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Editorial

Study of the Soil Water Movement in Irrigated Agriculture

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In irrigated agriculture, the study of the various ways water infiltrates into the soils is necessary. In this respect, soil hydraulic properties, such as soil moisture retention curve (SMRC), diffusivity, and hydraulic conductivity functions, play a crucial role, as they control the infiltration process, the soil water, and the solute movement. Modeling and flow simulation of soil water movement depends on the appropriate description of the hydraulic properties and their measurements (in situ and in the laboratory), upon which these are provided.

The aim of this special issue is to present a comprehensive review of the recent developments in the various aspects of soil water movement in irrigated agriculture. The above may be presented by a number of research topics that tackle one or more of the following challenges:

- Irrigation systems and one-, two-, and three-dimensional soil water movement;
- Three-dimensional infiltration analysis from a disc infiltrometer;
- Dielectric devices for monitoring soil water content and methods for assessment of soil water pressure head;
- Soil hydraulic properties and their temporal and spatial variability under the irrigation situations;
- Saturated–unsaturated flow model in irrigated soils;
- Soil water redistribution and the role of hysteresis;
- Soil water movement and drainage in irrigated agriculture;
- Salt accumulation, soil salinization, and soil salinity assessment;
- Effect of salts on hydraulic conductivity;
- Soil conditioners and mulches which change the upper soil hydraulic properties and their effect on soil water movement.

This Special Issue of *Water journal* contains eleven papers covering many aspects of the aforementioned challenges [1–11] and encompassing a wide range of different regions and conditions. Generally, the study of soil water movement in irrigated agriculture is certainly a basic chapter of the wider scientific area of soil physics. There, based in certain fundamental principles such as mass and energy conservation, least action, momentum transfer, etc., one can apply these, taking special consideration of the particular case of the soil, as being a non-homogeneous and anisotropic, three-phase medium, where solid soil particles of various shapes and substances co-exist with soil solution (water and soluble salts) and air. The changing and time-evolving nature of the soil as a whole is described by the various expressions of the soil properties (hydraulic, thermal, electrical, etc., which are appropriately used to formulate the basic laws, such as Darcy's law) which govern soil water movement in one, two, and three dimensions, solute transport, heat transfer etc. Therefore, in the study of soil water movement in irrigated agriculture, it is very useful to be able to measure or adequately evaluate these soil properties [1–5].

The climatic perturbations nowadays become more and more pronounced and evident, either as ice-melting due to temperature increase, tornedoes, storms, or large fires, lasting for quite a long time. Many others are escalating the need of rational and, if possible,

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sustainable irrigation agriculture. From the above, a great effort is required to avoid soil salinization and, perhaps, to develop methods by which one could make use of modern devices and sensors, such as dielectric sensors, for monitoring the salinity levels in various places and its evolution during the plant's growing period [6–8]. Another aspect is saving water, that is, making use of an appropriate method of applying irrigation water as drip irrigation, gravity vertical tube irrigation [3,9,10], etc., in either homogeneous or layered soil profiles.

Specifically, Elasbah et al. [9] investigated the impact of soil hydraulic properties and fertigation strategies on fertilizer distribution and use efficiency, under both surface and subsurface drip irrigation with 10 and 20 cm emitter depths, for tomato plants. Applying the HYDRUS-2D/3D model, they simulated soil water and fertilizer movement through the soil under surface and subsurface drip irrigation and analyzed what procedure is the best for the fertigation strategy, fertilizer distribution, and use efficiency. Simulation results showed that fertilizer leaching is significantly affected by the soil type, and that fertilizer leaching below the simulation domain was affected by varying irrigation systems. In addition, they showed that to reduce potential fertilizer leaching, fertilizers should be added at the beginning of irrigation events for subsurface drip irrigation and at the end of irrigation events for surface drip irrigation.

Fuentes and Chavez [1] studied another relevant problem regarding the connection of the numerical simulation with the hydrodynamic model, formed by the coupled equations of Barre de Saint-Venant and Richards, in an attempt to find the optimal flow for gravity irrigation in border strips of various lengths. In the numerical simulation, 10 types of soils of contrasting textures have been used, and three water depths have been applied. A linear relationship has been validated between the length of the border and the optimal irrigation flow.

In every irrigation practice, the role of the relevant soil hydraulic properties is very crucial. Among all the measurable quantities in soils, one of the most important is the saturated hydraulic conductivity (K_s), which is highly correlated with the optimization of the flow rate applied to the border or furrow in the gravity irrigation. It is, therefore, useful to explore ways of estimating K_s, using artificial neural networks, as this has been carried out by Trejo-Alonso et al. [2]. They constructed several artificial neural networks (varying the input data) to calculate the K_s. They compared their results with pedotransfer functions and other neural networks from the literature, and showed that the results of their artificial neural networks are in good agreement with some of them. Furthermore, they highlighted the need for further research to define an exact range of the amount of data required by a reliable artificial neural network.

Kargas et al. [4] presented another research topic concern for the investigation of the flux–concentration ($F(\Theta)$) relation, where Θ is the normalized soil volumetric water content for the case of one-dimensional horizontal flow, subject to constant concentration conditions. More specifically, the possibility of describing $F(\Theta)$ by an equation of the form $F(\Theta) = 1 - (1 - \Theta)^{p+1}$ is examined. It is shown that the flux-concentration ($F(\theta)$) relation can be described by a simple monoparametric expression. This parameter p is quite easily estimated from curve-fitting of the experimentally obtained $\lambda(\theta)$ data, with λ well-known Boltzmann transformation, to an analytic expression containing this parameter.

Wang et al. [3] presented a new water-efficient subsurface irrigation technique, the vertical tube irrigation, to address the water shortage in Xinjiang, China. They analyzed the infiltration characteristics and spatiotemporal distribution of moisture in layered soil, as well as the water-saving mechanism of vertical tube irrigation. The results showed that the vertical tube irrigation in layered soil facilitates the retention of water in the root zone, prevents deep leakage, reduces irrigation quantities, and improves the irrigation water productivity.

Peng et al. [5] proposed a zoning optimization method for the irrigation schedule to solve the problem of the connection between suitable irrigation schedules and different groundwater depths in shallow groundwater areas. Depending on the groundwater depth, whether it is greater or less than 2.5 m, the irrigation schedule could be appropriately arranged in a manner that is both quantitative and timely, e.g., applied at certain stages of the spring wheat growth. The main water-saving effect of the optimized irrigation schedule was that the yield, the soil water use rate, and the water use productivity increased, while the irrigation amount and the ineffective seepage decreased.

Soil salinization remains a serious and complex problem which inhibits crop production all over the world. This is why much of research work has attempted to cover it in its various aspects, through the investigation of a number of quite recent tools and methodologies. Certainly, the electrical conductivity of the saturated paste extract EC_e remains as the standard method, characterizing soil salinity. Nonetheless, it is laborious, time-consuming, and requires laboratory facilities. Research work establishing, the suitability of less demanding methods under certain conditions, such as the measurement of $EC_{1:1}$ or $EC_{1:5}$ (electrical conductivity of soil-over-water mass ratios), is undoubtedly welcome. Kargas et al. [6] investigated the effect of three different methods of obtaining $EC_{1:1}$ and $EC_{1:5}$, and the relationships between EC_e and each of the three of $EC_{1:1}$ and $EC_{1:5}$. The relationships between EC_e and each of three methods of obtaining $EC_{1:1}$ and $EC_{1:5}$ were strongly linear; however, it is necessary to describe in detail the method of preparation and extraction for determining $EC_{1:1}$ and $EC_{1:5}$, as well as the range of EC_e, in order to properly evaluate and compare the proposed equations.

In arid and semi-arid regions, mulched drip irrigation has been widely used in agricultural planting. The dynamics and distribution of soil salinity under the mulched drip irrigation conditions affect crop growth and yield. Guan et al. [10] monitored the soil salinity of a newly reclaimed salt wasteland for 9 years and investigated the effects of soil water on soil salinity distribution under mulched drip irrigation. The results showed, among others, that under long-term mulched drip irrigation, the soil salinity in 0–30 cm and 0–60 cm layers showed a sharp decrease in the first 3 to 4 years before beginning to fluctuate and showing an upward trend. During the growth period, soil salinity was generally higher at pre-sowing and in the late harvest period, and it decreased immediately after drip irrigation.

Nowadays, the estimation of θ through dielectric devices using the soil's apparent dielectric permittivity, ε_a, is the most widely used method. Kargas et al. [7] investigated the effect of high iron content on estimation of soil water content of two sandy loam soils, where ε_a measurements were obtained by two dielectric devices: the WET sensor, operating at a frequency of 20 MHz, and the ML2 sensor, operating at 100 MHz. The results showed that both sensors led to overestimation of ε_a. The WET sensor, operating at a lower frequency and being strongly affected by soil characteristics, showed the greatest overestimation. Compared to the Topp equation, the WET sensor measured a 2.3- to 2.8-fold higher value of εa. From the results, it was shown that the relationship of $\theta\text{-}\varepsilon_a^{0.5}$ remained linear, even in the case of soils with high iron content. Moreover, multi-point calibration is a good option where individual calibration is needed.

Paraskevopoulou et al. [8,11] examined the behavior of growth of four lavender species (*Lavandula angustifolia, L. dentata var. dentata and var. candicans, and L. stoechas*). These were established on an extensive green roof system used in urban agriculture under two different irrigation treatments [11], as well as in pots in the greenhouse using irrigation water of four different salinity levels [8]. In the first study, two levels of irrigation (high and low) within the available water range of an extensive green roof substrate were applied based on its hydraulic properties (i.e., water retention curve and hydraulic conductivity) [11]. The plant growth was reduced in the low irrigation treatment group. Among the various lavender species studied, *L. dentata var. candicans* showed the greatest growth, while *L. angustifolia* showed the least. This work highlights the need for further study of the effect of irrigation in relation to drought tolerance mechanisms, as well as both air and substrate temperatures, in extensive green roof systems.

In the second study [8], the pot growth of the lavender species irrigated with water containing 0, 25, 50, 100, and 200 mM of NaCl was investigated under greenhouse conditions. All lavender species showed signs of salinity stress, including chlorosis and followed by leaf and stem necrosis, at NaCl concentrations greater than 50 mM. *L. dentata var. dentata* showed the greatest plant growth, followed, in descending order, by *L. dentata var. candicans*, *L. stoechas,* and *L. angustifolia*. Despite greater growth of *L. dentata var. dentata*, the appearance of *L. dentata var. candicans* was relatively healthier. In areas with saline irrigation water, *L. dentata var. dentata* and *var. candicans* are proposed for the production of lavender nursery crops.

Overall, this special issue presents studies on soil water movement in irrigated agriculture, contributing to addressing the main challenges and limitations, and highlighting areas for further improvement and research.

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