Comparison on the performance of five different electromagnetic sensors in sphagnum peat

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Introduction

- Electromagnetic (EM) soil moisture sensors are widely used to measure water contents in porous media, particularly in the field.
- EM water content measurements are based on the determination of the dielectric permittivity (ε) which can be related to soil water content (θ) by a calibration function.
- However, the EM-method is affected by the properties of the medium investigated and until now there is little knowledge about its applicability to peat soils.
- In this study, the performance of five electromagnetic sensors to measure water content in sphagnum peat was investigated. For this an evaporation experiment under laboratory conditions was conducted using a large undisturbed sphagnum peat sample.

Experimental setup

- An undisturbed sphagnum bloc (40 x 60 x 29 cm) was sampled from a soli-ombrotrophic peat bog near Braunlage, GER.
- 5 different types of water content sensors were horizontally inserted into the sample at heights 11 and 17 cm.
- Except for the Trime PICO all sensors were immersed in the sample, including the corpus.

Results and Discussion

- At the beginning of the experiment the peat was saturated until water left the sample at the bottom.
- During the experiment the water content decreased by continuous evaporation from the top.
- Mean volumetric water content was reduced from 54 to 16 % over a time of 35 days.
- Cumulative evaporation loss was measured gravimetrically using two balances (Fig. 1).

Boundary conditions

- Large systematic differences in measured dielectric permittivity values between the sensor types were observed, especially in the wet range.
- The lower 5TM sensor showed unreasonable low permittivity values. This could be due to insufficient contact between the sensor prongs and the medium caused by the special geometry of this sensor.
- Application of calibration functions specific to organic soils and to the sensor did not lead to an agreement between sensors in the derived water content values.
- Water contents differed between the sensors by more than 30 Vol-% within one depth at the beginning of the experiment.
- This indicates that using general calibration equations for organic soils is insufficient when measuring water contents in sphagnum peat.
- The reason for the large differences between the sensors is unknown. Possible causes are: High diversity of organic substrates, low accuracy and precision of the sensors in the wet range.

Sensor calibration

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Calibration Function</th>
<th>Suggested for</th>
</tr>
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<tbody>
<tr>
<td>Trime PICO</td>
<td>$\theta = (-0.95 \varepsilon^2 + 192 \varepsilon + 1850) \cdot 10^{-4}$</td>
<td>sphagnum peat (generally TDR)</td>
</tr>
<tr>
<td>Hydra Probe</td>
<td>$\theta = (8.239 \varepsilon^2 - 2.2878 \varepsilon + 19.352) \cdot 10^{-4}$</td>
<td>sphagnum peat</td>
</tr>
<tr>
<td>WET-2</td>
<td>$\theta = 2.25 \cdot 10^{-3} \varepsilon^2 - 0.06 \cdot 10^{-3} \varepsilon + 0.247$</td>
<td>organic soil</td>
</tr>
<tr>
<td>5TM</td>
<td>$\theta = 2.25 \cdot 10^{-2} \varepsilon^2 - 2.06 \cdot 10^{-3} \varepsilon + 7.24 \cdot 10^{-4}$</td>
<td>peat soil and peat moss</td>
</tr>
<tr>
<td>GS3</td>
<td>$\theta = 0.118 \cdot \varepsilon - 0.117$</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

- Direct comparison of dielectric permittivities measured by different sensor types is not possible. This is due to differences in sensor measurement frequencies and geometries.
- Some sensor geometries seem less appropriate for peat soils as they may cause gaps between the sensor and the substrate during installation.
- We call for a sphagnum- and possibly peat type specific calibration equation for each sensor type, else water content measurements and estimations of the air filled porosity are erroneous.
- This will inevitably lead to inadequate interpretations and simulation results concerning: a) peat soil gas fluxes and b) hydro-bio-geochemical processes.

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Fig. 1: Experimental setup and sensors (not to scale).

Fig. 2: (a) Relative humidity in the laboratory and evaporation rate, (b) cumulative evaporation.

Fig. 3: (a) Dielectric permittivity measured by the sensors during the experiment, (b) Volumetric water content calculated using the calibration functions from Tab. 1.

Fig. 4: Calibration functions from Tab. 1.