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Data of hydraulic properties of North East and Central German soils

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Abstract

The paper presents a data base of soil hydrological properties of North East and Central German soils. Included are measured data of the soil water retention curve and the unsaturated hydraulic conductivity function. Information to geo reference, soil type and horizon are given. Additional soil physical data like particle size distribution, dry bulk density, organic matter content and other variables are presented and its measurement is methodically described. The data base includes original measurement results of 278 organic and of 497 mineral soil samples from 103 sites. The mineral soils cover a wide range of texture classes and dry bulk densities. The organic soils and samples vary in dependence on the degree of decomposition and mineralization, the dry bulk density and the total porosity.

1 Introduction

Knowledge of hydraulic functions is required for various hydrological and plant physiological studies. During the last decades numerous measurement procedures have been developed. Currently a broad array of methods exists for determination of soil hydraulic properties in the field or in the laboratory (Klute and Dirksen, 1986; Dane and Hopmans, 2002; Nimmo et al., 2002; Arya, 2002). The evaporation method is a frequently used procedure for measuring hydraulic functions of unsaturated soil samples in the laboratory (Wind, 1966; Becher, 1970; Schindler, 1980; Wendroth et al., 1993; Halbertsma, 1996; Bertuzzi et al., 1999; Arya, 2002). The method allows an accurate characterization of the water retention properties of the porous system, from saturation to the measurement limit of tensiometers, and of the unsaturated hydraulic conductivity in the range where significant hydraulic gradients occur in the sample (Schindler and Müller, 2006; Peters and Durner, 2008). The method of Schindler (1980) is a simplified setup of the WIND procedure. Only the total soil sample weight and tensions at two height levels are recorded at several times as basis for quantifying the hydraulic

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functions. Peters and Durner (2008) showed that despite the larger spatial distance of the tensiometers, effects of spatial and temporal nonlinearity are negligible in the data evaluation and that the method leads to precise and unbiased results, provided the usual assumption of water flow according to Richards' equation, with local equilibrium between water content and matric pressure, is valid (Durner and Flühler, 2005).

In the period between 1976 and 1992 soil hydrological properties – water retention curve and unsaturated hydraulic conductivity function – of 775 soil samples were measured with the evaporation method. The samples were collected from 103 sites located in North East and Central Germany. The data base includes the soil hydrological properties and additional information to the geo reference, the soil type and horizon, the particle size distribution, the dry bulk density and other parameters and is available at the ZALF homepage. Methodical information to methods and measurements techniques are given in the following.

2 Material and method

2.1 Soils and sites

Measurements of the water retention curve and the unsaturated hydraulic conductivity function were carries out in the laboratory with the evaporation method (Schindler, 1980). The 497 mineral soil samples cover a wide range of texture classes (AG Boden, KA4 1994) (Fig. 1). The 278 organic soils contain peat samples of different grades of decomposition and mineralization, several muddy substrates, as well as clay and sand soils rich in humus. Additionally to the soil hydrological properties, the particle size distribution, the dry bulk density, the organic matter content and other parameters were measured.

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2.2 Data base

The data (raw data) are collected in the soil hydrological data base of the Institute of Landscape Hydrology of the ZALF Müncheberg. The structure of the data base is the same as in the HYPRES database (Lilly et al., 1997). Table 1 gives an overview of the data base content.

2.3 Measurement of soil hydraulic properties with the evaporation method (Schindler, 1980)

Intact soil cores are taken in stainless steel cylinders (250 cm^3 volume, 6 cm height) with a sharpened leading edge to minimize soil disturbance during insertion. Two tensiometers are installed sidewise at depths of 1.5 and 4.5 cm above bottom, respectively. Cores are slowly saturated in the laboratory by placing them in a pan of water. After saturation, the sample is sealed at the bottom and placed on a balance. Its surface remains open to evaporation. Tensions (Ψ) and sample mass (m) are measured at time intervals. The measurement interval of both, sample mass and tension varied dependent on soil material and evaporation rate between 10 min (clay soils and sand at the end of measurement, when the hydraulic gradient increased rapidly) and 4 h (sand soils at the beginning of measurement, as long as the hydraulic gradient was small). The measurement was finished when the upper tensiometer reaches its tension limit. Tension was measured with mercury tensiometers (measurement range $0 < h < 70$ kPa, measurement accuracy 0.1 kPa). The mean hydraulic gradient (i_m) is calculated on the basis of the tension values in the interval. The flux (v) is derived from the soil water volume difference ΔV (1 cm^3 of water = 1 g) per surface area (A) and time unit (Δt). Single points of the water retention curve are calculated on the basis of the water loss per volume of the sample at time t and the mean tension over the sample at that time.

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The hydraulic conductivity (K) is calculated according to Darcy-Buckingham's law (Eq. 1).

$$K(\overline{\Psi}) = \frac{\Delta V}{2A * \Delta t * i_m} \tag{1}$$

where $\overline{\Psi}$ is the mean tension averaged over the upper tensiometer at position z_1 (4.5 cm above bottom) and the lower tensiometer at position z_2 (1.5 cm above bottom), Δt is the time interval, ΔV is the total evaporated water volume of the complete sample (equal to sample mass difference, Δm, in the interval), A is the cross sectional area of the sample, and i_m is the mean hydraulic gradient in the time interval, given by:

$$i_\mathrm{m} = \frac{1}{2} * \left(\frac{\Psi_{\mathrm{t1,upper}} - \Psi_{\mathrm{t1,lower}}}{\Delta z} + \frac{\Psi_{\mathrm{t2,upper}} - \Psi_{\mathrm{t2,lower}}}{\Delta z} \right) - 1 \tag{2}$$

where $\Psi_{\mathrm{t,upper,lower}}$ indicate the tension of upper and lower tensiometer values at time t, and Δz is the vertical distance of the tensiometers. At the end of the measurement, the residual amount of storage water is derived from water loss by drying in the oven (105 °C).

The assumptions for the validity of Eq. (1) are:

i) "quasi steady state" conditions, which means that flux and hydraulic gradient are approximately constant over the time interval.

ii) linear decreasing water content over the sample height in the measuring interval. Accordingly, the flux through the measured layer (half of the total flux) can be calculated from the soil water volume difference in the time interval. Results by Peters and Durner (2008) confirmed the validity of this assumption.

At the end of the measurement, the residual amount of storage water is derived from water loss upon oven drying (105 °C). The initial water content is determined by total water loss (evaporation part plus residual amount) related to core volume.

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Dry bulk density is derived from dry soil mass divided by core volume. For this reason the volume of the tensiometer holes ($1\,cm^3$) is subtracted from the core. The total measurement time depended on the evaporation rate and the soil water content in the measurement range (tension between 0 and about 60 kPa) and varied between 1 day for clay soils and maximum 10 days for sand soils. Figure 2 exemplarily presents measured hydraulic function with the evaporation method.

2.4 Methods of other physical properties

2.4.1 Particle size analyzes

The particle size distribution is an important basic soil physical variable for characterizing and classifying soils. Its measurement occurred by gravitational sedimentation (pipette method) acc. to Gee and Or (2008). Sedimentation analysis relies on the relationship between settling velocity and particle diameter. The pipette method is a direct sampling procedure. It depends on taking a small subsample by a pipette at a depth, h (10 cm for our analysis), at time, t, in which all particles coarser than d have been eliminated. Settling times are calculated using Stokes' Law (Eq. 3):

$$d = \sqrt{\frac{18\eta * h}{g(\rho_s - \rho_l) * t}} \tag{3}$$

where η is the fluid viscosity, h is the sedimentation length, d is the particle diameter, ρ_s is the particle density, ρ_l is the liquid density, g is the gravitational acceleration, and t is the time.

Preconditions are disintegrated soil material and a solution free off organic carbon. Organic carbon was destroyed by cooking in hydrogen peroxide (H_2O_2). Dispersion occurred by shaking in sodium pyrophosphate ($Na_4P_2O_7$). Analyzed particle classes where: clay (<0.002 mm), fine silt (0.002–0.0063 mm), medium silt (0.0063–0.02 mm), fine silt (0.02–0.063 mm). The sand fraction (fine sand 0.063–0.2 mm), medium sand

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(0.2–0.63 mm) and coarse sand (0.63–2 mm) was analyzed by sieving of the disperse solution.

2.5 Soil organic matter content and ash content

Soil organic matter: Dry combustion acc. to DIN ISO 10694 (1994),
Soil organic matter = organic C*1.724
Ash content: Combustion at 550 °C (DIN 19684 T3) related to the oven-dried soil sample (DIN ISO 11465).

3 Conclusions

The measurement of soil hydraulic properties like water retention curve and unsaturated hydraulic function is cost and time consuming. The presented soil physical data cover a wide range of North East and Central German soils and sites. The data provided here allow improving soil specific scientific investigations in an effective way and could be a help for companies which deal with practical applications like irrigation or soil and water management.

4 Data access

The data of the mineral soils are published under doi:10.4228/ZALF.1977.164. The data set contains 497 soil samples which covers a wide range of texture classes, dry bulk densities and organic matter contents.

The data of the organic soils are published under doi:10.4228/ZALF.1978.165.The data set contains 278 soil samples which cover a wide range of different degree of decomposition and mineralization as well as various dry bulk density and porosity.

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Table 1. Data base content and structure.

Basis data:	Site name Soil type acc. to FAO guidelines Local soil type (KA4) Geo reference (ETRS89) Sampling depth Site description (land use, region, geological origin) Sampling date Average annual rain fall Average temperature in January Average temperature in July Number of horizons
Soil properties:	Site name Geo reference Horizon Soil structure Dry bulk density ($cm^3\,cm^{-3}$) Organic matter content (%) Ash content (%) Saturated hydraulic conductivity ($cm\,d^{-1}$)
Particle size distribution (PSD):	Site name Geo reference Horizon Sample number Percentage of particle classes (mm) Clay: 0.002 Fine silt: 0.0063 Medium silt: 0.02 Coarse silt: 0.063 Fine sand: 0.2 Medium sand: 0.63 Coarse sand: 2
Soil water retention function:	Site name Geo reference Horizon Sample number Pair of values of water content ($cm^3\,cm^{-3}$) and tension (hPa)
Unsaturated hydraulic conductivity:	Site name Geo reference Horizon Sample number Pair of values of tension (hPa) and hydraulic conductivity ($cm\,d^{-1}$)

Soil and site description was done according to Arbeitsgruppe Boden (KA4, 1994).

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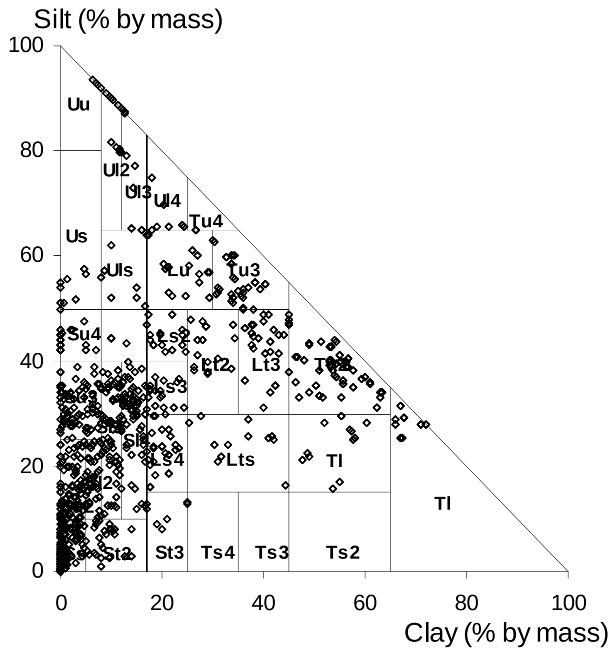

Fig. 1. Distribution of texture classes according to German classification (Arbeitsgruppe Boden, KA4, 1994) of the investigated soils.

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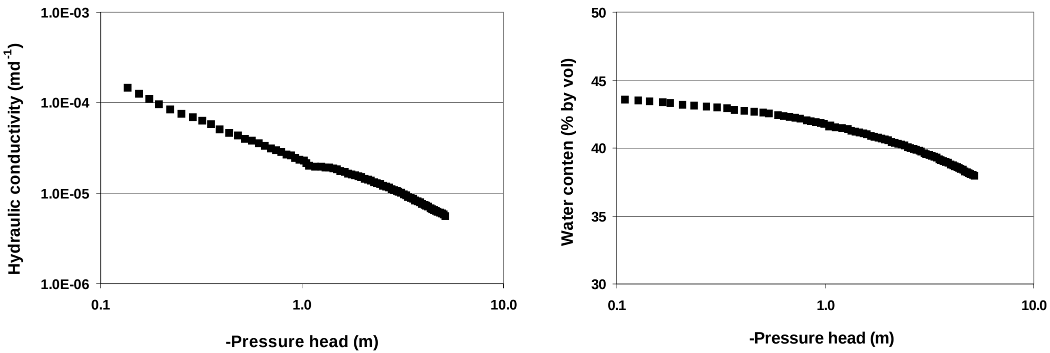

Fig. 2. Hydraulic conductivity function (left) and water retention curve (right) of a clay soil, Seelow (Oderbruch), Ap horizon.

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