SITE SPECIFIC AGRICULTURAL WATER MANAGEMENT WITH THE USE OF AN IRRIGATION WATER ADVISORY SOFTWARE

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ABSTRACT

Climate change enforces water scarcity and degradation of available water resources with a great impact on water resources management in agriculture. Water shortage conditions present difficulties in decision making and planning for water distribution and has already been upgraded to a great socio-economical and political issue, due to the high competition among different consumers such as agriculture, energy production and domestic use. To this purpose, this study introduces a user – friendly software developed in the Soil Science Institute (SSI) of Thessaloniki-Greece (Hellenic Agricultural Organization – DEMETER) with the objective to empower water management through irrigation advice.

Keywords: water management, irrigation advisory software, irrigation water amount, irrigation interval, irrigation duration

1. Introduction

Climate change affects the quantitative and qualitative status of water resources by altering hydrological cycles and systems which, in turn, affect variables including the intensity and frequency of floods and droughts, water availability, water demand and water quality. Therefore, water management is becoming increasingly difficult because the supply and demand for water resources will be substantially affected by climate change. Note that almost 80% of the available water is consumed by agriculture, and is characterized by insufficient management plans and low application efficiency. The basic problems in water resources management are the following:

- Insufficient temporal and quantitative determination of crop water needs that lead to over or under supply of irrigation water and limit the potential crop yield (Bohnert and Bressan, 2001).
- Intensification of agriculture and expansion of irrigated agricultural land without respective increase of water reservoirs (Caviglia *et al*., 2004). According to FAO (2002), 40% of the global yield production originates from irrigated agriculture which covers the 17% of the total agricultural land. Irrigated agricultural land was doubled in the period 1900-1950 and continues to increase in a constant rate.
- Low irrigation water efficiency. High water losses have been observed especially in open canal networks due to evaporation and non satisfactory maintenance and operation and their efficiency ranges between 30-80% (Litskas *et al*., 2010; 2014).
- Insufficient exploitation of drainage and waste waters for irrigation purposes (Panoras *et al*., 2000; Rahil and Antonopoulos, 2007).
- Water shortage exploitation for energy production due to increase in irrigation water demand.

Furthermore, under the EU Water Framework Directive (2000) many EU countries are reforming their water pricing and financing policies towards full cost recovery, including the pricing of water for agriculture. Definitions and methodologies to estimate irrigation water costs and cost recovery rates have been detailed by the European Commission Wateco Guidelines (Garrido and Calatrava, 2010). Also, the new CAP 2014-2020 focuses on the sustainable soil and water resources management and further encourages water pricing. Therefore, the challenge is to provide and support an enabling environment that contributes to more efficient, cost effective and equitable water resources management.

The objective of the proposed project is to empower water management at field scale, through the development of an innovative user – friendly software that provides irrigation advice according to the soil and crop characteristics and regional meteorological conditions.

2. Materials and methods

During the last ten years, SSI performs annually over 3000 agricultural soil analyses for more than 1500 farmers and ten major Greek agricultural cooperatives, providing also fertilization guidance with the use of advisory software. The software calculates the macronutrients and micronutrients fertilizer doses, for almost 50 crops grown under Mediterranean conditions. Furthermore it takes into account the physical and chemical properties in the field parcels (soil texture, pH, organic matter) and the determined concentration at the beginning of the season – soil analysis results - and calculates the recommendation fertilizer rates, the critical time and the manner of application (Papadopoulos *et al*., 2014b).

The interest and acceptance shown by the farmers for the fertilization guidance service have been extremely positive (Papadopoulos *et al*., 2014a), motivating SSI to upgrade the existing software to provide both fertilization and irrigation advice. The presented irrigation software takes into account simple soil properties like soil texture and organic matter of the field parcels, crop characteristics, the mean regional meteorological data and irrigation method information and yields the irrigation water amount, the irrigation interval and duration for every month of the growing season, for the selected crop.

The irrigation software is developed in programming language FORTRAN, in the form of executable software for any operating personal computer system. It employs user friendly windows environment where the user selects the region, the crop and the irrigation system, provides soil texture and organic matter (soil analysis results) and receives irrigation advice for the growing period.

2.1. Irrigation Scheduling

In the software, irrigation advice is based on irrigation scheduling (Heermann *et al*., 1990; Martin *et al*., 1990) according to mean regional meteorological conditions. The daily amount of the stored soil water is evaluated by the simple soil water balance equation (Georgiou and Papamichail, 2008; Georgiou *et al*., 2010) in the form:

$$SM_i = SM_{i-1} + (ET - P_e - IR)_i \qquad \text{where } D_{LAM} \leq D_i \leq D_{FC} \tag{1}$$

where SM_i is the soil water depth at day i, SM_{i-1} is the soil water depth the previous day (i-1), IR_i is the irrigation water, P_{ei} is the rainfall, ET_i is the crop evapotranspiration, D_{LAM} is the stored water at the lower available moisture limit and D_{FC} is the stored water at field capacity level (all units in mm). To meet crop water demands, SM_i should always be greater than D_{LAM}, otherwise when SM_i reaches D_{LAM}, the software proposes an irrigation with a water amount equal to the useful moisture, which is computed by the equation:

$$USM_i = (D_{FC} - D_{LAM})RD_i = \left[D_{FC} - F\left(D_{FC} - D_{pwp}\right)\right]RD_i \tag{2}$$

where USM_i is the useful moisture – irrigation water amount, D_{pwp} is the stored water at the permanent wilting point moisture level, RD_i is the root depth at day i when the irrigation is applied (all units in mm) and F is the soil water depletion fraction. After the irrigation application, a new round of calculations is beginning until the next irrigation, forming by this way the proposed irrigation schedule. Thus, the software yields irrigation amount results for every month of the growing period with a mean irrigation interval.

2.2. Specific soil moisture evaluation

In order to calculate USM_i, the volumetric moisture at field capacity, θ_{FC}, and permanent wilting point, θ_{pwp}, are defined by the soil water retention curve model of van Genuchten (1980):

$$\theta = \theta_r + (\theta_s - \theta_r)\left[1 + (a|h|)^n\right]^{-m} \quad (3)$$

where θ_r (cm^3cm^{-3}) is the residual moisture, θ_s (cm^3cm^{-3}) is the moisture at saturation, h (cm) is soil water pressure head, a (cm^{-1}) and n are empirical curve shape parameters. These parameters can be directly evaluated by fitting to pressure – moisture data in undisturbed soil samples or indirectly with the use of regression models (pedotransfer functions, PTFs) expressed as function of other soil parameters like particle size distribution, organic matter and bulk density (Aschonitis and Antonopoulos, 2013). The pedotransfer functions used for this purpose were proposed by Vereecken *et al*. (1990):

$$\theta_s = 0.838 - 0.283\rho_b + 0.0013(\%clay) \qquad r^2 = 0.849 \quad (4)$$

$$\theta_r = 0.015 + 0.005(\%clay) + 0.014(\%OC) \qquad r^2 = 0.702 \quad (5)$$

$$\ln(\alpha) = -2.486 + 0.025(\%sand) - 0.351(\%OC) - 2.617\rho_b - 0.023(\%clay) \qquad r^2 = 0.621 \quad (6)$$

$$\ln(n) = 0.053 - 0.009(\%sand) - 0.013(\%clay) + 0.00015(\%sand)^2 \qquad r^2 = 0.556 \quad (7)$$

where ρ_b (gcm^{-3}) is the soil bulk density, (%OC) is the percentage of the organic carbon, (%silt), (%clay) and (%sand) are the percentages of silt, clay and sand in the soil, respectively. Soil bulk density is also defined by the pedotransfer function of Manrique and Jones (1991) from soil organic carbon, as follows:

$$\rho_b = 1.510 - 0.113(\%OC) \qquad r^2 = 0.412 \quad (8)$$

The user of the irrigation software provides the %sand, %silt, %clay and %OC obtained from the soil analysis performed by the SSI for the soil-specific evaluation of θ_{FC} (at h_{FC} = -100 cm or -330 cm or -500 cm according to soil texture) and θ_{pwp} (at h_{pwp} = -15000 cm).

2.3. Crop Characteristics

The irrigation software contains extensive crop data bases for 37 different crops (8 field crops, 15 tree crops and 14 horticultural crops). Specifically, it contains the crop coefficients, crop growth stages and the soil water depletion fraction for each crop (Allen *et al*., 1998; Papazafiriou, 1996). Crop coefficients, K_c, are used to calculate daily crop ET from the reference ET (Allen *et al*., 1998). The evolution of root depth is described by the logistic function during the growth period as follows:

$$RD_i = RD_{max}\left\{1 + \alpha \cdot exp[-\beta \cdot (i - i_{max})]\right\}^{-1} \quad (9)$$

where RD_i is the root depth at day i, RD_{max} is the maximum root depth at day i_{max}, a and b are fitting parameters to root depth data. For each crop, RD_{max}, i_{max}, a and b are provided in databases, assuming that the initial root depth is 10 mm and RD_{max} (Allen *et al*., 1998; Papazafiriou, 1996) is reached at the one third of the growing period. The root depth of perennial crops (alfalfa and tree crops) after the installation year is assumed constant and given also in databases.

2.4. Irrigation System

In Greece, border, drip and sprinkler irrigation systems are mainly used by farmers in irrigation practice (Karamanos *et al*., 2005) and are considered in this software. In the case of border irrigation, the duration is calculated by the following equation:

$$T_i = 60 \cdot (d_n \cdot W \cdot L) \cdot Q_U^{-1} \quad (10)$$

where T_i is irrigation duration (min), L is the length of the furrow (m), W is the width of the furrow (m), Q_u is the water flow (lh^{-1}) and d_n is the irrigation amount (mm). In the case of drip irrigation, where water movement is three dimensional, it is assumed that due to symmetry, water flows solely from one emitter. In this case the irrigation duration is also calculated by Eq. (10) where Q_u is the flow rate of the emitter (lh^{-1}), L is the space between emitters (m) and W is the space between drip lines (m). The information concerning border and drip irrigation is provided by the farmer and involves the parameters W, L and Q_u. In sprinkler irrigation the software provides only the irrigation amount because the determination of irrigation duration requires specific technical parameter knowledge on behalf of the farmer, which in most cases is difficult to obtain. However, by receiving the necessary water amount, the farmer can control irrigation, as most sprinklers have adjusted hydrometers.

2.5. Meteorological Data

The irrigation software contains a vast number of meteorological data for 5900 Greek regions (cities and villages). The database comprises of cumulative monthly reference ET and rainfall. Reference ET is calculated by the FAO-56 Penman-Monteith (Allen *et al*., 1998) equation, from mean monthly meteorological data values of the period 1950-2000. Rainfall values are the mean of the same period. The values were provided by the works of Demertzi *et al*. (2014) and Aschonitis *et al*. (2015). When the user selects a region in the software, the meteorological data are loaded and monthly values of ET and rainfall are distributed equally on a daily basis during the months of the growing period.

3. Results

3.1. Example 1. Corn – Furrow Irrigation

A farmer receiving irrigation advice for corn under border irrigation must provide to the software user essential information regarding the region and the irrigation system (furrow length and width and flow rate). The farmer can also define the sowing date. Provided information is that sowing date is on 10^{th} of April, the region is N. Mesimbria (Thessaloniki Prefecture), the flow rate is 3600 lh^{-1}, the furrow length is L=250 m and width is W =0.80 m. From the databases, information on corn crop is loaded, concerning crop growth stages of 25/40/60/25 days, corn K_c is 0.3, 1.15 and 0.35, F=0.55, RD_{max}=750 mm, α and β are equal to 0.0002 and 0.2620, respectively. The user enters soil analysis data from the farmers field parcel which are sand%=16%, silt%=51%, clay%=33% and organic matter is 1.2%. The software suggests the application of 427 mm of water distributed by 142, 214 and 71 mm on June, July and August, respectively with mean irrigation intervals of 16 days and 237 minutes per irrigation, in order to provide the necessary amount of water.

3.2. Example 2. Alfalfa – Sprinkler Irrigation

A farmer receiving irrigation advice for alfalfa irrigated with sprinkler irrigation must provide essential information regarding the region and the age of the crop. Provided information is that sowing date is on the 20^{th} of March (crop installation year) and the region is N. Mesimbria (Thessaloniki Prefecture). Loaded information from the databases for alfalfa considers four cuts per year and crop growth stages are 10/30/25/10 days for the first cut and 5/10/10/5 days for the next three cuts. Alfalfa K_c is 0.4, 1.20 και 1.15 regardless of the number of the cut, F=0.55, RD_{max}=1000 mm, α and β are equal to 0.0001 and 0.2740, respectively. Soil analysis data entered as input parameters are sand%=16%, silt%=51%, clay%=33% and organic matter is 1.2%. In the case of alfalfa, the software suggests the application of 475 mm of water during the growing season, of which 91, 182, 91 and 91 will be applied on May, June, July and August, respectively.

3.3. Example 3. Apple Orchard – Drip Irrigation

A farmer receiving irrigation advice for an apple orchard under drip irrigation must provide essential information concerning the region, the age of the orchard, the flow rate of the emitters, space between emitters and space between drip lines. Provided information is that the region is Velventos (Kozani Perfecture) and that the orchard if a four years-old palmet plantation. From the database for apples, the software loads the crop growth stages which coincide with the days of the months from May to September, K_c is 0.60, 0.85, 1.00, 0.85 and 0.80 for each month (Papazafiriou, 1996), F=0.50, RD_{max}=500 mm which is assumed constant in the software after the installation year for perennial crops. Emitters flow rate is 8 lh^{-1}, spacing between emitters is L=1.5 m, distance between drip lines is W=3.5 m – both coinciding with the palmet dimensions. Input data provided by the user are results from the soil analysis sand%=16%, silt%=51%, clay%=33%

and organic matter is 1.2%. According to the results of the software 73, 147, 110 and 37 mm of water (a total of 367 mm) should be applied, with irrigation intervals of 12, 9, 11 and 19 days, on June, July, August and September, respectively. The irrigation duration is calculated at 443 minutes per irrigation, in order to provide the necessary amount of water.

4. Conclusions

The increasing worldwide shortages of water and costs of irrigation are leading to an emphasis on developing methods for irrigation planning that minimizes water use. The Soil Science Institute (SSI) of Thessaloniki-Greece has developed valuable tools in order to facilitate the management of the agricultural land in both fertilization and irrigation decision making. In this study the irrigation software is presented. With the use of the software, a farmer can receive site specific irrigation advice through a common soil analysis, by providing only limited irrigation system information. The software yields the monthly crop water requirements, in terms of water amount, irrigation interval and duration, according to the mean regional meteorological conditions. The software can further be expanded to provide irrigation advice based on real time regional meteorological data.

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