MONITORING AND CONTROL OF WATER AND FERTILIZER DISTRIBUTION IN GREENHOUSES

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Abstract

Throughout the European Union the use of closed growing systems in greenhouses is seen as an alternative to free drainage systems. In preparation to it a project was initiated at several European universities and institutes to introduce management and control systems to improve the quality of the product, the environment and the growing process.

As part of this project, tests were carried out at the IMAG-DLO institute. Growing channels and a trickle irrigation system with an NFT closed growing system were used. Responses on step and impulse changes of the EC value were studied in order to establish the dynamic behaviour of the supply system. A time delay algorithm for trickle irrigation and an aggregated dead zone model for closed growing channels were developed. The layout of water supply lines was investigated. A Tichelmann layout with forced circulation was installed in the greenhouse to overcome the large time delays, which occur as a result of the dead-end in the supply tube in the current layout.

Key words: discrete time model, ion selective measurement, ISFET sensor, EC level, aggregated dead zone model, liquid fertilizer dispenser, Tichelmann layout, water supply

1. Introduction

In the year 2000 the environmental protection act (NMP+, 1990) will enforce a decrease in environmental pollution in The Netherlands. This 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. Throughout the European Union similar laws are in preparation. Nowadays, there is still a widespread use of free drainage hydroponic growing systems, which drain off the surplus water (Van Os et al., 1991). Several research projects at IMAG-DLO are aimed at solutions for the problems connected to closed systems, i.e. the use of closed systems as growing system, sterilization of recirculating nutrient solutions and ion selective measurement and control.

In closed growing systems the drainwater is reused in 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 raw water and drainwater. In free drainage hydroponic growing systems, it is still quite common to dispense nutrients by a so called A/B diluter. These systems mix raw water with a dosage from only two stock solutions, the A and the B solution (Gieling et al.; 1989). A/B diluters are not able to control ion specifically. Moreover, as Kupers et al. (1991)

already stated, large time delays on changes in nutrient concentration are found in hydroponic growing systems. The control algorithms in standard commercial A/B diluters do not consider these large time delays, which often leads to instability in control.

In an NFT growing system the capillaries, nozzles, growing channels, roots 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 varies with the ionic flow rate. With the original source concentration at the nutrient dispenser, it dynamically influences the ion concentration at the root membranes.

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 drainwater of a nutrient supply system is feasible. It also shows 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 practice, Twente University of Technology in The Netherlands produced promising results on ISFET technology. Here, in close cooperation with Dutch horticulture supply industry, ISFET technology is fine tuned for applica-tion in greenhouses (Van de Vlekkert, 1991). In spite of it, practicable sensors are not yet available, which are appropriate for the main nutrient ions.

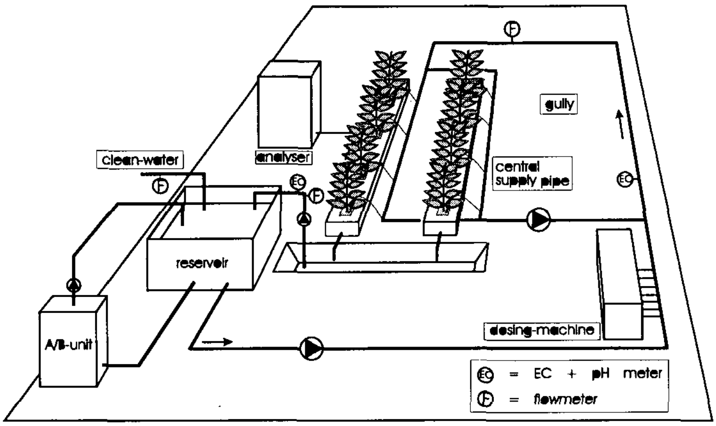

Figure 1 - The water supply system under test

2. Materials and methods

2.1 Experimental setup

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 a controlled climate. Eight growing channels, covered with a lid, contain tomato plants in small rockwool seedling blocks, which fit into square holes (8 cm x 8 cm) punched in the lid. A trickle irrigation supply tube with 74 small capillary hoses feeds two rows of 37 plants each. A supply tube with only 37 nozzles feeds the two outermost growing channels. An A/B diluter keeps the nutrient solution in a reservoir at a preset value. A separate pump feeds the nutrient solution into the supply lines of the trickle irrigation system. The water from the plants returns into a small buffer tank. Whenever the level in the small buffer tank reaches a preset value, the solution is pumped into the reservoir (Figure 1). The dead-end in the supply lines causes the time delay to increase along the length of the tube (Gieling et al. 1993).

2.2 Options for the layout of the water supply

Towards the end of the tube, fewer capillary hoses subtract water from an equal supply tube volume. The time delay in the supply tube will increase even more if the water supply through the capillaries is reduced to a minimum (Figure 2a). The diameter of the supply tube cannot be reduced to decrease the time delay. Then the pressure needed to drain out water of the capillary hoses would have to be increased,

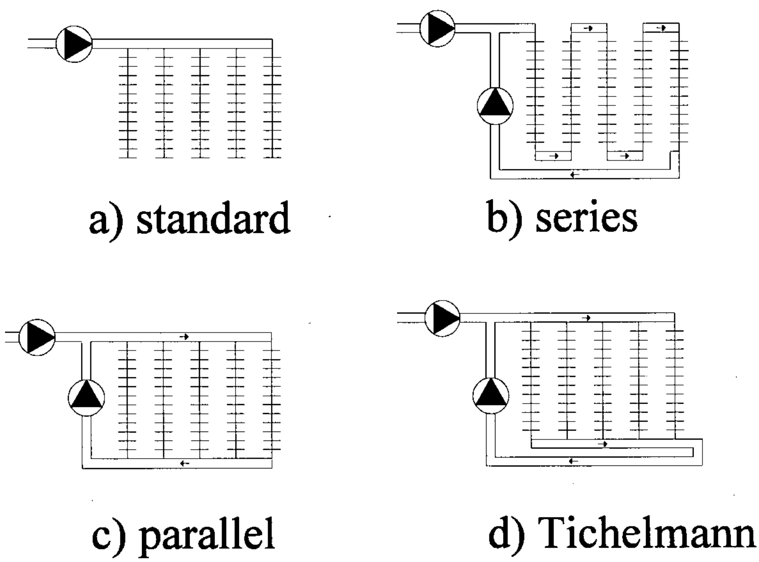

Figure 2 - Four optional designs

which leads to an unequal distribution of water. An opportunity is found by interconnecting the supply lines at their ends and create a supply system with a circulating water stream by means of an extra pump (Figure 2b,c,d).

A first alternative on the standard (Figure 2a) way of connecting the supply lines can be found in connecting them in series (Figure 2b). It means that the supply lines are connected outlet to inlet, which causes the pressure difference over the entire system to be very large. A fair difference in pressure in different parts of the system and an unequal distribution of water through the capillary hoses is the result of it.

A second option connects the outlets of the tubes in the same way as the inlets (Figure 2c). The main supply then situates at the same side as the main outlet. It means that the route of the water through the first supply tube is much shorter than the route through the last supply tube. Thus, the distribution of water in the entire system is not uniform.

A third water circulation system is known from heating technology as the Tichelmann system (Buitelaar et al., 1975; Von Zabeltitz, 1978). Here, the outlet of the system situates on the opposite side of the inlet (Figure 2b). Thus, the route of the water through the system is equal for all supply lines. Since the length of the routes in the system is equal for all supply lines, the distribution of the water is nearly uniform. The distribution of water will be entirely uniform, when also the resistance in the different routes are the same. For this purpose the resistance of inlet and outlet tubes should be small in comparison to the resistance of the supply tube (Von Zabeltitz, 1978). A common solution, is to decrease the diameter of the inlet tube with increasing length. Then the outlet is a mirror of the inlet. A model of the resistance of the tubes can be derived from the following standard equations and reveals if expectations are met (Arts et al., 1991).

$$\Delta Pw = \lambda \cdot \frac{L}{D} \cdot \frac{1}{2} \rho \cdot v^2 = \frac{128 \cdot \eta \cdot L \cdot Q}{\pi \cdot D^4} \tag{1}$$

$$v = \frac{4.Q}{\pi.D^2} \; ; \; \lambda = \frac{64}{Re} \; ; \; Re = v.\frac{D}{\nu} \; ; \; \nu = \frac{\eta}{\rho} \tag{2}$$

Here: Re=Reynold number; v = velocity ($m.s^{-1}$); D = diameter (m); ν = kinematic viscosity ($m^2.s^{-1}$); η = dynamic viscosity (Pa.s); ρ = density ($kg.m^{-3}$); λ = coefficient of friction; Q = flow through the tube ($m^3.s^{-1}$); ΔPw = pressure loss over tube (Pa); L = length tube (m).

In case of the Tichelmann system it holds that at one point in the system there can only exist one pressure. At the main inlet of the system (point A) exists a pressure created by the pump (Figure 3). At the main outlet of the system (point J) exists a pressure lower than at point A, caused by the pressure drop over the system. Because of these two pressure points, the pressure drop along the supply lines must be the same. The viscosity is equal for all points. It means that the resistance of the tubes depends on the dimensions of the tubes and the distribution of the flow through the supply lines. The following system of equations (3) can be derived. The

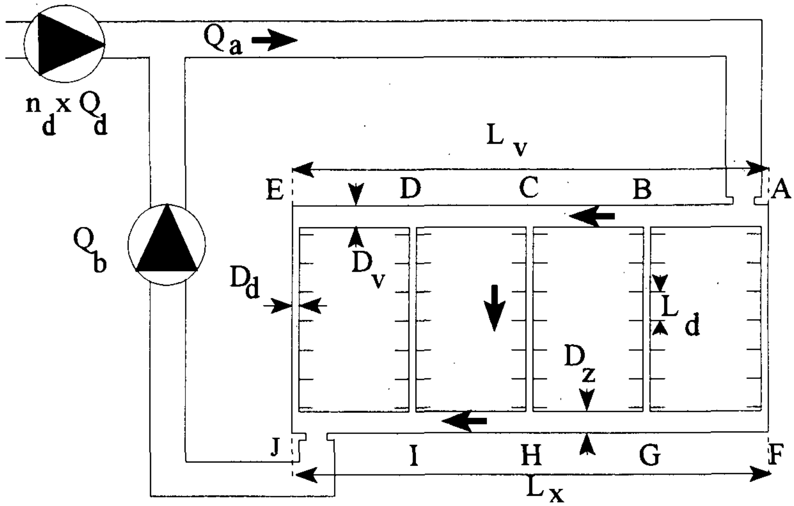

Figure 3 - Actual layout

equations are a result of the pressure differences over each supply tube (Figure 3).

$$\begin{cases} \Delta P_{AF}+\Delta P_{FG}=\Delta P_{AB}+\Delta P_{BG} \\ \Delta P_{BG}+\Delta P_{GH}=\Delta P_{BC}+\Delta P_{CH} \\ \Delta P_{CH}+\Delta P_{HI}=\Delta P_{CD}+\Delta P_{DI} \\ \Delta P_{DI}+\Delta P_{IJ}=\Delta P_{DE}+\Delta P_{EJ} \end{cases} \tag{3}$$

Equation (2) can be substituted in the system of equations (3). The first equation results in formula (4) when substituted with values of the present experiment.

$$\frac{0.6}{D_d^4}\sum_{x=1}^{36}(a_1\cdot Q_a-x\cdot Q_d)+\frac{L_{z_1}}{D_z^4}(a_1\cdot Q_a-37\cdot Q_d) = \frac{L_{v_1}}{D_v^4}(1-a_1)\,Q_a + \frac{0.3}{D_d^4}\sum_{x=1}^{73}(a_2\cdot Q_a-x\cdot Q_d) \tag{4}$$

Equation (4) is specific for the first equation only in the system of equations in (3). The system of equations can be extended for k supply lines. The system of equations then consists of (k-1) equations (5), and the information that $a_1+a_2+\ldots a_i+\ldots a_k=1$

$$\frac{L_{d_i}}{D_d^4}\sum_{x=1}^{w_i}(a_i\cdot Q_a-x\cdot Q_d)+\frac{L_{z_i}}{D_z^4}\sum_{x=1}^{i}(a_x\cdot Q_a-w_x\cdot Q_d) = \frac{L_{v_i}}{D_v^4}\left(1-\sum_{x=1}^{i}a_x\right)\cdot Q_a + \frac{L_{d_{i+1}}}{D_d^4}\sum_{x=1}^{w_{i+1}}(a_{i+1}\cdot Q_a-x\cdot Q_d) \tag{5}$$

In equations (4) and (5): i=index number $\{1 \leq i \leq (k-1) \mid i \in N\}$; k=number of supply lines; Q_a=inlet flow ($Q_b + n_d \cdot Q_d$) ($m^3.s^{-1}$); Q_b =base flow ($m^3.s^{-1}$); Q_d=nozzle flow ($m^3.s^{-1}$); L_d =nozzle distance on supply tube i; L_v =length inlet tube; L_z=length outlet tube; D_d =diameter supply tube; D_v =diameter inlet tube; a_i=fraction flow supply tube i, w_i = number of nozzles on supply tube i; n_d=total number of nozzles (296).

In the experiment described, the system consists of five supply lines (i=5). An analytic solution exists for the system of equations. However, numerical solutions are calculated in the present experiment with the mathematical software package Matlab. Q_b varies from 0 to $8.88 \cdot 10^{-4} m^3.s^{-1}$. Each Q_b results in a specific system of equations.

3. Results and Discussion

The data in Table 1 and Table 2 show the improvement in total delay time from ±20 minutes in the standard layout to ±5 minutes in the Tichelmann layout with forced circulation. Comparison of the values of time delay in the supply lines of both tables shows, that the distribution of the inlet flow over the five supply lines is more uniform in the Tichelmann layout, than in the standard layout. In Table 1 the supply lines 1 and 5 show a much larger time delay than 2, 3 and 4. The reason is, that these two supply lines only have 37 capillaries to empty them and the other three have 72 capillaries. Table 2 does not show these differences, because here the time delays are the result of the circulation speed and not of the speed of the water due to the loss through the capillaries.

The diagram in Figure 4 shows the distribution of the inlet flow over the five supply lines as a function of the circulation flowrate. It shows that the distribution is poor for low flowrates. The actual distribution stays within a boundary of 2.5%/-2.5% of the ideal distribution at a circulation flowrate of $4.5 \cdot 10^{-4}$ $m^3.s^{-1}$.

Table 1 - The delay time (minutes) of the standard water supply system specified according to the component parts

		supply line				
		1	2	3	4	5
main inlet line		6	6	6	6	6
distribution	1		0,11	0,11	0,11	0,11
"	2			0,18	0,18	0,18
"	3				0,3	0,38
"	4					0,84
supply line		21,25	12,4	12,4	12,4	21,25
total delay time		27,25	18,52	18,7	18,99	28,68

Table 2 - The delay time (minutes) of the Tichelmann water supply system specified according to the component parts

		supply line				
		1	2	3	4	5
main inlet line		4,04	4,04	4,04	4,04	4,04
distribution	1		0,12	0,12	0,12	0,12
"	2			0,19	0,19	0,19
"	3				0,28	0,28
"	4					0,53
supply line		0,83	0,89	0,91	0,9	0,84
total delay time		4,86	5,05	5,25	5,25	6

The minimum difference between actual and ideal distribution is found at a circulation flow of $8.8*10^{-4}$ $m^3.s^{-1}$.

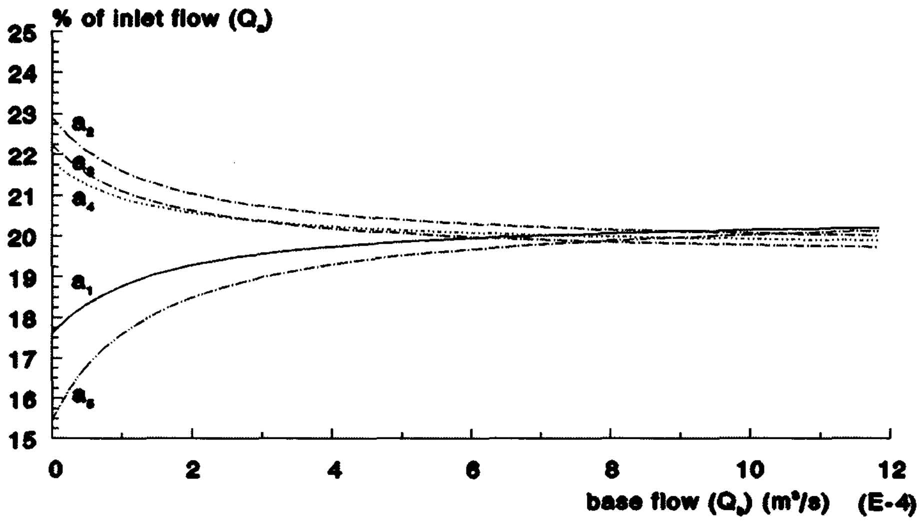

Figure 4 - Distribution of the inlet flow over the supply lines as a function of the circulation flow rate with a capillary flow of 5.10^{-7} m^3/s

4. Conclusions

In the considered water supply system, the delay time between inlet tube and last trickle nozzle was reduced from ±20 min to ±5 min, because of the application of the circulation pump. The Tichelmann layout ensures, that the flow is equal for all supply lines. However, the circulation flow needs a value of 3 to 6 times the total capillary flow, to ensure this equal distribution of the inlet flow over the supply lines. The pressure drop across the supply tubes, caused by the circulation flow, might induce a difference in water supply between the first and the last capillary in a plant row. Here, it should be advised to use capillaries - or nozzles - with a Q_d less dependent of the pressure in the supply lines.

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