Estimating soil water retention in soil aggregates using an 'additivity' model for combining structural and textural pore spaces

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Abstract

The ‘additivity’ model aiming to estimate water retention characteristic of aggregated soil layers is based on two main hypotheses: (1) subdivision of pore space into structural and textural pore spaces and their water retention characteristics; (2) estimation of water retention of both spaces as a linear combination of fractions of their main components. The adequacy of this model was tested with experimental data of measured water retention characteristics of soil cores consisting from aggregates 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 <0.25 mm. The results demonstrated a good agreement with measured data as well as the sensitivity of the ‘additivity’ model 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 in composing soil water retention from water retention of its soil constituents (i. e., Zeiliguer and Voronin 1988, Zeiliguer 1992; 1997).

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 structural and textural 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 and structural 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 for each soil water pressure head h is equal to sum of soil (gravimetric) water content of soil textural and structural sub-spaces

$$W(h) = W^T(h) + W^S(h). \tag{1}$$

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

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

here, ε_C^S, ε_C^T - respectively, pore volumes (averaged by dry mass of soil volume) of structural and textural subspaces, $W_{i,R}^T$- gravimetric residual water content of textural soil components (assuming that due to big dimension of soil aggregates structural residual content is $W_{i,R}^S = 0$), $W_{i,0}^T$ is the specific to *i*th fraction of soil components soil gravimetric water content at saturation, and $S_i^T(h)$ is the specific to *i*th fraction of soil components (aggregates and soil elementary particles) relative saturation, N^S, N^T is the total number of structural (aggregates) and textural (soil elementary particles) component fractions.

Figure 1 shows data on water retention of (textural) fractions of soil elementary particles (Michurin 1975; Stakman,1969) that has been used in this work. The Weibull equation was successfully used to fit steep experimental dependencies (Zeiliguer and Voronin 1988). Therefore it was found that a more accurate fit of some of data in Figure 1 could be obtained using a linear combination of two similar Weibull equations to fit water retention data. Use of a linear combination of two Weibull equations for *i*th textural fraction of soil component is given in the following form:

$$W_i^T(h) = W_{i,0}^T \left\{ q \exp\left[-\left(h/h_i^{'} \right)^{m_i^{'}} \right] + (1-q) \exp\left[-\left(\left(h/h_i^{''} \right) \right)^{m_i^{''}} \right] \right\} + W_{i,R}^T \tag{3}$$

where $h_i^{'}$, $h_i^{''}$ and $m_i^{'}$, $m_i^{''}$ were shape parameters, *q*- empirical parameter .

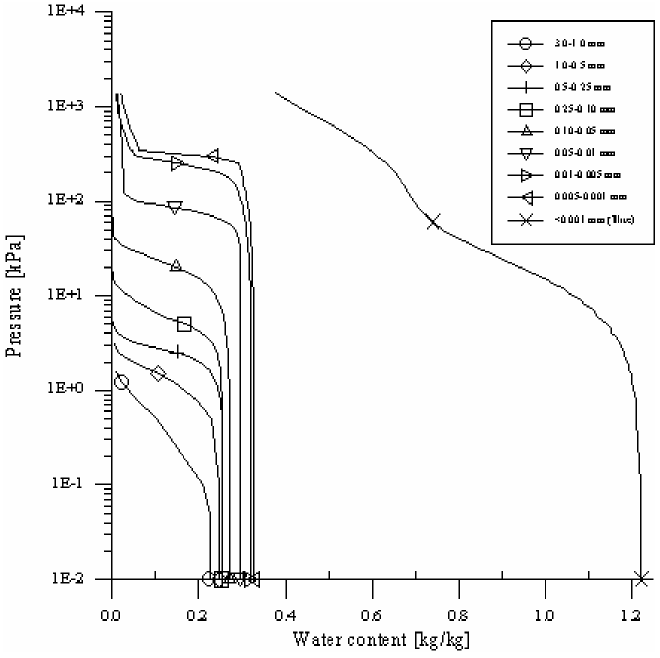

Figure 1. Water retention of samples (after [*Mitchurin 1975*], [Stackman 1968]) containing soil elementary particle fractions. Fraction d<0.001 mm is represented by the illite clay fraction.

Materials

To validate ‘additivity’ model we used the data on water retention and soil physical parameters of soil cores consisting of fractions of aggregates obtained *in vitro* by T.N. Pochatkova (Pochatkova 1981). The following soil were used for model validation:

- ✓ five horizons horizons (A_d, A_1, B_1, B_2 and BC) of Ordinary Chernozem (Halpic Chernozem) from Kammenaya Steppe (Kursk, Russia) shown at Figure 2;
- ✓ two horizonts (B_1 and B_2) of Dernovo-Podzolic Soil (Podzoluvisol) from Chashnikovo (Moscow Region, Russia);
- ✓ one (A_1) of Kashatanovaya Soil (Halpic Kastanozem) from Volgograd Region (Russia);

From these samples the following individual aggregate fractions were used to fabricate soil cores: 10-7; 7-5; 5-3; 3-2; 2-1; 1-0.5; 0.5-0.25; <0.25mm).

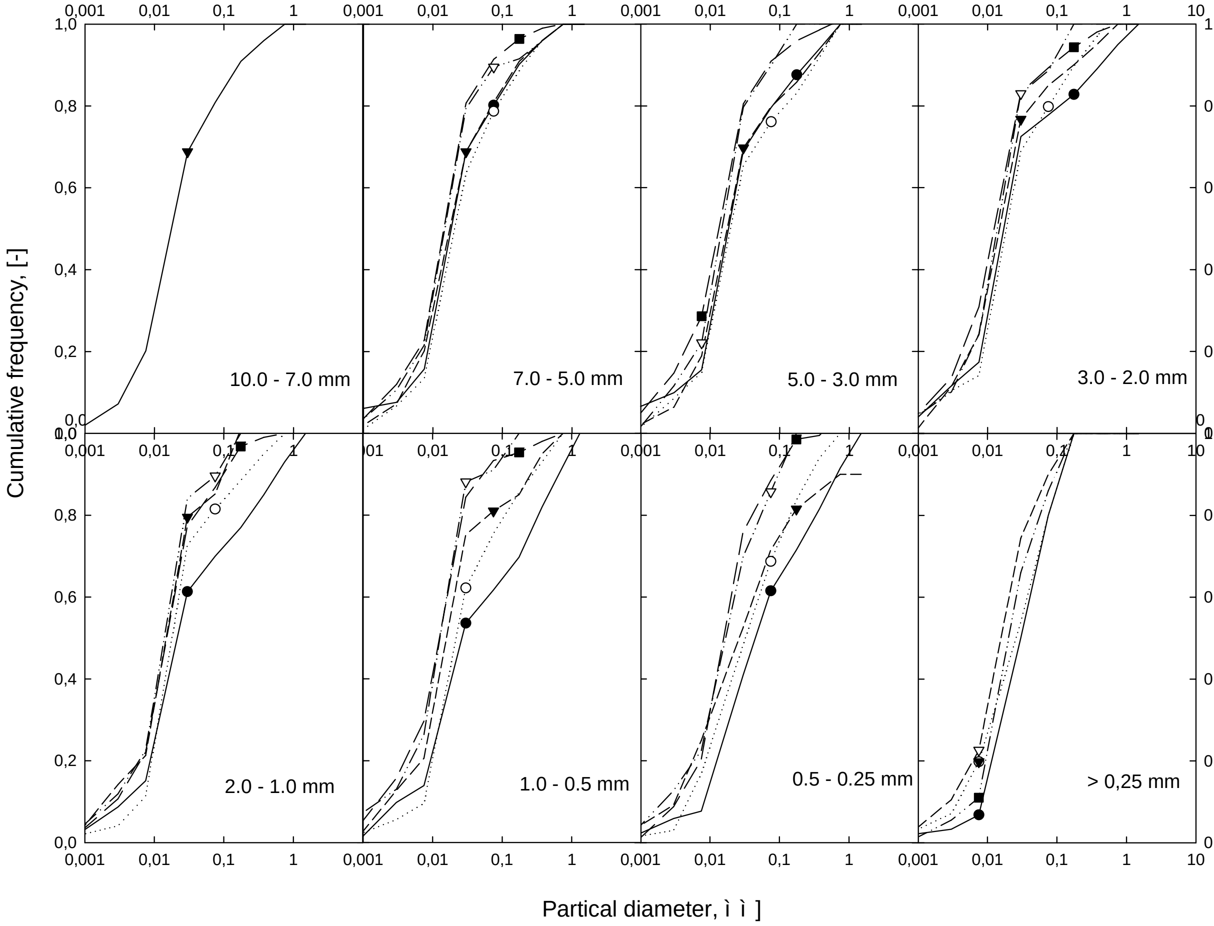

Figure 2. Elementary particle size-distribution of samples of soil cores with individual aggregate fractions of ordinary chernozem samples taken out from following horizons: Ад (○); A1 (▲); B1 (▼); B2 (+); BC (x).

After initial water saturation by capillary arising at these cores water retention characteristics were measured in drainage experimentation in porous plate equipment.

Results

The performance of the ‘additivity’ model can be judged from Figure 3 showing comparison of the measured ($W^m(h)/\varepsilon^m$) and calculated ($W^c(h)/\varepsilon^c$) soil relative saturation of samples of individual fractions of samples of ordinary chernozem. At this Figure at each soil core (fraction of aggregate diameter) two estimated curves are shown.

Conclusions

With the aim of some assumptions and hypotheses we developed ‘additivity’ model to estimate water retention of aggregated soil. Input parameters of the model are divided into two parts. First is done by physical soil parameters like bulk density, dry density of aggregate as well as structural and textural soil components (aggregate and soil elementary particle) size-distribution. Second set is done by empirical parameters fitted for Weibull equation parameters of water retention characteristics of fractions of textural components (soil elementary particles).

A validation of the model was done by comparison with measured water retention of soil cores fabricated from fraction of aggregates taken from some layers of three types of soil. Obtained by ‘additivity’ model results as well as measured soil water retention characteristics are quite sensitive to the dimension (diameter) of both soil components (aggregates and elementary particles) size-distributions.

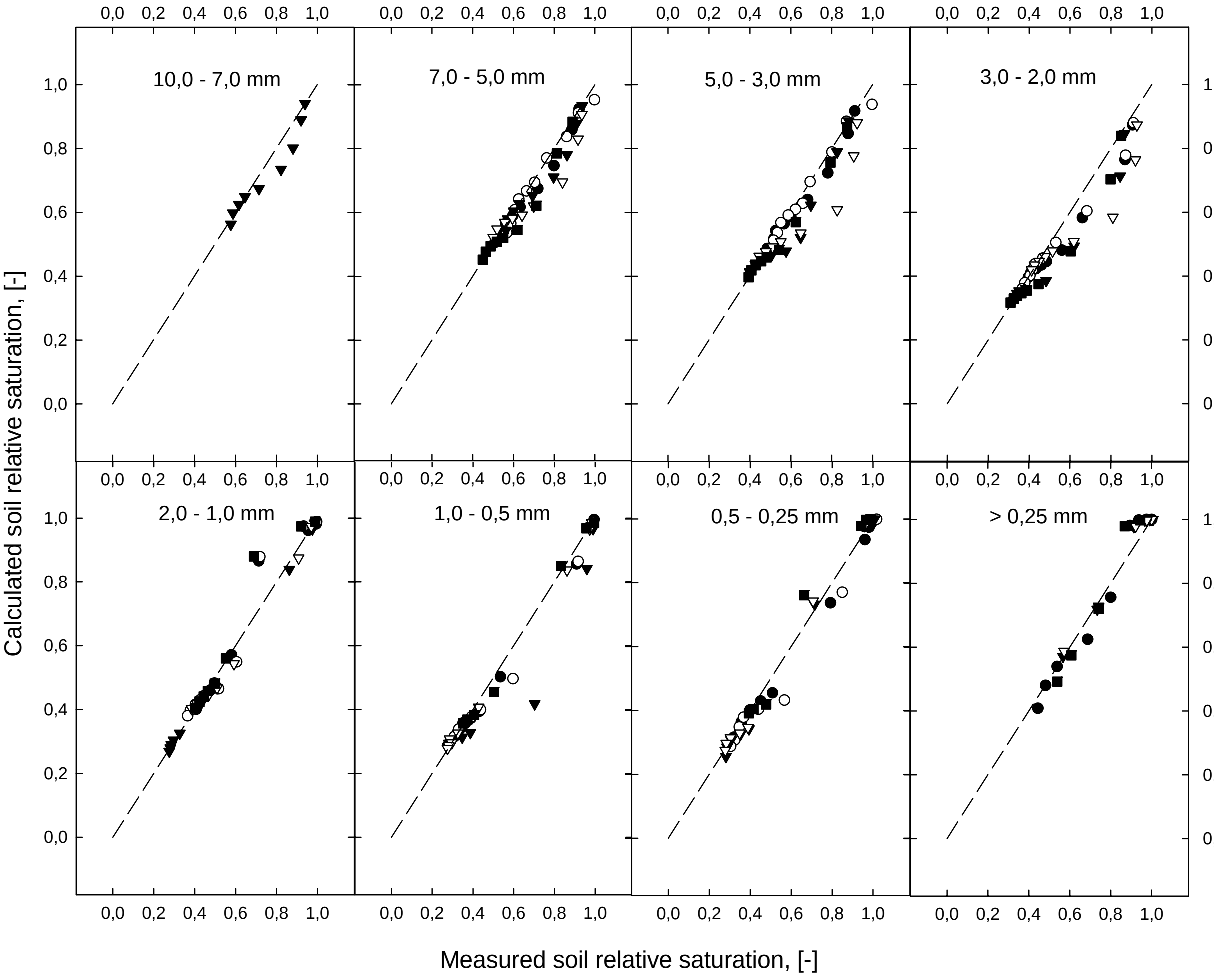

Figure 3. Measured and calculated by ‘additivity’ model soil relative saturation of samples of individual fractions of ordinary chernozem for samples taken out from following horizons: Aд (○); A1 (▲); B1 (▼); B2 (+); BC (x).

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