a root restriction above 30 cm. Next the indices for the three zones are weighted 4, 2, and 1 with increasing depth and the weighted average computed for 0-30 cm. Report as 1.0 to 5.0 index to the nearest 0.1 or on a 100 base. Computation of the index is directed towards plant growth. If the interest is water transmission, importance should be given to the depth that the index is 2 or less.

Tables A1, A2, and A3 give, respectively, the classes of structure, those of moist rupture resistance, and an example of application.

Table A1. Soil quality classes of structure.

Class	Criteria
1	All structures with common or many stress surfaces irrespective of other features, massive, platy with firm or stronger horizontal rupture resistance, all weak structure except granular, moderate very coarse prismatic, all columnar.
2	All structures with few stress surfaces irrespective of other features, platy with friable horizontal rupture resistance, weak granular, moderate very coarse and coarse blocky and coarse and medium prismatic, strong coarse and very coarse prismatic.
3	No stress surfaces, platy with very friable horizontal rupture resistance, moderate medium blocky and very fine and fine prismatic, strong very coarse blocky and medium prismatic.
4	No stress surfaces, moderate granular, moderate very fine and fine blocky and very fine prismatic, strong fine prismatic and coarse blocky
5	No stress surfaces, strong granular, strong very fine through medium blocky and very fine prismatic.

Table A2. Soil quality classes of moist rupture resistance.

	Moist Rupture Resistance				
Texture Class	Loose	Very Friable	Friable	Firm	Very Firm &Stronger
A	2	3	3	2	1
B	3	4	3	2	1
C	4	5	3	2	1
D	5	5	3	1	1

Table A3. Comparison of the morphology index for traffic and non-traffic interrows in a long term controlled traffic experiment. [1, 2]

Depth	Structure Rupture Resistance	SRI[3]
Cm	**Non-Traffic**	
0-3	Moderate to weak fine granular, Very friable	3.7
3-6	Moderate very fine subangular, Very friable	4.3
6-14	Moderate to strong, fine blocky, Friable	4.0
14-20	Moderate fine to medium blocky, Friable	3.3
20-25	Moderate fine blocky, Very friable	4.3
25-30	Moderate fine blocky, Very friable	4.3
0-10		4.0
10-20		3.6
20-30		4.3
0-30		3.9(73)
	Traffic	
0-3	Strong very coarse platy, friable	1.7
3-18	Massive, Firm	1.3
18-22	Moderate medium to coarse blocky, Firm	2.3
22-30	Moderate fine blocky, Very friable	4.3
0-10		1.4
10-20		l.5
20-30		3.9
10-30	1	1.8(20)

[1] At Rogers Farm, University of Nebraska, located in Southeast Lancaster County. The soil is Wymore, an Aquertic Argiudoll, fine, smectitic, mesic. The map unit is Wymore silty clay loam, 7 to 11% slopes, Brown et al (1980). All parts 0-30 cm are fine-silty or fine. The observations were made 7/19/97.

[2] Ksat is by the Amoozemeter (Amoozegar, 1992). Water column 10-25 cm. For traffic 0.02 cm hr^{-1} and for non-traffic 0.3 cm hr^{-1}.

[3] Structure-Rupture Resistance Index. Raindrop-impact crust, macropores, and cracks not present.