Decision Support for Optimised Irrigation Scheduling

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Abstract

> The system, developed under the FLOW-AID (an FP6 project), is a farm level water management system of special value in situations where the water availability and quality is limited. This market-ready precision irrigation management system features new models, hardware and software. The hardware platform delivers a maintenance-free low cost dielectric tensiometer and several low-end irrigation or fertigation controllers for serving different situations. The software includes a complete, web based, Decision Support System (DSS) that consists of an expert planner for farm zoning (MOPECO) and a universal irrigation scheduler, based on crop-water stress models (UNIPI) and water and nutrient uptake calculations. The system, designed also to service greenhouse fertigation and hydroponics, is scalable from one to many zones. It consists of 1) a data gathering tool which uploads agronomic data, from monitored crops around the world, to a central web Data Base (DB), and 2) a web based Decision Support System (DSS). The DSS processes intelligently the data of the crop using Crop Response Models, Nutrient Uptake Models and Water Uptake Models. The central system returns over Internet to the low-end controller a command file containing water scheduling and nutrient supply guidelines.

INTRODUCTION

Since crop mineral uptake models allowing a better adjustment of the nutrient solution are available, a decision support system (DSS) based on these nutrient uptake models can be developed. This system provides a tool for better management of irrigation systems with the aim to save water and nutrients and to reduce environmental impact (Sigrimis et al., 2001; Ferentinos et al., 2003; Anastasiou et al., 2005). The objective of the DSS is to develop a context sensitive strategy for managing irrigation and nutrient supply of closed or open irrigation systems with constraints on the quantity and quality of water supply. The economical (i.e. quality and quantity of crop yield) and the ecological (i.e. the contamination of water table, nature conservation) factors affecting the strategic decisions are also considered.

This paper elaborates on water and nutrient uptake models, open and closed hydroponic systems and technologies to achieve instant matching of supply to needs. Under saline conditions (Savvas et al., 2008; Pardossi et al., 2008) it is critical to know the characteristics of yield response to salinity of the particular crop of interest. Under such conditions it is important to know "how to" manage the water supplies and fertilizer injection "the best way possible", in order to minimise water and fertilizer consumption while respecting the environment. The Hortimed project (www.hortimed.org) has elaborated on finding "the best way possible" of managing open or closed irrigation systems (Stanghellini et al., 2005). These methods are now enhanced in FLOW-AID including "deficit" irrigation experiments for further water savings and advanced technologies (wireless sensor networks for climatic data collection, web Data Base and

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DSS tools) to assist growers - the "how to"- and expands to service both protected and open field applications. Within the DSS concept the "smart irrigation sensor" approach is also discussed.

MATERIALS AND METHODS

Nutrient Uptake and Salinity Buildup

The transport of ions (Fig. 1) from C1 concentration [root-solution] to C2 [stem-flow] is accomplished either through root energetic transport processes or through osmotic phenomena developed between leaves and root solution. Numerous biotic processes and environmental conditions drive the nutrient uptake and will exhibit sufficient predictability only under normal plant living conditions. In creating an uptake model Ux we assume plant behaves normally, as under favourable production conditions and far from extremes or any stress condition. Eq. 4 was adopted to express the influence of dominant environmental factors (Yu et al., 2001, Savvas, 2002) while plant-ion specific dyadic uptake behaviour is expressed by the normal operating point ($k_{x,0}$, C_0, EC_0, E_0, NE_0, R_0). The generalizing term $\eta_{x,t}$ is included to modulate the environmental effect for specific conditions (crop stage, health status, root temperature, stress), which under normal operating conditions is set to unity. The value of this term $\eta_{x,t}$ will be the return from expert mode routines when such knowledge becomes available from research or experience.

Model Fitting
Going from Time Integrated Variables to instant rate or time_independent variables

The fact is that Concentration of uptake ion(x), $C_{U,x}$, is difficult to measure as frequently as needed, even for experimental purposes. The same difficulty we have with the Evapotranspiration rate, E_t, except if it is an estimate of an accurate model. Our aim is to develop a method to fit on-line an estimating model of instant E_t. This is based on measurements of accumulated Transpiration, *i.e.* from periodic water balance of the system such as the measurement of the refill water and the leaching part, with each irrigation cycle. Equation 1 holds for integral nutrient uptakes (SU_x), which is measured every (t_2-t_1) interval (i.e. weekly or longer):

$$SU_{xt_1}^{t_2} = \int_{t_1}^{t_2} [C_{U,x} * E_t]_t \, dt \qquad (1)$$

We can invert eq. 1 to fit a given model of $C_{U,x}$ if we have sufficient and independent data on SU_x and E_t. Instant transpiration measurement is usually possible by lysimeters or stem flow meters or, after some assumption for soil-root volume, with root-zone sensors. For the instant transpiration estimate E_t, a model of sufficient accuracy is:

$$E_t = [aSo + bVPD + c\sqrt{W_{sp}} + d]_t \qquad (2)$$

where So is solar irradiance, VPD is vapour pressure deficit of leaf-to-ambient and W_{sp} is wind speed, suitable for open field cultivation. However in most practical applications the water uptake is available only as an accumulated transpiration (*SE*) between two time instants, *i.e.* between irrigation cycles or every 24 hours, as expressed in eq.3:

$$SE_{t_1}^{t_2} = \int_{t_1}^{t_2} E_t \, dt = \int_{t_1}^{t_2} [aSo + bVPD + c]_t \, dt \cong \sum_{i=n_1}^{n_2} [a\overline{So} + b\overline{VPD} + c]_i \Delta t \qquad (3)$$

where $t_2 - t_1 = (n_2 - n_1)\Delta t$ and Δt is the recording interval (*i.e.* every 10min), during which So and VPD are recorded as averaged samples. A method to estimate (a,b,c) for the available

data is explained in Sigrimis et al. (2001). The same gradient method is used below for the $C_{U,t}$ model fitting.

Similarly, ion uptakes are only measured as accumulated variables (Eq. 1), every day or two, in experimental setups or every about 15 days the shortest in production facilities. Given that an accurate model of E_t is regressed on-line, using Eq. 3 and the gradient descent method described above, it can be used to provide instant data for Eq. 1. Therefore the same computational tool can be used to estimate the nutrient uptake model parameters of Eq. 4 (see Fig. 2). This method will greatly enhance the usefulness of recorded experimental data for building models for $C_{U,x}$.

C_U Model Selection

The kernel form $y = \dfrac{k_1 + k_2 x}{k_2 + x}$, normalized to $y = \dfrac{1 + kx}{k + x}$, was selected (Anastasiou et al., 2005) to quantify nutrient uptake concentration. It has the capability of expressing both increasing responses, such as a) rising concentrations (C) in the root zone and the light intensity (R) or assimilation rate and b) decreasing trends such as that observed with increasing transpiration intensity E_t.

A complete model of the uptake concentration is described by equation 4:

$$C_{U,x} = k_{x,0} \left[\frac{1 + k_{x,C}[C_t / C_0]}{k_{x,C} + [EC_t / EC_0]} \right] \left[\frac{1 + k_{x,E}[E_t / E_0]}{k_{x,E} + [NE_t / NE_0]} \right] \left[\frac{1 + k_{x,P}[R_t / R_0]}{k_{x,P} + [R_t / R_0]} \right] \eta_{x,t} \quad [4]$$

where, C is concentration in the root zone (ppm), C_U is concentration in the sap flow (ppm), E_t is the transpiration (ml s^{-1} plant^{-1}), NE is the transpiration intensity (ml s^{-1} cm^{-2}) and R is the photosynthetically active radiation (PAR, W m^{-2}). The indices are: t for time, 0 for standard (or known) conditions and x for ion element x. The advantage of the selected rational lies in the fact that if, when we do not know its value, we set $k_{x,*}=1$, we get unity result. The η_t parameter was discussed earlier.

The negative effect of salinity on crop yield may be lessened by reducing transpiration (Li et al., 2001). Experimental data were used to determine nutrient uptake and plant tolerance to salinity (Heuvelink et al., 2003; Li et al., 2001; Lorenzo et al., 2003; Sigrimis et al., 2001), as well as results from Yu et al., (2001), Savvas et al., (2008).

The Smart Sensor

An expert system is under development which will monitor all time responses from irrigation start to soil moisture sensor response signature. The concept is as follows: the installed system will "study" for some time the "time-behavior" of the sensor and more specifically the transients which carry information about soil properties, root zone water profile and soil moisture level. This virtual root zone sensor approach (two sensors at two different depths with online intelligence) is a smart system to draw conclusions on soil properties, plant water demand and water deficit, sufficient to successfully manage irrigation water. This intelligent system will be capable to decide what type of "excitation" to use in order to securely arrive to stable estimates about the above mentioned properties and will become part of the decision support system.

RESULTS

DSS Application

This system consists of the following parts (Fig. 3):

1. Monitoring and Control Hardware (irrigation controller nodes)
2. A decision support system (DSS-software for a PC)

This decision support system is a web based service which computes water allocations to maximise water value and delivers schedulers to the irrigation controllers. This service is based on the following modalities:

1. **Data Gathering-Uploading**. A data collection software module provides farmers with tools to manage (remote specify, see Figure 3 and http://143.233.183.205:6500/flowaid) their sites (nodes, one or many in each farm zone) and the variables monitored by each node. An uploading utility (Flowaid-DUP) transmits data from the farm computer to a web DataBase through the Internet.

2. **Water Management**. This core of the DSS uses farm mapping information from a farm planning/zoning tool (see MOPECO, Ortega et al., 2004) and crop response models (UNIPI) to allocate available water to different zones, based on real time decision.

The developed DSS application is based on general mathematical models for the estimation of evapotranspiration and uptake of major nutrients (macroelements) of the plants. Based on the estimated evapotranspiration, the composition of the irrigation water and the nutrient uptake, the DSS is capable of calculating the amount of water in the system and the composition of the nutrient in each subsystem (substrate, tank, drainage, etc.). At the same time, it enables calculation of water and nutrient inflows and outflows.

The water schedules are passed to the irrigation controllers in different forms to comply with most commercial controllers (week dynamic schedules, one or two parameter water uptake models or virtual root zone moisture threshold). The irrigation nodes will ensure that the allocated optimal amount of water per plot is applied and distributed according to real-time conditions.

The program window for the Water Uptake Model (WUM) provides a number of parameters that the user can select and construct appropriate WUM and must provide startup estimated parameters. The DSS at the advanced mode will be able to regress onto Node uploaded data and derived or primary Variables, and thus conduct frequent model fitting. In a studied case this fitting for Eq. 2 achieved accuracy of predicted WU better than 3%, equivalent to very accurate meters, under variable weather conditions (fig. 4). Such an approach provides robustness as well as intelligence for detection of ubnormal deviations on E_t and call the routine for "Diagnostics".

CONCLUSIONS

The following facts were identified in previous studies of the DSS:

In **open systems**, the main objective of the irrigation management is to control the irrigation dose or frequency such that the amount of water applied be enough and only enough to maintain the root solution under a certain salinity threshold or EC_{max}. To achieve "minimum leaching" under an open or semi-closed watering system, methods of accurate water uptake estimates or direct root zone monitoring have been developed. In open systems the system is chemically safe and deviations between real uptake and supplied nutrients do not raise or accumulate, except may be costly.

In **closed** or semi-closed irrigation systems the main objective is to correct the nutrient solution based on the nutrient uptake and salinity build-up. With the correct management of the nutrient solution and the aerial environment one can slow the salt accumulation process and hence bleed less, which means both water and nutrient saving.

Based on above facts for Open and Closed irrigation systems the DSS aims to minimize water use in Open systems and modulate nutrient supply in Closed systems (to conserve root solution and thus save fertilizers and water). A better understanding of nutrient uptake will be the tool to better water and salinity management. Technology advances, and the introduced smart root zone sensor, avail more real time data on water measurement and thus better fit of models and then better nutrient estimates. We call this approach "virtual root zone measurements", which will enable us to better manage water and fertilizers, both becoming more and more precious and costly. The present status of the technology permits climate and EC and pH monitoring to enable adaptation of feeding solution EC and pH as well as some macro nutrient adaptation (i.e. N/K)

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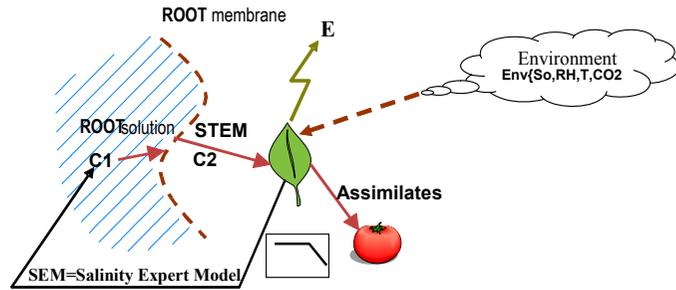
Figures

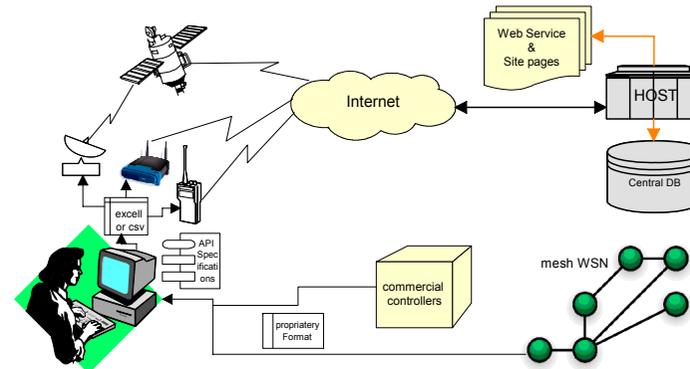Fig. 1. Nutrient transport, Salinity buildup and
Irrigation Management model.

Fig. 2. From integral measurements to rate functions.

Fig. 3. Flow-Aid Data Collection Layout and possible communications.
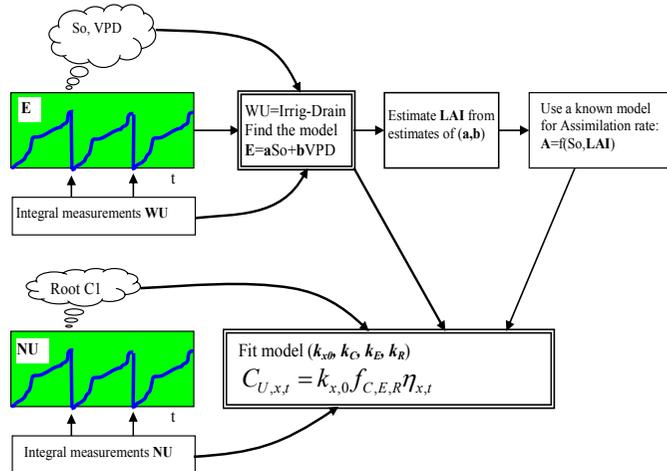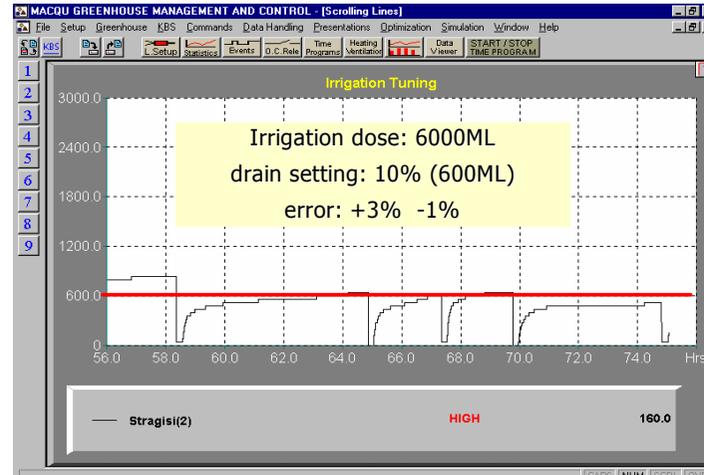

Fig. 4. Drain volume control from accurate WU estimates.