THE DYNAMIC BEHAVIOUR OF SALINITY CHANGES IN A CLOSED NFT GROWING SYSTEM

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Abstract

In the Netherlands a law will enforce the use of closed growing systems in greenhouses. A project is initiated at IMAG-DLO to introduce ion-selective measurement and controlled injection of singular liquid nutrients in closed growing systems.

As part of this project step and impulse response tests are carried out to study the dynamic behaviour of salinity changes in an NFT growing channel. The paper describes a time delay algorithm for the trickle irrigation system and an aggregated dead zone model for the growing channels in closed NFT growing systems. It suggests a Smith Predictor as a controller for a nutrient dispenser system.

Ion-selective measurement on a practical scale will only be available for a few nutrient ions. Controlled injection of singular liquid fertilizers will need information on plant uptake of ions which cannot be measured in relation to ions which can be measured.

Keywords: discrete time model, ion selective measurement, ISFET sensor, EC level, aggregated dead zone model.

1. Introduction

In the year 2000 the environmental protection act (NMP+, 1990) will enforce a decrease in environmental pollution in The Netherlands. The law in particular envisages the quality of the surface water in the greenhouse district, by making it mandatory upon the grower to use closed growing systems. Nowadays, there is still a widespread use of open ended hydroponic growing systems which drain off the surplus water (Van Os et al., 1990). Several research projects at IMAG-DLO are aimed at solutions for the problems connected to closed growing systems, i.e. the use of closed systems as growing systems, sterilization of recirculating nutrient solutions and ion selective measurement and control.

In closed growing systems the return water is reused to produce the new nutrient solution. In general there is no on line information on the nutrient uptake of a plant. Hence, nutrient supply systems which are to be used in closed growing systems should have a direct feedback from ion specific sensors in order to be able to dispense the right amount of liquid stock solutions to the mixture of clean water and return water. The A/B diluters, which are still in use with open ended hydroponic growing systems, (Gieling et al.; 1989) are not able to control ion specifically. Moreover, the control algoritmes which are in use in these A/B diluters do not take into account the large time delays which are normaly found in hydroponic growing systems (Kupers et al.; 1991).

In an NFT growing system the capillaries, nozzles, growing channels, root hairs and substrate seedling blocks form obstacles in the course of the water flow. The influence of roots and rockwool blocks can be interpreted as an intrinsic diffusion resistance of the growing system. The gradient of the ion concentration across this diffusion resistance is a function of the ionic flow rate. Together with the original source concentration at the nutrient dispenser, it dynamically influences the ion concentration at the root membranes.

For a successful introduction of proper control engineering techniques in both A/B diluters and in the novel ion specific dispencers, models are needed which describe the dynamic system properties of the growing system in use.

Earlier work on ion selective measurement and control (Albury et al., 1985; Bailey, 1985; Hashimoto et al., 1989; Gieling et al., 1989; Heinen, 1991; Kupers et al., 1991; Van de Vlekkert et al., 1991) showed that ion selective measurement of nutrient ions in the return water of a nutrient supply system is feasible. It also showed that research groups in several countries are interested in the application of ion-selective sensors. Most sensing systems in use by these groups are not easily applicable in a greenhouse.

In respect to this purpose promising results are produced on ISFET technology at Twente University of Technology in The Netherlands. It started with a first publication of Bergveld in 1971. During the last five years ISFET technology is fine tuned for application in greenhouses in close cooperation with Dutch horticulture supply industry (Van de Vlekkert, 1991). In spite of it, practicable sensors appropriate for the main nutrient ions are not yet available on a large scale.

This paper describes tests which were carried out to study the responses to step and impulse exitations in the EC level, leading to the dynamic characteristics of the transfer function of the nutrient supply process in the root environment of a closed NFT growing system.

2.Materials and methods

In contrast with earlier research (Young et al., 1986) the NFT growing system in use during these tests applies trickle irrigation with one nozzle per plant, rather than pumping the nutrient solution to the upper end of the growing channels. The NFT growing system is situated in a greenhouse with controlled climate. A growing channel, covered with a lid, contains tomato plants in small rockwool seedling blocks. The seedling blocks fit into square holes punched in the lid, each 8cm x 8cm large. A trickle irrigation supply pipe with 74 small capillary hoses, each one connected to a nozzle, feeds two rows of 37 plants each. An A/B diluter unit pumps the nutrient solution into the trickle irrigation supply pipe; the return water from the plants is pumped into a buffer tank.

A computer system with 8 analog input channels measures the EC on 8 equally interspaced places in a growing channel, starting at the first nozzle. The data are saved in a file on harddisk in 10 s intervals.

The EC is measured with specially designed sensors and electronic circuits. The flat shape of the EC sensors enables placement on the bottom of the channel just in front of a plant (= the end of the preceding plant compartment). Because of its flat shape the sensor does not interfere with the flow of the nutrient water film.

2.1. The trickle irrigation system

First test results have shown that some properties of the trickle irrigation system influence directly the dynamic behaviour of water and ion transport in the supply system as a whole. The pressure drop across the supply pipe is negligible. As a result, a constant flow of $\pm 0.5 \cdot 10^{-6}$ m^3s^{-1} is produced by each trickle capillary. The volume of the first segment of the trickle irrigation supply pipe (fig 3, S1) is flown through by all capillary flows except for the first one. The last segment (fig 3, Sn) is flown through by only one. This phenomenon causes an increasing delay time along the supply pipe (fig 4). The time delay between arbitrary capillaries w and v is expressed by (1).

$$\Delta t(v \rightarrow w) = \frac{L \cdot \pi \cdot D^2}{4 \cdot Fd} \cdot \sum_{x=v}^{w-1} \frac{1}{n-x} \qquad w=1..73 \tag{1}$$

where: L = distance between two capillaries = 0.30 (m), D = diameter of supply pipe = 0.018 (m), Fd = capillary flow = $\pm 0.5 \cdot 10^{-6}$ (m^3s^{-1}), n = 74, Δt = time delay (s) between arbitrary capillaries w and v.

The diagram in figure 4 shows the time delay as a function of the serial number of the capillary. The 95% reliability interval, the output of the model and the measured values clearly indicate that the the model is a good approximation (coefficient of determination = 0.998).

2.2. The growing channel

Young et al. (1986) already stated, that "the most appropriate model for an NFT channel from a control standpoint is the aggregated dead zone model". In such a model the channel is subdivided into a chain of compartments, where each compartment is considered to behave like a stirred tank. In continuous time this leads to:

$$V(j) \cdot \frac{dECg(j,t)}{dt} = -Fg(j) \cdot ECg(j,t) + Fg(j-1)ECg(j-1,t-dtg(j)) + Fd \cdot ECd(j,t-dtg(j)) - r + e \tag{2}$$

$$Fg(j) = Fg(j-1) + Fd - Fp \tag{3}$$

$$ECd(i,t) = ECh(t-dt(i)) \tag{4}$$

where: j = number of compartment, t = time (s), ECg(j,t) = EC in compartment j at time t (mS/cm), ECd(j,t) = EC of nozzle j at time t (mS/cm), ECh(t) = EC at diluter machine (mS/cm), Fd = nozzle flow (m^3/s) and equal for all nozzles, Fp = water uptake by the plant (m^3/s) and equal for all plants, Fg(j) = flow at output of compartment j (m^3/s), dtg(j) = time delay (s) from the nozzle at plant j to the output of compartment j , dt(i) = time delay (s) from diluter unit to nozzle i, V(j) = effective volume of channel compartment j (m^3), r = plant uptake of nutrients (m^3/s), e = error of the model

The model for one compartment after discretisation:

$$ECg(j,k+1) = a \, . \, ECg(j,k) + b1 \, . \, ECg(j-1,k-dt1) + b2 \, . \, ECd(j,k-dt2) + - \frac{r}{Fg(j)} + e(j,k+1) \tag{5}$$

dt1 = time delay (s) for the output of compartment j-1 in whole sample intervals; dt2 = time delay (s) for the output of the nozzle at plant j in whole sample intervals; e(j,k+1) = modelling error in compartment j at time k+1

The time delay between the A/B diluter and nozzle i is described by formula (1) and the next relation:

$$dt(i) = \Delta t(i) + dth \tag{6}$$

dt(i) = delay time (s) between nozzle i and AB-unit, dth= delay time (s) between AB unit and nozzle 1, Δt(i) = time delay (s) between nozzle i and nozzle 1.

The relation between the two inputs and the output for one compartment has been determined according to a first-order difference equation (5). The model and its coefficients that fits to measured data of the experiment is given in (7) The results are depicted in figure 5. The sample interval is 9 s.

$$ECg(j,k) = +\, 0.986 \cdot ECg(j,k-1) + 0.0033 \cdot ECd(2j,k-38) + + \, 0.0117 \cdot ECg(j-1,k-1) \tag{7}$$

2.3. The control system

The control of the EC in a growing system needs a model of the whole nutrient supply system. It consists of partial models of the reservoir, the main supply pipe, 8 trickle irrigation hoses, growing channels and return pipe (fig. 1).

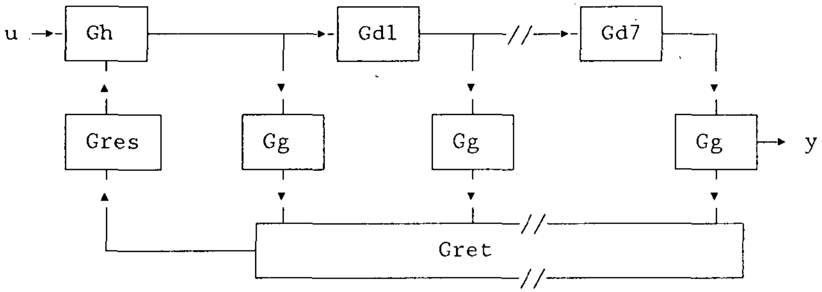

Fig 1 The model of the whole nutrient supply system

In figure 1: Gh = transfer function of the main supply pipe; Gdi = time delay between trickle capillaries; Gg = transfer function from nozzle 1 to output of the growing channel; Gret = transfer function of the return pipes; Gres = transfer function of the reservoir.

The EC value in the growing channel is the output of the controlled process (y). The input of the process is the main nutrient supply pipe (u). The discrete time transfer functions between arbitrary inputs and the output can easily be determined. To control the process of the whole system, a 'Smith Predictor' will be used (fig. 2) (Stephanopoulos, 1984). G3 and G4 together form the hart of the Smith Predictor. If the process model (G3) is a perfect representation of reality, then G2 and G3 cancel each other out, or: if G3 = -G2, then EC~ = G4*u. The control value (u) will be calculated from the difference between ECs and the prediction of ECg(37,t+dt).

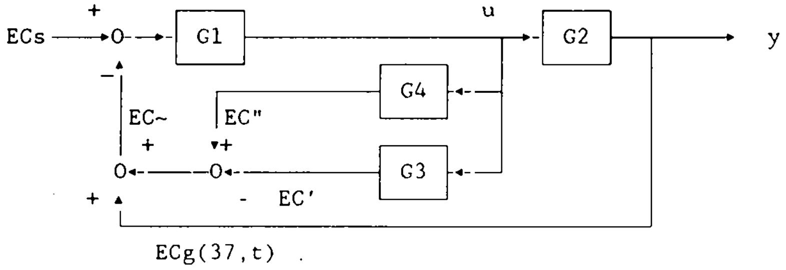

Fig 2 Feedback system with delay time compensation.

In figure 2: G1 = the controller; G2 = the process; G3 = model of the process; G4 = model of the process without time delays; EC' = G3*u; EC" = G4*u; EC~ = ECg(37,t) - EC' + EC"; ECs = setpoint for EC at output y.

3.Discussion and Conclusion

As can be seen from fig. 4 the model of the trickle irrigation pipe sufficiently discribes the time delays as a function of the serial number of the capillary. During the test it appeared that the capillaries get gradually blocked, a process that has not been accounted for in this model. As a result the parameters are changed and the time delays increase, although the structure of the model remains the same.

A variance analysis of the aggregated dead zone model for the growing channels shows that the variance of the output ECg(j,t) is 37 times as high as the variance of the model error for one compartment. The root growth in the growing channels causes a gradual change of the parameters of the model. A static model could be a good alternative for the dynamic model of the growing channels, without its problems.

The project showed that it is feasible to build discrete time domain models of the growing channels and the trickle irrigation pipes to define the dynamic behaviour of an NFT growing system. It suggests that large time delays in the process transfer function can be handled with a standard control engineering tool such as the Smith Predictor.

EC is not the only parameter of interest in closed growing systems. The concentration of each individual ion should be controlled, since it is unknown which ions were used by the plant. For this purpose ion-selective sensors are needed. It is expected that ion-selective sensors will be available on a practicable scale for a few ions only. For this reason control of individual ions will need information on the relation between the uptake of nutrient ions which can be measured and the ones which cannot be measured.

4. Acknowledgements

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6. Attachments

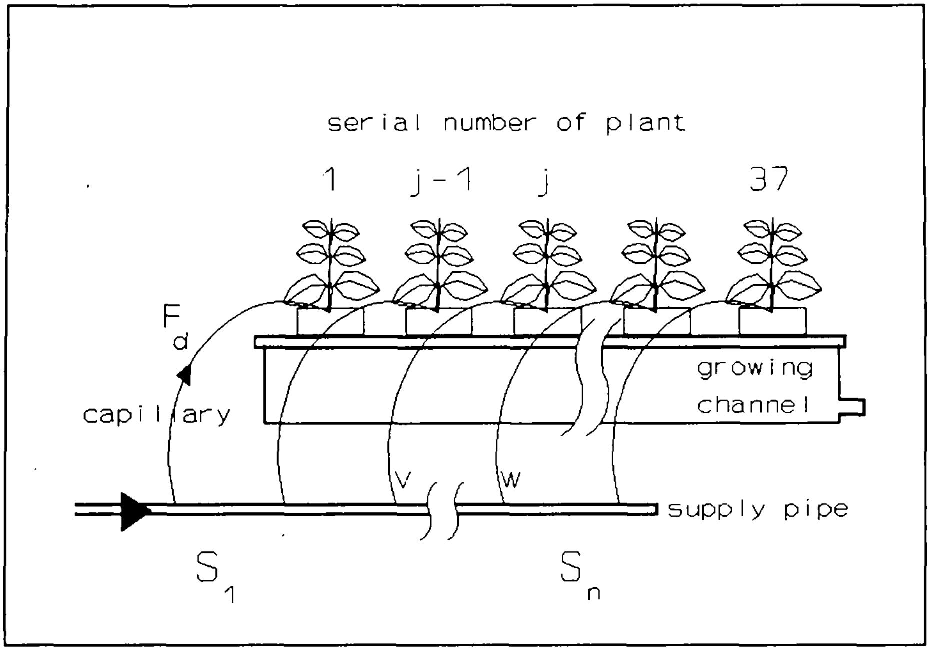

Fig 3 Nutrient supply pipe with capillary hoses, plants and growing channel.

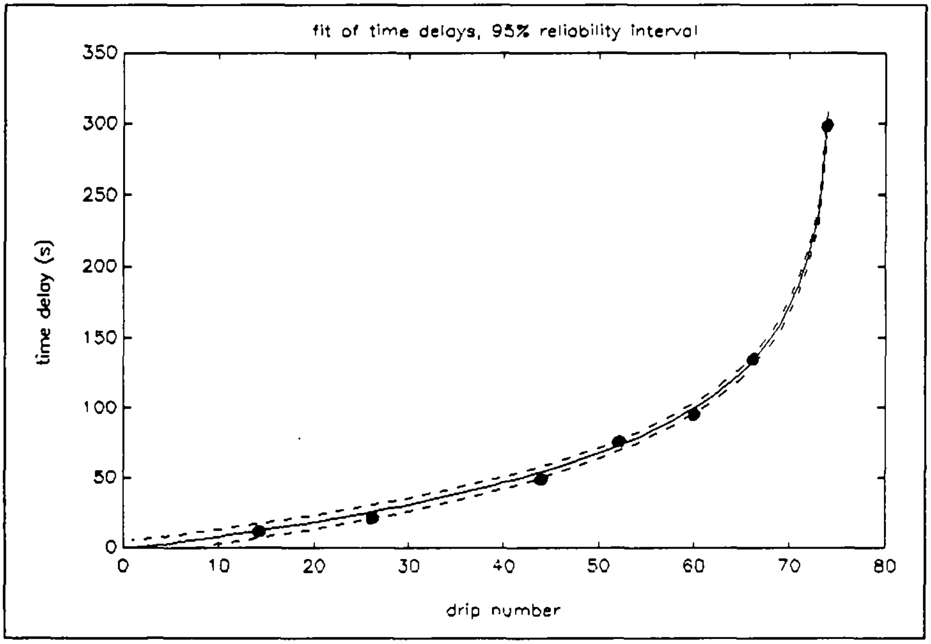

Fig 4 Measured time delays (dots) and modelled (solid line) time delays of the nozzles, with 95% reliability interval (dashed lines) as a function of serial number of nozzle.

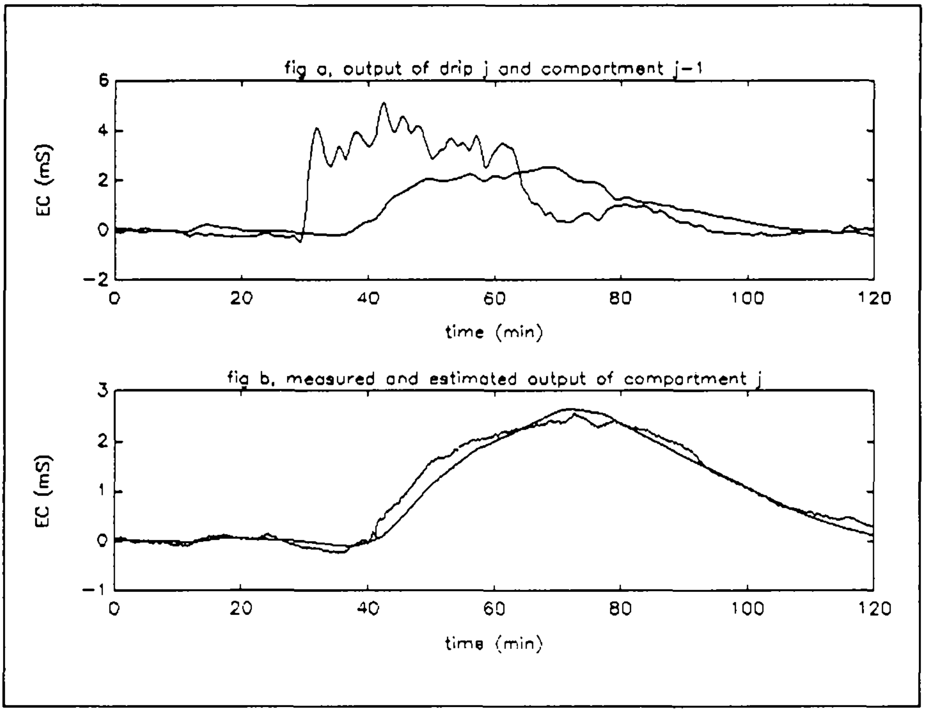

Fig 5 a) Input signals of compartment j-1 (fluctuating line) and nozzle j
b) Measured and estimated (smooth line) output of compartment j