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Editorial

Special Issue "Soil Hydrology in Agriculture"

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1. Introduction

Understanding the hydrological behavior of soils is essential for managing and protecting agricultural (and natural) ecosystems. Soil hydrological behavior not only mainly determines crop responses to water and nutrients provided by irrigation and fertilization, but also the timing for soil tillage, environmental conditions for plant diseases, among other factors. In the sound management of irrigation water, in relation to specific environmental conditions and cropping systems, the knowledge of local water flow conditions in zones explored by the root systems is indispensable. Once the irrigation method has been established, only the knowledge of the laws governing water flow allows for the establishment of the necessary irrigation frequencies and rates to optimize the distribution of soil moisture, reducing the effects of water stress within the established limits and containing water wastage.

Soil hydrology also controls deep percolation fluxes of water and nutrients, as well as water and nutrient runoff. Only by studying water dynamics in soil can the contribution of groundwater to water consumption be quantitatively determined. Moreover, the water volumes infiltrating into the soil due to rainfall are strictly linked and governed by the laws of water flow in the soil. No evaluation of water quantities being added to groundwater circulation can be made without first determining the water volumes moving in the zone between the soil surface and aquifer.

The use of process-based soil-plant-atmosphere models, relating soil hydrology to crop growth, dates back several decades ago [1].

More recently, models are incorporated in decision support systems to be used for quantifying the effect of alternative farm managements [2], among many other decisions, such as landscape planning [3] and crop yield responses as affected by climatic change [4]. This, in turn, may allow for site-specific management of spatially variable soil (Agriculture 4.0). It is thus evident that soil hydrology is a key factor in food security and sustainable development goals (SDG2) [5,6].

The crucial link between soil hydrology and optimal management of water and solutes in agriculture calls for advancements in field-based monitoring and prediction tools for a better understanding of water and nutrient balance and, specifically, of all the functional processes involved (namely, evapotranspiration, groundwater recharge, nutrient and salt transport) [7,8]. Understanding these processes has obvious consequences on the water and solute management in agriculture, suggesting optimal irrigation methods, water volumes and fertilizer amounts to keep crop yields, while minimizing environmental problems (e.g., nitrate leaching towards groundwater, soil salinization).

The complexity of soil water flow and solute transport processes has encouraged the widespread use of mathematical models, corresponding as closely as possible to real phenomena [9]. Efforts have been mainly devoted to develop increasingly sophisticated parameterizations of the interaction between soil, vegetation and the atmosphere in the so-called soil–plant–atmosphere continuum (SPAC) transfer schemes [10,11]. The estimation of water and solute balances at different spatial and temporal scales is a fundamental task of these models. Under most climatic conditions, the ability of the root zone to match evapotranspiration and precipitation depends on the soil's infiltration capacity, root zone storage and water-holding capacity, as well as on the temporal dynamics of the precipitation process, relative to that of evapotranspiration. Knowledge of the physical and hydraulic properties of the shallow vadose zone is, therefore, a key element in correctly modeling the soil–groundwater–atmosphere exchange processes. Moreover, for large-scale applications, an evaluation in statistical terms of the variability of these properties is also necessary [12].

The body of knowledge on the link between hydrology and agriculture available at present, both theoretical and experimental, is extensive. Nevertheless, knowledge gaps still exist. The purpose of this special issue is to fill some of these gaps.

In this sense, the papers selected for this special issue address a range of issues—all deal with the interaction of soil hydrology and agriculture in seeking effective management of water and nutrients. Most of the contributions integrate monitoring and modeling components at applicative scales, from field to district scales.

Specifically, this special issue deals with the following major topics:

1. Hydrological properties for model applications and their changes over time;
2. Model calibration and water balance;
3. Irrigation management and effects on soil hydrological processes and salinity.

In the following paragraphs, details of each of the papers included in each of these major topics will be provided.

2. Hydrological Properties for Hydrological Model Applications and Their Changes over Time

Modeling soil hydrological behavior in large areas, which may exhibit high spatial (and temporal) variability, requires finding adequate datasets of soil hydraulic properties (SHP) at the scale of concern. Measuring SHP at applicative scales remains a complex task, mainly because of the spatial heterogeneity of the vadose zone. Thus, a major objective for soil scientists and hydrologists is to develop practical procedures for measuring SHP and their spatial distribution. The paper by Zumr et al. [13] investigated the seasonal variability of the nearly saturated hydraulic conductivity of topsoil—due to agricultural management, climate, kinetic energy of rainfall and crop and root growth—by using an innovative automated tension minidisk infiltrometer. The main outcome was that the temporal k(h) variability was higher than the spatial variability. Similarly, the study by Chandrasekhar et al. [14] reviewed the quantitative effects of different agricultural management practices on SHP and the subsequent response of the water balance components. With the objective of overcoming the limitations of using SHP constant over time, they applied a pore evolution model to two datasets to evaluate its suitability to predict soil pore space dynamics after disturbance. They conclude that the limiting factor to calibrate and apply such modeling tools is not in the theoretical part, but it is rather the lack of soil structural and hydrologic data. Bombino et al. [15] analyzed some hydrological processes, namely, water infiltration and surface runoff at the plot scale on a steep slope under four soil management practices: mechanical tillage, total artificial protection of soil and soil cover with two different rates of vegetal residues. Overall, they concluded that the retention of vegetal residues over the soil may be advisable to reduce surface runoff generation rates, particularly for saturated soils.

The methods to hydraulically characterize a soil, either in situ or in the laboratory, remain extremely difficult to implement on large applicative scales. This is the reason why so-called pedotransfer functions (PTFs) are often used to estimate hydraulic properties using readily available soil properties [16]. However, a large amount of uncertainty exists in applying PTFs to soil conditions, different from those under which PTFs were derived [7,17,18]. In this sense, Basile et al. [19] analyzed the sensitivity of a model based on Richards' equation to the variability of SHP parameters, as measured by or estimated by PTF. The preliminary analysis showed the parameter n of the van Genuchten (vG) equation to be significantly more sensitive than k_{sat}, although the former was much less variable. Then, despite PTF showing a very close agreement with the measured data, they lost the information on spatial variability. This effectiveness of using PTFs was evaluated by using above-ground biomass estimated by remotely sensed normalized difference vegetation index (NDVI) as data for quality control. In the paper by D'Emilio et al. [20], PTFs were estimated for 359 Sicilian soils by implementing five different artificial neural networks (NNs) to estimate the parameter of the vG model for the water retention curve. The Akaike's information criterion indicated that the most efficient NN model was trained with a relatively low number of input nodes.

3. Model Calibration and Water Balance

The optimal management of water and nutrients in agriculture is being increasingly based on mathematical models, simulating storages and fluxes of water and solute along the soil profile. To be of actual interest for both agricultural and environmental purposes, these models should produce information on the daily evolution of soil water contents in the soil profile, the root water uptake and actual evapotranspiration, the percolation fluxes and their quality in terms of solute (nitrates, for example) concentrations and the runoff production.

In order to provide reliable predictions, these models need to be adequately calibrated and validated. In fact, because of the differences between SHPs measured in the laboratory and their effectiveness in describing real field processes [21,22], modeling is always required to be coupled with adequate field-based monitoring of soil (possibly long-term), allowing for a continuous evaluation of the predictive capability of models for a better management of the water and nutrient balance. In this respect, the effort of the special issue authors in producing field-measured hydraulic properties—as reported in Section 1—is highly valuable. Also, before calibration and validation, these models have always been preliminarily tested for sensitivity to specific parameters and processes to be simulated.

This special issue includes several papers dealing with this topic.

The paper by Cai et al. [23] analyzed the sensitivity of the Common Land Model (CoLM) to the root uptake function and root distribution using a three-year dataset from a maize crop. They proposed a modified root water uptake function that played a significant role in optimizing the simulation of water and heat fluxes. Feki et al. [24] assessed the impact of four infiltration models (SCS-Curve Number, Green and Ampt, Philip and Ross) on soil water content simulations, simulated by the model FEST-WB (flash flood event-based spatially-distributed rainfall-runoff transformations-water balance). They found the Ross solution to be better in its performance through soil water content monitoring.

Vidana Gamage et al. [25] compared the water balance calculated alternatively on water content data coming from distributed actively heated fiber-optics (AHFO) and point-based Frequency Domain Reflectometry (FDR) sensors (i.e., 5TE sensor, Decagon Inc., Pullman, USA). Overall, this study showed the potential of the distributed sensor to provide a more accurate value of soil water content at field scale and to reduce the errors in water balance for shorter wet periods. Slama et al. [26] dealt with field measurements and modeling by using Hydrus 1D to evaluate the effect of drip irrigation, irrigation regime on root uptake, root zone salinity and solute return flow to groundwater. Simulations showed that relative yield accounted for 54%, 70% and 85.5% of the potential maximal value when both water and solute stress were considered for deficit, full and farmers' irrigation, respectively. Coppola et al. [27] illustrated an irrigation management tool for simulating flow of water (and solutes) in heterogeneous agri-environmental systems (named FLOWS-HAGES) and applied it to simulate district-level water needs, scheduling over the course of an irrigation season. Specifically, the model allows the daily optimal sequence of hydrants opening in order to guarantee that the discharges flowing inside the distribution pipe network are delivered under optimal pressure head distribution in the system. Wegehenkel et al. [28] calibrated an agrohydrological model using long-term data (22 years) measured by time domain reflectometer probes and tensiometers and coming from three agricultural experimental field plots. They demonstrated the benefits of long-term experiments in calibrate and validate model parameters, especially for those of the water uptake function. Lu et al. [29] analyzed the issue of upscaling evaporation measured at small scale (pots) to the lysimeter scale. A series of corrections were proposed to reduce the effects of crop densities, representative areas per plant and soil moisture conditions on pots results.

All the papers mentioned above are based on the use of field scale experimental data to analyze hydrological processes and calibrate models. Most of the models were physically based models. However, we also included in this major topic the paper by Liang et al. [30], who explored a data-driven model based on machine learning as an alternative to a physically based overland flow and transport model. The results indicate that the NN model with two hidden layers performed the best among the selected data-driven models, accurately predicting runoff water quantity and quality over a wide range of parameters.

4. Irrigation Management and Effects on Soil Hydrological Processes and Salinity

Arid and semi-arid countries (e.g., Tunisia, Israel, India, etc.) are frequently forced to use low-quality water (i.e., brackish water, drainage water, treated waste water) to develop their agricultural production [31]. Using low-quality irrigation water is often associated with soil salinization risk. In case of shallow groundwater, excessive irrigation can lead to an increase in groundwater table and root zone salinity levels by upward salt flux [32,33]. In these cases, it may be necessary to reduce the volume of drainage water requiring disposal or treatment that in turn could deteriorate the environment. On the other hand, water quantity and quality are considered the major factors affecting crop productivity.

There is thus the need for irrigation systems and management practices, which can simultaneously fulfill these two diverging requirements.

The paper by Jin et al. [34] compared the distribution of soil water content under mulched drip irrigation and flood irrigation. They also explored the effects of mulched drip irrigation on infiltration and groundwater recharge. Results showed that soil water content under mulched drip irrigation was generally larger than under flood irrigation in the initial growth stage. However, an opposite trend was observed in the main growth stage. Moreover, infiltration depth under flood irrigation was deeper than that under mulched drip irrigation.

The salt distribution in the root zone depends (besides in management practices and other environmental factors) on the complex non-linear processes of water flow and solute transport in soil determining variable distributions and the storage of solutes and water along the whole root zone, as well as their upward and downward fluxes. The effect of all these processes on the response of a crop to irrigation with saline water cannot be assessed without a detailed spatio-temporal monitoring of water contents and solute concentrations in soils during irrigation with saline water [8].

Nachshon [35] provided a review on cropland soil salinization, with examples of soil salinization processes from croplands around the world, by discussing the effects of salinity coming from different sources. Slama et al. [26] also discussed the effects of different irrigation regimes on root zone salinity. Soil water content and salinity were monitored in a fully drip-irrigated potato plot with brackish water (4.45 dS/m) in semi-arid Tunisia. Root zone salinity was the lowest, and root water uptake was the same with and without solute stress for the treatment corresponding to the farmer's irrigation schedule (273% ET).

5. Conclusions

The title of this special issue "Soil Hydrology in Agriculture" is very broad, encompassing, therefore, a large variety of problems, research and issues. Contributions have come from different parts of the world (three from North Europe, three from China, two from North America and seven from European and non-European Mediterranean countries), with a large incidence of countries with limited water resources. Another aspect that is instantly reflected from the published papers is the large number of research studies involving field measurements and application of physically-based modeling. Because of the previously mentioned differences between lab-measured and field-measured hydraulic properties, this trend reflected in this special issue is very much welcome. In fact, as reported in Sections 1 and 2 of this paper, soil hydrological processes require the knowledge of SHP at the scale of process under study. Furthermore, the coupling of these measurements with physically-based models improves the transferability of the obtained results.

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