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HYDROLOGICAL CHANGES OF FENS SITES IN THE COURSE OF SOIL DEVELOPMENT

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SUMMARY

This study deals with the change and evaluation of soil hydrological properties of peat soils (FAO: Terric Histosols) in the course of soil development. For 84 fen sites in 19 fen regions in North-East Germany, besides ash content, unit water content and dry bulk density, the unsaturated hydraulic conductivity, the water retention function and the wetting properties were measured. The porosity decrease. Opposed to that, the macro pore space and the capillary rise increased. With the start of consolidation processes and the development of segregation structure, first of all a noticeable reduction of the macro pores and the unsaturated hydraulic conductivity began. In the course of further soil development and decreasing aggregate size, these processes reversed. Both parameters increased starting from segregation structure horizon, to earthyfied fen and weak moorshyfied fen horizon until finally partly exceeding the starting values of the pedogenetic almost unchanged fen in the strongly moorshyfied stadium. Differences in wetting properties could not be explained by changes of peat properties as a result of soil development. Additionally, field measurements at 84 fen sites of 19 fen regions in North- East Germany were carried out to study the hydraulic performance directly under field conditions Capillary water supply of all soil development stages was not limited up to 70 cm ground water level depth. Worsening plant water supply could be the result of sapric horizons (mud) in the capillary fringe, ground water levels deeper than 70 cm below soil surface, low hydraulic conductivity in the ground water zone and hysteresis effects, affected by high ground water level dynamics in the course of the day.

Keywords: *fen, soil development, soil hydrological properties, capillary rise, pore space distribution*

INTRODUCTION

Oxidative as well as biochemical processes led to the reduction of peat thickness up to the total loss of fens. Fens seam to loss there biological and hydrological function in the course of intensive soil development (Klimkowsk *et al.,* 2010). Kechavarzi *et al.,* (2010) reported about significant changes of physical and hydraulic properties as the result of peat decomposition. Less decomposed peat had higher saturated hydraulic conductivity values, a lower air entry pressure and drained faster than degraded peats. They conclude that decomposition and pedogenic alterations lead to the loss of structural pores. According to Sauerbrey and Zeitz (1999), degradation is seen as a reduction in suitability for plant production and as a difficulty for soil workability. Schultz-Sternberg *et al.,* (2000) conclude in their report on the status and future development of fens in Brandenburg, that they have been destroyed by amelioration measures during the 1960 s and 70 s and have therefore lost their main function within nature and water balance. Soil hydrological laboratory and field investigations were performed to clarify to what extent the soil water balance and the plant water supply of fens in Northeast Germany have been changed due to soil development.

MATERIAL AND METHODS

SITES

Soil hydraulic properties were measured from 84 sites of 19 fens regions in North and North-East Germany. The sites included mire types- paludification and percolation mires, as well as deep and shallow mud underlain ancient lake mires- with the soil types earthyfied fen (Erdfen), weak moorshyfied fen (Fenmulm) and moorsh (Mulm). The choice of the site was an attempt to consider a wide range of existing fen types, soil development stages and land use systems within these investigations. Different pedogenetic changed soil types of deep and shallow fens, with and without sapric horizons (mud) in the profile were considered. The land use varied between fallow, pasture, low input and intensive meadow, arable land and forest. The investigations of this study consider the soil types earthyfied fen (Erdfen), weak moorshyfied fen (Fenmulm) and moorsh (Mulm) with the horizons following Succow and Joosten, 2001. Moreover, half fen soils (AMO) with organic matter content lower than 30 % as well as sand covered fens were included.

nH: Pedogenetic almost unchanged peat below the water table.
nHa: Peat subsoil horizon with segregation structure in consequence of swelling and shrinkage.
nHv: Earthyfied peat topsoil horizon, crumbles and small-polyhedric aggregates.
nHvm: Weak moorshyfied topsoil horizon, intermediate stage between nHv and nHm
nHm: Moorsh topsoil horizon, small aggregates, under dry conditions powder-like, under wet conditions smeary

The climate of the study region is characterized by an annual precipitation of 500 to 650 mm, an avarage annual air temperature of 8.1 – 8.5 °C and a potential evapotranspiration of 550 – 650 mm/yr.

LABORATORY MEASUREMENTS

Disturbed samples were taken to measure the ash and lime content, the water penetration time as measure for the rewetting properties (Schindler *et al.,* 2015) and the unit water content w1 (Ohde, 1950, modified by Schmidt 1989). From the undisturbed cylinder cores, the actual water content, the water retention curve and unsaturated hydraulic conductivity function were measured using the evaporation method (Schindler *et al.* 2015).

Short description of the evaporation method:

The measurements can be performed either at undisturbed or disturbed soil samples. The samples are taken in 250 cm^3 stainless steel cylinders. The soil cores are slowly saturated by placing them in a pan of water. The tensiometers are inserted and the core is sealed at the bottom. The assembly with the core is placed on weighing scales and the soil surface is exposed to free evaporation. Tension (Ψ) and sample mass (m) are recorded at consecutive times. The hydraulic gradient is calculated on the basis of the tension recorded during the time interval. The water flux is derived from the associated soil water volume difference. Single points of the water retention curve are calculated on the basis of the water loss per volume of the sample at time t_i and are related to the mean tension in the sample at this time. The unsaturated hydraulic conductivity (K) is calculated according to the Darcy-Buckingham law (Equation 1).

$$K(\Psi_{mean}) = \frac{\Delta m}{aA\rho_{H2O}\,\Delta t\, i_m} \qquad (1)$$

where: Ψ_{mean} is the mean tension over the upper tensiometer at position z_1 (3.75 cm above the bottom of the sample) and the lower tensiometer at position z_2 (1.25 cm above the bottom), geometrically averaged over a time interval of $\Delta t_J = t_{i+1} - t_i$, with i =1…n, j = 1…n-1; Δm is the sample mass difference in the time interval (assumed to be equal to the total evaporated water volume ΔV_{H2O} of the whole sample in the interval); ρ_{H2O} is the density of water and is assumed to be 1 g cm^{-3}; a is the flux factor (in the case of rigid soils a = 2); A is the cross sectional area of the sample and i_m is the hydraulic gradient averaged over the time interval.

Data points of the water retention curve are pairs of mean tension at time t_i and t_{i+1} for i = 1…n and the corresponding volumetric water content. Generally, the soil is assumed to be rigid. A data set of a single sample consists of plenty user-defined water retention and hydraulic conductivity data pairs. At the end of the measurement cycle, the residual amount of storage water is derived from the water loss upon oven drying (105 °C), and the initial water content is calculated. The dry bulk density is derived from the dry soil mass.

FIELD MEASUREMENTS

The soil type classification was carried out on the basis of structure evaluation according to Succow and Joosten (2001). Organic matter content was used in order to decide whether the soil was fen or already half fen soil. Accordingly, the organic matter content of 30 cm topsoil must exceed 30 % (AG Boden, 2005). Otherwise, in case of organic matter content ranging between 15 and 30 % fen soil is not classified as fen but rather as half fen soil. Soil types, as well as stratification of horizons were characterized by the soil pit and auger holes in the field (Tab. 1). The kind of land use was apparent at the site. The fen depth was measured by means of a penetration probe. Generally, ground water level, tension and water content were measured at the soil depths of 10, 30 and 50 cm. In order to evaluate the capillary function of the sites, tension measurements were mainly carried out on sunny and rainless days with high transpiration demand and dry past weather conditions.

Table 1: List of measurements and methods used in the field

Parameter	Method/ Equipment
Tension at depth of 10, 30, 50 cm	Mobile field tensiometer
Water content at depth of 10, 30, 50 cm	TDR, Easy Test
Ground water level	Ground water table in the auger hole
Saturated hydraulic conductivity	Time of ground water rise in the auger hole
Fen depth	Penetration probe
Soil type	Succow and Joosten, 2001
Soil structure	Succow and Joosten, 2001
Kind of land use and intensity	Visual and information from farmers

Tension and hydraulic gradient above ground water table are good indicators when characterizing the capillary properties of the system (Fig. 1), provided that measurements are carried out in dry periods. In the sites influenced by ground water, the tension distribution is determined by the ground water level. At equilibrium state ($v = 0$, $i = 0$), the absolute value of tension is an equivalent to the gravitational potential. The tension distribution in the soil profile allows the identification and the assessment of water flow direction as well as the soil hydrological properties. Upward hydraulic gradients ($i > 0$) resulting in ground water flow under pressure in the ground water zone and capillary rise above the ground water table. Hydraulic gradients $i < 0$ resulting in downward water movement. Capillary rise is sufficient, if the hydraulic gradient in the capillary fringe only differs slightly ($0 < i < 2$) from the equilibrium state. Reversing, the case of high tensions in the profile can be indicated by capillary defects or deep ground water levels. Opposed to that, perched water at the soil surface at deep ground water levels are indications of reduced infiltration.

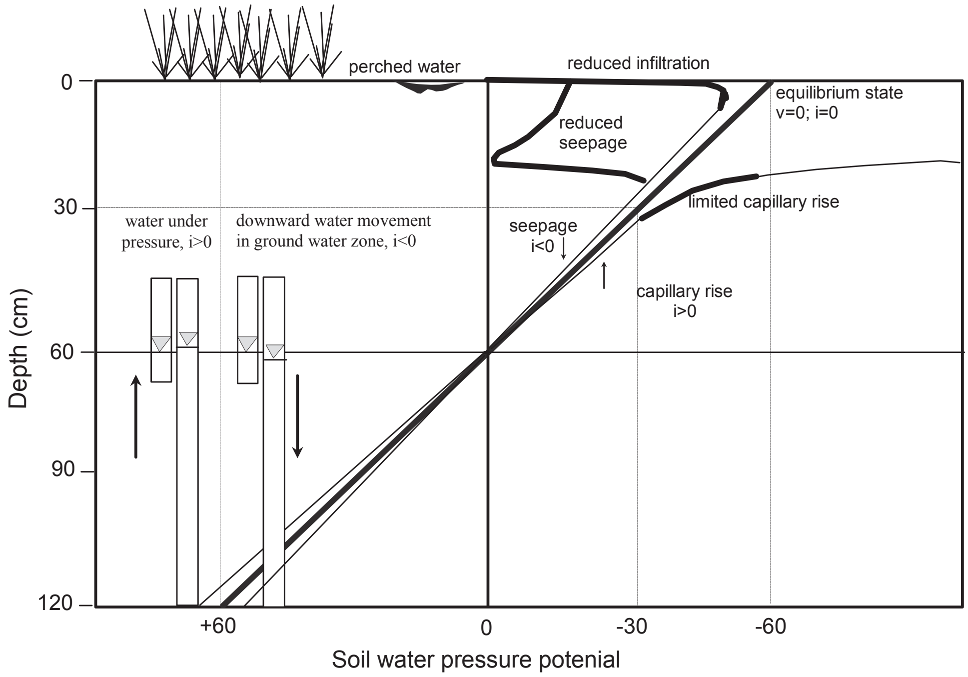

Figure 1: Soil water potentials as indication of flow direction and soil hydrological function at ground water influenced sites- positive below and negative above a free-water table.

RESULTS AND DISCUSSION

PORE SIZE DISTRIBUTION AND CAPILLARITY

The porosity (GPV) decreased and the dry bulk density (DBD) increased with increasing soil development (Fig. 2). The wide macro pores MP1 (> 50 µm) are very important for the capillary plant water supply at ground water sites. As the cause of segregation structure, MP1 decreased in the first stage of soil development from nH (9.9 % by vol.) to nHa (7.3 % by vol.). Afterwards with further increases of soil development the soil aggregates become finer. As the result of this, the wide macro pores increased again and reached its maximum (10.8 % by vol.) at the final stage of moorshyfication (nHm). However, the differences between the horizons were not significant. The small macro pore space MP2 (10-50 µm) was significantly lower in all soil development stages than in the original peat. The largest differences were measured between the nH (21.9 % by vol.) and the nHa horizon (9.9 % by vol.). The capillary rise was calculated based on the single measurements of the unsaturated hydraulic conductivity. Strongly diminished capillarity due to soil development (Tab. 2) could not be observed. The height of capillarity rise was estimated for a steady state capillary flux of 5 mm*d^{-1}. Pedogenetic not or onlyweakly developed fens (nH) showed best capillarity (Table 2). However, the capillary rise of the pedogenetic heavily changed soils was also high and differed only a little and not significantly from the unchanged fens. On the contrary, the fen horizons with segregation structure (nHa) as well as the half fen soil (AMO) showed reduced values of the heights of capillary rise. In these soils, however, a capillary height of about 60 cm was also achieved.

The measured wetting time varied between a few seconds and several hours. The differences between the soil types were small and not significant. The lowest wetting time was almost always measured at full saturation. With decreasing moisture, the wetting properties of the soils changed very differently. There was no systematic and no statistical correlation between soil development and wetting properties.

GROUND WATER LEVEL AND CAPILLARY PLANT WATER SUPPLY

The tension conditions of the earthyfied and the weak moorshyfied fen as well as the sand covered fen sites differed only negligibly from the equilibrium state. Compared with the other soil types, the hydraulic gradients showed clearly diverging conditions at the moorsh and, though only faintly, also at the half fen soil. The tension values were significantly higher in moorsh than in earthyfied fen. However, it is to be noted that the ground water levels were also significantly deeper at moorsh and half fen sites (71 cm, SD 23 cm and 75 cm, SD 22 cm) compared to the earthyfied and weak moorshyfied fen sites (47 cm, SD 17,7 cm and 59 cm, SD 16,7 cm). Due to this ground water level differences, a direct comparability of hydraulic properties of soil types was therefore not possible.

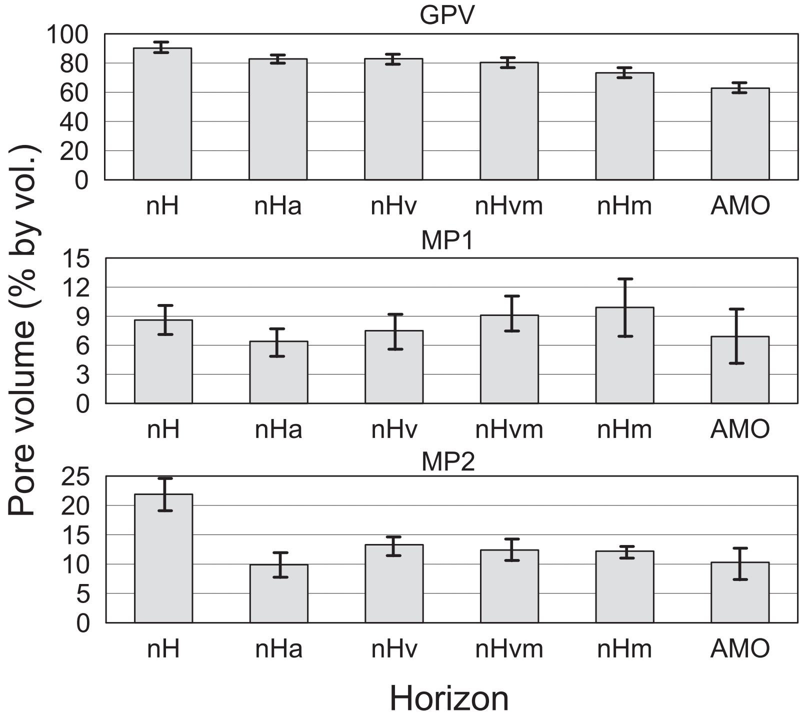

Figure 2: Porosity (GPV) and macro pore space MP1 (>50 m) and MP2 (10-50 m) of fen horizons (ash content 0 < x < 70 %) and AMO soils (70% < x < 85 %) with the range of significance.

Table 2: Height of capillary rise in peat horizons for a capillary flux of 5 mm * d^{-1}.

Horizont	n	x %	z cm	SD cm
nH	39	6 - 54	87	37
nHa	33	6 - 56	58	41
nHv	36	7 - 62	68	43
nHvm	22	9 - 63	73	31
nHm	30	9 - 59	77	32
AMO	21	71 - 85	61	43

n: number of samples; x: ash content; z: height of capillary rise; SD: standard deviation

With increasing ground water level, the capillary rise decreased and the tensions in the top layers of the soil strongly increased. Figure 3 presents this relationship for fen soils without sapric horizons (mud) in the capillary fringe. Ground water levels up to 70 cm were sufficient for capillary water supply for all considered soil types. The hydraulic gradients were small and differed only marginally from the equilibrium state. With increasing ground water level, the tension at 10 cm soil depth increased exponentially. During the field measurements it became clear, that the hydraulic conditions in the field were strongly influenced by the occurrence of sapric horizons (mud) and its location depth in the profile (Fig. 4). Mud in the capillary fringe zones partly reduced the capillarity and sometimes led to very high tensions in the topsoil layer even when mud thickness was low. At other sites however, effect of mud on the capillary rise was rather low. Consequently the coefficient of determination of the relation between tension and ground water level showed to be significant but the correlation was weak (r^2 = 0.42).

CONCLUSIONS

Shallow ground water levels should be aspired for reduction of peat loss and for protection of fens as landscape features, assumed the planned land use is ensured. Capillary water supply of all soil development stages was not limited up to 70 cm ground water level at the investigated fen sites in Brandenburg and Mecklenburg-Vorpommern. Most critical for capillary plant water supply and peat protection are the formation of segregation structure (nHa horizon) and mud in the capillary fringe. However, important are not only the existence of mud but rather its consistency and structure. The soil stratification, the existence, the consistency and the structure of mud as well as the hydraulic conductivity of the underground have to be more strongly considered for the specification of controlling ground water levels at fens sites in future.

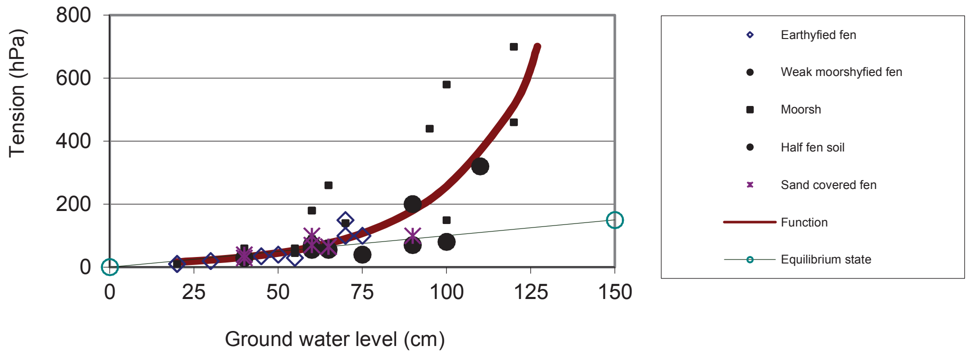

Figure 3: Tension at 10 cm soil depth (h10) at varying ground water levels (GWF) for soil types without mud in the capillary fringe zone, (h10 = exp (-0.034738 * GWF + 2.071349); r^2 = 0.73; n=48).

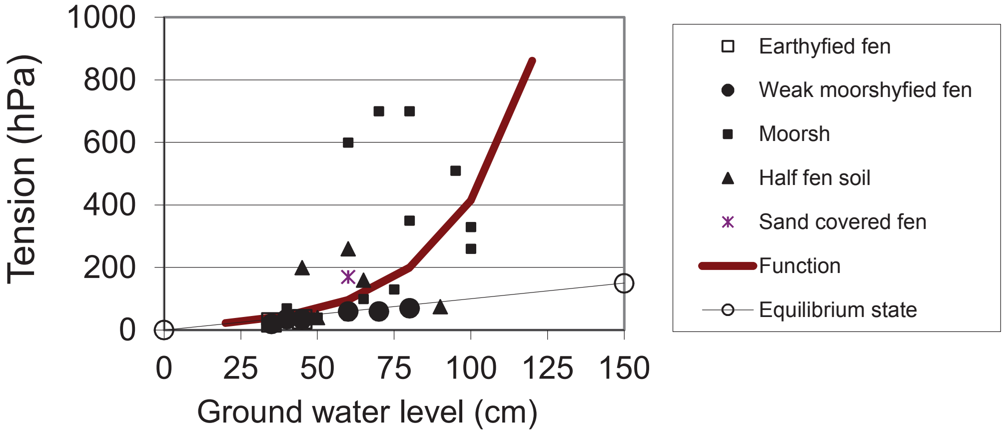

Figure 4: Tension at 10 cm soil depth (h10) at different ground water levels (GWF) for soil types with mud in the capillary fringe, (h10 = exp (-0.036633 * GWF + 2.362686); r^2 = 0.42; n=36).

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