Agricultural Water Management 208 (2018) 465–477

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Evaluation of an operational real-time irrigation scheduling scheme for drip irrigated citrus fields in Picassent, Spain

Dazhi Li[a,b,*], Harrie-Jan Hendricks Franssen[a,b], Xujun Han[a,b,c], Miguel Angel Jiménez-Bello[d], Fernando Martínez Alzamora[d], Harry Vereecken[a,b]

[a] Institute of Bio- and Geosciences (IBG-3): Agrosphere, Forschungszentrum Jülich GmbH, Leo-Brandt-Strasse, 52425 Jülich, Germany
[b] Centre for High-Performance Scientific Computing in Terrestrial Systems (HPSC-TerrSys), Geoverbund ABC/J, Leo-Brandt-Strasse, 52425 Jülich, Germany
[c] School of Geographical Science, Southwest University, Tiansheng Road 2 Beibei District, 400715 Chongqing, PR China
[d] Institute of Hydraulic and Environmental Engineering (IIAMA), Universitat Politècnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain

ARTICLE INFO

Keywords:
Irrigation scheduling
Data assimilation
Real-time control
Citrus trees
Land surface model
Stem water potential method

ABSTRACT

Irrigated agriculture is very important for securing food production for an increasing population over the next decades. Given scarcity of water resources, optimal irrigation management is needed to reduce water while realizing maximal crop productivity. The new method of integrating soil water content measurements and the Community Land Model (CLM) using sequential data assimilation (DA) is promising to improve the prediction of soil water status and efficiently design irrigation strategies. Soil water content measured by FDR (Frequency Domain Reflectometry) was assimilated into CLM by LETKF (Local Ensemble Transform Kalman Filter) to improve model predictions. Atmospheric input data from GFS (Global Forecast System) were used to force CLM in order to predict short-term soil water contents. The irrigation amount was then calculated on the basis of the difference between predicted and targeted soil water content over the root zone.

During the real-time irrigation campaigns in Picassent (Spain) in 2015 and 2016, there were 6 fields irrigated according the data assimilation-optimization approach (CLM-DA), 2 further fields according the FAO (Food and Agriculture Organization) water balance method and also 2 fields traditionally according the farmers preference. The required amount of irrigation water for each citrus field was applied by SCADA (supervisory control and data acquisition system). Compared with the traditionally irrigated fields by farmers, 24% less irrigation water was needed for the CLM-DA scheduled fields averaged over both years from July to September, while the FAO fields were irrigated with 22% less water. Stem water potential data and soil moisture recordings of the CLM-DA scheduled fields did not indicate significant water stress during the irrigation period. The CLM-DA scheduled fields received less irrigation water than traditionally irrigated fields, but the orange production was not significantly suppressed.

Overall, our results show that the CLM-DA method is attractive given its water saving potential and automated approach, ease of incorporation of on-line measurements and ensemble based predictions of soil moisture evolution.

1. Introduction

1.1. Water scarcity and irrigation scheduling

The world's population has exceeded 7 billion and will continue to increase with a high rate (https://en.wikipedia.org/wiki/World_population). To feed the increasing population, our agriculture must produce more food. Irrigated agriculture accounts for 40% of food production, and 70% of fresh water withdrawals are used by irrigation (Vereecken et al., 2009; Playán and Mateos, 2006). Irrigation is important for the food security of the world (McLaughlin and Kinzelbach, 2015). Given climate change and increased groundwater pollution, we are facing a global water crisis and stronger constraints on water resources (Vörösmarty et al., 2000; Iglesias and Garrote, 2015). Groundwater recharge in semi-arid areas is usually limited, resulting in unsustainable groundwater use for irrigation and groundwater depletion (Scanlon et al., 2012). Therefore, efficient water use by irrigation scheduling is needed to allocate irrigation water rationally.

Irrigation scheduling aims to minimize water use while maintaining the agricultural production (Evans et al., 1991). Scheduling efforts can

* Corresponding author at: Institute of Bio- and Geosciences (IBG-3): Agrosphere, Forschungszentrum Jülich GmbH, Leo-Brandt-Strasse, 52425 Jülich, Germany.
E-mail address: d.li@fz-juelich.de (D. Li).

https://doi.org/10.1016/j.agwat.2018.06.022
Received 31 December 2017; Received in revised form 15 June 2018; Accepted 19 June 2018
Available online 20 July 2018
0378-3774/

have a long-term focus or short-term focus, which includes real-time scheduling (Ticlavilca et al., 2013). With irrigation scheduling we decide when and how much to irrigate. When to irrigate is related to the sensitivity of crops to water stress, which determines the threshold when yield and quality reduction occur under water shortage. How much should be irrigated depends on the water deficit between the current and targeted water status (Evans et al., 1991). In order to make decisions regarding irrigation scheduling, the water stress condition needs to be known. Depending on the type of water stress information available, the irrigation scheduling approaches can be divided into: soil moisture measurements based, evapotranspiration (ET) based and plant water stress based (Evans et al., 1991; Jones, 2004; Pardossi and Incrocci, 2011).

Many devices can give information on soil moisture status including dielectric sensors using Time Domain Transmissivity (TDT) and Frequency Domain Reflectometry (FDR) (Peters et al., 2013), tensiometers (Smajstrla and Locascio, 1996), capacitance probes (Fares and Alva, 2000), neutron probes and cosmic-ray probes (Zreda et al., 2012). The combination of soil moisture information from sensors and predictions by a given model allows to calculate the future water deficit (Blonquist et al., 2006):

The ET based irrigation scheduling calculates the irrigated water amount by the difference between daily actual ET and precipitation (Davis and Dukes, 2010). Evapotranspiration is defined as the sum of evaporation from the soil surface and transpiration from the crop (Allen et al., 1998).

Water stress information from crops can be obtained by different indicators like sap flow (Fernández et al., 2001), stem water potential (Choné et al., 2001; Fernández and Cuevas, 2010), trunk diameter fluctuation (Moriana et al., 2010), leaf stomata pressure, canopy temperature (Clawson and Blad, 1982) and crop water stress index (CWSI) (Moran et al., 1994).

1.2. Drip irrigation scheduling for citrus

Compared with all the major types of surface irrigation (furrow, flood, or large scale sprinkler irrigation), drip irrigation is seen as the most water-efficient and precise method (Provenzano, 2007). Lots of irrigation scheduling methods were tested on drip irrigated fields on the base of measuring soil or plant water status and evapotranspiration (Dabach et al., 2013). For the drip irrigation of citrus trees, there are plenty of different indicators of plant water stress like stem water potential and soil capacitance, and also several ways to determine evapotranspiration like the FAO method, lysimeter and eddy covariance (EC) method (Jiménez-Bello et al., 2015).

Stem water potential (Sdoodee and Somjun, 2008) and daily trunk shrinkage (Velez et al., 2007) were used to schedule irrigation for citrus orchards world widely. Also the water balance method for drip irrigation scheduling is popular. For example, Sammis et al. (2012) used a two-dimensional soil water balance model for drip irrigation scheduling. The traditional way of drip irrigation scheduling was often based on a simple water production function or water balance model, while ignoring the complex interaction between soil and vegetation (Barrett and Skogerboe, 1980). A new development is the use of complex models and weather data, combined with mathematical optimization methods (Shang and Mao, 2006). Advanced modeling and programing technology offers a new possibility to calculate soil water status. Various controlling and decision support methods were introduced into irrigation scheduling. Simulated annealing (Brown et al., 2010), genetic algorithms (Irmak and Kamble, 2009; Wardlaw and Bhaktikul, 2004) and computational neural networks (CNN) (Pulido-Calvo and Gutiérrez-Estrada, 2009) were used to support decisions concerning the irrigated water amount. To predict short or medium scale soil water balance conditions, weather forecast data are also important (Lorite et al., 2015).

In this work, the Community Land Model (CLM) (Oleson et al., 2010) is used to estimate soil and crop water states. Data assimilation (DA) combines direct and/or indirect measurements and dynamic models to get optimal estimates of model states (Reichle, 2008). Han et al. (2016) already illustrated the potential of sequential DA to improve irrigation scheduling with CLM model predictions. In the past already hydrological models like HYDRUS (Autovino et al., 2018) and simpler water balance models (Rallo et al., 2017) were used for irrigation scheduling, but not a land surface model that couples the water and energy cycles. The use of data assimilation in this context is also a novel contribution for the irrigation scheduling of citrus or other fruit trees.

The main objective of this paper is to provide a new approach for irrigation scheduling by introducing the combination of data assimilation and land surface modeling, with the possibility of real-time on-line control and the possibility to ingest different types of measurement data. The CLM-DA method combines model predictions by a land surface model, weather prediction and soil moisture data measured by capacitance probes.

We illustrate our approach for the near real-time irrigation scheduling of citrus trees near Picassent, Valencia (Spain). During the irrigation campaign for the Picassent site (near Valencia, Spain) from July to October in 2015 and June to October in 2016, three different irrigation scheduling methods were tested for 10 citrus fields, including the CLM-DA method proposed in this paper, the FAO water balance model and a traditional method based on farmer's experience. The CLM-DA method combines model predictions by a land surface model, weather prediction and soil moisture data measured by capacitance probes. These information sources are optimally combined using sequential data assimilation, to predict drought stress for the next days and schedule irrigation accordingly. The applied irrigation amounts were measured by a water meter, and then divided by the irrigation area to get the water depth. Stem water potential and citrus production indicating the possible water stress were also measured.

2. Materials and methods

2.1. Research site and experimental set-up

The research site is located near Picassent in Spain (39.38°N, 0.47°E), in a semi-arid region. Precipitation is concentrated in spring, autumn and winter, and the yearly average precipitation amount is 453 mm, with an annual average daily maximum temperature of 22.3 °C and an annual average daily minimum temperature of 13.4 °C (https://en.wikipedia.org/wiki/Valencia#Climate). The crop growing at the test site is citrus, with major management procedures like fertilization and weeding carried out by the orchard owners. Although the citrus varieties differ between the fields, there are no significant differences in crop management, fertilization and tree ages. Information on field-specific tree ages were lacking, but all the trees were mature (older than 15 years) and in full-production stage. As precipitation during the main growing period of citrus in summer is rare, the water demand of the citrus trees almost entirely depends on irrigation. Drip irrigation is being used in these citrus tree fields, with two pipelines and 8 ~ 10 emitters for each tree. Detailed information about the types of citrus plant, spacing, and vegetative growth character can be found in Table 1.

Within the area of Picassent, the meteorology observatory of IVIA (Instituto Valenciano de Investigaciones Agrarias) provides meteorological data (http://riegos.ivia.es/). Twelve FDR probes were installed in the context of the EU-project AGADAPT since 2013, spreading over the irrigation plots (see Fig. 1), measuring soil water content at four depths (10 cm, 30 cm, 50 cm, and 70 cm). During June and July 2015, 12 more FDR probes were installed in the field to enhance the observation density. The FDR probes were installed close to a drip emitter and a representative tree of average size in the orchard. The FDR soil water content measurements (10 cm and 30 cm) in the irrigated area