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Research Paper

Forecasting hourly evapotranspiration for triggering irrigation in nurseries

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Predicting water requirements for plants is crucial in constrained nurseries during periods of intense sunlight. The temporal variations of evapotranspiration, an irrigation indicator, are described using a time series model with a seasonal component, whose parameters are identified. The resulting hourly time-scale predictive model, which makes it possible to anticipate crop water requirements, was applied to two climatic zones in steady-state weather with good accuracy. As the proposed predictive model only requires storing previous data without a significant computational effort, it can be easily used in real time. We compared predictive and real-time irrigation triggering algorithms on two plots with different irrigation thresholds in a typical nursery, and showed that the predictive approach could avoid crop exposure to water stress. In order to validate our approach, both algorithms were implemented in real-time field experiments using a standard input–output terminal to trigger the automatic irrigation of two rose plots (*Rosa sinensis*). When water availability was unrestricted, irrigation took place earlier in the predictive case and thus maintained the substrate properly moistened more frequently. When a midday no-irrigation period was imposed as a constraint in order to simulate water-limited resources or hydraulic network overload, irrigation was triggered slightly earlier in the "predictive" plot, and water deficit peaks remained below irrigation thresholds more frequently than in the static threshold approach.

1. Introduction

Crop water requirements vary substantially during the growing season in nurseries depending on the interactions between crop canopy size and structure on the one hand, and weather conditions on the other hand. Understanding or acquiring information on crop water requirements is important to use irrigation water more efficiently. A nursery is composed of a set of plots in which crops at different growth stages have different water needs. Due to the low storage capacity of substrate containers, the high water requirements of crops during sunny periods and the rapid fluctuations of

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water contents, container irrigation requires very specific watering methods, with continuous dripping system being on the rise. Evaluating substrate water contents once a day is not sufficient. Moreover, given that the irrigation network can usually supply only a limited number of plots due to the limited capacity of its main line, irrigation control is complex for nursery workers. Since water availability is the most critical factor for plant survival and development, water requirement forecasts represent a valuable tool for irrigation management.

Beeson et al. (2004), point out that the water availability and its consumption by container nurseries will decline significantly in the coming decade. To successfully meet the challenges of reduced public water consumption by container nurseries, they suggest that industries implement effective irrigation management techniques and best management practices. Among the ways that these authors propose to improve irrigation efficiency, they suggest that further investigation into technology and procedures for ‘plant demand-based’ irrigation management where watering is applied only when needed and in the required amount is needed.

Irrigation management in nurseries at the short-term decision level can be considered in two main different ways, i.e. substrate or plant water status estimates with special sensors or models based on climatic parameters. Miranda, Yoder, Wilkerson, and Odhiamb (2005) developed a distributed irrigation control system for site-specific management with an autonomous controller that used soil water potential measurements to control the amount of water applied to each specific management area. Caceras, Casdesus, and Marfa (2007) designed and assessed a control tray adapted for automatic irrigation for container-grown ornamental plants and a tensiometric method. Grant, Davies, Longbottom, and Atkinson (2009) compared the water use and plant growth in two overhead irrigation systems scheduled by the substrate volumetric moisture and on plant evapotranspiration (ET). Lopez-Urrea, Martin de Santa Olalla, Fabeiro, and Moratalla (2006) showed that the FAO-56 Penman–Monteith equation for calculating hourly reference evapotranspiration values was more accurate than the ASCE Penman–Monteith method under semiarid weather conditions in Spain. Ben Asher, Bar Yosef, and Volinsky (2013) developed a remote controlled system that used the actual evapotranspiration as a boundary condition for instantaneous calculations of the soil water balance components based on the hydraulic properties of the soil. Davis and Dukes (2010) studied the capability of three brands of ET-based irrigation controllers to schedule irrigation in a typical residential landscape, compared to a theoretical soil water balance model. A daily soil water balance model was used to calculate the theoretical irrigation requirements and compare it with the actual amounts of water applied. They found that whatever the modality, less water than required was applied throughout the seasons. The ET-controllers were able to adjust to prevailing weather, unlike the conventional irrigation timers. The purpose of these studies mainly concerned the evaluation of current evapotranspiration. In other words, most evapotranspiration studies focus on estimations, but less on prediction. Controllers above based on available measured data are of standard types.

Using reference evapotranspiration ET_0 as an indicator for triggering irrigation can offer an advantage for nursery workers since mixed-farming irrigation control is hard to tackle. A few studies have dealt with evapotranspiration forecasting using time series analysis. Marino, Tracy, and Taghavi (1993) used time series modelling was investigated to forecast the monthly reference for crop evapotranspiration. Hess (1996) proposed a daily irrigation scheduling algorithm based on ET prediction. An ARIMA (AutoRegressive Integrated Moving Average) model was also used by Duce, Snyder, and Spano (2000) to forecast daily and hourly references for evapotranspiration. In the latter study, the analysis showed a wide scatter of calculated *versus* forecast values, particularly for hourly values.

The accurate forecasting of ET_0 in nurseries using climatic parameters could allow for the efficient management of plot valve opening. Despite the computational power of meteorological centres, the weather forecasts used to calculate ET_0 are only accurate on a regional scale; their performance decreases at the local scale. Such poor performance is due to the fact that current weather forecasting uses coarse elementary square meshes that are 10 km wide. The recent developments in supercomputers and observing systems, the results from most recent research in numerical prediction weather systems, make it possible in national weather services of a limited number of European countries, to achieve meshes between 4 km and 2.5 km wide (Seity et al., 2011).

In this paper, we are interested in a local ET_0 forecasting method that can be easily integrated into a real-time automaton connected to a local weather station. One of the benefits of standalone controllers is that they are not limited by the need for a full weather station and no weather forecast fees are claimed by the manufacturers.

Our approach constitutes an alternative to the non-predictive (or the static threshold) irrigation triggering used in commercial irrigation controllers. The objective was to derive a simple reference hourly evapotranspiration predictive model, to develop and test a predictive irrigation algorithm and to compare its irrigation triggering performance with the non-predictive algorithm. In the predictive regime, irrigations were triggered based on forecast ET_0 value whereas in the non-predictive figure, they were triggered based on ET_0 value calculated at the end of each measurements period.

The paper is organised as follows: the first part describes the method used to compute the reference hourly evapotranspiration (ET_0). The second part focuses on the model identification by using the time series analysis theory. A SARIMA (Seasonal AutoRegressive Integrated Moving Average) model with minimum variance, allowing hourly ET_0 forecasting during steady-state weather, is proposed. An application of the ET_0 predictive model to other climatic zones is presented in the third part. In the last part, the simulation results of irrigation triggering using the predictive approach and the non-predictive approach are compared, and finally irrigation triggering using the two approaches in nursery rose field experiments is presented.