Functional characterization of soil structure field descriptions

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Abstract

Databases all over the world contain soil structure descriptions, made in the context of soil surveys. They can be helpful in providing qualitative indications as to important soil properties such as rooting depth, permeability and biological activity. Modern applications of soil expertise, using modelling techniques, require more quantitative input. Continuous – and class pedotransferfunctions (pdf's) have been developed to relate soil characteristics from soil survey to physical and chemical parameters needed for quantitative applications. Most emphasis has been so far on the continuous pdf's and a case will be presented for class-pdf's using soil horizons and pedons as carriers of information. On the other hand, modelling of physical soil processes is hampered by implicit assumptions of homogeneity of the flow domain, following existing flow theory. Descriptions of soil structure can help to devise more representative sampling techniques and simulations of field conditions by defining preferential flow patterns. New monitoring techniques allow more precise measurements. Coupling soil survey expertise with process knowledge from soil physics allows more realistic representation of field conditions in simulation models than either discipline can achieve and is therefore a good example of hydropedology at work.

Key Words

Bypass flow, macropores, simulation.

Introduction

Soil databases all over the world contain soil profile descriptions of soil structure for each soil horizon in terms of type, grade and size of aggregates (“peds”) and of soil consistencies as an estimate of soil stability. These qualitative characterizations allow reasonable indications as to rooting patterns, soil permeabilities , structural stability and occurrence of biological activity. Modern methods to quantify plant growth or to study effects of global climate change include use of simulation models that need specific parameters, also for the soil. Important parameters are hydraulic conductivity K(h) and moisture retention h(o) relations. Measurements of these physical characteristics are often cumbersome and costly so much attention has been paid to deriving methods that allow reliable estimates of such parameters using basic data from soil survey such as texture, organic matter content and bulk density by developing pedotransferfunctions (Bouma 1989; Pachepsky and Rawls 2004). Both continuous en class pedotransfunctions can be distinguished, the latter linking specific soil horizons or pedons to measured functional properties, such as K(h) and h(0). While pedology and soil survey move towards quantification, soil physics and hydrology increasingly suffer from limitations imposed by the underlying assumption of flow theory that soils are anisotropic and homogeneous, which- of course- they are not. Soil structure descriptions can be helpful to overcome these problems by:(i) improving physical measurements by e.g. defining representative sample sizes or subsampling procedures, and (ii) defining boundary conditions for the flow regime in terms of preferential flow in heterogeneous soil. Combining field descriptions of soil structure with process knowledge of soil physicists, as promoted by Hydropedology, can lead to much improved field characterization of soils in terms of their flow regimes and this, in turn, is important as a contribution by soil science to larger models now in use, covering the entire earth system.

Pedotransferfunctions

Bouma (1989) and Pachepsky and Rawls (2004) have discussed pdf's, distinguishing two types: continuous and class. The first type is most common and relates basic soil characteristics such as texture, organic matter content and bulk density to hydraulic characteristics such as hydraulic conductivity, K(h), and moisture retention , h(o). Often these characteristics are related to the parameters of the flow equations of van Genuchten. Pdf's allow rapid derivation of physical flow characteristics that are difficult to measure and can thus be quite helpful for hydrological studies. However, particularly in well structured soil, results can be poor because of bypass flow where water moves quickly downwards along the vertical faces of peds through an unsaturated matrix (Booltink and Bouma 2002). Also, hydrophobicity can result in uneven infiltration that is not predicted by models assuming homogeneity.

Class pdf's are presented for a given soil horizon a given soil type or as a characteristic for the soil type as such, which is used as a "carrier of information" as is common in soil survey interpretations (Bouma 1989). Indicating the variability among different hydraulic conductivity and moisture retention curves measured in different taxonomically identical horizons, allows calculations expressing internal and spatial variability of the particular soil type being studied. Systematic studies, exploring the feasibility of this approach for different soil horizons have not been made. They would be particularly valuable for structured soil horizons where the homogeneous flow model does not work.

Using structure descriptions to improve sampling for physical measurements

A standard soil core of 300 cm^3 may contain some 20,000 individual sand grains when a sandy soil is sampled. When sampling a strong, fine subangular blocky structure with peds of, say, 1 cm diameter, the number reduces to, perhaps 200 and the sample will probably still be representative for the horizon being sampled. When, however, a coarse prismatic structure is encountered, only part of the prisms will fit into such a core. A plea can therefore be made to use soil structure descriptions for defining representative volumes for sampling. Anderson and Bouma (1973) showed that any K-sat could be measured in a B horizon of a well structured silt loam soil by varying the height of the core. This could be explained quantitatively by defining pore-continuity patterns based on dye studies. This method was refined using thin sections and was used to predict K-sat of four clay soils in the Netherlands (Bouma *et al.* 1979). But why go to all this trouble to calculate K-sat while measurement is much easier? The most interesting result of the latter study was the observation that "Pore necks" with a width of 30 micron governed "saturated flow" occupying less than 0.1% of the soil volume. Such values were recently reported by Young (NRC 2009) using modern scanning techniques. This result implies that bulk density and porosity are too coarse a measure to predict K and are therefore unsuitable. Returning to the example of the prismatic soil, the recommendation has to be that large samples are needed, containing al least 20 peds (Bouma 1989). Sometimes, selective sampling is needed, for instance when bleached areas occur around prisms. Then, separate sampling of the peds and the bleached areas and determination of the relative surfaces they occupy is a feasible procedure. Just putting in soil cores at random in pedal soils results in an enormous variability that is not due to soil heterogeneity but to using the wrong sampling procedure. Occurrence of macropores, such as worm channels or vertical cracks, can offer special problems even when using large samples as advocated. Bouma (1991) showed that K-sat, defined as the flux at pressure head zero at gradient 1 cm/cm, varied between 80 m/day and 1 cm/day depending on the method of measurement. Observing macropores should therefore alert phycisists to improve measurement procedures.

Using structure description to provide boundary conditions for physical flow models.

Occurrence of macropores, as discussed here and as described in soil structure descriptions, can define boundary conditions for flow models when functional characterization using dyes is included. Bypass flow was measured in a dry clay soil and the processes could be well simulated by separating the flow model into two parts: one calculating vertical infiltration into the peds and one for lateral infiltration into the peds for bypass water moving down the walls of prisms. (Hoogmoed and Bouma 1980; Bouma 1991). Another example was presented for a silt loam soil with worm channels using the same approach (Bouma *et al.* 1983). These examples demonstrate that soil structure descriptions can form the basis for defining subsystems for flow in structured soils and, as such, demonstrate the hydropedology approach.

Conclusions

1. Pedotransferfunctions (pdf's) make soil data useful when deducing basic physical flow characteristics. They should, however, be used with care as they may yield irrelevant results in structured soils. Emphasis is now on continuous pdf's and more attention to class-pdf's may be profitable.
2. Soil structure descriptions made during soil survey and available in soil databases can be used to fine-tune soil physical sampling procedures, as demonstrated in this paper. Using standard sample sizes implicitly assumes that soils are homogeneous and isotropic. They are not and when using standard-size samples, irrelevant results may be obtained.
3. Soil structure descriptions combined with functional characterization with dyes, can improve simulations of water regimes in field soils as was demonstrated in this paper.
4. Hydropedology promotes combination of tacit knowledge of soil survey with process knowledge of soil physics/hydrology. Both disciplines will have more impact when cooperating.

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