

Methods note · Land and freshwater

Calibrating soil-moisture probes for organic tundra horizons

Elín Bjarnadóttir · 14 October 2026

Fictional author and institute · Editorial demonstration, not peer reviewed

ABSTRACT

Dielectric soil-moisture probes convert a material-dependent electrical response into a water-content estimate. This methods note synthesises organic-soil calibration experiments, freeze–thaw dielectric research, and uncertainty guidance to examine transfer from mineral to organic horizons. A fictional core calculation separates gravimetric and volumetric content and shows how drying shrinkage can alter the reference value before a sensor equation is fitted. The discussion considers calibration domains, independent validation, sensing support, saturation, installation, raw-output preservation, and the difference between liquid-water response and total water during freezing. It recommends no universal equation, drying procedure, or ecological threshold. The practical implication is to match calibration and phase-state interpretation to the intended inference, and to report a narrower relative signal when absolute water content remains insufficiently constrained.

Keywords: soil moisture · organic horizons · dielectric calibration · freeze–thaw · bulk volume

A source-based editorial text, not a report of original Still North research. Examples and imagery are illustrative.

A water-content number begins as an electrical response

A soil-moisture probe does not count water molecules in a fixed box. It measures an electrical response influenced by the surrounding material, then converts that response into a water-content estimate through a calibration. A factory equation can work well in the materials for which it was developed and perform poorly in a different organic horizon. The sensor can be stable, repeatable, and correctly installed while its reported volumetric water content remains biased.

This methods note asks when a calibration derived for mineral soil can be transferred to organic tundra material. It synthesises Bircher and colleagues' organic-layer calibration study, Mavrovic and colleagues' freeze–thaw dielectric experiments, and NIST uncertainty guidance. It is not a calibration certificate, a product recommendation, or a new soil study. Every mass, volume, threshold, and sensor reading in the worked case is fictional.

Name the water quantity and the soil volume

Volumetric water content is water volume divided by bulk soil volume, conventionally reported as cubic metres per cubic metre. Gravimetric water content is water mass divided by dry-soil mass. They are not numerically interchangeable, particularly in low-density organic material. Converting from gravimetric to volumetric content requires bulk density and an appropriate water-density convention. A laboratory spreadsheet should retain both the original masses and the volume definition used for the conversion.

The relevant volume can itself be difficult to establish. Organic soil may compress during sampling and shrink during drying. Using a final shrunken volume when the intended target is the field bulk volume changes the

measurand. Water in moss, air gaps around the probe, roots, and layering can also affect whether a small core represents the material sensed by the instrument. A neat calibration curve cannot compensate for mismatched sample supports.

Dielectric probes exploit the strong contrast between liquid water and other soil components, but frequency, bound water, conductivity, temperature, and soil structure influence their response. A calibration therefore belongs to a sensor type, measurement configuration, material domain, and environmental range. Treating the equation as a universal physical constant overstates what empirical fitting establishes.

What the organic-soil evidence actually supports

Bircher and colleagues developed calibration functions for two particular sensor types using northern organic surface materials and compared responses with mineral soils. They found material-dependent differences and sensor-specific behaviour. In their analysis, the manufacturer calibrations performed adequately for the studied low-organic mineral materials, while organic horizons required different treatment. The result supports examining calibration transfer, not assuming that every factory equation is wrong.

The study also considered shrinkage and charring during drying, showing that the reference method needs scrutiny alongside the probe. For one sensor type, the response in wet organic material became strongly nonlinear and approached saturation. A more elaborate polynomial cannot restore sensitivity that the instrument no longer provides. Calibration may improve the estimate within an informative range while still leaving very wet conditions weakly resolved.

Published functions are valuable starting evidence, but their scope should be preserved. Transferring a function to a different instrument revision, saline site, organic horizon, or installation requires checking compatibility. It is especially important not to copy coefficients from a paper into a logger while changing the raw output variable or its units. Raw voltage, apparent permittivity, and a manufacturer's already-converted water content are different inputs.

Worked example: a correct core with the wrong denominator

Fictional worked example. An intact organic-soil sample occupies 250 cubic centimetres at the chosen field-volume reference. It has a wet mass of 180 grams and a dry mass of 60 grams under a suitable, documented laboratory procedure. The water mass is 120 grams, corresponding approximately to 120 cubic centimetres of water. Reference volumetric water content is therefore $120/250 = 0.48$ cubic metres per cubic metre.

The gravimetric water content is $120/60 = 2$ grams of water per gram of dry soil. That value is not 200% pore saturation. It uses dry mass, not bulk volume, as its denominator. If the sample shrinks to 200 cubic centimetres during drying and the analyst silently uses that smaller volume, the calculated volumetric content becomes 0.60. The 0.12 difference arises from the volume convention before any probe equation is fitted.

Suppose a nearby, support-matched probe reports 0.34 using its mineral-soil conversion. A fictional decision rule labels values below 0.40 as dry. The factory output would cross that threshold, while the reference value would not. This is not a recommendation for a real ecological threshold. It shows why an absolute decision can be sensitive to calibration even when the sensor captures rainfall pulses and seasonal direction convincingly.

One paired sample does not justify adding 0.14 to every future reading. The discrepancy can vary across wetness, temperature, bulk density, and material. A defensible calibration needs a range of paired responses and reference contents, plus observations not used to fit the function. A constant adjustment is appropriate only if evidence supports that form within the required domain.

Design calibration around the intended inference

Begin with the question. Detecting the timing of wetting may require reliable relative response; comparing absolute water contents between mineral and organic horizons requires more. Estimating water storage additionally requires layer thickness and spatial representation. A single probe at one depth cannot supply a whole-profile storage estimate by multiplying its value by an arbitrary soil depth.

Obtain calibration materials that represent the relevant horizons and structural conditions. Record organic content or an appropriate material description, bulk density, temperature, conductivity where relevant, and sample handling. Wetting and drying sequences may behave differently. Preserve adequate contact without compacting the sample into an unrealistically dense state merely to

make the probe fit. Where intact and repacked samples differ, that difference is part of the transfer question.

Choose the simplest function that captures the measured response adequately over the usable range. Inspect residuals against water content, material, temperature, and sequence. Validate with independent samples or deployments, rather than reporting only fit statistics from the calibration set. An apparently strong relationship can still have systematic errors large enough to alter the intended decision.

Freezing changes the interpretation

Liquid water and ice have very different dielectric behaviour. When soil freezes, a sharp fall in a probe's unfrozen-soil water estimate need not mean that water drained away. Some of the signal change reflects phase transition. Reporting the resulting series as total soil water throughout winter would therefore require a model and validation that account for frozen conditions.

Mavrovic and colleagues compared instruments operating at different frequencies during laboratory freeze-thaw cycles. They found important discrepancies in modelled and measured permittivity and highlighted hysteresis between freezing and thawing. Their study also showed that transfer between lower-frequency probes and microwave measurements requires calibration. A field probe cannot become a direct satellite-equivalent observation solely because both respond to soil water.

Pair water-response records with soil temperature and appropriate freeze-thaw flags. Define whether winter values are excluded, retained as raw electrical response, or converted through a validated frozen-soil method. Do not replace frozen-season values with zero total water. The raw record may remain useful for phase-state questions even when an unfrozen volumetric-water-content interpretation is not defensible.

Uncertainty and field transfer

The uncertainty budget should include wet and dry masses, reference volume, sample representativeness, sensor response, calibration fit, and transfer to field conditions. Some contributions are shared across samples, such as a balance bias or a volume convention. NIST guidance requires appropriate sensitivities and covariance when combining standard uncertainties. More frequent logging does not average away a shared calibration bias.

Installation can create additional errors through air gaps, disturbed roots, cable movement, and changed drainage. Record orientation, depth reference, horizon boundaries, and any maintenance. Probe replacement should preserve raw output and calibration version so a step can be assessed. A laboratory-derived function remains a model of field response, not proof that the installed instrument samples an undisturbed representative volume.

Limits and the value of a qualified number

This note does not prescribe drying conditions for every organic material or endorse a universal calibration equation. The cited experiments involve particular sensors, soils, and temperature ranges. A local programme may reasonably use a published function if compatibility and

independent checks support it, but should not imply site-specific calibration that was never performed.

A useful result states the water-content definition, material domain, raw response, calibration version, temperature treatment, and uncertainty relevant to the decision. Where absolute content remains weakly constrained, report the narrower signal that the evidence supports. The goal is not to make a probe appear more precise. It is to know whether its number describes water, phase state, or a material-dependent electrical response before asking it to explain the tundra.

References

1. Bircher, S., and colleagues (2016). Soil moisture sensor calibration for organic soil surface layers. *Geoscientific Instrumentation, Methods and Data Systems*, 5, 109–125.
2. Mavrovic, A., Pardo Lara, R., Berg, A., Demontoux, F., Royer, A., and Roy, A. (2021). Soil dielectric characterization during freeze–thaw transitions using L-band coaxial and soil moisture probes. *Hydrology and Earth System Sciences*, 25, 1117–1131.
3. National Institute of Standards and Technology. Technical Note 1297, section 5: Combined standard uncertainty.