Int. Agrophysics, 1993, 7, 221-227

SHRINKAGE DETERMINATION OF SOIL AGGREGATES

W. Owczarzak, S. Rząsa, Z. Kaczmarek

Univeristy of Agriculture, Department of Soil Science, Mazowiecka 42, 60-623 Poznań, Poland

A b s t r a c t. The present paper describes shrinkage determination method and results obtained in the conditions of modelled compaction (density, porosity). The investigations were carried out on 1.0 and 50.0 cm^3 modelled cylindrical aggregates. Ten soils of different texture (from sand to clay) and different amount of organic matter were selected for the investigations.

The device used to measure the shrinkage makes it possible to achieve simple, safe and fairly accurate determination of shrinkage-limit and moisture at shrinkage-limit. The value of shrinkage is mainly affected by soil texture, particularly clay content, amount of organic matter and initial soil moisture.

The correlation between shrinkage value and clay content in the soil was determined in the paper. Moreover, the relationship between moisture at shrinkage-limit and hygroscopic capacity (*H*), particularly maximal hygroscopic capacity (*MH*), was established.

K e y w o r d s: method, shrinkage, soil aggregate, moisture

INTRODUCTION

Soil shrinkage has usually been treated marginally in investigations of soil physical properties. This has been mainly caused by methodological aspects - namely by the lack of well designed, tested and uniformized shrinkage determination methods for agrotechnics.

Soil mechanics has focused on shrinkage problems to the largest extent and it is adjusted to the needs of various engineering constructions [1,8]. However, the shrinkage-limit and moisture at shrinkage-limit determination is difficult to adapt for agrotechnical purposes, particularly for soil aggregate or arable layer shrinkage investigations. In the case of cultivated soils, moisture and porosity changes take place in a very wide range of values as compared with those of the ground. Therefore the Department of Soil Science, University of Agriculture, Poznań, carried out studies to improve and adapt previous methods [1,8] in order to investigate different soil structures - cohesive, aggregate, natural, modelled, etc.

The aim of our studies was to determine the shrinkage and moisture values at shrinkage-limit by the use of a device constructed by the authors for the purpose of measuring the parameters. There was also an attempt to determine the correlation between shrinkage moisture and the higroscopic capacity and maximal higroscopic capacity.

METHODS

Ten soils were chosen for the investigations on the basis of their genetic aspect, texture as well as physical and chemical properties. Table 1 presents the most important properties - texture and organic matter content.

To investigate the problem of soil shrinkage, the assumptions and concept of modelled aggregate structures have been used, which were published in a separate methodological paper in 1983 [2]. The crucial element of the

Table 1. Properties of investigated soils

Parent materials of soil (Locality)	Soil porfile	Soil genetic type	Fractions (%)		Soil texture	Organic matter (%)
			<0.002 mm	0.05-0.002 mm		
Alluvial sands (Nowy Tomyśl)	20	mucky soil	3	13	Ls	2.58
Deposits of Riss (Krotoszyn)	44	lessive soil	4	18	Ls	1.47
Alluvial deposits (Puławy)	41	alluvial soil	5	45	SL	3.08
Deposits of Würm glaciation (Wierzchosławice)	1	black earth	11	31	SL	1.98
Loess (Sandomierz)	31	chemozem	14	67	SiL	4.78
Alluvial deposits (Stare Pole)	5	alluvial soil	16	51	SiL	2.40
Carpathian flysch (Nowy Sącz)	48	brown soil	24	56	SiL	1.65
Jurrasic limestones (Przymilowice)	50	rendzinas	26	24	SCL	3.17
Interglaciation clays (Gniew)	9	black earth	35	38	CL	4.00
Tertiary clay (Witaszyce)	56	-	71	25	C	0.00

concept is to determine many physical and mechanical parameters of soil structures in strictly controlled conditions - on samples of definite shapes and sizes, at assumed moisture and density levels.

Two types of cylindrical soil aggregates were studied in the present investigations, namely their volumes: V=1.0 cm^3 (d=1.128 cm, h=1.0 cm) and V=50 cm^3 (d=h=3.993 cm). Each soil type was compacted in special 5.0-cm-high forms, using five compaction moisture states (I-V) using the so-called tempering effect at conditions of the compacting effect of consolidating water. To form cylindrical aggregates V=1.0 cm^3, special sampler was used [2] and to form aggregates of V=50 cm^3 - special metal rings of dimensions given above. The formed aggregates were dried at laboratory conditions. The water loss throughout this process caused a decreased volume of aggregates, or their shrinkage. Shrinkage measurement was carried out in two ways:

- for 1 cm^3 aggregates using a micrometric screw when the aggregate reached air-dry state (hygroscopic moisture),
- for 50 cm^3 aggregates - using the self-constructed device to measure volumetric changes of modelled aggregates due to their shrinkage as well as three-axial swelling. Figure 1 shows a diagram of the device with a description of its main elements.

Measurements of volumetric changes were performed alongside measurements of moisture changes. Thus characteristics of the correlation between moisture decrease and dimi- nishing volume of the aggregate was obtained. Figure 2 presents such correlations for 2 randomized soils at a given level of compaction and formation moisture.

RESULTS

Numerous publications concerning the modelled aggregate structures [2,4-6] have often stressed that soil consolidating moisture at compaction proves to be one of its basic factors which affect soil compaction. Various volumetric compaction values are obtained in

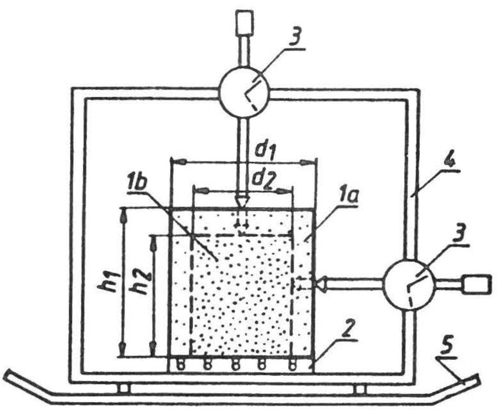

Fig. 1. Scheme of device for measurement of soil shrinkage: 1a- soil sample before shrinkage, 1b- soil sample after shrinkage, 2- perforated plate, 3- measuring sensors, 4- stand, 5- scale pan.

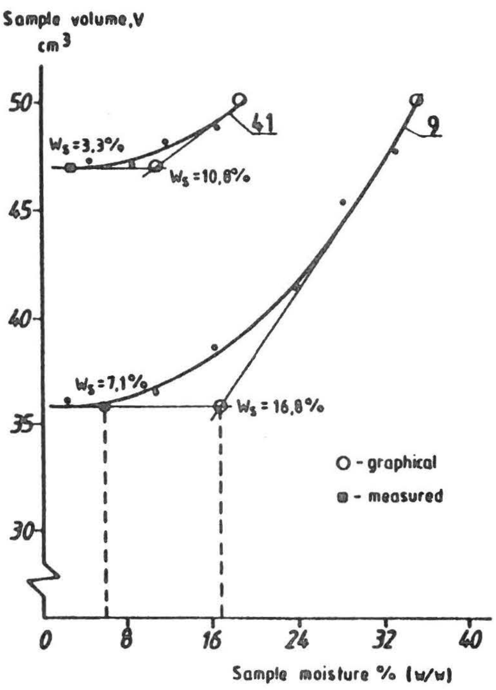

Fig. 2. Graphical appointed and measured value of soil shrinkage limit.

the process of compaction depending on the amount of water in the soil.

Figure 3a presents compactibility curves of the investigated soils. Volumetric compaction increases at low values of compaction moisture. Then it is found to drop significantly at higher moisture states. Each of investigated soils has a specific compaction curve.

Soil aggregates lose their original moisture through evaporation due to overdrying. Water escapes the aggregates and as a result, quite significant compacting strength is formed inside the aggregate which compact its inner structure. The more water evaporates, the greater the possibility to compact its inner structure, which means decreasing the original volume. Consequently, the bulk density is increased.

Figure 3b presents changes in bulk density of investigated soils due to their overdrying. Aggregate shrinkage was found to cause very significant changes in their three-phase systems i.e., bulk density, and also in porosity, comparing to the compaction bulk density.

The graphs presented in Fig. 3 indicate clearly that texture and aggregate moisture at compacting influence the changes in soil compaction. The increase of bulk density is relatively small in sandy soils (Nos 20,44,41). In soil No. 44, bulk density increases from 1.714 g/cm^3 to 1.845 g/cm^3 at compacting moisture 18.56 % weight, thus causing a change in porosity from 37.0 % to 32.2 %, respectively. Loamy and clayey soils undergo considerably bigger changes. For instance, soil No. 9 aggregates reach bulk density 1.177 g/cm^3, which corresponds to a change in porosity from 54.7 % to 27.7 % - an almost twice decreased value.

Table 2 presents shrinkage (s) and moisture and shrinkage-limit (Ws) depending on the compaction moisture of aggregate models. Fairly wide compaction moisture intervals (Wz), that have been assumed in our studies, cause significant differences in the size of aggregate shrinkage. The differences are bigger when the soil contains more colloids. Moisture at shrinkage-limit also depends on compaction moisture. In this case, however, the differences prove to be relatively not very big. Smaller values of compaction moisture always cause a lower shrinkage-limit than at higher values of compaction moisture.

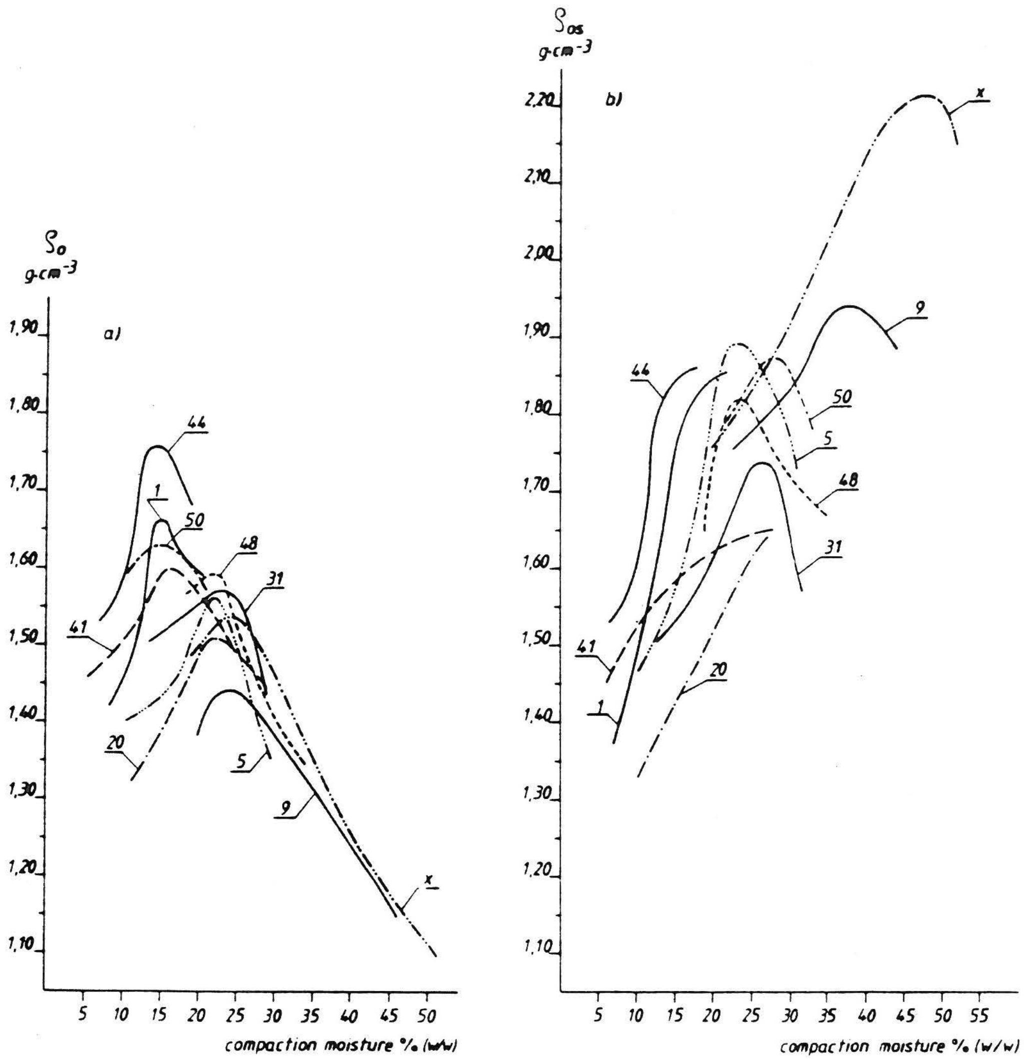

Fig. 3. Dependence of bulk density on consolidating moisture and shrinkage of soil aggregates: a) after consolidation, b) after shrinkage.

The shrinkage size (s) expressed in % of volumetric changes, is calculated according to the following equation:

$$s = \frac{V - Vs}{V} \cdot 100\ \% \qquad (1)$$

where s - shrinkage in %, V - volume at compaction in cm^3, Vs - volume obtained by the aggregate at moisture of the shrinkage-limit in cm^3.

Making use of the measured shrinkage (s) and aggregate volume after shrinkage (Vs), it is very simple to find the porosity after shrinkage according to the equation:

$$Ps = \frac{P - \%\,s}{Vs} = \frac{P - \%s}{V\,(1 - s)} \qquad (2)$$

where Ps - porosity after shrinkage %, P - porosity at compaction %, s - shrinkage in non-titre values: V, Vs, $\%\,s$ - acc. to Eq. 1.

Figure 4 presents shrinkage value for 1.0 cm^3

Table 2. The intervals of shimkage moisture and shrinkage of different texture soils

Soil profile No.	Water consolidated soil aggregates		Shrinkage interval of soil aggregates	
	interval of consol. moisture	moisture interv. at shrinkage limit	V=1.0 cm^3	V=50 cm^3
	% by weight			
20	12.8-24.6	2.81-3.25	1.80- 7.90	1.87- 3.98
44	11.3-18.6	2.85-3.62	0.00- 7.10	1.90- 6.61
41	10.6-29.0	3.09-3.69	0.00- 9.10	0.00-11.78
1	9.2-22.0	2.98-3.28	0.00-13.00	0.81-11.30
31	8.7-31.7	3.80-4.12	0.50-15.50	4.00-16.20
5	16.0-32.1	2.69-6.44	5.50-22.50	7.93-20.70
48	16.2-31.8	3.32-3.76	5.20-19.50	3.20-20.70
50	14.7-34.6	3.32-6.13	6.90-21.00	6.80-28.00
9	22.4-46.7	3.44-7.65	18.90-37.40	15.20-42.20
56	18.5-45.2	5.76-7.36	15.60-50.30	13.80-47.10

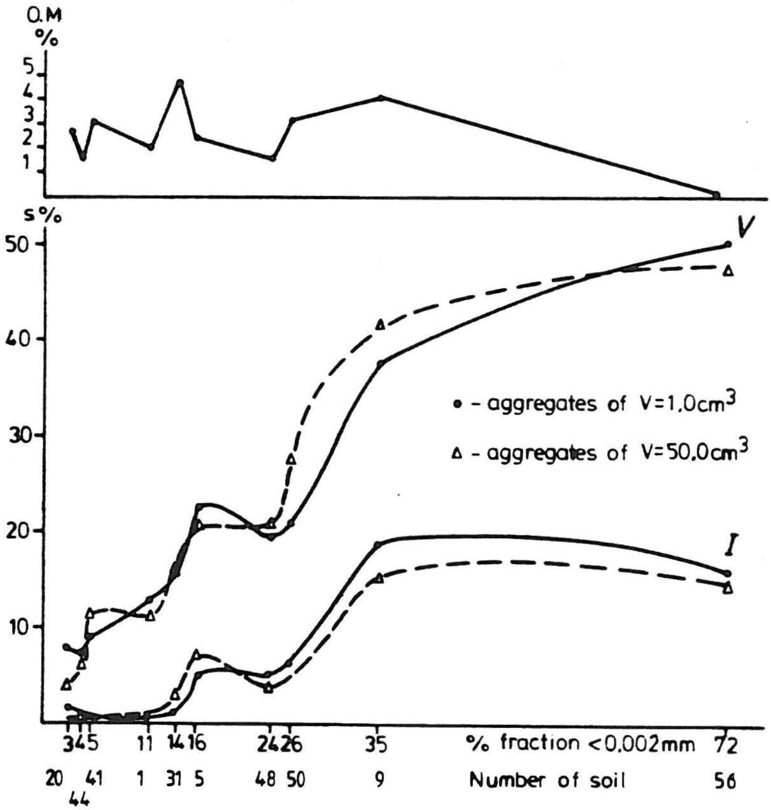

Fig. 4. Dependence of weak and strong consolidated soil aggregates on clay and organic matter content.

and 50.0 cm^3 aggregates, for two boundary states of compaction moisture (*I* and *V*) - depending on the contents of colloidal fraction. Aggregate shrinkage increases together with an increase of colloids in the soil as well as with the increase of soil compaction moisture. However, a modifying influence upon these correlations is played by the varied contents of organic matter. A bigger content of this substance reguires greater moisture of the soil at the compaction phase. It must be noted here that it causes an increased shrinkage at aggregate drying. The size of the aggregates exerts no significant influence on shrinkage values. Shrinkage seems to be uniform in the entire volume of aggregates at the so-called free shrinkage (absence of boundary conditions). The only difference concerns the time in which the aggregates reach moisture at shrinkage-limit.

However, the above moisture determination at shrinkage-limit (*Ws*) proves to be cumbersome and labour-consuming. Therefore there was an attempt to determine the moisture according to other characteristic moistures such as: hygroscopic moisture (*H*) or maximal hygroscopic water (*MH*). Figure 5 presents a correlation between moisture at shrinkage-limit and moisture at *H* and *MH*. There is a strict correlation determined by high correlation coefficients, between the moistures mentioned above. Thus, it is possible to determine the moisture at shrinkage-limit on the basis of *MH* or *H* determinations [7].

CONCLUSIONS

1. During shrinkage or swelling there occur basic changes in the three-phase structure of the soil, particularly in the structure of the arable layer, but first of all in the structure of soil aggregates.

2. The factor that has a decisive effect on shrinkage value proves to be mainly soil texture, particularly clay content and the amount of organic substance as well as initial moisture of the soil.

3. As a result of shrinkage, soil aggregates can reach extreme compaction, sometimes much stronger than compaction by Proctor's method.

4. The device used to measure shrinkage enables a simple, safe (in comparison with mercury volumetrometer) and accurate determination of shrinkage value and moisture at shrinkage-limit.

5. There is a possibility for a fast and relatively simple yet approximated determination of moisture at shrinkage-limit on the basis of hygroscopic capacity determination (*H*) and particularly maximal hygroscopic capacity (*MH*), which is indicated in the correlations in Fig. 5.

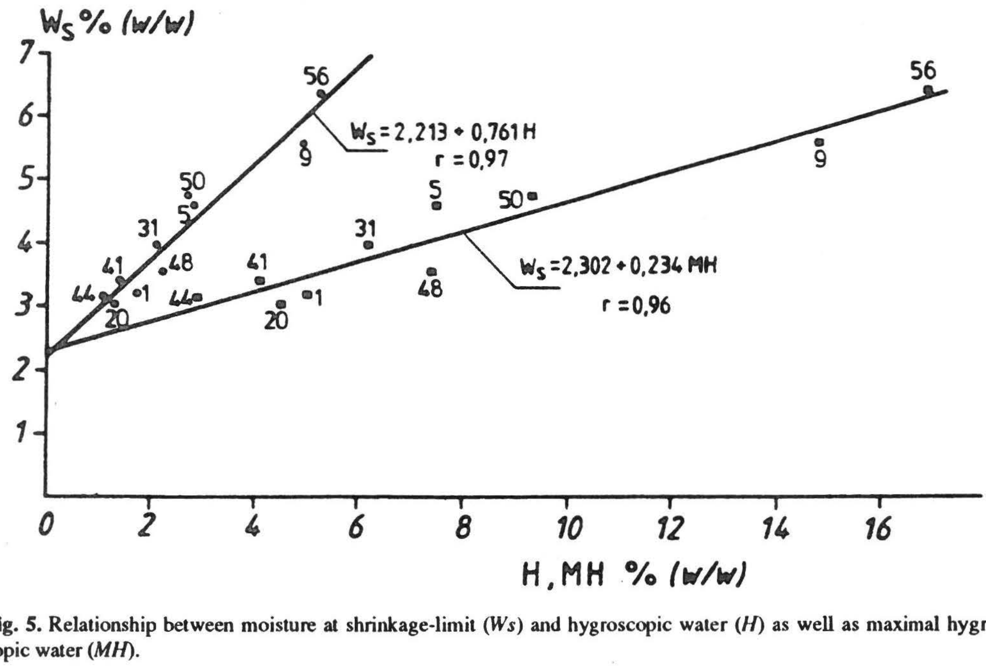

Fig. 5. Relationship between moisture at shrinkage-limit (*Ws*) and hygroscopic water (*H*) as well as maximal hygroscopic water (*MH*).

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