DECISION SUPPORT FOR OPTIMISED IRRIGATION SCHEDULING

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Abstract

The system, developed under FLOW-AID (an FP6 project)[1], is a water management system that can generally be used at farm level in situations where the water availability and quality is limited. This market-ready precision irrigation management system is focused on new 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 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 and consists of 1) a data gathering tool that uploads agronomic data, from monitored crops around the world that have internet connectivity, to a central web DB, and 2) a web based DSS that processes intelligently (Crop Response Models, Nutrient Uptake Models, Water Uptake Models) the data of the crop and downloads to the fertigation controller a command file containing water scheduling and nutrient supply guidelines.

INTRODUCTION

Since crop mineral uptake models allowing a better adjustment of the recirculating 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 Nutrient uptake models, 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 (Stangellini *et al* 2005).

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[1] FLOW AID Farm Level Optimal Water management: *Assistant for Irrigation under Deficit Ct 036958*

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 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 very far from extremes or any stress condition. Eq. 4 was adopted to express the influence of dominant environmental factors (Yu *et al* 2001) 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 $\eta_{x,t}$ may return from special expert mode routines when such conclusions become available from research or experience.

Model fitting

Going from Time Integrated Variables to instant rate or time_independent variables

The fact is that $C_{U,x}$ is difficult to measure as frequently as needed, even for experimental purposes. The same difficulty we have with the E_t, except if of a model estimate. Our aim is to develop a method to fit on-line an estimating model of instant E_t, based on measurements of accumulated Transpiration, *i.e.* water balance of the system, if we measure the refill water and the leaching part, with each irrigation cycle. Then, equation 1 holds for integral uptakes (SU), as measured every (t_2-t_1) week or longer intervals:

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

For the instant transpiration estimate E_t needed, a model of sufficient accuracy is:

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

Instant transpiration measurement is usually possible by lysimeters or stem flow meters or, after some assumption for soil-root volume, with root-zone sensors, but in most practical applications only the water uptake is available as an accumulated transpiration between two time instants, *i.e.* between irrigation cycles or every 24 hours:

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

where t_2-t_1=(n_2-n_1)Δt 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

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[2] For a protected environment such as a greenhouse production the term on wind speed is not needed

data is explained in Sigrimis et al 2001. The gradient method used is similar to the one given below for the $C_{U,E}$ model fitting.

Similarly, ion uptakes are only measured as accumulated (eq. 1), every day or two, in experimental setups or every about 15 days in production facilities. Given that an accurate model of E_t is regressed on-line, using eq.3 and the method described above, it can be used to provide instant data for eq 3. Therefore 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 $C_{U,E}$.

C_U Model Selection

The kernel form $y = \frac{k_1 + k_2 x}{k_2 + x}$, normalized to $y = \frac{1 + kx}{k + x}$, was selected (Anastasiou *et al* 2005) to quantify nutrient uptake concentration, and 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.

A complete model of the uptake concentration is given by the following mechanism:

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

where, *C* is concentration in the root zone (ppm), C_u is concentration in the sap flow (ppm), *E* 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 indexes are: *t* for time, 0 for standard (or known) conditions and *x* for element x. The advantage of the selected rational lies on the fact if we set $k_{x,*=1}$ (when we do not know its value) we get unity result.

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 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 performs water allocations to maximise water value and delivers schedulers to the irrigation controllers. This service depends 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 to many in each farm Zone) and the monitored variables by each node. An uploading utility (Flowaid-DUP) transfers 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, 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 WUM provides a number of parameters that the user can select and construct his own WUM and provide startup estimated parameters. The DSS at the advanced mode will be able to regress onto Node uploaded data (wDBC derived or primary “Variable x”), and thus conduct frequent model fitting. In a studied case this fitting for eq2 achieved accuracy of predicted WU better than 3%, under variable weather conditions, equivalent to very accurate meters. Such an approach provides robustness as well as Intelligence for detection of ubnormal deviations on ET and Call Diagnostics routine.

CONCLUSIONS

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 ECmax. Uniformity, along the lines of the plants, of both climate (ventilation, radiation etc) and irrigation (pipe pressure, dripper blockages etc) must be designed into the system to avoid excessive leaching requirements. 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 there is no need for accurately estimating or frequently measuring the nutrient uptake because deviations between uptake and supplied nutrients do not grow or accumulate. The system is chemically safe and only a good recipe to start with is enough.

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. The present status of the technology permits climate and recycle EC and pH monitoring to enable adaptation of feeding solution EC and pH as well as some macro nutrient adaptation (i.e. N/K) regarding the needs of growth and development, based on expert rules. When more accurate nutrient uptake models become available more detailed nutrient management is also possible on-line. An estimate of toxic element build-up is also possible to avoid *poisoning* of the crop. Since closed systems recirculate the drain water there is no need for precise management of the irrigation quantity, except keeping it below an excessive and unnecessary amount that simply overloads system components.

Based on above conclusions for Open and Closed irrigation systems the DSS effort is to minimize water use in Open systems and to modulate nutrient supply in closed systems (to conserve root solution and thus save fertilizers and water). It becomes more and more evident that better knowledge on Nutrient Uptake will be the tool to better Water and Salinity management. Technology advances avail more real time data on nutrient measurement and thus better fit of models and better nutrient estimates and we call this approach "virtual root zone measurements".

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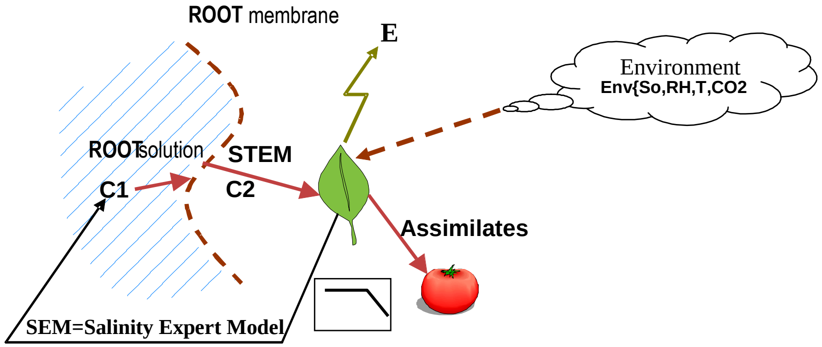


Fig.1 Nutrient transport, Salinity buildup and Irrigation Management model

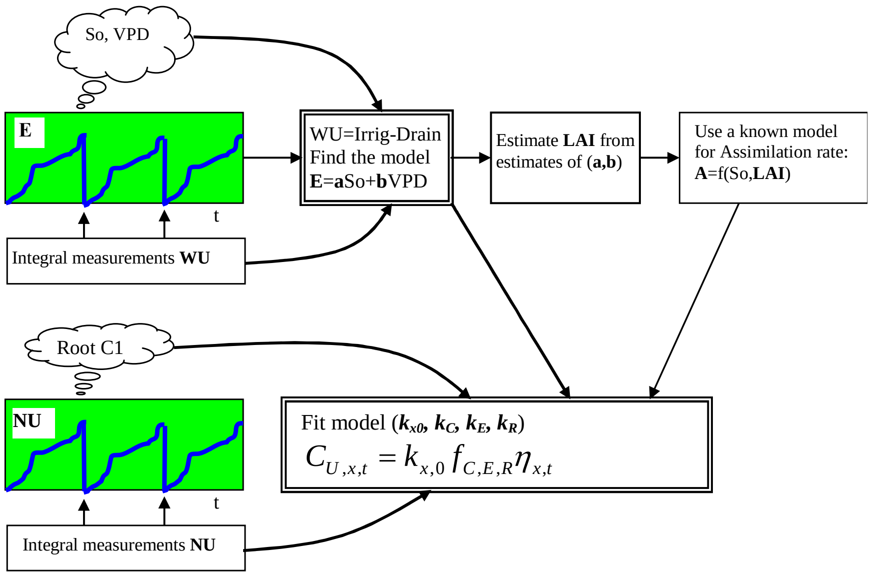


Figure 2: From integral measurements to rate functions

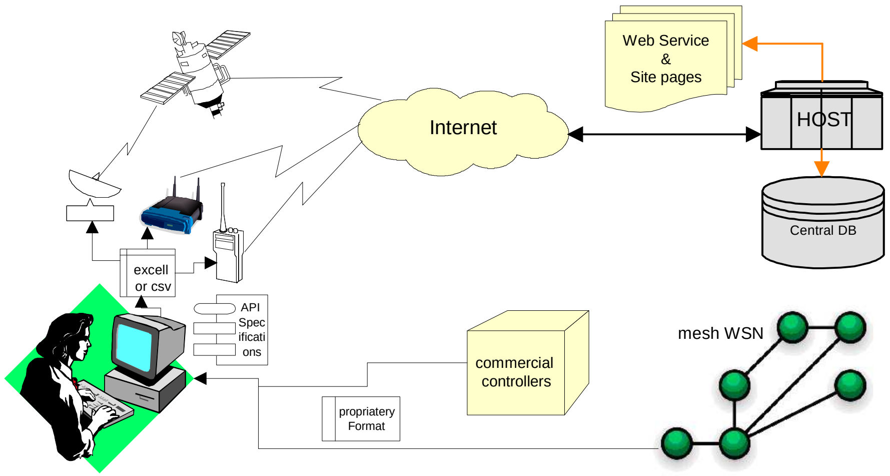
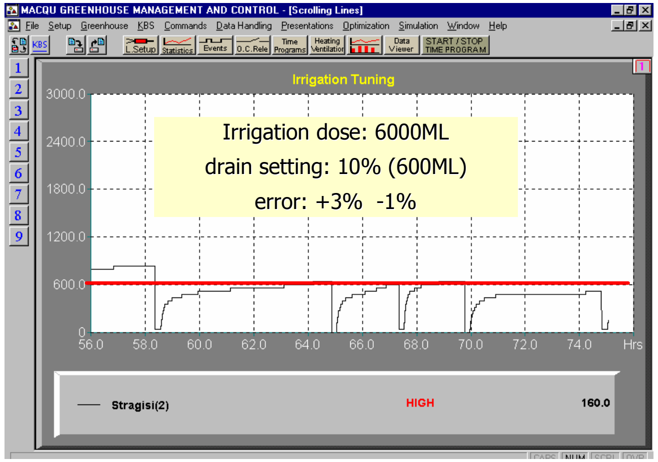


Fig. 3 Flow-Aid Data Collection Layout and possible communications



Irrigation dose: 6000ML

drain setting: 10% (600ML)

error: +3% -1%

Fig. 4: Drain volume control from accurate WU estimates