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Influence of rock fragments on hydraulic properties of Ultisols in Ratchaburi Province, Thailand

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ABSTRACT

In Thailand, stony soils are mainly located in hillside areas. Even though they have physical limitations for agricultural use and they are exposed to a risk for soil erosion, they continue to be used for crop production. A good understanding of the hydraulic characteristics of soils containing an important fraction of rock fragments is crucial for soil and water management in these areas. The objective of this study was to investigate the influence of different rock fragment contents on effective hydraulic properties of skeletal soil with a clay content lower than 35% using measurements of the water retention curve and the hydraulic conductivity. A tension infiltrometer was used to determine the field hydraulic conductivity at four pressure heads (h) of 0, − 30, − 60 and − 120 mm. Soil water retention was determined on a pressure plate between − 33 and − 1500 kPa. Finally, the Hydrus-1D was used to predict soil moisture dynamics using the obtained effective hydraulic parameters. The results show a decreasing water retention capacity with increasing rock fragment content. The saturated hydraulic conductivity decreased with increasing stone contents from 0 to 20%, but then increased for increasing stone content. Contradicting behavior can be observed using field and lab measurements, clearly exposing the need for a better understanding of the functioning of stony soils.

1. Introduction

Soil hydraulic characteristics play an important role in optimal soil water management and soil conservation practices. Knowledge of these properties is essential to evaluate the ability of the soil to store water and predict water and solute fluxes, which may affect the crop yield and the fate of agrochemicals, ultimately affecting ground water quality. Thus, hydraulic properties can be used as an indicator of soil water storage, water and nutrient transport, evaporation, plant water uptake, erosion and runoff, and ground water recharge (Poesen and Ingelmo-Sanchez, 1992; Zhongjie et al., 2008). Most significant hydraulic phenomena take place in the unsaturated (vadose) zone between the soil surface and the groundwater table.

Skeletal soils are mostly located in hillside areas and have physical limitations for crop production due to the presence of rock fragments. Stony soils are often related to negative effects on soil hydraulic characteristics and water availability (Fies et al., 2002; Sauer and Logsdon, 2002; Cousin et al., 2003). Focusing on the influence of rock fragments on soil water retention, many researchers state that a high rock fragment content usually has a negative effect on water retention in the soil (Ingelmo et al., 1994; van Wesemael et al., 1995; Fies et al., 2002) resulting generally in less plant-available water. Nonetheless, the type and size of rock fragments also affect soil water retention. For example, soil containing porous rock fragments can retain higher water content in the soil at the drier end of the soil moisture range (Ingelmo et al., 1994). In addition, small rock fragments can absorb a higher mass fraction of water on their surface than larger rock fragments do (Poesen and Lavee, 1994). Furthermore, the presence of rock fragments on the soil surface significantly decreases available water content (AWC) due to the fact that rock fragments have higher heat conduction than stoneless soil does, leading to increased evaporation rates that result in a reduction of AWC (van Wesemael et al., 1996). Beibei et al. (2009) also indicated that the rock fragments embedded on the soil surface could decrease the water infiltration rate. Sauer and Logsdon (2002) pointed out that the saturated hydraulic conductivity tended to increase with increasing rock content. Comparing the results of these different

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studies is difficult, since they were conducted under different climates (Ingelmo et al., 1994; Poesen and Lavee, 1994; van Wesemael et al., 1995; Sauer and Logsdon, 2002; Cousin et al., 2003 and Baetens et al., 2009) and often on disturbed soil samples with varying packing protocols (Beckers et al., 2016; Fies et al., 2002; Beibei et al., 2009; Ma et al., 2010 and Novák et al., 2011).

Soils containing rock fragments, or skeletal soil, are widely spread in mountainous and hillside areas. In Thailand, they are mostly distributed in the Northern and Western mountain ranges and are identified as one of the problem soils for agricultural use (Office of Soil Survey and Land Use Planning, 2012). Nevertheless, they are often being used for hillside farming for some economically valuable crops. Their major limitations are tillage difficulties, restriction of root growth, water erosion, and water stress. Scientific data showing the influences of rock fragment content on hydraulic properties (i.e. K_s and water retention curve) is scarce, even though such data is crucial to gain a better understanding of processes governing water dynamics in stony soils.

Therefore, this paper aims to investigate the influences of rock fragment content on hydraulic conductivity and water retention curves using field and laboratory measurements. Whereas, the applied methodological approach is not new as such, there is a great need for field and lab data for various soil types to better understand the behavior of stony soils.

2. Materials and methods

2.1. Study area and experimental site

The field experiment was conducted on a hillside at the Queen Sirikit Demonstration Farm, Bo Wi village, Suan Phueng district, Ratchaburi province, which is located in the west of Thailand (13°28′N, 099°16′E). The elevation of the site is 165 m above mean sea level (Fig. 1). The experimental site is characterized by a tropical savanna climate with a mean annual temperature of 26 °C. The mean annual rainfall and potential evapotranspiration (Allen et al., 1998) were 1089 and 516 mm, respectively. The local topography is hilly with slopes of 9 to 25%. The soil present is classified as a Kanhaplic Haplustult (Soil Survey Staff, 2014) with loamy-skeletal particle-size class and with a volumetric rock fragment content higher than 35% at most locations. Based on the soil morphological properties, the soil is developed on mixed residuum of metamorphic rocks (i.e. quartzite, sandstone, shale, and phyllite). The soil textural class is a gravelly sandy clay loam to very gravelly clay. The volumetric percentage of rock fragments increases with depth ranging from 44 to 85%. The diameter of the rock fragments mainly belongs to the 10–70 mm fraction within the first 0–80 cm. In the deeper horizon, rock fragment diameters are of 50 mm or larger. Soil pH (1:1 H_2O) is acid to strongly acid. Soil moisture and nutrient dynamics at this field site were previously described in Garré et al. (2013) and Hussain et al. (2015). Table 1 summarizes the most important soil properties. The experimental area was established after clearing a secondary forest (shrub and bamboo) by tractor in 2009.

2.2. Field measurements

The infiltration measurements were conducted on 9 locations at 2 depths: 0–5 cm and 20–25 cm (soil horizons with different rock fragment content) (Fig. 1) with a tension infiltrometer, with a similar design as described by Perroux and White (1988) to determine field saturated and unsaturated hydraulic conductivities (K_h) at pressure heads (h) of 0, − 30, − 60 and − 120 mm (so called K_s K_{-30}, K_{-60} and K_{-120}, respectively). The locations of the measurements were chosen so as to cover zones with different rock fragment content and were located in the alleys between the erosion plots in order not to disturb the plots. The outlet of the infiltrometer was 50 mm in diameter. The infiltration measurement was continuously operated until steady-state conditions were obtained, according to the recommendations by Verasan et al. (2011). Prior to the hydraulic conductivity measurements, vegetation was cut to ground level where it was present and plant litter and rock fragments were completely removed in order to have a clean, bare soil surface. At each measurement location, a thin layer (5–10 mm) of moist contact sand was applied to the ground surface and leveled. Then, the measurements were done from low to high tension (Li et al., 2008). The difference in hydraulic conductivity at different pressure heads, therefore, is an indication of the relative magnitude of potential water flow through the different pore-size classes.

In order to investigate the hydraulic behavior of skeletal soil, we

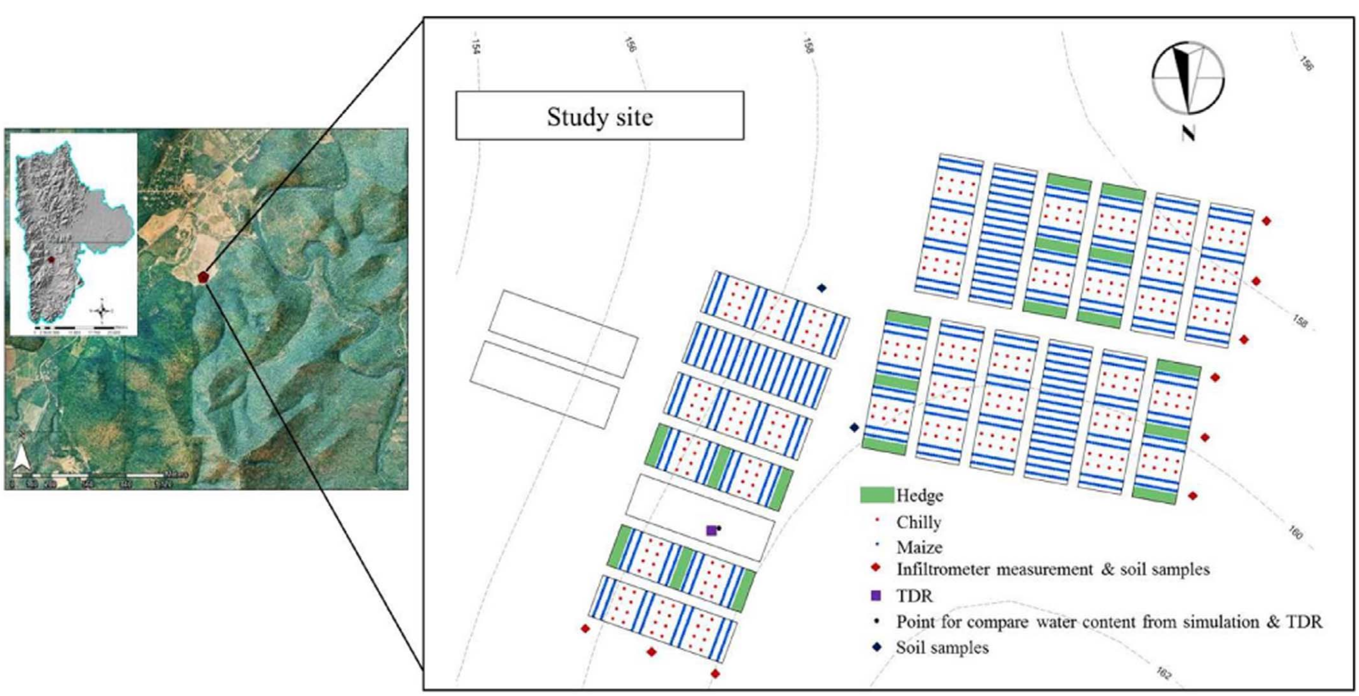

Fig. 1. Field experimental site at Bo-Wi village, Suan Phueng district, Ratchaburi province Thailand.