A Whole-Soil Modeling Approach for Field Capacity Assessment

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Introduction and objective

Field capacity (FC), the most frequently cited soil physical quantity, has been defined as the amount of water held in the soil after the rate of downward movement of water has decreased to a negligible value. As such, FC is a subjective property of a soil profile or of a part of it. The purpose of defining or determining FC for agricultural management is mostly related to irrigation. FC is also used in hydrologic modeling, where a well-established FC allows the use of bucket models as a substitute for data-intensive Richards' equation based algorithms. Recent publications on the subject focused on the establishment of relations between FC and hydraulic properties determined in single soil layers or soil samples, without considering the vertical variability natural to many soil profiles.

Irrigated agriculture is the prime client of FC assessment. The profile depth considered for FC assessment is important as rooting depths may vary for the same soil depending on crop, soil water regime and irrigation management. The objective of this work is to add to existing knowledge investigating FC, how it is affected by the considered profile depth, and how a compacted layer may influence FC.

Materials and Methods

Soil data

Soil data were obtained from a Typic hapludox from São Paulo state, Brazil (22° 42' S, 47° 38' W) with a clay content of 0.17 kg kg^{-1} in the 0-0.15 m layer, 0.19 kg kg^{-1} in 0.15-0.45 cm layer and 0.23 kg kg^{-1} in deeper layers. Bulk density increases from 1430 kg m^{-3} in the top layer to around 1700 kg m^{-3} in the subsoil. For sampling and measuring, the soil was subdivided in 5 horizontal layers of 0.15 m each. For each layer, the average soil water retention curve was established based on 24 sampling points; K_s was measured in 10 sample rings; and unsaturated hydraulic conductivity was determined from instantaneous profile experiments at 46 locations for pressure heads ranging from zero to -2 m. Resulting parameters of the Van Genuchten-Mualem equations are presented in ***Table 1***

Table 1 – Soil hydraulic parameters (Van Genuchten-Mualem equations)

depth, m	θ_r	θ_s	α, m^{-1}	n	λ	K_s, m d^{-1}
0 - 0.15	0.113	0.469	5.93	1.608	-0.361	0.382
0.15 - 0.30	0.138	0.362	4.21	1.759	1.130	0.328
0.30 - 0.45	0.112	0.332	3.71	1.551	2.156	0.240
0.45 - 0.60	0.144	0.329	3.92	1.527	1.298	0.175
0.60 - 0.75	0.142	0.351	4.25	1.487	1.756	0.175

Modeling

The SWAP model (Kroes et al. 2008, Alterra Report 1649, online version at www.swap.alterra.nl), employing a numerical Richards' equation modeling approach was used to analyze the importance of profile depth and compaction on FC assessment. Simulations were run for scenarios with no evapotranspiration, no rainfall and considering a unit hydraulic gradient at the lower profile boundary. The initial conditions were defined by a near-saturated soil profile (h=-0.01 m) down to a predefined depth z_d and an unsaturated soil below that (h decreasing to -0.20 m at z_d + 0.1 m, and to -3.3 m at z_d + 0.25 m).

Simulations were run (1) using profile data from ***Table 1*** and for five profile depths (z_d = 0.15, 0.30. 0.45, 0.60, or 0.75 m) (2) for a soil homogeneous except for a compacted layer: data from the 0-0.15 m layer (***Table 1***) were extended down to 1 m and a compacted layer was simulated by a tenfold lower K_s at depth 0.05-0.10, 0.20-0.25, 0.35-0.40, 0.50-0.55 or 0.65-0.70 m (see ***Figure 1***).

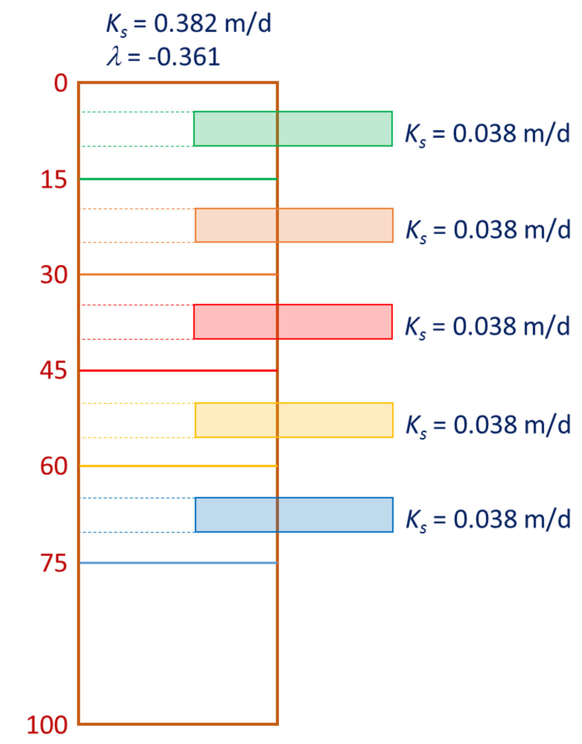

Figure 1 *– Schematic representation of the soil profile used for FC determination with a compacted layer at one of the five indicated depths*

Results and Discussion

1. Simulations using profile data from Table 1

Results from these simulations show that

a) Comparing the five profile depths, the difference in initially saturated soil depth disappears within one day of drainage;
b) After one or two days, hydraulic gradients remain rather constant at values between 0.2 and 1, with lower values for the shallower soil (***Figure 2***).

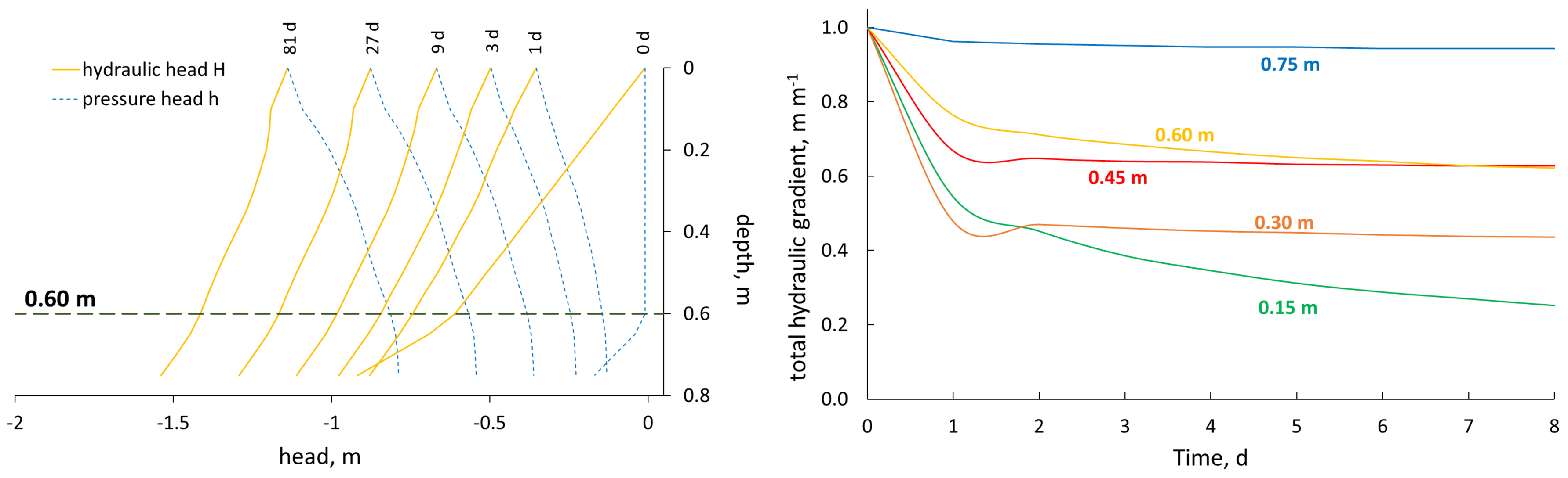

Figure 2 *– (left) hydraulic and pressure head over depth and time for the 0.60 m deep soil profile and (right) hydraulic gradient over time at the bottom of the soil profile for five simulated depths.*

From the fairly constant values of the hydraulic gradient over time it can be seen that the hydraulic conductivity at the lower limit of the soil profile determines FC: for a unit gradient, FC can be considered to correspond to the water content at which hydraulic conductivity at the lower profile boundary equals a pre-established bottom flux. Depending on soil hydraulic characteristics of the soil profile, real hydraulic gradients may be lower or higher than one and a proportionally higher or lower hydraulic conductivity will then correlate to field capacity. In the here evaluated soil, lower gradients occur when smaller profile depths are considered.

2. Simulations for a soil with a compacted layer

In accordance with an expected quasi-steady-state condition, results from these simulations show that the presence of a compacted layer causes hydraulic gradients to be lower immediately above and higher within the compacted layer. Below de compacted layer, hydraulic gradients and pressure heads are almost unaltered when compared to a simulation without compacted layer (***Figure 3***).

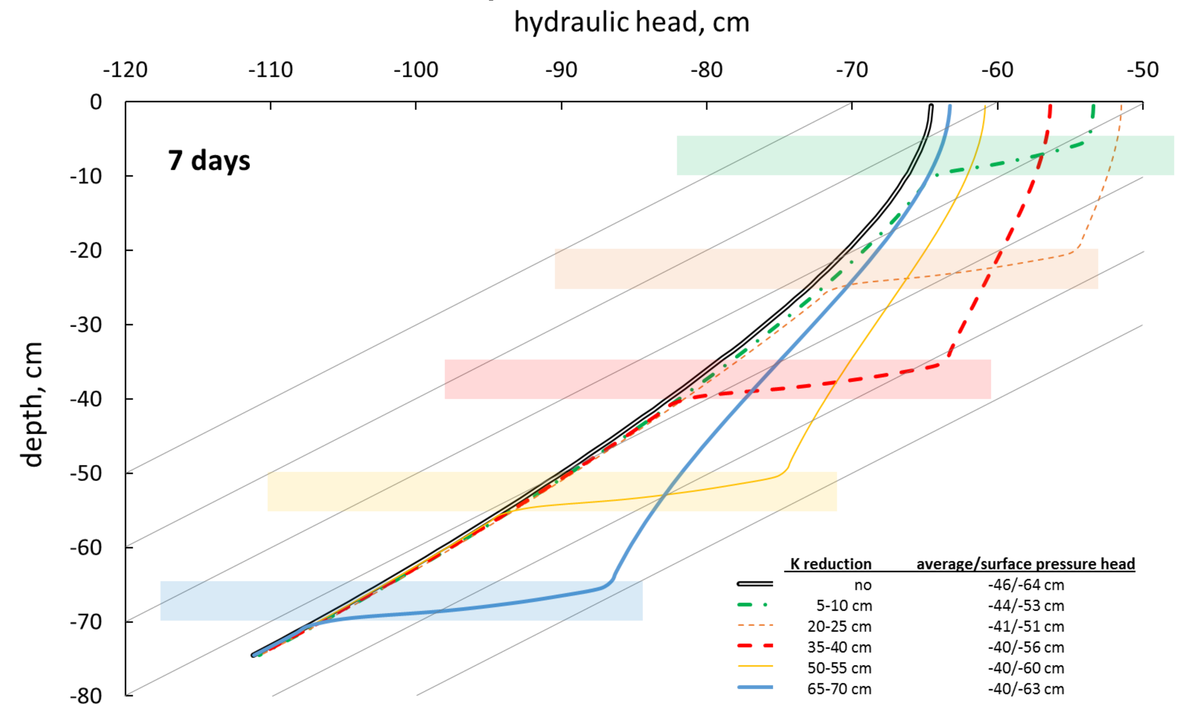

Figure 3 *– Hydraulic head versus depth after 7 days of drainage, obtained from simulations with a compacted layer (reduction of K) at one of five depths positions, as well as without compacted layer.*

Consequently, if a flux-criterion is to establish FC, a compacted layer at any position causes FC to correspond to a higher water content. When the compacted layer is at a depth shallower than the lower profile bound, the high hydraulic gradient in the compacted layer makes the overlying layers to be wetter. On the other hand, if the compacted layer occurs below the lower profile bound, the hydraulic gradient at the profile bottom will be smaller and FC will correspond to a higher hydraulic conductivity and water content.

Conclusions

FC is determined by the unsaturated hydraulic conductivity at the bottom of the considered profile, together with the hydraulic gradient, in obvious dependence of the criterion to establish a negligible bottom flux, which is set by economic or environmental boundary conditions.

In the evaluated soil, after 1 or 2 days hydraulic gradients remained fairly constant at values smaller than 1, lower for the shallower profiles, suggesting that the K(θ) function is the most useful soil property in FC determination.

In response to a pronounced layering or compaction, hydraulic gradients may diverge during redistribution. A compacted layer at any depth affects FC, leading to a higher water content at FC.

The unit hydraulic gradient allowing computational and experimental simplifications in the analysis and design of internal drainage studies may be questionable especially when considering shallower soil depths or strongly layered soils.