A DECISION-MAKING SYSTEM FOR AGRICULTURAL WATER MANAGEMENT IN TREE CULTIVATIONS

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ABSTRACT

The aim of this work is the development of a decision-making system for an optimal agricultural water management for olive and citrus crops. This decision-making system combines a space-time simulation of an unsaturated flow with the minimum irrigation needs ensuring optimal plant growth. These approaches will be implemented in one of the most intensively cultivated and productive area of Crete, Greece. The study area is located in the northern part of Chania, Crete where olive and citrus are the main crops. Geoinformation, such as meteorological, land use, geology and tree cultivation data, was used for the creation of the above decision-making system. In addition, field measurements were performed to determine soil moisture, soil composition as well as leaf area index. Based on these data, the decision-making system provides a two-dimensional (2D) dynamic spatiotemporal imaging parameters which are directly related to the hydraulic characteristics of the soil. Subsequently, these parameters are used for the optimal scheduling of the irrigation needs for olive and citrus crops, ensuring crop yields and water resources savings.

Keywords: irrigation; Crete; tree cultivations, groundwater flow, simulation.

1. Introduction

In the last few decades there is an increasing interest in olive and citrus crops and their products worldwide. The reason for this interest is not only from the agronomical point of view which implies an economic profit but also is also related to environmental and human health aspects. Citrus trees are relatively sensitive to drought conditions while olive trees have remarkable tolerance to drought making this species as one of the most suitable for cultivation in arid and semiarid areas. The purpose of irrigation is to supply crops with the water necessary for normal plant growth especially during the drought sensitive crop growth stages. An interesting task for both cultivations is the study of reducing irrigation water supplies while at the same time ensuring their productivity. Deficit irrigation (DI) is a watering strategy using different types of irrigation application methods. The correct application of DI requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest (Fereres and Soriano, 2007). The water saved using this method can be used for other purposes or to irrigate extra units of land (Zhang and Oweis, 1999).

The knowledge of the characteristic soil-moisture curves is particularly important for understanding the flow in the unsaturated zone as a factor that can affect the vegetative growth and yield of horticultural crops. This knowledge is crucial for designing irrigation systems, maintaining soil moisture at desired levels for optimal agricultural productivity. This paper presents a modeling approach for assessing and simulating the unsaturated flow in the most productive olive and citrus growing region of Crete (Greece). The MIKE SHE model was employed in this study. The proposed modeling approach can be a useful decision support tool which can aid decision makers in the difficult task of managing water resources in agricultural application.

2. Study area

The study area is located in the North-Western part of Crete in Chania (Figure 1). The area is about 200 km^2, with an elevation ranging from zero to 750 m MSL. The main geological formations in the study area are classified based on their permeability in granular alluvial deposits of high to moderate permeability, miocene deposits of moderate to low permeability, granular non-alluvial deposits of low to very low permeability, and impermeable formations of low to very low permeability. The study area is the most important agricultural region of Chania, dominated by the cultivation of olive and citrus. These crops, especially the citrus trees, have particular water requirements mainly during summer. Therefore, optimal irrigation scheduling is important in order to maximise the uptake efficiencies of water (Alva *et al.,* 2006). For the simulation inputs, the time series data from eighteen soil moisture sampling points (S.M. 1-18) obtained at four different soil depths, were used (Figure 1).

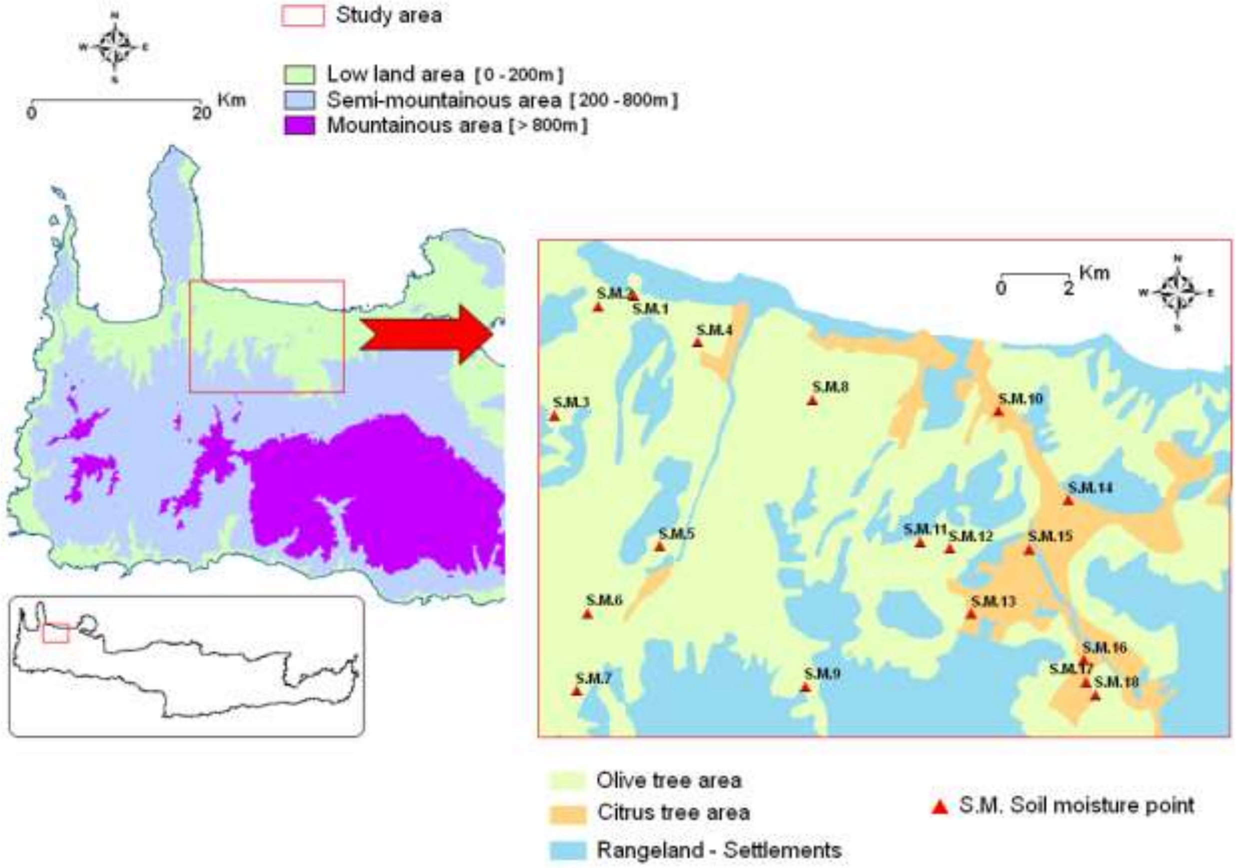

Figure 1: The island of Crete, the study area and the sampling points.

3. Methodology

MIKE SHE, developed by DHI Water & Environment, is an advanced, deterministic, fully-distributed and physically-based hydrological and water quality modeling system (Im *et al.,* 2009). The soil water movement module employed for this application consists of two main sub-modules: evapotranspiration (ET), and unsaturated zone (UZ). Detailed descriptions of the modeling procedures and of the mathematical formulation can be found in MIKE SHE user's manual (DHI, 2007). The inputs to the integrated hydrological model MIKE SHE were the model domain, the topography, the geology, the land use, the rainfall, the potential evapotranspiration, the leaf area index (LAI) and the root depth of the cultivations. All the required data was obtained from bibliography or/and field measurements.

In the MIKE SHE model the simulation of unsaturated flow was performed solving the Richards equation using the finite differences method. To solve the Richards equation two important hydraulic functions that characterize each soil profile are required (DHI 2007): a) the characteristic soil moisture retention curve vs. hydraulic head, and b) the curve of unsaturated hydraulic conductivity vs. hydraulic head. There are numerous empirical equations to determine the above mentioned hydraulic curves-parameters of the Richards equation; the empirical equations of Van Genuchten were applied in this work. In order to determine the parameters which are necessary for using Van Genuchten equations (θ_s, θ_r, *a, n*, K_s,*)*, it is necessary to know the soil texture based on soil mechanical analysis of sand, silt and clay. The soil texture was estimated using soil mechanical analysis-measurements that took place at the eighteen different locations of the soil moisture sampling points [(S.M. 1-18)].

Using the above mechanical analysis, the range of the hydraulic parameters can be can be determined from literature (Balland *et al.,* 2008). Based on the above range, the specific hydraulic values of the Van Genuchten equations were calculated during the calibration process. The calibration process was performed using the AUTOCAL analysis tool of MIKE SHE. AUTOCAL is a generic tool performing automatic calibration in a MIKE SHE environment. The automatic calibration process was performed based on the soil moisture data collected at eighteen different locations of the study area (S.M. 1 -18) and for four depths (0.1, 0.2, 0.3, and 0.4 m) (Figure 1) at each location. The model was calibrated for the period of October 1, 2014 to April 15, 2015, by matching the soil moisture content derived by the modelling approach with the soil moisture measurements at the eighteen different locations and four depths. During these time period no irrigation was considered in the study area, as they correspond to the wet season where irrigation needs are covered by rainfall.

4. Results

A very good correlation between field measurements and the simulation results was determined based on various statistical indices. These indices verify the good calibration process. In all cases, values of correlation coefficient (R), range from 0.85 to 0.97 which demonstrate clearly the good agreement between the field measurements and the simulation results. The MIKE SHE model can illustrate spatial-temporal distribution of soil moisture in relation to the soil depth at specific locations for the entire simulation period. For demonstration reasons, Figure 2A shows the two-dimensional chart of soil moisture in the unsaturated zone, at location S.M.13 (citrus tree area). The vertical axis shows the depth of the unsaturated zone, while the horizontal the period of simulation. The contour lines represent the soil moisture which ranges from 0.08 to 0.45 cm^3/cm^3. In October and November where rainfall is minimal, soil moisture exhibits low values in the upper layers of the unsaturated zone. However, during the period of December to April, soil moisture increases in the deeper layers, as a result of increased rainfall events. These 2D soil moisture results can also be represented in terms of soil moisture pressure (Figure 2B).

Thus, a method for selecting the right time to apply irrigation can be determined based on soil moisture pressure data. Specifically, according to bibliography the soil moisture pressure for olive and citrus trees should be maintained above -5 m and -100 m, respectively, at the depth of 30 cm for an optimal plant growth and yield (Michelakis *et al.,* 1996; Shirgure, 2013). Based on the above and taking into consideration the soil moisture pressure results of the MIKE SHE modelling system an appropriate irrigation programme for olive and citrus trees can be designed.

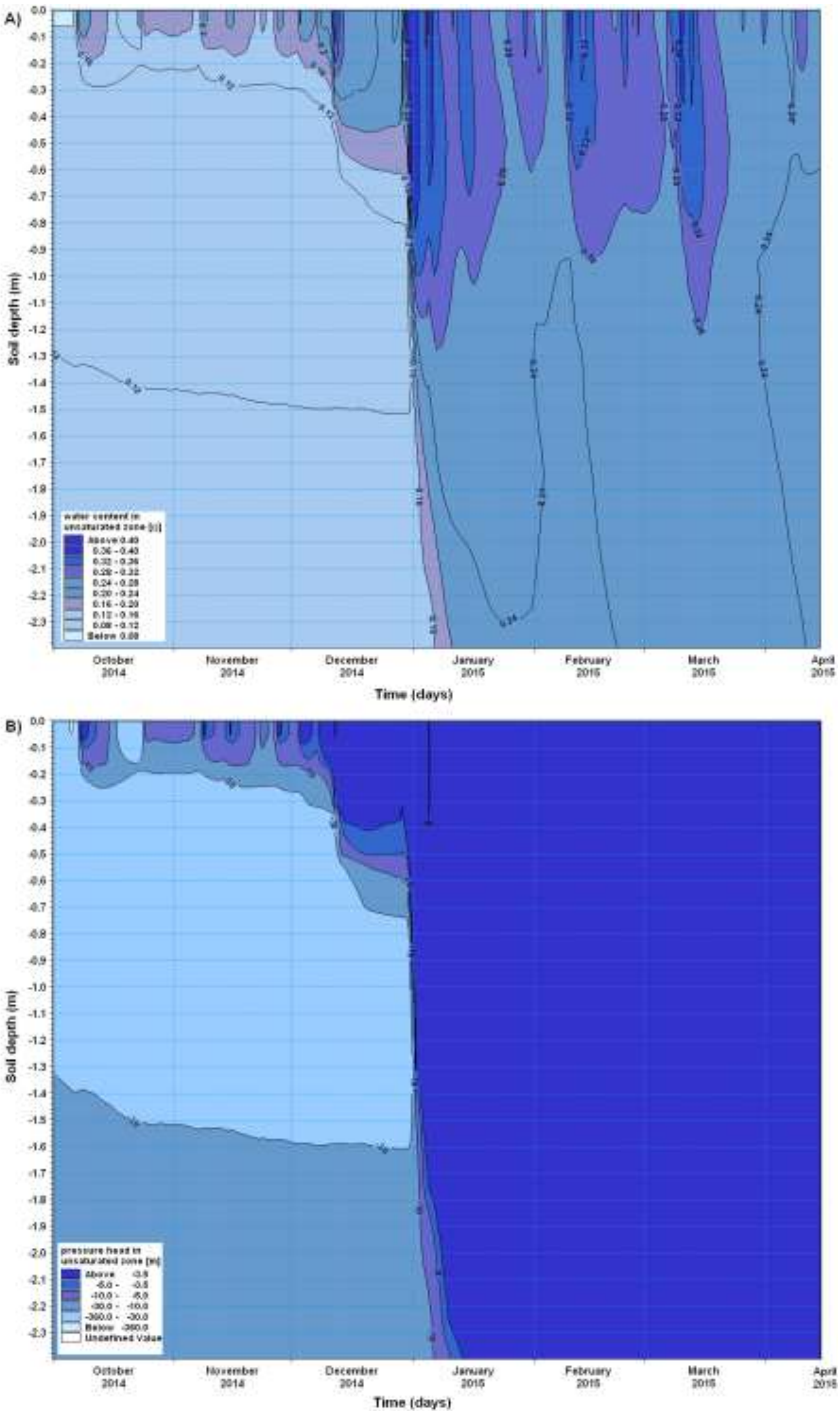

Figure 2: The simulation results of (A) soil moisture, and (B) soil moisture pressure with respect to simulation time at location S.M.13.

5. Conclusions

The determination of soil-water balance is important for the accurate estimation of the irrigation requirements for olive and citrus orchards which have particular needs for water, especially during summer. The proposed modeling approach provides a useful tool for organizing an effective irrigation based on the proper water management in the unsaturated zone. This modeling approach allows the continuous monitoring of soil moisture and head soil pressure level at every grid point of the simulation area. The soil pressure head was estimated by a successful calibration process of the unsaturated flow based on soil moisture time series data at different soil depths. Next, a proper irrigation schedule can be designed for the entire study areas based on the simulation results of the soil pressure head.

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