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Soil Must be Kept at Field Water Content for Evaluation of Soil Physical Quality

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Abstract: Soil water content has very large effects on soil physical properties. However, it is not widely known that the changes in soil physical properties that occur when soil dries are not necessary reversible by re-wetting the soil. In this paper, we report the effects of drying on two types of physical properties. Firstly, we consider the Atterberg limits: the plastic limit, the liquid limit and the plasticity index. In this case, we find that air-drying soil and re-wetting it reduces the plasticity index. This is equivalent to saying that air-drying and re-wetting makes the soil more "sand like". Then we consider the content of readily-dispersible clay (RDC) in the soil. When soil is dried from field capacity, the content of RDC is reduced. Drying beyond about –3 MPa results in low levels of RDC that are not reversed by 2 weeks in water. On the other hand, the effects of drying down to –0.45 MPa causes reductions in RDC that can be reversed within 4 days. It is concluded that in studies of the physical quality of soils in the field, soil samples should not be allowed to become drier than at the time of sample collection or than they have been in the field.

Key words: Atterberg limits; Effective stresses; Readily-dispersible clay; Soil physical quality, van der Waals force

INTRODUCTION

The evaluation of soil physical quality requires accurate measurements of soil physical properties. In this paper, we show that not only the measurement methods are important but also the method of soil storage and pre-treatment.

It is well-known that when soil is subjected to increasing mechanical pressure, p, applied externally, its porosity decreases as shown in simplified form in Fig. 1. Plastic (irreversible) compression follows the virgin compression line (VCL). When the stress is reduced, the strain does not re-trace the same path, but instead follows an approximately elastic (reversible) path. The maximum value of stress applied in plastic compression is known as the pre-compression stress, p_c.

Subsequent variations of stress, but below p_c, the strain varies according to the elastic (reversible) path. If the stress exceeds the previous p_c then the strain path rejoins the VCL producing a new, higher value of p_c. The value of p_c, therefore, is the maximum value of stress to which the soil has been subjected previously.

When soil dries, a similar phenomenon occurs. At a given matric water potential, Ψ, the soil is subjected to effective stress that can also decrease the porosity. The main differences between soil compression by externally-applied mechanical stress and internally-applied stress due to the pore water are:

(1) as the pore water suction, $h = -\Psi$, becomes larger, the soil desaturates and only a portion, X, of the pore water suction is effective.

(2) in unsaturated soil, the effective stress does not act on the whole soil, but only on the saturated parts of it that lie between air-filled pores. In dry conditions, the effective stress may act only on groupings of clay particles.

In the same way as shown in Fig. 1, the effective stress due to the pore water can compress (i.e. decrease the porosity) of the soil. The soil porosity, then depends on the greatest value of effective stress, p_c, to which the soil has been subjected previously.

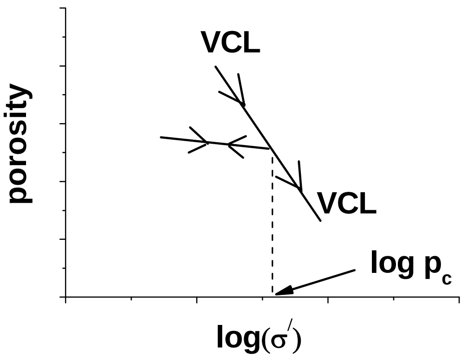

Fig. 1. Reduction in soil porosity caused by increasing effective stress, σ′.

The enormous effect of effective stresses can be understood when it is known that in agriculture, the externally-applied mechanical stresses are usually smaller than 10 MPa, whereas pore water suctions, h, developed during drying can reach 500 MPa. Compression of the soil by pore water suction has been shown to modify the soil pore size distribution and hence the shape of the water retention curve (Baumgartl, 2003).

To a first approximation, the mean effective stress, σ', due to pore water acting on bulk unsaturated soil is:

$$\sigma' = Xh \qquad (1)$$

Plastic compression of soil (i.e. along the VCL shown in Fig. 1) occurs mainly by re-arrangement of the mineral particles.

Soil particles are not normally in direct contact, but have water (actually, electrolyte solution) between them. The thickness of this layer of water is governed by the balance between the repulsive force due to the interactions between the electrical double layers and the attractive van der Waals force (Israelachvili and Adams, 1978). The repulsive force depends strongly on the nature of the particle surface, adsorbed cations and the electrolyte solution, whereas the attractive force is essentially independent of both the nature of the particle surface and of the composition and concentration of the electrolyte solution (Israelachvili and Adams, 1978).

As soil dries, electrical double layers become compressed and the distance between the particles decreases progressively. While the attractive and repulsive forces remain balanced, the system behaves elastically and reversibly. That is, any decrease in particle separation during drying can be re-gained on re-wetting.

However, at small separations (<5 nm), the attractive van der Waals forces exceed the repulsive forces and the particle surfaces fall into strong adhesive contact (Israelachvili and Adams, 1978). This change is essentially irreversible.

In this paper we investigate the effects of different intensities of drying on two types of soil physical properties. Firstly, we consider the Atterberg consistency limits. Then, secondly, we examine the content of readily-dispersible clay in the soil.

MATERIALS AND METHODS

The experiments were done with four different arable soils from northern France having a range of clay and organic matter contents.

The soil samples were collected from agricultural soils, that had not been recently tilled, in the spring of 2008. The samples were stored in plastic bags that were then stored in hermetic plastic boxes in a cold room (4 °C) until required. These procedures ensured that the samples remained moist and had minimal biological activity.

The compositions of the soils were analysed by standard methods.

The Atterberg consistency limits were measured using conventional methods very similar to those described by McBride (2008). The lower plastic limit, PL, was measured with 10 replicates. The upper plastic limit (or liquid limit), LL, was measured using the Casagrande method with 4 different water contents. The plasticity index, PI, was calculated as PI =LL-PL.

The content of readily-dispersible clay (RDC) was measured using a method based on that described in Czyż et al. (2002). In this method, 5 g of moist soil is added to 125 mL of water in a 150mL bottle and a small energy input is applied by inverting the bottle 4 times. After 16 h of sedimentation, a sample of the suspension is collected from the bottle and its turbidity is measured with a Hach 2100AN turbidimeter. This measures the concentration of colloids in suspension through the amount of white light that is scattered. The turbidimeter gives readings in units of NTU, and we normalize this in terms of the original concentration of soil particles in the suspension in gL^{-1} to give turbidity, T:

$$T = NTU/(gL^{-1}) \tag{2}$$

The water retention characteristics of the soils were determined using conventional methods in the range of pore water suctions from 10 hPa to 15000 hPa.

The water retention data were fitted to the van Genuchten equation (van Genuchten, 1980):

$$w = (w_{sat} - w_{res})\left[1 + (\alpha h)^{n}\right]^{-m} + w_{res} \tag{3}$$

where w_{sat} and w_{res} are the saturated and residual gravimetric water contents, respectively, α (hPa^{-1}) is a scaling factor for the matric suction, and m and n are parameters which govern the shape of the curve. The van Genuchten equation was fitted with the Mualem (1976) restriction:

$$m = 1 - \frac{1}{n} \tag{4}$$

Sub-samples of the soils were dried to different water contents in 4 different ways:

(a) drying on ceramic pressure plate extractors,
(b) drying over saturated salt solutions,
(c) slow drying in air until the required gravimetric water content had been attained, and
(d) oven drying at different temperatures.

Gravimetric water contents after the different intensities of drying produced by the method (c) were converted into the corresponding pore water suctions using the inverted form of Eqn. (3) which is given in Eqn. (5):

$$h = \frac{1}{\alpha} exp\left[\frac{1}{n}\left\{exp\left[-\frac{1}{m} ln\left(\frac{w - w_{res}}{w_{sat} - w_{res}}\right)\right] - 1\right\}\right] \tag{5}$$

Pore water suctions are reported on a logarithmic scale of

$$pF = \log_{10} h \tag{6}$$

where h is in hPa. This is helpful because of the wide range of values of h used.

The pF values corresponding to oven-drying and air-drying at different temperatures were calculated according to the procedure of Dexter and Richard (2009).

RESULTS AND DISCUSSION

Details of the compositions of the studied soils are given in Table 1.

Table 1. Some Physical Properties of the Studied Soils.

Soil	Sand g/100g	Silt g/100g	Clay g/100g	OC g/100g
Villamblain	1.7	65.2	33.1	1.30
Boigneville A	8.0	66.0	26.0	1.33
Boigneville B	7.8	68.6	23.6	2.89
Faux Perche	5.3	82.9	11.8	1.21

This illustrates that a range of soil textures was used. Also, of special interest are the Boigneville A and B soils. These are basically the same original soil but with significantly different contents of organic carbon (OC). These had received 20 years of different tillage treatments. Boigneville A had been conventionally tilled , whereas Boigneville B had been direct-drilled (no till), but with some soil disturbance down to 50 mm depth. All the soil samples were collected from the tilled (disturbed) layers.

The results of the Atterberg limit tests are shown in Table 2. Results are presented for soil samples that has been kept at field water capacity (FWC) since sample collection and for soil samples that had been air-dried for 2-3 weeks in the laboratory

Table 2. Measured values of the Atterberg consistency limits. Results are given in kg (100 kg)$^{-1}$.

Soil	PL	LL_{FWC}	LL_{AD}	PI_{FWC}	PI_{AD}
Villamblain	27.4	43.4	41.0	16.0	13.6
Boigneville A	22.9	37.1	35.1	14.2	12.2
Boigneville B	34.8	53.9	46.5	19.1	11.7
Faux Perche	24.5	33.2	30.2	8.7	5.7

Drying and re-wetting had no statistically-significant effect on PL. However, the results in Table 2 show that there were large effects on LL. For the four soils investigated, the mean reduction in PI due to air-drying and re-wetting was:

$$\Delta PI = 3.8 \text{ kg } (100 \text{ kg})^{-1}. \tag{7}$$

The reduction in PI shows that the soil had become more "sand like". In fact, the soil even felt more sand-like as it was much more "gritty" during the mixing and moulding process. Particle size analysis by scattering of laser light showed that micro-aggregates of about 100µm diameter had been formed by the drying and re-wetting process. The strength and stability of these micro-aggregates was illustrated by their ability to withstand destruction by intensive moulding when wet.

Fig. 2 shows an example of how the content of RDC changed with drying to different values of pF. All four soils behaved in a similar way.

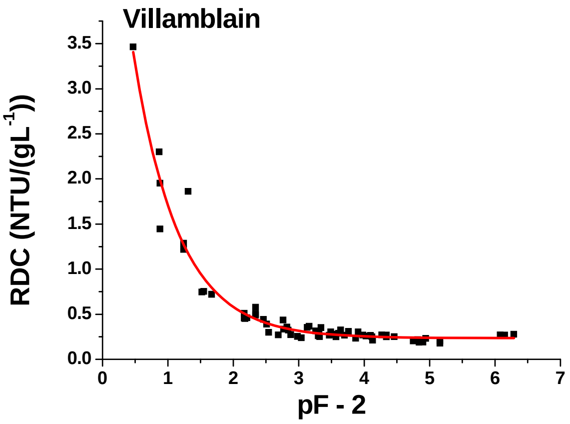

Fig. 2. Values of RDC obtained with Villamblain soil that has been dried to different values of pF.

The RDC data for the slowly air-dried samples were fitted to

$$RDC = k + A\exp(-x/x_0), \qquad (8)$$

where x = pF – 2. At field capacity (h = 100 hPa), x = 0 and $RDC_{fc} = k + A$. Eqn. (8) shows how the amount of RDC decreases with increasing pF. Different soils have different values of k, A and x_o.

Drying of soil beyond about pF4.5 modified the soil irreversibly such that two weeks in water did not result in any increase in RDC. A similar effect of air-drying on RDC was found for 19 Polish soils by Gaţe (2006). We conjecture that in this range, van der Waals attractive forces control the particle spacing.

In contrast, drying of soil from pF2 to pF3.65 caused reductions in RDC that were reversible. Re-wetting to pF2 for four days caused the value of RDC to increase back to its original value. We conjecture that in this range, repulsive forces between the electrical double layers control the particle spacing.

CONCLUSIONS

1) The results show that air-drying or oven-drying of soil to values of pF>4.5 and re-wetting it resulted in the soil becoming more "sand-like" due to the formation of stable micro-aggregates.

2) Drying soil to values of pF>4.5 resulted in smaller contents of readily-dispersible clay when the soil was immersed in water. The effect was irreversible for periods of at least two weeks.

3) We conclude that soil samples after collection from the field should not be allowed to dry beyond about pF3.65 (Ψ=-0.45 MPa) before measurement of physical properties. Any further drying is likely to produce irreversible changes in physical properties.

4) We recommend that soil samples collected from the field be equilibrated at pF2 (Ψ=–100 hPa) on a sand table for one week before measurement of the content of readily-dispersible clay. This has the effect of standardizing the initial conditions.

5) To measure the physical properties that soil has in the field, soil samples must not be allowed to become drier than they have been in the field.

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