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A multi-frequency approach to soil moisture measurements

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The greatest challenge in estimating soil water content from dielectric measurements derives from the dependence of soil permittivity on, a number of additional environmental (such as salinity, temperature) and structural (bulk density, texture etc.) parameters besides water content. The ideal relationship between soil dielectric permittivity and water content (sometimes referred to as universal relationship) is one that performs satisfactorily under all possible instances of the additional variables. We show that when permittivity is measured at a single frequency, an ideal relationship does not exist. This is true in spite of conventional wisdom suggesting that those effects can be mitigated by increasing the measurement frequency. As a consequence, high frequency techniques, such as TDR, are often believed to provide the greatest accuracy. However, this is only partially true. While soil permittivity is indeed only slightly affected by salinity in the frequency range characteristic of TDR, the effects from texture are much more pronounced there compared to lower frequency techniques. This is due to the dielectric properties displayed by bound water (abundant in fine textured soils), which differ substantially from those of free water (predominant in coarse soils). Multivariate statistical analysis suggests that a much more robust predictor for soil water content can be obtained from permittivity measurements at multiple frequencies. As an alternative to classical broadband spectroscopy, which appears too sophisticated and expensive for most practical applications, we provide an example of dielectric measurements at three different frequencies, combined with soil electrical conductivity and temperature, as an alternative predictor for water content. Such measurements are conveniently obtained with a traditional capacitance sensor through a slight modification of circuitry. The proposed method was tested for four different soils (sand, sandy loam, silt loam and clay) and four salinities (pore water from 0 to 15 dS/m). The regression analysis with multi-frequency predictors was carried out through an artificial neural network. Results show considerable improvement of the proposed multi-frequency approach over conventional single frequency measurements.