ACTA STEREOL 1993; 12/2: 249-254
PROC 6ECS PRAGUE, 1993
ORIGINAL SCIENTIFIC PAPER

WHAT KIND OF INFORMATION CAN BE EXTRACTED FROM MANUALLY SEGMENTED TWO-DIMENSIONAL SECTIONS OF SOIL MACROSTRUCTURE ?

Dietrich WERNER[1], František DOLEŽAL[2,3]

[1]Landwirtschaftliche Untersuchungs- und Forschungsanstalt Thüringen, Naumburger Straße 98, Jena 9 - Zwätzen, Germany
[2]Výzkumný ústav meliorací a ochrany půdy, Žabovřeská 250, 156 27 Praha 5 - Zbraslav, Czech Republic
[3]corresponding author

ABSTRACT

The effect of heavy agricultural machinery upon soil macrostructure was investigated by several methods complementing each other. One of them was the evaluation, both qualitative and quantitative, of thin impregnated soil sections of the size about 60 x 80 mm. The quantitative evaluation was based on manually drawn contours of soil pores (≥ 70 microns) on a sheet of graph paper onto which the magnified image (15 x) of the soil section was projected using polarized light. The quantification consisted in measuring the intercept lengths in the pores, using systems of parallel testing lines. Some sample statistics of the intercept length distribution were related to other soil properties of mechanical and hydraulic nature; at the same time, the morphometric data yielded supplementary information about the soil macropore structure that could not be obtained in other way. More recently, an attempt at manual re-evaluation of the old images was undertaken in order to explore whether more information can be extracted from them and to suggest algorithms for their automated processing. Because of the lacking spatial information, the effort was focused on evaluating the planar images as such. Anisotropy was not considered. Additional information is contained, in particular, in the distribution of the radial contact distances from a random point in matrix to the nearest macropore. On the contrary, the methods based on treating pores as individual particles are probably of little use.

Key words: macropores, sections, soil, structure.

INTRODUCTION

It has been recognized long ago that the geometry of soil macropores has to be studied quantitatively, if one wants to understand their role in soil hydrology and ecology. Several studies on this theme have already been published and the subject is developing rapidly (e. g., Kretzschmar, 1988; Rappoldt, 1992). However, a principal question remains how to relate the observed structural features to the soil behaviour. It is mainly the system of mutually connected pores which is of interest, as well as the degree to which the soil matrix between the macropores can be supplied with the transported substances (water, oxygen, nutrients, pollutants, etc.) or can dispose them, via the macropores. Hence, the spatial structure of the macropores, only detectable with three-dimensional testing objects (like the disector, cf. Sterio, 1984), has to be studied, as well as the connectivity of the pores in space.

The collection of new data, however badly needed it is, remains a laborious task, and the data usually suffer from incompleteness and non-representativeness. The old data, if they are at hand, are therefore of interest, too, and should be re-examined. These data, however, originate mostly from soil sections of lower dimensionality (planar or linear) and cannot answer fully the questions posed above.

A collaborative research on the inadvertent compaction of agricultural soils caused by heavy machinery and other reasons, was conducted for more than a decade in former East Germany and Czechoslovakia (Werner, 1982, 1987; Werner and Feldhaus, 1986). Among the methods used to document the changes occurring with the soil structure, the macropore morphometry was implemented as described below. Several hundreds of manually segmented images of soil macrostructure were made and are at the disposal of the authors. This paper is an attempt to examine if these images can be exploited more fully and, if yes, to initiate such exploitation. More general conclusions, pertaining to other types of materials, can also be drawn.

MATERIALS AND METHODS

The data re-examination has been done so far only for the loamy chernozem soil of Kamenné Žehrovice, Czech Republic.

Undisturbed soil cores with the volume of 250 cm^3 were sampled in the field, using metal rings, from the shallow subsoil (depth 30 cm). The samples were air-dried and saturated in vacuum with a thermosetting resin. When hard, the samples were cut into slices that were subsequently ground, polished and affixed between two thin glass plates. The resulting thin soil sections, of the dimensions of about 60 x 80 cm and about 70 microns thick, were first examined qualitatively under a light microscope. A typical partial area of each section, about 2.7 x 2.7 cm, was then selected and projected onto a screen, magnified 15 times. The light used for projection was polarized so that a distinction could be made between pores and the transparent grains of soil skeleton. A sheet of graph paper with the millimeter raster of reddish colour was attached to the screen and the contours of pores, as well as of the skeleton grains, were drawn manually on the paper with the black drawing ink. Inevitably, the shapes of the smallest traced pores could not be recognized properly and were simplified as quasi-circles. The interior of the skeleton grains was blackened. The size of the images was 40 x 40 cm. The minimum pore size recorded was 1 mm in the images, i. e. about 67 microns in reality. This value, corresponding approximately to the soil section thickness, was rounded in the subsequent analyses up to 70 microns.

The quantitative analysis of the images was done mainly manually. Only isotropic images are reported here. The basic measurement, carried out in the past, consisted in overlaying a raster of 40 parallel test lines 1 cm apart and 40 cm long onto the image and in recording the number and size of the intercepts in which the lines intersected the traces of macropores in the image. The correlation of intercept counts and lengths on neighbouring test lines was not tested precisely but seems to be negligible, except for the largest pores. In this way, the intercept lengths L_{ij} were obtained, where $i = 1,\dots,n$ is the test line serial number, $j = 1,\dots,N_i$ is the intercept serial number within the i-th test line, n is the total number of the test lines and N_i is the total number (count) of intercepts on the i- th test line.

The parameters evaluated in the past were, in particular:

1) the mean intercept length L (called "equivalent diameter" in previous papers and reports),

2) the relative dispersion $S_N = \sigma_N^2 / N$ of the intercept counts N_i, where N is the mean intercept count on a test line and σ_N^2 is the dispersion of intercept counts N_i on individual test lines,

3) the pore volume fraction P, and

4) the specific length of the pore boundaries per unit area, L_A. (as a matter of fact, the quantity $(L_A\ n\ l)\ /\ (\pi\ A)$, called "pore frequency", was presented previously, with l being the test line length, A the sampling area, and $\pi = 3.14\dots$). The simple interpretation of L_A as a specific length is, of course, only possible if either the pore structure or the test lines, or both, are isotropic.

In addition, the quantities P and L_A were evaluated separately in the past for three cumulative classes of the intercept lengths (interpreted previously as pore size classes):

a) ≥ 70 microns in reality (1 mm in the image scale),
b) ≥ 200 microns in reality (3 mm in the image scale),
c) ≥ 500 microns in reality (7.5 mm in the image scale).

The first of these classes comprised all macropores recorded. The other two allowed to detect, roughly but not exactly, an influence of the resolution threshold upon the quantities estimated.

In the course of re-evaluation of the images, some further quantities were manually measured and calculated, in particular:

5) the quantities similar to those listed above but pertaining to the soil matrix rather than to the macropores,

6) the pore counts per unit area applied to individual pore size classes, where the pore size was defined as the longest chord C of the pore trace in the image (cf. Stoyan and Beneš, 1991),

7) the distribution of the radial contact distance s, i. e. the shortest distance from a random point in the matrix to the nearest macropore (Rappoldt, 1992).

RESULTS

Some results of the measurements made in the past are overviewed in Tbl. 1. Physical properties of the soil are given in Tbl. 2. Additional measurements, made only as a trial on a subset of the sample No. 3/1, are summarized in Tbl. 3. The intercepts in pores (L_P) were also measured, with the results slightly different from those in Tbl. 1, because of the sampling error and of microheterogeneity within the section area. Fig. 1 shows a typical part of the image. All lengths and areas are given in the image scale (lengths must be divided by 15 to get real figures). The intercepts between the first (last) pore boundary and the window edge were counted, too.

Table 1. Old morphometric results for samples taken in Kamenné Žehrovice, 1987, depth 30 cm, horizontal sections: $n = 40$, $l = 40/15$ cm, $A = 40x40/(15x15)$ cm,
P ... pore volume fraction in % resulting from intercepts larger than indicated (in μm),
L ... mean intercept length in μm,
L_A ... boundary length per unit area, in cm^{-1}, resulting from intercepts larger than indicated (μm),
S_N ... relative dispersion of intercept counts.

Sample	Treatment	P			L	L_A			S_N
		70	200	500		70	200	500	
4/1	not compacted	22.2	11.0	2.7	139	47.8	10.3	1.3	0.284
4/2		25.6	14.0	4.3	153	50.3	12.5	1.8	0.258
25/2		22.5	12.1	5.3	151	44.8	9.2	1.7	0.243
8/1	compacted by truck four times	20.1	11.0	2.8	150	40.3	10.0	1.3	0.308
8/2		21.9	13.5	4.3	171	38.4	11.6	1.9	0.263
3/1		16.9	8.5	2.3	142	35.7	8.0	1.0	0.407
3/2		17.1	7.8	1.9	129	39.7	7.3	0.9	0.394
12		24.9	13.4	3.0	146	51.0	12.3	1.4	0.246

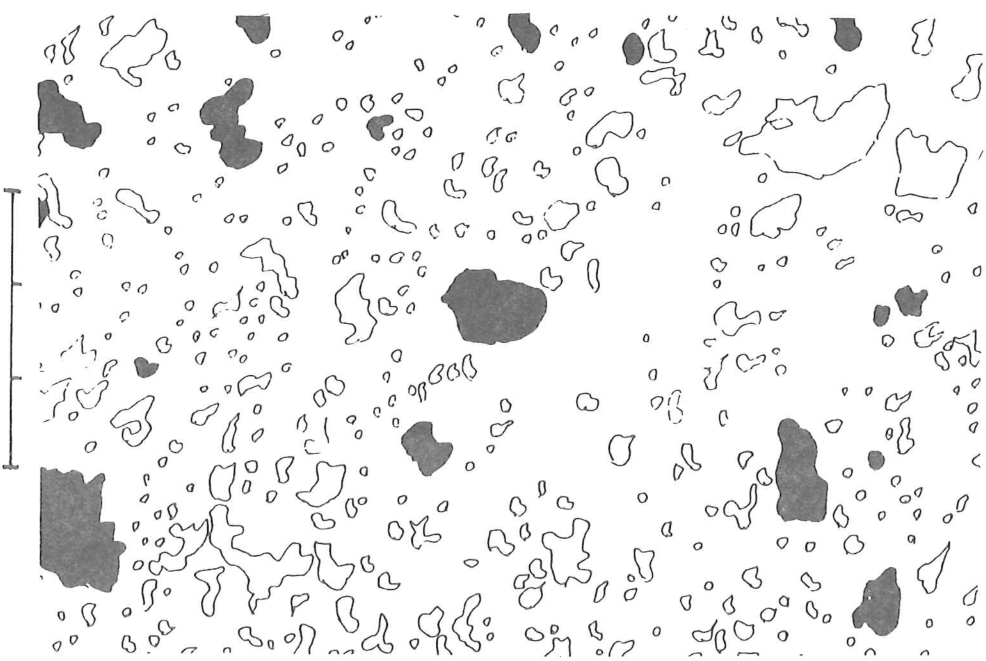

Fig. 1. A part of the manually drawn image of macropore boundaries (closed curves with empty interiors) and skeleton grains (black spots) in a thin soil section, Kamenné Žehrovice, 1987, depth 30 cm, sample No. 3/1, horizontal section. The line segment on the left denotes 3 mm in reality and 45 mm in the image scale.

Table 2. Average physical properties of the soil studied, Kamenné Žehrovice, 1987, depth 30 cm:
BD ... dry bulk density in $g.cm^{-3}$,
TP ... total porosity in % by water pycnometry,
MP ... macroporosity in % (TP - water content retained at the suction head of 3.3 m), believed to correspond to pores with diameter above 10 μm,
K_v ... vertical saturated hydraulic conductivity in $m.day^{-1}$, geometrical mean.

Treatment	BD	TP	MP	K_v
not compacted	1.52	42.6	12.0	4.3×10^{-1}
compacted by truck, 4x	1.69	36.4	3.3	1.6×10^{-3}

Table 3. Basic statistics of the newly measured parameters, Kamenné Žehrovice, 1987, depth 30 cm, sample No. 3/1 (compacted by truck, 4x), horizontal section:
L_P ... intercept length in a pore (mm),
L_M ... intercept length in the matrix (mm),
C ... the longest pore chord (mm),
s ... radial contact distance (mm),
density ... total count divided either by the total test line length (n l) or by the sampling area (A),
fraction ... volume fraction in %, equal to the total length of intercepts within a given phase (pores or matrix) per unit test line length.

Parameter:	L_P	L_M	C	s
total count:	223	234	333	188
mean:	2.22	13.26	2.59	1.94
std.dev.:	1.92	13.94	2.46	1.53
n l (mm):	3600	3600	-	-
A (mm^2):	90000	90000	15000	90000
density:	0.062 mm^{-1}	0.065 mm^{-1}	0.022 mm^{-2}	-
fraction:	13.8	86.2	-	-

DISCUSSION

Although it is not a purpose of this paper to compare different treatments one can pursue in Tbl. 1 an influence of compaction: the total macroporosity P(70) is lower, while the heterogeneity of macropores, expressed as S_N, is larger in the compacted soil. Werner (1987) discusses this aspect in detail.
Macroporosity from the intercept counting (P in Tbl. 1, fraction of L_P in Tbl. 3) is much larger than that from water retention measurements (MP in Tbl. 2). This may indicate that some of the macropores are either isolated or connected via smaller pores. Also, the retention was measured on samples parallel to, but different from those used for morphometry.
The distributions of all newly measured structural parameters (L_P, L_M, C, s) are qualitatively similar, with the arithmetic mean roughly equal to the standard deviation (Tbl. 3). Hence, one can suggest the exponential distribution as a simple theoretical model of them, except for the radial contact distance s where the

frequency graph exhibits a non-zero mode. Because of the limited extent of data, however, we did not try to test these hypotheses. The exponential distribution is being also used for intercept lengths between rock fissures (e. g., Priest and Hudson, 1981). There is a striking difference between the mean values of L_M and s which indicates that L_M might be unsuitable to characterize the proximity to macropores of a general point in the matrix.

Counting individual pores (more exactly, the pore traces in the section), as well as estimating their size distribution, using either the longest chord C or another parameter to define the pore size, may seem meaningful for the pore structures similar to that in Fig. 1. It is however of little sense. One must realize that both phases, the pores and the matrix, are typically continuous and mutually interwoven and cannot be treated as sets of "particles". The continuity of macropores may sometimes become critical, as illustrated by the comparison of hydraulic conductivities K_v in Tbl. 2 for the non-compacted soil and the compacted one. For a more complex understanding of the true pore structure, in particular of the pore connectivity, spatial probes could have been employed, such as the disector.

The distribution of the radial contact distances s can be used to construct a model of diffusion processes in soils with macropores (Rappoldt, 1992). It is therefore recommendable to determine the distribution of s routinely in the future.

As a conclusion, one can state the information contained in the old soil structure images is relevant, even if it is incomplete, and that it has not yet been fully exploited. Many irreversible changes of the soil structure have occurred in the past and continue to occur, all over the world. Therefore, the information of old images is unique, and a further analysis of it, both empirical and theoretical, is worth while.

REFERENCES

Kretzschmar A. Structural parameters and functional patterns of earthworm burrow systems. Biol Fert Soils 1988; 6: 252-61.

Priest SD, Hudson JA. Estimation of discontinuity spacing and trace length using scanline surveys. Int J Rock Mech Min Sci 1981; 18: 183-97.

Rappoldt C. Diffusion in aggregated media. Doctoral thesis. Agricultural University, Wageningen, The Netherlands, 1992.

Sterio DC. The unbiased estimation of number and size of arbitrary particles using the disector. J Microsc 1984; 134: 127-36.

Stoyan D, Beneš V. Anisotropy analysis for particle systems. J Microsc 1991; 164: 159-68.

Werner D. Quantitative Kennzeichnung der morphologischen Ausbildung von Bodenverdichtungen auf der Grundlage von Bodenschliffpräparaten. Zwischenbericht. Forschungszentrum für Bodenfruchtbarkeit Müncheberg - Bereich Jena, 1982.

Werner D. Makrostrukturelle Charakterisierung von raddruckverdichteten und magnetisierten bindigen Böden der CSSR. Bericht. Forschungszentrum für Bodenfruchtbarkeit Müncheberg - Bereich Jena, 1987.

Werner D, Feldhaus D. Charakterisierung der Makroporosität verdichteter Ackerböden durch Bildanalyse von Schliffpräparaten. Arch Acker- und Pflanzenbau und Bodenkunde 1986; 30: 671-80.