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Influence of stone content on soil hydraulic properties: experimental investigation and test of existing model concepts

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Rock fragments in soil, in this contribution referred to as "stones", play an important role for water flow in the subsurface. To successfully model soil hydraulic processes such as evaporation, redistribution and drainage, an understanding of how stones affect soil hydraulic properties (SHP) is crucial. Past investigations on the role of stones in soil have focused on their influence on the water retention curve (WRC) and on saturated hydraulic conductivity K_s, and have led to some simple theoretical models for the influence of stones on effective SHP. However, studies that measure unsaturated SHP directly, i.e., simultaneously the WRC and hydraulic conductivity curve (HCC) are still missing. Also, studies so far were restricted to low or moderate stone contents of less than 40%.

We conducted a laboratory study in which we examined the effect of stone content on effective WRC and HCC of stony soils. Mixtures of soil and stones were generated by substituting background soil with stones in weight fractions between 0% (fine material only) to 100% (pure gravel). Stone sizes were 2-5 mm and 7-15 mm, respectively, and background soils were Sand and Sandy Loam. Packed samples were fully saturated under vacuum and subsequently subjected to evaporation in the laboratory. All experiments were done in three replicates. The soil hydraulic properties were determined by the simplified evaporation method using the UMS HYPROP setup. Questions were whether the applied measurement methodology is applicable to derive the SHP of the mixtures and how the gradual increase of stone content will affect the SHP, particularly the HCC.

The applied methodology was successful in identifying effective SHP with a high precision over the full moisture range. WRC and HCC were successfully obtained by HYPROP, even for pure gravel with a size of 7-15 mm. WRCs changed qualitatively in the expected manner, i.e., an increase of stone content reduced porosity and soil water content at all suctions. However, the effect on SHP could not be modelled by assuming stones to be simply impermeable objects that occupy a part of the soil space. This was indicated by a nonlinear increase of the van Genuchten shape parameter α and a decrease of n with increasing gravel content, the latter indicating a widening of the effective pore-size distribution. Saturated conductivity decreased with increasing stone content, but then steeply increased for stone contents $> 40\%$. Unsaturated hydraulic conductivity curves of stone-soil mixtures showed a less pronounced decrease with increasing suction as compared to the pure components, again indicating a widening of the effective pore-size distribution and a nonlinear dependence of the effective unsaturated conductivity on stone content.