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Can we use electrical conductivity for predicting unsaturated soil hydraulic conductivity ?

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In soil physics, water retention and hydraulic conductivity are key parameters for predicting water fluxes in soils. Determination of these hydrodynamic characteristics in the lab, particularly unsaturated hydraulic conductivity (K), is most often complicated, time consuming and error-prone. These difficulties often prohibit the examination of numerous soil samples for determining these parameters as would be necessary to get a good estimation of the field variability. In this case, an indirect and easy to measure variable, closely linked to water retention or hydraulic conductivity, would be helpful in the assessment of these parameters. Electrical conductivity (EC) is a good candidate for such a variable because, in a porous medium, its magnitude is largely determined by the number of water filled pores and their connectivity. Relationships between water content (or saturation) and EC have been established both from empirical or theoretical point of view for some time. However, relationships between EC and unsaturated hydraulic conductivity are much scarcer, as are experimental data. We present relationships between EC and water content or water potential for three soil types: a Silty clay loam, a Loam and a Sand. We also present experimental / theoretical relationships between EC and unsaturated hydraulic conductivity. The soils were cored undisturbed in the field and water retention was measured concomitantly with electrical conductivity. Hydraulic conductivity was determined with the Wind evaporation method and from steady state measurements for low suctions. Soil Electrical conductivity variation with water content was fitted to Waxman and Smits (1968) equation that showed the importance of the surface conductance (ECs) in the electrical conduction, particularly for the Silty clay loam soil. An analysis and fit to Waxman-Smits equation with bibliographic data combining water content and electrical conductiv-

ity for (non-saline) soils (n=13) shows a linear relationship between Clay/(Li+Sa) and ECs (r^2=0.97), where Clay, Li and Sa are respectively clay, silt and sand content of the soil. We further tested if unsaturated hydraulic conductivity could be estimated from electrical data using the formation factor (F=ECw/EC, where ECw is EC of soil solution) corrected for surface conductance and a modified Katz and Thompson (1986) type equation. We show that this type of equation can describe well the unsaturated hydraulic conductivity as a function of matric potential (h) (r^2=0.96, n=84 (K,h) pairs, RMSE=0.46 for logK, six soils: 3 measured in this study and 3 from literature data) and the coefficient of this equation can be predict if saturated hydraulic conductivity (Ksat) and Ecs (which can be estimated from texture as shown above) are known. The final equation relating K to formation factor, Ksat and texture only as input was further tested with the large UNSODA soil hydraulic database. As the database contains no electrical data, the formation factor at saturation was calculated from a mean formation factor (Fsat=4.63) and a mean Waxman-Smits saturation exponent (n=2.27) estimated from the bibliographic data analysis. The result shows a good agreement between measured and predicted K (RMSE =1.1 on logK, 191 soils, $\sim$3000 data points). This gives some confidence in the derived relationship for estimating K for a wide range of soil.

As a conclusion, this study shows that the use of electrical conductivity can be useful in the estimation of unsaturated hydraulic conductivity variations in the lab or even in the field provided that matric potential is known or measured. However, more experimental data combining electrical and hydraulic properties for unsaturated soils are needed.