Estimating soil water retention of soil aggregate samples using the 'additivity' model for combination of intra- and into-aggregate pore spaces

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Abstract

The developed ‘additivity’ model aiming to estimate water retention characteristic of aggregated soil layers is based on two main hypotheses: (1) of a subdividing of pore space to intra- and inter-aggregate pore subspaces as well as and their water retention characteristics; (2) estimating of water retention of both subspaces as a linear combination of fractions of their main components. The adequacy of this model was tested on experimental data of measured water retention characteristics of soil cores consisting from fractions of aggregate of Halpic Chernozem, Podzoluvisol, and Halpic Kastanozem, soils. Experimental cores were prepared from separated individual aggregate fractions with size ranges of 10-7, 7-5, 5-3, 3-2, 2-1, 1-0.5, 0.5-0.25, and <0.25mm. The obtained results demonstrated the good agreement with measured data and sensitivity of the ‘additivity’ model to respond to the size of aggregates, textural component distribution and aggregate density.

Key Words

Aggregated soil, soil structure, soil water retention, soil components, additivity model

Introduction

Soil water retention measurements are relatively time-consuming and become impractical when hydrologic estimates are needed for large areas. In many applications, estimating water retention from basic soil data available from soil survey becomes an alternative to measurements. Statistical regressions are most often used to estimate the soil water retention characteristics from soil texture, bulk density, organic matter content, and other basic soil properties. For water retention, one approach consists in estimating soil water contents at several soil water potentials with a separate regression equation for each potential. Several studies tested the regression-based water retention estimates with different data used to develop the regressions. Results of such testing were put together consequently extrapolation of some regression equations beyond their development region was unsuccessful. Yet another approach to soil water retention estimation that is not based on regressions consists of predicting soil water retention from water retention of its soil constituents (Zeiliguer and Voronin 1988; Zeiliguer 1992; 1998). The hypothesis is that soil water retention can be approximated by summing up water retention of pore subspaces related to the soil components is the base of the developed ‘additivity’ model.

Methods

“Aggregated” Soil Medium model Description

Soil structure has a major effect on soil's ability to retain and to transport water. This is especially true for aggregated soils in which pore space consists of interconnected intra- and inter-aggregate pores with distinct hydraulic properties. When a proportion of the inter-aggregate pore space is significant, the conventional description of water flow with “one pore region – one continuum” models oversimplifies water retention and flow.

An ‘addivity’ model to estimate the aggregated soil water retention is based on the following assumptions:
pore space of an aggregated porous medium can be subdivided into textural (into-aggregate) and structural (intra-aggregate) quasi-homogeneous pore regions using the values of bulk density and aggregate density;
water retention of both regions in the range of soil potentials between -1500 and 0 kPa can be estimated separately using the 'additivity' model;
water retention associated with soil textural fractions is measured on samples consisting exclusively of those textural fractions;
water retention of aggregate and textural fractions of the same size are assumed to have the same parameters;
contributions of textural and structural fractions into the total water retention are proportional to the volumes of pore subspaces associated with the corresponding fractions.

Soil structural components, i.e., aggregates, or peds, create two own contiguous pore subspaces where soil water is retained. First textural sub-space is created in interior part of these structural components that is build by textural components of these elements, i.e., soil elementary particles. Second structural sub-space is created in exterior part of the same structural components that build by them-self. There are not soil elementary particles in it. Subscripts "T" and "S" denote textural and structural pore subspaces, respectively. Soil water content (gravimetric) for each soil water pressure head h is equal to sum of soil water content of soil textural and structural sub-spaces

$$W(h) = W^T(h) + W^S(h) \quad . \quad (1)$$

Application of the additivity hypothesis for the capillary and residual water contents of both textural and structural components provides following equation:

$$W(h) = W_C^S \frac{\sum_{j=1}^{N^S} f_j W_{j,0}^T S_j^T(h)}{\sum_{ji=1}^{N^S} f_j W_{j,0}^T} + \left(W_C^T - \sum_{i=1}^{N^T} f_i W_{i,R}^T \right) \frac{\sum_{i=1}^{N^T} f_i W_{i,0}^T S_i^T(h)}{\sum_{i=1}^{N^T} f_i W_{i,0}^T} + \sum_{i=1}^{N^T} f_i W_{i,R}^T \qquad (2)$$

where W_C^S and W_C^S are gravimetric water content of both sub-spaces at saturation, f_j and f_i are fraction of jth structural and ith textural component, N^S and N^T are total number of components of both sub-spaces, $W_{j,0}^T$ and $W_{i,0}^T$ are gravimetric water content at saturation, $S_j^T(h)$ and $S_i^T(h)$ are relative saturation.
Figure 1 shows data on water retention of soil textural components (Michurin 1975; Stakman,1969) that has been used in this work. To use these data with various capillary pressure values, we needed to fit an equation to data. Water retention curves of monofractional samples are very steep (Figure 1). The Weibull equation was successfully used to fit steep experimental dependencies (Zeiliguer and Voronin 1988). Therefore we found that a more accurate fit of some of data in Figure 1 could be obtained using by applying a linear combination of two similar equations to fit water retention data. Use of a linear combination of two Weibull equations is given in the following form:

$$W_{i,e}(h) = W_{i,0}\left\{ q \exp\left[-\left(h/h_i'\right)^{m_i'} \right] + (1-q)\exp\left[-\left(\left(h/h_i''\right)\right)^{m_i''} \right] \right\} + W_{i,R} \qquad (3)$$

where h_i', h_i'' and m_i', m_i'' shape parameters.

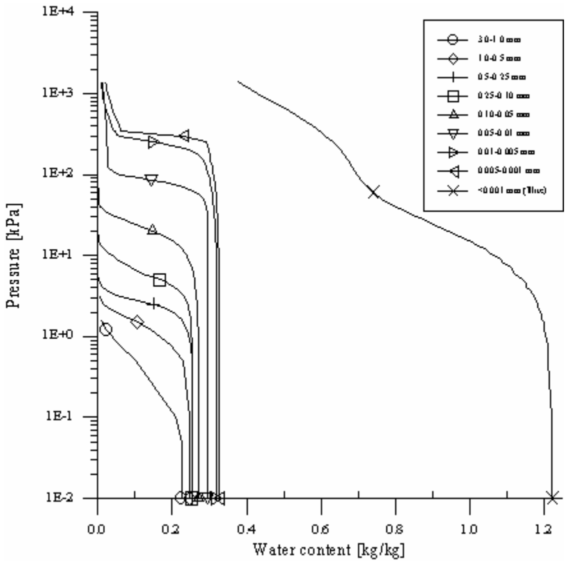

Figure 1. Water retention of samples after (Mitchurin 1975) and (Stackman 1968) containing soil textural fractions. Fraction d<0.001 mm is represented by the illite clay.

A code based on the modified Marquardt algorithm was used to find seven parameters h_i', h_i'', m_i', m_i'', q, $W_{i,0}$ and $W_{i,R}$.

Materials

In this work, we used the data on water retention and soil physical parameters obtained by T.N. Pochatkova (Pochatkova 1981). The following soil samples were used for model validation:
five horizons horizons (A_d, A_1, B_1, B_2 and BC) of Ordinary Chernozem (Black Soil) from Kammenaya Steppe (Kursk, Russia);
From these samples the following individual soil aggregate fractions were separated: 10.0-7.0mm; 7.0-5.0mm; 5.0-3.0mm; 3.0-2.0mm; 2.0-1.0mm; 1.0-0.5mm; 0.5-0.25mm; <0.25mm). The special soil cores were prepared from these separated individual fractions of aggregates. Initially the cores were saturated with water by capillary arising. The water retention characteristics of packed cores were measured in drainage experimentation in porous plate equipment.

Results

The overall performance of the model as well as its performance in various capillary pressure ranges can be judged from Figure 2.

Conclusion

The ‘additivity’ model was tested on estimation water retention of soil cores fabricated from individual fractions of aggregates taken from five horizonts of ordinary chernozem. The model is based on subdivisions of soil pore space into two sub-spaces of structural and textural soil components. Results of the testing shows a good agreement of obtained results with measured data.

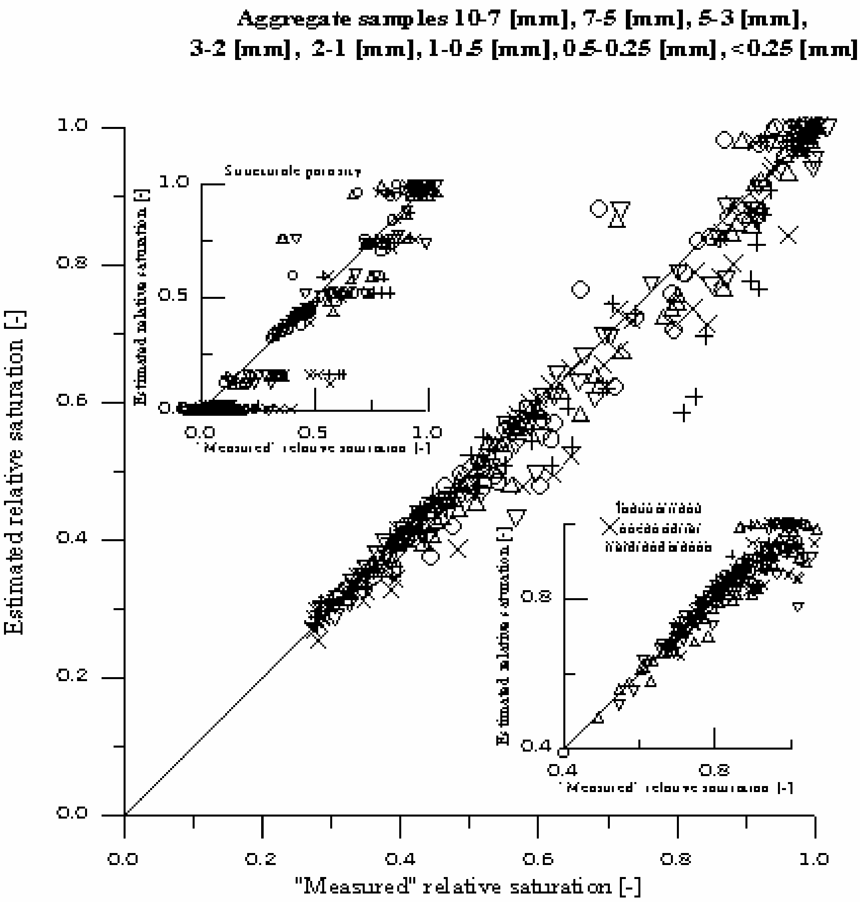

Figure 2. Comparison of the experimental and simulated water retention characteristics of samples of individual fractions of samples of ordinary chernozem: Ад - A1; B1; B2; BC.

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