Shrinkage of organic soils

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Introduction

Peat and other organic soils (both referred to as organic soils in the following) are characterized by flexible pore structures, resulting in changes of the soil volumes on a short- and a long-term basis. In drained peatlands, a combination of physical (shrinkage, settlement, consolidation, erosion, compaction) and biological (mineralization) processes (Stephens and Speir 1969) causes these volume changes and leads to a progressive loss of surface heights (subsidence).

This study is part of the project 'Establishment of the German peatland monitoring programme for climate protection – Part 1: Open land' which – among other goals – aims to estimate CO_2 emissions from organic soils from subsidence data. To derive CO_2 emissions from surface motion measurements, it is necessary to partition physical processes causing surface motion under given field conditions from biological ones. Shrinkage and swelling are known to have an substantial influence on surface motion (Schothorst 1967; Irwin 1977; Nieuwenhuis and Schokking 1997), but to date there is only one study for Polish organic soils providing a comprehensive analysis of shrinkage in dependence on soil properties (Ilnicki 1967).

Here, we investigated maximum shrinkage (S_{max}) measured at 579 samples from 136 organic soil horizons covering a wide range of different soil properties. We (1) evaluated the influence of degree of decomposition, soil horizon and substrate compositions on S_{max} and (2) derived empirical relationships between S_{max} and soil organic carbon (SOC) content and bulk density (ρ_b).

Materials and Methods

Samples of organic soils were collected with sample rings (244.3 cm³, $V_{saturated}$) from 22 different field sites. All soil profiles were fully described regarding peat substrate (Tab. 1), soil horizons (Tab. 2, Ad-hoc-AG Boden, 2005) and degree of decomposition.

Samples were fully saturated from below and then dried at temperatures ≥ 80°C to determine ρ_b from $V_{saturated}$. The volume of the oven dried sample ($V_{ovendry}$) was determined with a structured light 3D-Scanner (RangeVision Spectrum, Krasnogorsk, Russia) and the open source 3D graphic suite Blender (Blender Foundation, Amsterdam, The Netherlands). Maximum shrinkage (S_{max}) was calculated as

$$S_{max} = \frac{V_{saturated} - V_{ovendry}}{V_{saturated}} \cdot 100\% \qquad (1).$$

Afterwards, the mean values and standard errors of S_{max} for all replicates of one horizon were calculated. The number of replicates varied between three and six in most cases, depending on sample stability. To calculate SOC, total carbon and, for carbonate containing samples inorganic carbon (TIC), were determined by dry combustion (RC 612/TRUMEC, LECO Corporation, St. Joseph, USA) from separate samples. The degree of decomposition was determined according to von Post (1922) and afterwards classified as fibric (H1 – 4), hemic (H5 – 7) and sapric (H8 – 10). This classification deviates slightly from the Guidelines for soil description (FAO 2006) to achieve a more balanced sample distribution.

Table 1 Classification of peat substrates.

Class	Plant remains and/or content of soil organic carbon (SOC)
moss	*Sphagnum* species, brown mosses
gramin.	*Phragmites, Scheuchzeria, Carex, Eriophorum, Cladium* and other graminoids
wood	any kind of wood, such as birch, alder, pine (> 35% wood constituents)
moss+gramin.	mixed substrates (e.g. *Sphagnum* with *Eriophorum*)
amorph	amorphous, plant remains are not determinable, but SOC ≥ 15%
organo-mineral	soils with SOC between 7.5% and 15%

Table 2 Classification of soil horizons according to the German soil classification system (Ad-hoc-AG Boden 2005).

Horizon Abbreviation	Description
Hr	permanently saturated ('reduced') conditions, not altered by secondary pedogenetic processes
Hw	alternating saturated-unsaturated conditions and thus temporarily subjected to aerobic conditions, not yet altered by secondary pedogenetic processes
Ha	subsoil horizons of intensively drained sites, polyhedral aggregates caused by swelling and shrinkage, crumbly when dry (Ha) or prismatic aggregates with vertical cracks (Ht) as transition horizon to underlying peat. Due to a low number of samples, Ha and Ht horizons are combined.
Hv	earthified, topsoil of moderately drained peatlands, crumbly structure caused by aerobic decomposition, plant remains not visible anymore
Hm	moorshy peat, topsoil of deeply drained and intensively cultivated peatlands, dusty or small-grained structure when dry caused by intensive aerobic decomposition, plant remains not visible anymore
organo-mineral	soils with SOC between 7.5% and 15%

The statistical analysis was carried with R (R Core Team 2020). The effects of degree of decomposition, horizon and peat substrate on S_{max} were investigated with Tukey-Kramer significance tests (HSD.test from 'agricolae' package; Mendiburu 2021) with a significance level of 0.05. Tukey-Kramer tests were chosen due to unbalanced sample sizes.

Results and Discussion

Figure 1 shows S_{max} in dependence on degree of decomposition and peat type (Fig. 1A), horizon (Fig. 1B) and peat substrate (Fig. 1C). The degree of decomposition had a strong influence on S_{max} values. The effect of the peat type was only significant for the fibric class with median values of S_{max} of 40% for bog and 63% for fen peats. Differences between bog and fen peats of the hemic and sapric classes were not significant. Fen peats showed decreasing S_{max} values with increasing degree of decomposition. Differences were most pronounced between hemic (median S_{max} 61%) and sapric (median S_{max} 44%). In contrast, fibric bog peats had lower S_{max} values than hemic bog peats. The results suggest that *Sphagnum* remains in fibric bog peats have a stabilizing effect and are able to prevent large pores from collapsing during desiccation. Ilnicki (1967) also report that mosses reduce shrinkage. As soon as plant remains are broken down into smaller particles by decomposition, the stabilizing structure is lost, enabling stronger compression. In this study, this is reflected by the higher values of S_{max} for hemic bog peat. Amorphous and sapric peat shrinks less as the soil matrix is already compacted as a result of decomposition, former shrinkage (and possibly, load by agricultural machinery).

The results also showed a clear difference in S_{max} of the different horizons (Fig. 1B). Organo-mineral horizons and Hm horizons showed the lowest S_{max} values. As to be expected, organo-mineral horizons showed the highest values of ρ_b (0.73 ± 0.24 g cm^{-3}). Almost all Hm, Hv and Ha horizons (98%) were defined as sapric with still relatively high values of ρ_b (0.38 ± 0.15 g cm^{-3}). This is a clear indicator that S_{max} values can be expected to be low, as the soil matrix is already decomposed and compacted. Surprisingly, Ha horizons showed significantly higher values of S_{max} than organo-mineral and Hm horizons despite a strong alteration of the original structure and past shrinkage. These high values of S_{max} may be a result of the polyhedral soil structure (aggregates) which may allow inter- and intragranular shrinkage.

Horizons in the range of water level fluctuation (Hw) showed a wide range of S_{max} which can be explained by the larger sample size, the comparatively high range of different peat substrates, degrees of decomposition and differences in peat type. They were characterized by median ρ_b values of 0.12 ± 0.04 g cm^{-3}. Most of Hw-horizons from bog peat were fibric (76%), while those from fen peat were hemic (57%). These two classes showed large differences in S_{max} (Fig. 1A) which are also reflected in the high variance of S_{max} of Hw horizons.

In contrast, a large proportion of Hr horizons (48%) was defined as hemic with low ρ_b (0.11 ± 0.03 g cm^{-3}). They showed significantly larger S_{max} values than all other horizons, except the aggregated horizons (Ha).

When comparing peat substrates, organo-mineral soils, amorphous organic soils and moss peats showed the smallest S_{max} values and shrunk significantly less than the graminoid and wood peats (Fig. 1C). However, it should be mentioned, that there were only three samples in the wood peat class. The S_{max} values of organic soils composed of a mixture of moss and graminoids were between these two groups. As discussed in the preceding, Sphagnum or other moss remains had a stabilizing effect on the pore matrix.

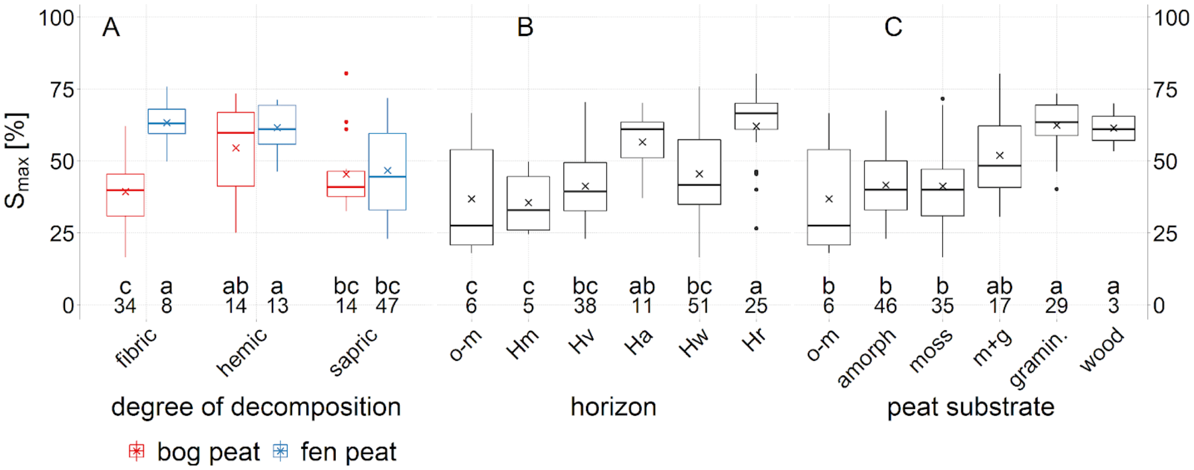

Figure 1 Maximum shrinkage (S_{max}) in dependence on A: degree of decomposition and peat type, B: soil horizon and C: peat substrate. Crosses show the mean values. Same letters (a - c) indicate non-significant differences (α = 0.05). Numbers indicate sample size for each group. Abbreviations: Hm = moorshy topsoil, Hv = earthified topsoil, Ha = aggregated subsoil, Hw = subsoil in range of water level fluctuation, Hr = permanently saturated subsoil, o-m = organo-mineral, m+g = moss+gramin.

Maximum shrinkage correlated with SOC (Fig. 2A) and ρ_b (Fig 2B) values. Correlations differed in dependence to the peat type. Overall, fen peat soils showed stronger correlations between S_{max} and SOC or ρ_b values than the bog peat soils. Further, SOC values had weaker correlations to S_{max} than ρ_b values. This confirmed our expectation as ρ_b values are dependent on the pore volume (Ilnicki, 1967) and usually show a stronger correlation to the degree of decomposition than SOC values. The clearest dependency was found for fen peat soils between S_{max} and ρ_b where S_{max} values decreased with increasing ρ_b values. The large scatter and consequently poor correlation between S_{max} and ρ_b of the bog peat is reasoned by the large variance of S_{max} values, especially for ρ_b values around 0.1 g cm^{-3}. As both fibric and hemic moss peats have ρ_b values around 0.10 g cm^{-3} but significant differences in S_{max} values, the high variance was expected. However, the parabolic slope of the fitted regression, is an indicator for the stabilizing structure of Sphagnum remains and corresponds with the results shown in Fig. 1A.

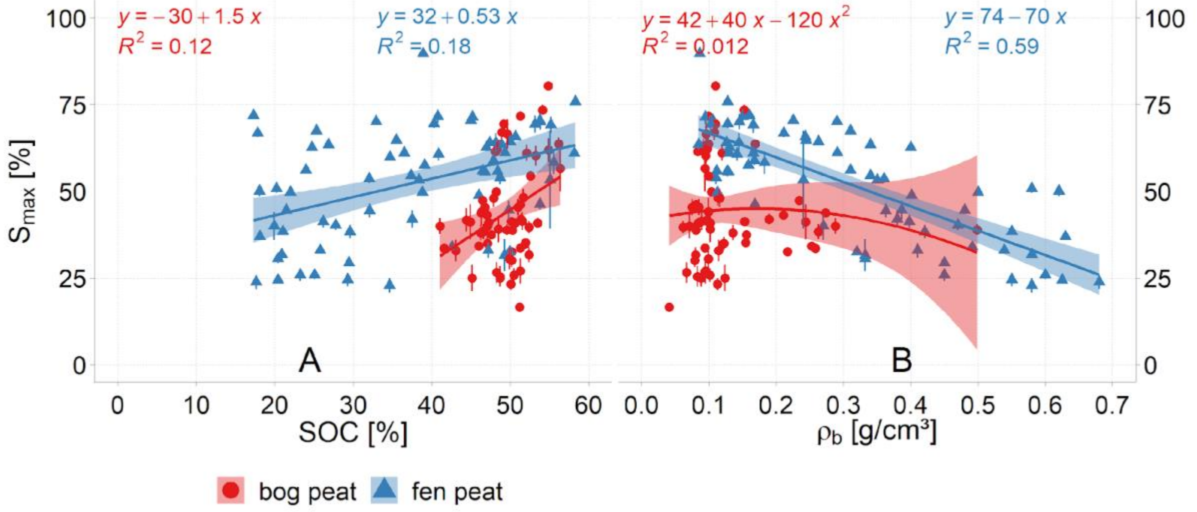

Figure 2 Maximum shrinkage (S_{max}) in dependence on A: soil organic carbon content (SOC) and B: bulk density (ρ_b) for bog and fen peat. Organo-mineral soils are not shown. Ribbons and error bars represent standard errors (for points without error bars, the standard error is not determinable due to a loss of soil material in the other replicates).

Conclusion

The results showed that shrinkage is strongly dependent on the degree of decomposition, horizon, peat substrate, peat type and ρ_b values. Soil organic carbon and ρ_b values could be used as predictor for S_{max} with the lowest uncertainty between S_{max} and ρ_b for the fen peat soils. The shrinkage behavior of bog peat soils was influenced by the presence and stability of *Sphagnum* remains.

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