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ACCESSIBILITY OF MOST FREQUENTLY USED PHYSICAL PARAMETERS OF SOIL STRUCTURE, RELIABILITY OF MEASURED VALUES, LACK OF REPLICATES AND WAYS OUT OF THIS DILEMMA*

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A b s t r a c t. Assessment of soil structure and still more its changes is impeded by peculiarities of sampling and measurement. Unavoidable local destructions tend to advance use of small numbers of replicates, samples or sampling locations. Ways out of this dilemma are discussed using the results which were obtained in the project 'Qualitative and quantitative assessment of soil structure functions for the sustainable agricultural plant production'. Bulk density(BD) and saturated hydraulic conductivity (CSAT) are the most frequently used primary parameters of soil structure. The stastistical behaviour of these both is most different. High variability of CSAT usually precludes measurement at a sufficient number of replicates for statistic analysis - particularily at soil depths below topsoil. BD has smaller variability but much smaller sensitivity as well. For measurements at greater depths in soils it is preferable nevertheless owing to the lower number of necessary replicates. A two-level outflanking procedure might facilitate sampling problems by first applying an easy-going nondestructive, unspecific method to create a narrow grid of values as a first step which might help to rationalize choice of sampling locations for destructive samplings and in-situ measurements.

K e y w o r d s : bulk density, saturated hydraulic conductivity, limited data-sets, outflanking techniques

INTRODUCTION

Reliability of assessment of functions depends on the solidity of the basis, i.e., on the available data. Since there is no parameter which reflects soil structure in one single unit this means first of all to identify auxiliary parameters. The suitability of such a parameter depends on several properties. Besides describing an important feature of soil structure, it has to be easily acquired. For assessmant of soil structure this means measurement on undistrubed samples or in-situ. Both techniques are laborious if compared with many other ones which are used in soil science and cause severe damage at the sampling sites. This is particularily relevant concerning the question of numbers of replications.

Investigations of Baranowski *et al.* [1] showed that saturated hydraulic conductivity and bulk density were the most frequently used - primary parameters which were directly measured in soils. Important functions like moisture retention characteristic and unsaturated hydraulic conductivity are in many cases calculated on the basis of these both parameters [15].

But even data on these both parameters are in many cases so difficult to obtain, that small sets of values have to be tested thoroughly for the possibility to extract reliable results before deciding to abstain from further effort. Another way to minimize damage at sampling sites would be outflanking by use of

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a two-level procedure [6,8]. This implies taking first a momentary spacial distribution of easily, cheaply and nondestructively obtainable values. As a second step locations for sampling are chosen on the basis of this data field. Now it is possible to spot or avoid extreme or prevalent positions for sampling as might be requested by the aim of the investigation.

In front of this background it is worth while to compare the information which is supplied by different methodes to obtain these parameters and to examine how far their results are interdependent. In case of close correlation of values the question arises which parameter or method should be preferably used weighting the effort to obtain them in a reproducible and representative way in the requested number of replications for the required scale, i.e., for the area in question.

In the following text the discussion is limited on measured values of bulk density and saturated hydraulic conductivity and the dilemma of extreme scarcity of values.

MATERIALS AND PROCEDURES

Data for bulk density and saturated hydraulic conductivity were supplied by the group Wimmer [16]. They were obtained from a field experiment which was laid out to observe the development of soil structure due to different trafficing. The soil was a chernosem (Fuchsenbigl) developed on 80 cm periglacial loess covering gravelly river deposits. The authors used 200 cm^3 soil core samplers. Saturated conductivity was measured with a falling head device, bulk density was calculated separately for 3 sets of samples from 0-15 cm depth and one set from 30 and from 60 cm depth. For in-situ measurements a Guelph-permeameter was used. Details of sampling are explained in the above quoted paper. Data in this text consist of mean values, maxima, minima and number of replicates. Data for references were taken from earlier investigations of the author [4,5].

Preliminary screening was performed on a lawn in a public park in Hannover (Herrenhäuser Gärten). Methods included total density (γ-probe), water content (neutron-probe) working down till 30 cm depth (Troxler-probe), penetration resistance probing down to 80 cm depth (Eijkelkamp) and electromagnetic induction down to 150 cm (GEONICS M38). Every probing action was completely performed on one day.

RESULTS AND DISCUSSION

Saturated hydraulic conductivity

Figure 1 shows arithmetic and geometric means, maximal and minimal values and numbers of replicates. The difference between both treatments (trafficed and non trafficed) is clearly recorded with both methods. As the

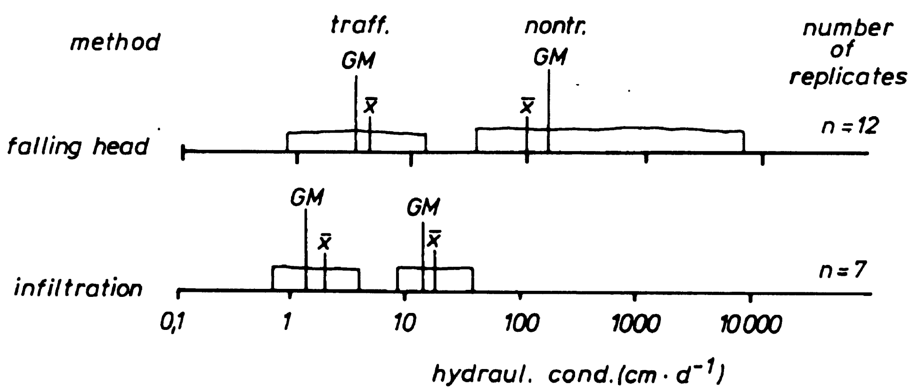

Fig. 1. Range and mean values (GM= geometric m) of hydraulic conductivity of the trafficed and the nontrafficed plot, measured on core samples with falling head permeameter and *in situ* with infiltrometer permeameter.

figure shows there is no overlap of values regardless of the method.

Measurement of saturated hydraulic conductivity does not require expensive equipment and is highly sensitive to any changes in structure [9]. Therefore it is frequently chosen in order to trace safely even small differences of soil structure. This is confined however to determination by direct measurement of hydraulic flow. Data of saturated hydraulic conductivity which were calculated on the basis of other primary data like grain size distributions [2] are not promising here because their sensitivity is smaller by orders of magnitude.

As can be seen from Fig. 1 absolute values as well as their distribution are different if obtained with different apparatus. This reveals a main problem of this kind of methode. It consists in the difficulty to obtain a 'relevant elementary volume ' (REV) which might represent the particular soil and ascertain, that differences in results are caused only by the soil properties and not by the relation between sample size and heterogeneity of soil structure i.e., lastly by the procedure of measurement .

Here a compromise has to be reached between the necessity to determine correctly the boundaries of the hydrodynamic field and the necessity to obtain a volume large enough to avoid the bias of artificially opened blind pedogenetic pores (Fig. 2).

It is well known that forcing sample rings into the soil disturbs soil structure. The extent of this depends largely on the relation between diameter and length of the samplers [10]. So for not to spoil the advantage of core sampling, samples will have to be short (f.e.10 cm length) or they would require big diameters and thus would become heavy. Practically this means to confine oneself on samplers which are too short to satisfy the request of a REV, or to confine oneself on a less strictly determined hydrodynamic field.

If maximal sensitivity of the analysis is required, the only way out of this dilemma is to increase the number of samples in oder to find out a reliable lowest value of conductivity [3].

A different approach to avoid this dilemma is to use measurements in situ. But this again makes it difficult to determine the geometric boundaries of the sample and to make sure that flow pattern and hydraulic gradient were captured evenly. A good and close approximation of these both values will do for calculating hydraulic conductivity for many purposes. But accuracy and sensitivity are decreased both and thus the main advantage of

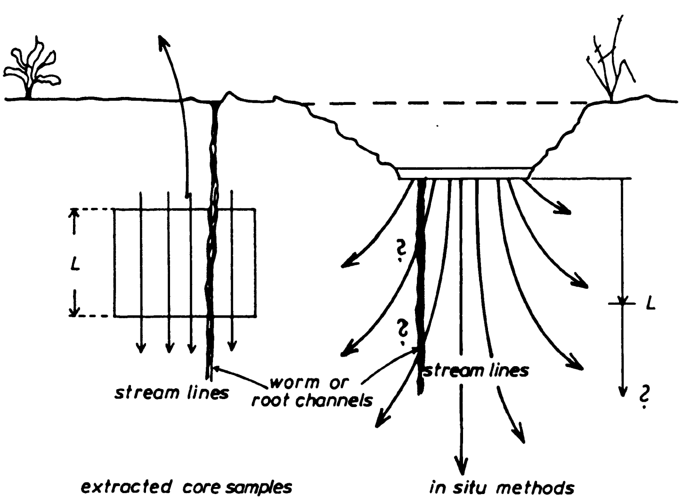

Fig. 2. Percolation system in a core sampler (left, source, sink and hydraulic gradient well defined) and *in situ* under an infiltration permeameter (right, sink and thus hydraulic gradient less exactly defined).

this kind of parameter to detect changes in soil structure is lost.

This might be seen comparing the results in Fig. 1. With the easily obtained core samples a higher number of replicates was measured for obvious reasons than with the infiltration method. The differences of both mean values are greater in the former case than in the latter one. Wether this is outweighted by the smaller range remains open because it is not known what an increase of the number of replicates would bring about. But increasing this number in case of field methodes is far more time consuming than with core samplers. It woúld also cause more damage on the field. So it will be avoided frequently, particularily if values at greater soil depths are in question.

There is another difficulty inherent with flow measurements in soils: Soil is stable against the stress which streaming water exerts on its structure only as long as the hydraulic gradient which is applied remains smaller than the maximal one which occurred in the individual soil [5].

The weight of this problem again depends on the use for which saturated conductivity values were determined. It becomes serious if they are used to calculate unsaturated conductivity with methods like those described by van Genuchten [14] and Mualem [11].

If measurement of saturated hydraulic conductivity on core samples is chosen, the wide range of values makes it necessary to work with a great number of replicates per soil or soil depth, respectively. Experience showed, that with 11-13 replicates a fairly representative median can be expected.

Bulk density

If the data of Wimmer *et al.* [16] are subjected to an assessment similar to that for hydraulic conductivity two points merit attention (Fig. 3).

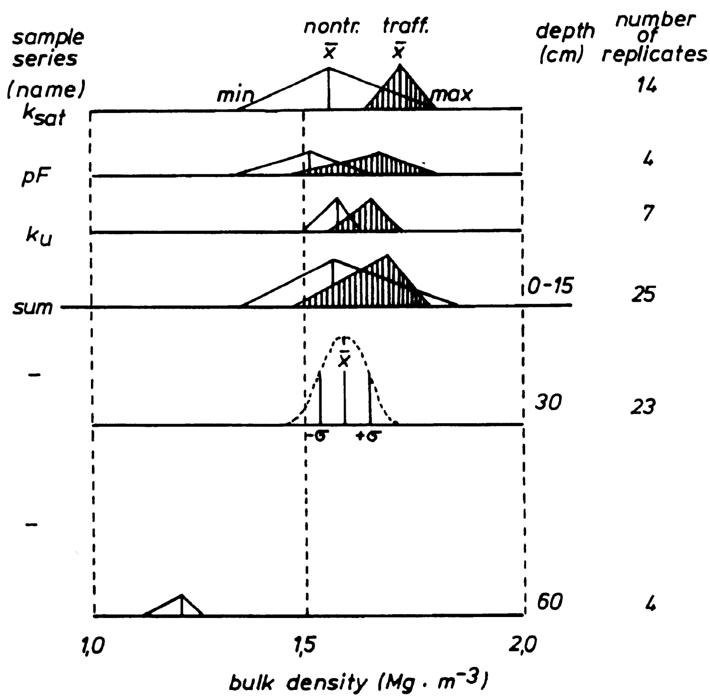

Fig. 3. Range and arithmetric mean of bulk density on the trafficed and the nontrafficed plot. Values for topsoil from three sets of samples separately plotted (k_{sat}, pF, k_u) and joined to make one sample (sum). For 30 cm only mean and number of replicates were available, for 60 cm depth range and arithmetric mean.

The available data prevent calculation of standard deviation. But if the total error (range in Fig. 3) is applied to estimate standard deviation using the rough-and-ready estimators given by Snedecor and Cochrane [13], than a mean approximated value is obtained of 0.067 Mg/m^3. This is well in line with values which were obtained from different soils applying the same sampler technique [7]. It is used therefore to estimate the frequency distribution for the sampling depth of 30 cm where only the mean value was available. The difference to the values at greatest depth where only mean and range were given, can be reliably assessed (Fig. 3).

Frequency distributions overlap at all three sets of samples from the topsoil (0-15 cm depth). So from the practical point of view most of the advantage is compensated which come up from the smaller variation if compared with the results of hydraulic conductivity measurements. Combining all values from the uppermost depth does not improve the situation (Fig. 3). Thus if very small changes in soil structure are expected it pays better to measure saturated hydraulic conductivity than bulk density in order to ascertain a difference. This confirms earlier experience [9].

If the observed differences between bulk densities of trafficed and not trafficed plots are to be assessed, then the relation towards subsoil values is judged. As a reference base the general depth function of void ratios (soil packing characteristic) might be useful. The general form of such a regression is log-normal linear with falling slope [4]. If such a linear regression line is drawn (Fig. 4) the comment towards the results shown in Fig. 3 would be: (a) There is a very strong compaction in the profile reaching down deeper than 30 cm. It might be brought about by pedogenetic development but as well by general agricultural practices. (b) Recent change in trafficing did change structure in the topsoil, but to an extent that is negligible compared with the general compaction (a).

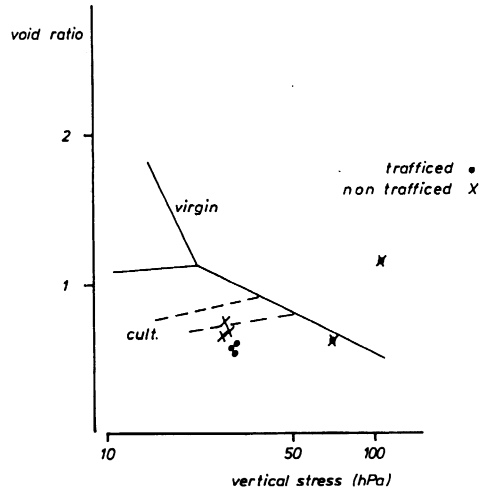

Fig. 4. Void ratios calculated from measured bulk densities of both plots, for assessment compared with the general soil packing characteristic for a virgin soil and the same soil in regularily cropped state [4].

Prescreening procedure

Core sampling and in situ measurements will create more damage on soil and crop than other kinds of sampling. It is the more troublesom the greater soil depth is unto which samples are needed.

The consequence of this is in many cases to extract the samples from so few pits as ever possible. This however limits the representativity of the result for the area for which the samples had been taken.

The same kind of difficulties come up if the exact location has to be selected for firmly installing equipment for permanent recording of data. Since this is a general problem with soil science measurements on spacial basis, ways out have been tried.

One way to outflank this dilemma is to use a two-step approach. First step is to work out a narrow grid of values by surveying with a method that operates undestructively, cheaply and easily. It is not necessary that this method be highly specific for one parameter.

Next step is to screen out all positions with extreme readings of the measured parameter, or to find out the area where the most frequent value prevails homogeniuosly.

In Fig. 5 results are shown of surveying with an electromagnetic induction technique. The measurements were taken on a 10 m-grid thus giving 66 readings on an area of 50 times 100 m. The values give the bulk electric conductivity of a soil volume of about 0.75 m^3 extending down until 1.5 m.

This method is preferable before the others which were applied on the same area primarily because of the relatively high depth of the included sector and the short time for the procedure (shortest of all, 2 h for 66 measurements). The values of penetration resistence include a depth down till 0.8 m. These measurements were most time consuming, 10 h were needed for two persons to measure 66 grid points [8]. Both methods show the same part of the area as the most homogenous and thre extreme one, respectively (Fig. 5).

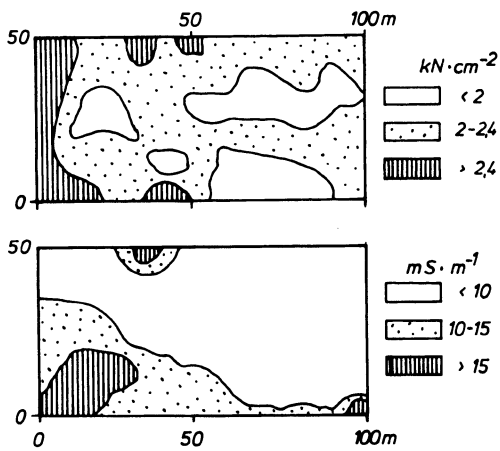

Fig. 5. Datafields of 66 readings on a 50x100 m area obtained with an electromagnetic probe (below) and a mechanical penetrometer (above) as prescreening for the choice of sampling sites. Values for comparability joined into three classes.

If compared with these results the use of the Troxler probe proved less promising. Working depth was only 0.30 m, so the field data do not necessarily aggree with those from both other methods. Besides from this its transport and use require special attention.

CONCLUSIONS

It is generally expected, that mathematical modelling on the long run will replace laborious measurements in many cases. This will be particularily important for extension work.

Saturated hydraulic conductivity determined at a well defined depth interval of a soil seems to be one key parameter. It is a sensitiv measure of structural changes and an essential term for calculating unsaturated hydraulic conductivity with most modern procedures. It is preferable ahead of bulk density if relative changes in structure are asked for.

For more absolute assessment of compaction state however bulk density is the only reliable parameter that is easily accessible. There is no comparable reference system for hydraulic conductivities in soil profiles.

In such a situation it is essential to have the right value for these parameters. The requirements for right choice of method, representativity and reproducibility of these data will be higher than in cases, where they are used directly. This is not commonly recognised yet, though it is obvious from the fact that data in use in a widely applied model exert much higher influence compared with those which were produced for a singular occasion - thus even small shortcomings in the particular ways of acquirement will have multiplied consequences.

Discussion on the previous pages shows, that this is a problem which is not solved yet to an extent that satisfies even modest requirements.

Physical soil parameters provide the same kind of methodical trouble as all other scientific measurements. But in comparison with chemical soil parameters there is an additional difficulty. That is the fact that structure-dependent parameters can not be determined from composite samples. Each core sample or each in situ measurement has to be treated separately.

Where damage on the investigated site or shortage in labour precludes measurements at a sufficient number of replicates a prescreening technique might help to outflank the dilemma of shortage of information.

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