SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

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PURPOSE OF THE STSM:

Interpreting and simulating hydrological processes need considering that the soil is not rigid (Bagarello et al., 2017). For this reason, a number of challenges still remain unresolved for both theory and practice for data collected by ponding infiltrometer methods and usual experimental procedures (Angulo-Jaramillo et al., 2000). They include questions on how to consider and characterize the physical and hydraulic characteristics of the soil surface directly impacted by rainfall, which develop a heterogeneous soil profiles presenting a fine layering organization (Assouline, 2004). Under such conditions, the steady-state water flow analysis based on usual analysis procedures, which generally assume homogeneity and isotropy are generally found to be inadequate, yielding negative values of hydraulic conductivity (Logsdon and Jaynes, 1993). Di Prima et al. (2017) demonstrated that both rainfall simulation experiments and infiltration runs carried out by applying water at a relatively large distance from the soil surface (BEST-H procedure) determine a certain degree of compaction and mechanical breakdown. Therefore, K_s values estimated by these methodologies are more appropriate than those obtained with a low height of water pouring to characterize the soil surface directly impacted by rainfall. However, a soil hydraulic characterization simultaneously carried out with the BEST-H procedure along the three existing BEST algorithms and other, well tested methods for K_s estimation, such as rainfall simulation experiments, is necessary to experimentally assess the predictive performances of the BEST procedure, that are still largely unknown notwithstanding that simple and rapid methods of soil hydraulic characterization have a noticeable practical interest. In general there is the need to understand which BEST algorithm can be satisfactory adopted to proper estimate K_s for the specific case of an infiltration experiment implying an alteration of the soil surface.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

Soil materials used in this investigation were taken from three Sicilian sites with different physical properties. According to the USDA classification, a sandy-loam soil (SL soil) and an unstructured clay-loam soil (CL soil) were sampled at the Faculty of Agriculture of the Palermo University. A clay soil (C soil) was sampled at the experimental station for soil erosion measurement at Sparacia of the University of Palermo, approximately 100 km south of Palermo.
In this investigation we used the rainfall simulator of the Kraijenhoff van de Leur Laboratory for Water and Sediment Dynamics at Wageningen University, the Netherlands. A total of thirty storms were simulated at rainfall intensity R = 60 mm h^{-1}. The experiments were carried out on small rectangular soil plots encased in a transparent plexiglass box. Two different thickness of the soil layer were considered in this investigation in order to evaluate the effect of the two-layer seal-undisturbed soil system on rainfall infiltration. In particular, fifteen rainfall simulations (RS experiments), five for each soil, were carried out

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placing a 75-mm layer of soil over a 75-mm layer of sand. Surface runoff from the runoff collection compartment was collected at 3 min intervals from the moment at which the runoff started to run out of the outlets until the differences in the measured runoff rates became negligible, signaling a practically steady-state process. The steady-state runoff rate, r (mm h^{-1}), values were estimated considering the runoff rates of the last stage of the experiments, describing the steady-state phase of the process. Then, the saturated soil hydraulic conductivity K_s was estimated by subtracting the steady-state runoff rate from the rainfall intensity (White et al., 1989). After each rainfall run the thickness of the seal layer was measured using a ruler. A sample of the seal layer was also collected after each RS-T run using a 50-mm diameter ring. In this case, the risk of compaction or shattering of the sampled soil volume was minimized since the thin seal layer could be easily separated from the underlining sand layer. These samples were used to determine the dry soil bulk density, ρ_b (g cm^{-3}), of the seal layer.
A total of 30 Beerkan infiltration experiments (Lassabatere et al., 2006) were carried out, ten for each sampled soil. A small diameter (i.e., 50 mm) ring inserted to a depth of 10 mm was chosen to detect more clearly potential effects of soil disturbance due to water. For each studied soil, five runs were carried out by pouring water at a small height above soil surface, i.e. at a height of 0.03 m (low, BEST-L runs). Water was applied from 0.25 m for the other 5 runs (high, BEST-H, runs). In this case, the soil surface was not shielded to maximize possible damaging effects of water impact. For each infiltration run, cumulative infiltration, I (mm), was plotted against time, t (s), and a linear regression line was fitted to the last data points, describing the near steady-state conditions, in order to estimate the experimental steady-state infiltration rate, i_s (mm h^{-1}), and the associated intercept, b_s (mm). Then, the three existing BEST algorithms, i.e., BEST-slope (Lassabatere et al., 2006), BEST-intercept (Yilmaz et al., 2010) and BEST-steady (Bagarello et al., 2014a), were applied to estimate the saturated soil hydraulic conductivity, K_s (mm h^{-1}). Since a fitting of the infiltration model to the transient data is required with BEST-slope and BEST-intercept, for these algorithms the quality of the fit of the models to the infiltration data was evaluated by controlling both the general shape and the relative error, Er (%).

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Rainfall simulation experiments

For the three studied soils, the mean K_s values of the RS and RS-T experiments ranged from 13.9 to 25.5 and from 15.9 to 26.2 mm h^{-1}, respectively. Visually, the change in soil structure at surface after the simulated storms was evident. The compaction of fine material from the destroyed aggregates formed a thin (thickness of ~1 mm) and highly dense layer (seal). Under the conditions simulated here, the soil bulk density has increased of 38.7-42.1 %, depending of the soil, due to soil surface sealing of the initial undisturbed soils. The different soil thickness did not have a statistically detectable effect on the measured K_s values according to a two-tailed t test at P = 0.05. This parameter was therefore representative of the hydraulic behavior of the least permeable layer (i.e., the seal layer), which controlled the flow at the late-time of the process. In other words, in both the RS and RS-T experiments the infiltration process was dominated by a similar developed seal at the surface of the bare soils exposed to the direct impact of raindrops.

Performances of the BEST Algorithms

The three BEST algorithms, were not equivalent. The BEST-slope algorithm yielded physically plausible estimates (i.e., positive K_s values) in 16 of 30 infiltration runs (53% of the cases), with the BEST-L procedure showing better results than BEST-H, yielding failure rate values of 7 and 87 % respectively. The percentage of successful runs was of 100% with BEST-intercept. However, for this latter algorithm, the performance in term of fitting of the transient cumulative infiltration model to experimental data were less accurate for BEST-H than BEST-L. With reference to the Low runs, the BEST-intercept algorithm led to acceptable Er values (i.e., $Er \leq$ 5.5%) for the SL and CL soils. On the other hand, critical Er values (i.e., Er >> 5.5%) were obtained for the High runs and for both Low and High runs for the C soil. Finally, although the percentage of successful runs was of 100% with BEST-steady, there were no other means to evaluate the performance of BEST-steady algorithm since with this algorithm K_s is directly estimated. However, even if BEST-steady appeared to be more robust than the other algorithms and always provided estimates of the hydraulic parameters there are no studies proving that a high success rate implies necessary a good soil hydraulic characterization. In other terms, there are no reasons supporting the hypothesis that BEST-steady may be more appropriate to determine K_s data, whereas BEST-slope and BEST-intercept failed or yielded high Er values, especially for infiltration runs implying sealing of an initially undisturbed bare soil. To overcome this lack, in the following section a comparison with independent K_s data estimated by rainfall simulation experiments was done in order to assess the predictive potential of the three BEST algorithms.

Comparing rainfall simulation and Beerkan infiltration experiments

The K_s comparison carried out by applying different procedures to analyze the same infiltration run and independent rainfall simulation experiments allowed to identify BEST-steady as the more appropriate algorithm to estimate hydraulic properties from the High runs. This result likely depend on the fact that BEST-steady considers exclusively the late phase of the infiltration process, i.e., when the seal is fully developed. Limiting the hydraulic characterization to the stabilized phase avoids the uncertainties due to specific shape of the cumulative infiltration and a no clear distinction between the early- and late-time infiltration process because the progressive alteration of the soil surface (Bagarello et al., 2014b). Another implication of this result was that, in both cases, the developed seal layer ruled the infiltration process and the estimated K_s values were representative of the seal. In other words, the experiments presented in this study suggest that if any seal forms at the surface during a BEST-H infiltration test the BEST-steady estimates should better characterize the hydraulic properties of the seal. The superiority of BEST-steady over the other algorithms is also indicative of the fact that new three-dimensional infiltration models should be developed in the future, also taking into account that interpreting and simulating hydrological processes need considering that the soil is not rigid (Bagarello et al., 2017).

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