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A Fuzzy Decision Support System for irrigation and water conservation in agriculture

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ABSTRACT

Since agriculture is the major water consumer, web services have been developed to provide the farmers with considerate irrigation suggestions. This study improves an existing irrigation web service, based on the IRRINET model, by describing a protocol for the field implementation of a fully automated irrigation system. We demonstrate a Fuzzy Decision Support System to improve the irrigation, given the information on the crop and site characteristics. It combines a predictive model of soil moisture and an inference system computing the most appropriate irrigation action to keep this above a prescribed "safe" level. Three crops were used for testing the system: corn, kiwi, and potato. This Fuzzy Decision Support System (FDSS) favourably compared with an existing agricultural model and data-base (IRRINET). The sensitivity of the FDSS was tested with random rainfall and also in this extended case the water saving was confirmed.

1. Introduction

Water conservation in agriculture is becoming an increasingly important issue in the Mediterranean countries, in view of the current changes both in climate and in the agricultural practices. There is a great need for irrigation system modernization to cope with the increasing value and decreasing availability of this commodity. Decision Support Systems (DSS) are now recognized as a fundamental tool in environmental management and planning. Since Guariso et al. (1985) first introduced DSS many studies have reported advances in their use for the management of water resource. McIntosh et al. (2011) reviewed the experience of a global group of environmental decision support systems (EDSS) developers, emphasizing the key challenges and structures in EDSS development. The integration between large-scale models and socio-economic and environmental issues in the EDSS context was considered by van Delden et al. (2011) and by Lehmann and Finger (2014), who developed a bio-economic model to optimize management decisions in potato production in the Broye catchment (Switzerland). The importance of involving stakeholders in the irrigation management was considered in MONIDRI (Fais et al., 2004) advocating participatory planning, whereas the relevance of farmers as valuable sources of local knowledge was underlined by David et al. (2012). Integrated DSS have been developed for the Mediterranean countries (IRRIGATE, Merot and Bergez, 2010), southern Italy (Portoghese et al., 2013), and north-west China (Ge et al., 2013). State-of-the-art information technology tools were adopted in dealing with the smart management of the water resource: the multi-agent approach for spatial modelling was used by van Oel et al. (2010), whereas the fuzzy approach in the definition of a multi-criteria decision framework was adopted by Chen and Paydar (2012). On the control side, an application of model predictive control has been reported (McCarthy et al., 2014), requiring very detailed information on weather, soil and crop to calibrate a complex crop model.

The reference model used in our study is IRRINET (Rossi et al., 2004; Mannini et al., 2013) that assists farmers in their irrigation scheduling. The web service engineered around the IRRINET model provides the farmers with an irrigation suggestion based on the kind of crop, soil characteristics, plot location, and meteorological data (temperature, precipitation, etc.). The advice, issued on a daily basis, suggests the amount of irrigation to be applied to the plot in order to keep the soil water content in a safe band between the field capacity and the wilting point, providing just the right amount of water for full crop development. The software assumes that the previous advice has been fully implemented and therefore it operates on an open-loop basis, i.e. without incorporating any information on whether any irrigation (suggested or otherwise) was actually applied.

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List of symbols and abbreviations

Symbol

a,b,d	Fuzzy model consequent parameters
c	Number of clusters
ET_c	Crop Evapotranspiration (mm/d)
Irr	Irrigation (mm)
I	Irrigation singleton (mm)
m	Fuzzy exponent
N	Number of experimental observations
P	Vector of consequent model parameters
RI	Sum of daily rain and irrigation (mm)
T_{sum}	Growing Degree Days (GDD) (°C d)
U	Soil moisture (mm)
U_{low}	Soil moisture lower threshold (mm)
U_{high}	Soil moisture upper threshold (mm)
v_i	Centroid of i-th cluster
ΔT	Daily variation of T_{sum} (°C d)
μ_i	Degree of activation

Abbreviations

mfs	Membership functions
CER	Canale Emiliano Romagnolo
DSS	Decision Support System
EDSS	Environmental Decision Support Systems
FCM	Fuzzy C-Means (Bezdek, 1981)
FDSS	Fuzzy Decision Support System
IPI	Irrigation Performance Index
N_{mfs}	Number of membership functions
PP	Phenophase
RF	Rain Forecast
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
VAF	Variance Accounted For

The IRRINET software is managed by CER (Canale Emiliano Romagnolo), a water consortium in the Emilia-Romagna region, Northern Italy, and the irrigation advices it provides are based on a very complex mathematical model developed by CER itself (Rossi et al., 2004; Mannini et al., 2013) that describes the water balance in the soil based on the Penman–Monteith equation. This model estimates the daily water needs for a given crop based on past irrigations, soil characterization, and current meteorological conditions. The IRRINET model is context-dependent and requires real-time data for computing the next irrigation, therefore it cannot be used outside its native environment nor can it be operated in an off-line mode to generate alternate irrigation strategies. In the present context we use this model as a tested data source, which together with the field data (precipitation, temperature, etc.), provides the necessary benchmark for DSS calibration and testing.

1.1. The IRRISAVE project

Recently a joint venture by A.T.I. srl and the Department of Information Engineering of the University of Florence (DINFO) was set-up to develop a prototype irrigation system, called IRRISAVE, conceived to overcome the present limitations of IRRINET:

- The implementation of the advice is left to the goodwill of the farmer, since no automatic actuation is provided;
- Each advice assumes that the previous one was implemented. In the medium to long range this may lead to a considerable divergence between the actual and expected crop condition if some suggestions were not put in practice;
- The advice is based on the current meteorological conditions, disregarding micro-scale climate or any short range rain forecast.

To mend the above shortcomings, the IRRISAVE irrigation system should provide a fully automated system of which the soil moisture model and the irrigation decision maker form the software core.

Fig. 1 illustrates the development stages of the IRRISAVE project, the first two of which are described in this paper. In Step 1 an independent soil moisture model is calibrated with the IRRINET database and its internal model. In Step 2 a set of irrigation rules is designed to automate the irrigation suggestions and assess the relative water saving by comparison with the IRRINET advice. In Step 3, yet to be implemented, the FDSS will be deployed on the field, closing the loop from the irrigation advice back to the FDSS. The algorithmic parts of the project described here were developed in the Matlab platform, using the Fuzzy Toolbox for developing the inference system producing the irrigation advice.

2. Structure of the decision support system

The inner structure of the DSS of Fig. 1 is detailed in Fig. 2. It is composed of three main parts:

- *The predictive soil moisture model*, calibrated with data produced by the IRRINET model using the same inputs drawn from its agro-meteorological database;
- *The irrigation inference system*, consisting of a fuzzy inference system to decide the timing and amount of irrigation on the basis of the crop phenophase, previous irrigations, and the prescribed soil moisture thresholds;
- *The irrigation performance index* (IPI), consisting of the sum of the past irrigations

$$\mathrm{IPI} = \sum_k \mathrm{Irr}(k), \tag{1}$$

to which additional energy costs may be added to take into account the pumping overhead costs. This refinement can only be added after the kind of irrigation (sprinkler, ridge and furrow, etc.) has been specified as each one has its own peculiarity, efficiencies and additional operating costs.

In the sequel each module is described in details and the performance of the FDSS is compared against IRRINET in terms of consistency of the advice and water savings. The possibility that the computed advice may impair crop productivity by providing a sub-optimal irrigation is ruled out by the fact that IRRISAVE adopts the same “safe” soil moisture thresholds that were tested by IRRINET in many years of successful farming practice (Mannini et al., 2013).

2.1. Analysis of available crop data

The IRRISAVE soil moisture model was calibrated and validated using the large IRRINET proprietary database including both vegetable and fruit crops. The database consists of a very large