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LABORATORY EVAPORATION EXPERIMENTS IN UNDISTURBED PEAT COLUMNS FOR DETERMINING PEAT SOIL HYDRAULIC PROPERTIES

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SUMMARY

Hydraulic properties of mineral and organic soils differ in several aspects. Due to the high amount of organic components, strong heterogeneity, and shrinkage and swelling of peat, accompanied by changing soil volume and bulk density, modelling of water flow in peat soils with Richards' equation and the commonly applied van Genuchten-Mualem (VGM) parameterization is difficult. We determined hydraulic properties from various peat soils, covering a broad range of degradation states and land use histories, by laboratory evaporation experiments and evaluated the applicability of VGM to describe measured water content and pressure head data by inverse modelling of the experiments.

KEYWORDS: peat land, evaporation experiment, laboratory lysimeter, hydraulic properties, hydrological modelling

INTRODUCTION

The German joint research project "organic soils" aims to improve the understanding and quantification of greenhouse gas (GHG) emissions from organic soils in Germany. One of the key parameters controlling the GHG emissions from organic soils is water table depth. Thus, a detailed analysis of the hydrology in the different project test sites is essential for an accurate spatial up scaling of the information of local GHG emission measurements to the regional and national scale. A sub-project deals with the hydrological modelling for the different test sites. For the interpretation and numerical modelling of observed water table fluctuations, knowledge about peat soil hydraulic parameters is crucial. In contrast to most mineral soils, peat soils are characterised by dynamic physical and hydraulic properties. This is caused by a high compressibility and by a large propensity to shrink and swell under changing moisture regimes (Schwärzel et al., 2002).

Since 50 years, evaporation methods are used to determine the unsaturated hydraulic conductivity and water retention function. The method was first introduced by Gardner and Miklich (1962). Ever since several modifications of the evaporation method with simultaneous measurements of evaporation rate and pressure head have been developed (Wind, 1968, Wendroth et al., 1993; Šimůnek et al., 1998). In these studies, soil hydraulic parameter were estimated by combination of pressure head data at different depths, evaporative water loss and the total water content. The advantage of the method is the simple determination of unsaturated hydraulic conductivities between -50 to -700 cm, while a disadvantage is that good estimates of the conductivity close to saturation cannot be made because hydraulic gradients are too small in the wet range (Šimůnek et al., 1998). However, peat soils often are subjected to saturated or almost saturated conditions.

We investigate the possibility of the evaporation method to determine peat soil hydraulic properties for both the wet (>-50 hPa) and dry range (<-50 hPa) by using not only tensiometer but also time domain reflectometry (TDR) water content measurements. In numerical simulations using HYDRUS-1D, the experimental data were used for an inverse estimation of the soil hydraulic parameters. The object of this study is to evaluate the differences of the hydraulic properties of peat soils and to assess the applicability of the commonly applied van Genuchten-Mualem (VGM) parameterization developed for mineral soils to describe soil water flow in peat soils. Here, we focused on the results of two sampled peat land sites, Zarnekow and Anklam.

MATERIAL AND METHODS

Study areas and sampling

Five different peatland sites were included in this study (Fig. 1a). These sites cover a broad range of different peat soils, i.e. bogs and fens with different degradation stages and land uses (Table 1). In this paper, we present results of the two sites Anklam and Zarnekow, which are both situated in the river valley Peenetal, in Northeast Germany, close to the Baltic Sea. At every research site two undisturbed soil columns (diameter: 30 cm, height: 20 cm), from the surface layer (0-20 cm depth), were collected.

Table 1: Description of the sampled peatland sites

No.	Peatland site	Peatland type	Peat substrate	Land use/Vegetation
1	Zarnekow	fen	humified peat	extensive grassland
2	Anklam	fen	sedges, reeds, fossil woods	succession to reed and willow
3	Spreewald	fen	fen wood, sedges, reeds	Alder forest
4	Großes Moor	bog	shallow amorphe peat	extensive grassland
5	Schechenfilz	bog	sphagnum peat/moss	natural

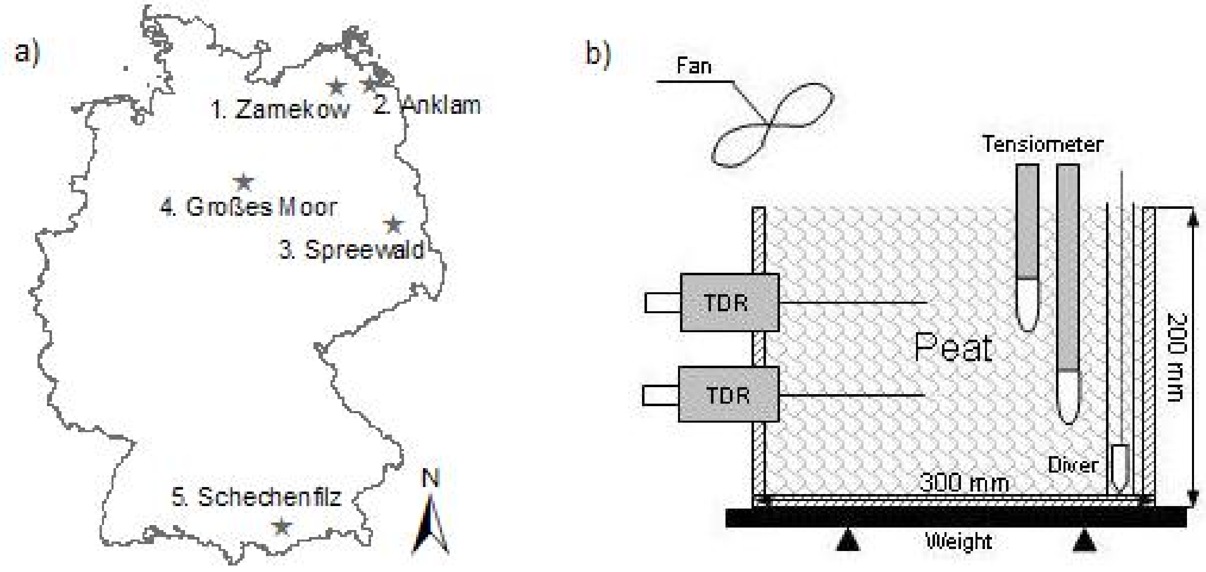

Fig. 1: a) locations of the study areas in Germany; b) experimental setup of the laboratory lysimeter.

Laboratory evaporation experiments

All samples were investigated by the same setup. A laboratory lysimeter was placed on a balance (Sartorius Signum 1, Satorius AG, Goettingen Germany) and equipped with two time domain reflectrometry (TDR) probes (TRIME-PICO 64, IMKO GmbH, Ettlingen Germany), two tensiometers (UMS T8; UMS-GmbH, Munich Germany) and a water level logger (Mini-Diver, Schlumberger water services, Delft Netherland) (Fig. 1b). TDR probes were installed horizontally and tensiometers vertically at depths of 6 and 12 cm. Weight, pressure head, moisture, water level, and laboratory air temperature and humidity were recorded continuously by data loggers. TDR readings of travel time were translated into water contents using the peat-specific calibration curve provided by IMKO. Before the evaporation experiment, the samples were saturated from the bottom through a vertically inserted pipe. Afterwards, the sample surface was exposed to evaporation, which was enhanced by a fan. All experiments were carried out as bare soil experiments, i.e. all plants were removed.

RESULTS AND DISCUSSION

The drying period of one of the columns of site Zarnekow is illustrated in Figure 2. During the experiment the measured evaporation rate decreased from about 0.6 mm h^{-1} to 0.2 mm h^{-1}. The overall trend was superimposed by fluctuations that were caused by varying air temperature and humidity. The observed decrease of the evaporation rate was accompanied by decreasing water level, water contents and pressure heads. Field and laboratory examination of the peat sample indicated that its bulk density increases with depth. The measured water contents are consistent with this observation. At saturated conditions, the TDR probes showed higher water contents at 6 cm than at 12 cm depth.

The total water content of the column was determined by drying the probes at the end of the experiment. It was 55 % at the end of the experiment and extrapolated to a total water content of 69 % at the beginning of the experiment (Fig. 2, total water content). The total water content differed from the measured water contents derived from the TDR-probes. Here, we applied the peat-specific calibration curve provided by IMKO to relate TDR electromagnetic wave travel times to water contents. However, as the physical properties of peats present large variations, water contents derived by application of a universal peat calibration curve have to be considered as highly uncertain. By separate experiments with smaller columns, we currently derive site-specific calibration curves. Using these calibration curves, the accuracy of the TDR water contents will be increased and remaining uncertainty can be quantified. Further deviations between total water content and TDR water content are caused by the onset of shrinking of peat, which causes a bias towards higher water contents measured by TDR than the total water content, which is still based on the initial soil volume.

We used TDR water content and pressure head data to derive depth-specific water retention characteristics of the different peat columns (Fig 3a). First results of our study indicate that the degradation of peat soils from different study sites, affect moisture retention characteristics depending on the degree of peat decomposition. Kechavarzi *et al.* (2009) demonstrated that less decomposed peats draining faster than degraded peats. The first results our study point out the same trend. The little decomposed peat from the site Anklam drains faster than the more decomposed peat from Zarnekow (Fig. 3a).

For the evaporation experiments at the two columns from Zarnekow, inverse simulations were performed using HYDRUS-1D to estimate van Genuchten-Mualem (VGM) parameters. So far, due to the uncertainty in the TDR water contents, we only used the measured pressure head data in the objective function of the inverse solution. The R^2 for the regression of predicted vs. observed pressure heads was 0.97720 for column 1 and 0.98092 for column 2. Figure 3b and Figure 3c show the water retention curves derived i) from the TDR and tensiometer data and ii) from the inversely estimated VGM parameters. The VGM parameters for column 1 do well describe the retention curve derived from TDR and tensiometers. For column 2 (Fig. 3c) the inversely estimated water retention function strongly deviate from the one derived from TDR and tensiometers. The VGM parameterization is not capable to describe both the dynamic data from the evaporation experiment as well as the water retention curve derived from the TDR and tensiometer data. The inversely estimated 'optimal' parameter set is the result of a trade-off in describing the water retention and hydraulic conductivity curve.

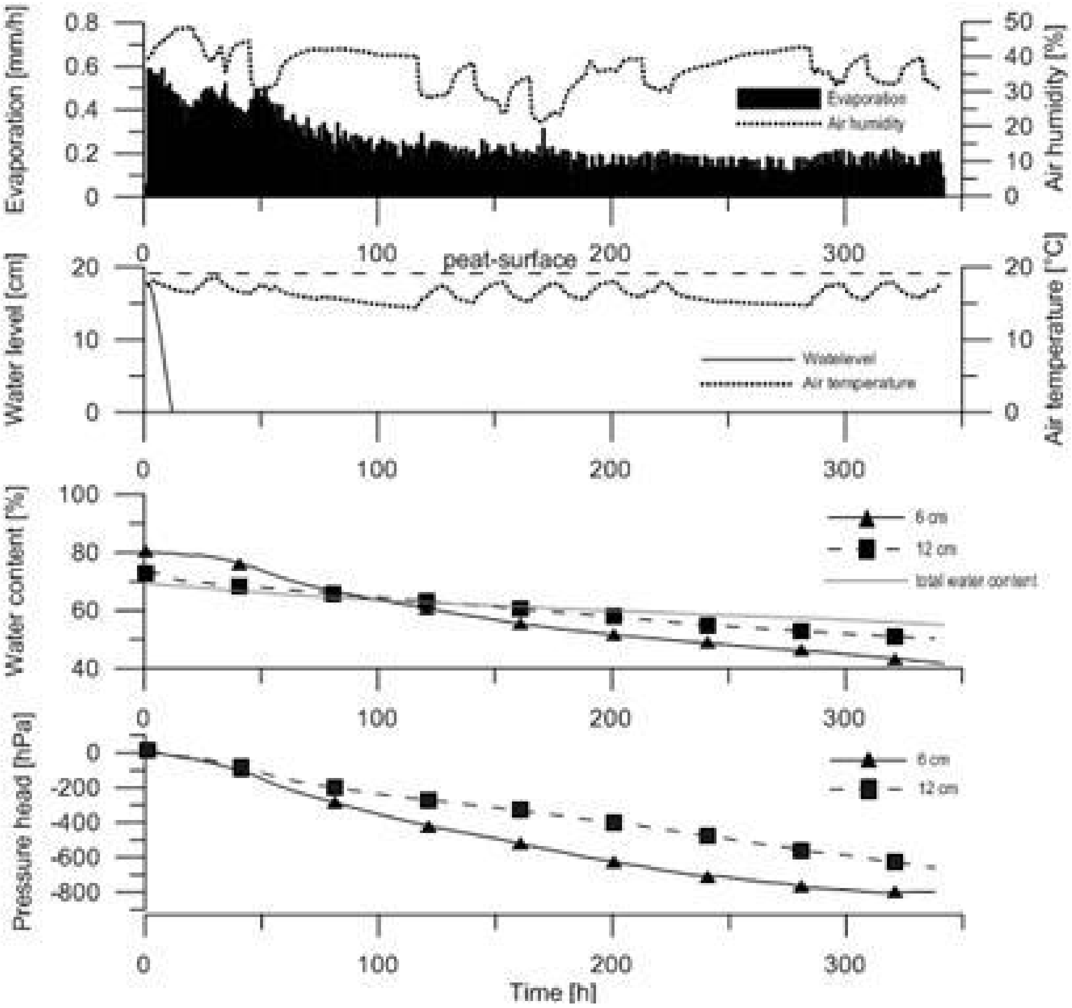

Fig. 2: Evaporation experiment of column 2 from study site Zarnekow. Shown are pressure head, water content (measured with TDR-sensors and total water amount by drying the probe), water level, irrigation, temperature, evaporation and humidity over the 340 hours period of the experiment.

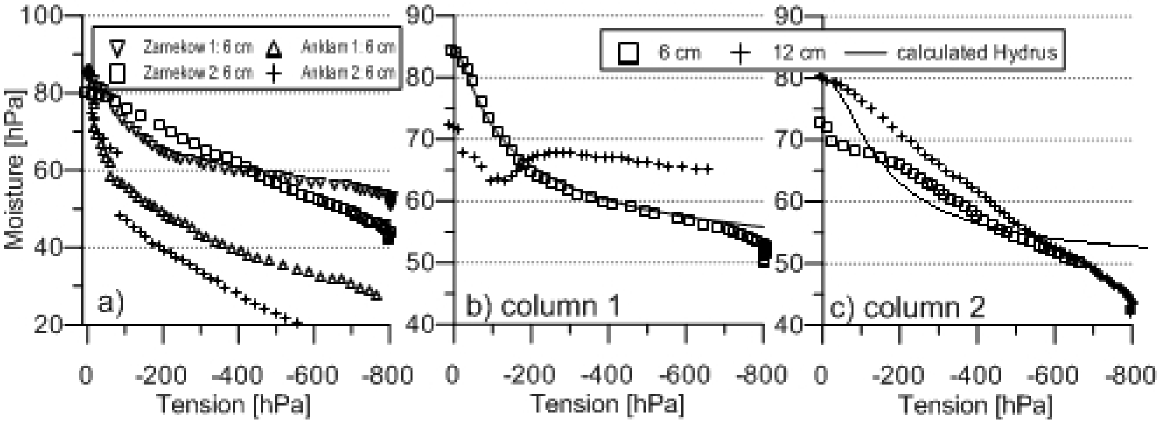

Fig. 3: a) TDR and tensiometer based water retention curves of the samples from Zarnekow and Anklam in 6 cm depth b) and c) Zarnekow column 1 and 2: water retention curves (derived from TDR and tensiometers) in 6 cm and 12 cm depth compared with retention curves derived from inverse simulation of evaporation experiments using van Genuchten-Mualem parameters. Measured curve in 12 cm depth (column 1) unusual and probably caused by meassurement errors.

CONCLUSIONS

The van Genuchten-Mualem (VGM) parameterization of the water retention and hydraulic conductivity function is the most frequently used parameterization to model water flow with Richards' equation in mineral as well as organic soils. While the applicability of the VGM parameterization to describe water retention characteristics of peat soils can be evaluated by directly measuring water content at specific pressure heads, the accuracy of the hydraulic conductivity function can only be assessed by dynamic, e.g. evaporation, experiments. Results of this study indicate that VGM parameters derived from inverse parameter estimation using data from such experiments describe water retention and hydraulic conductivity curves that in some cases strongly differ from retention curves derived directly from TDR and pressure head data. We explain this discrepancy primarily by the fact that with the parameter estimation by inverse modelling of the evaporation experiment the optimal set of VGM parameters must describe both the retention and hydraulic conductivity characteristics. Thus, discrepancies indicate the incapability of VGM parameterization to describe soil water flow in peat soils. Discrepancies are further caused by uncertainty in the water content data, which is currently assessed by site-specific TDR calibration curves. Next, we analyze by inverse modelling how modified hydraulic parameterizations (e.g. the dual-porosity model) and the inclusion of shrinkage characteristics improve the description of the drying of peat soils.

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