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Applicability of Darcy-based models to predict vertical water fluxes in paddy fields

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Rice is one of the world's most important staple foods and it is typically grown in rice paddies which are usually flooded for much of the growing season, causing significant percolation through the soil profile. The amount of water percolated depends on the ponding water level and on the hydrological properties of the soil, which in paddy fields is mainly articulated into a rooted soil horizon (muddy layer), a hardpan, and a subsoil. In addition, the percolation can be affected (reduced) by a shallow water table depth, which is commonly present in many rice growing areas.

In the models proposed to compute rice field water fluxes, three approaches are mostly used to simulate the vertical percolation: fixed percolation rate set by the user (e.g. implemented in YIELD, Cropwat and ORYZA models), Richard's equation (e.g. in Hydrus, SWAP, FLOWS), or the Darcy's law (e.g. SAWAH, WatPad introduced by Facchi et al., 2018). The fixed percolation approach is suitable when information on average percolation is available and percolation is known to be roughly constant along the season. On the opposite side, the application of the Richard's equation requires the knowledge of the thicknesses and the soil properties (i.e. parameters of the soil water retention curve and unsaturated conductivity curves) of all soil horizons in the profile. Somehow in the middle of the two previous approaches, the Darcy-based models require only a few soil parameters; WatPad only needs the thickness of muddy and hardpan layers and saturated hydraulic conductivity of the hardpan. Obviously, both the Darcy and Richard's approaches need the groundwater level if the water table is close to the soil surface.

The use of a Darcy's model allows data collection to be focused on a small number of highly relevant soil characteristics, and this can be particularly useful when considering modelling applications over large spatial areas. However, this type of model lacks theoretical support for calculating water fluxes during periods when fields are in unsaturated conditions and, more importantly, for defining water potential values under the hardpan, especially when the water table is far from the soil surface. If the unsaturated flow is often very small or even negligible, errors in defining the soil water potential under the hardpan can lead to significant errors undermining the Darcy-based models.

A series of comparisons were made between the WatPad model and the SWAP model, considering deep groundwater table conditions. Results show that the two models gave nearly overlapping vertical percolations when in the Darcy's model: i) the atmospheric pressure is set at the lower side of the hardpan and ii) the head loss due to the muddy layer is neglected. Indeed, these two simplifications affect the estimated percolation with similar errors and different signs, almost canceling each other out.

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