# Feedback Control of Water Supply in an NFT Growing System

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**Keywords**: constant drain return, tipping bucket flow sensor

## Abstract

**The paper explores a concept of irrigation control, where the supply of nutrient solution is controlled without the use of predictive uptake models but rather by the use of a direct feedback of a drain flow measurement. This concept proves to be a viable approach. Results are presented, showing the compensation of changes in water uptake due to variations in global radiation, with a very tight control of the drain flow, keeping it constant over long periods of time.**

**A tipping-bucket type flow sensor and its use in controlled water supply to a tomato crop is described. A calibration procedure for the tipping-bucket instrument is presented.**

## INTRODUCTION

Commercially available control equipment for water and nutrient supply use classic analogue or digital P, PI and PID controllers. In so called A/B type of systems, A or B type of solute mixtures are subsequently added into a mixing tank or injected into the main stream of the supply water (Gieling et al., 1996).

The growing system in use has a large influence on the dynamic properties of the controlled process. In case of NFT (Nutrient Film Technique), the root mat will gradually fill up the growing channel and thus alter the delay time and dead time of the overall system. In growing systems with an artificial growing medium (i.e. rockwool, perlite), the growing medium may cause a time delay (comparable to a stirred tank). However, the physical characteristics of the growing medium will change over time, e.g. due to ageing effects. As a consequence, most commercially available systems show problems in compensating relatively fast changes of the nutrient uptake or - in case of re-circulating systems - changes in the composition of solution in the return tank due to addition of clean water (Kupers et al., 1992). Especially control of nutrient application will suffer from these problems, as system identification of this sub-process shows (Gieling et al., 1997). To solve it, solutions from modern control theory have been suggested (Chotai et al., 1991; Gieling et al., 1997).

The control of water supply is more direct, since most of the disturbance is caused by fluctuations in water uptake by the plant and is less dependent on changing properties of the growing system. The principle of a “controlled constant return of drain water”, with its intrinsic ability to compensate for changes in water uptake, will give opportunities to the control of water supply. This principle is discussed in section 3.1.

However, the good functioning of a drain flow sensor is of importance if constant drain return is chosen as control strategy. During the research project experience with propeller type of instruments showed that they easily get polluted and stop functioning. Other types of instruments (eddy-current, heat-balance, etc.) were too expensive for application in horticultural practice. The tipping-bucket instrument (Fig. 1), is a cheap and simple alternative. When the spoon or bucket is full, it will tip over and cause a pulse on the output of the instrument. However, the instrument shows problems with linearity. During the time that the spoon is in the down position, water will leave the reservoir without touching the spoon. Hence it will not be counted. This effect is larger when the water flow from the reservoir is large. A calibration procedure - as discussed further on – handles this problem.

Proc. Sensors in Hort. III
Eds. I. Shmulevich et al.
Acta Hort. 562, ISHS 2001

## MATERIALS AND METHODS

In a 150 $m^2$ greenhouse, a feedback controlled watering system supplies water to a NFT closed growing system with eight rows of 37 tomato plants each. As an actuator a standard commercial A/B water and nutrient supply system (PRIVA) is applied (Fig. 2). This actuator system switches on for one minute. The off time till the next one minute on-time, is modulated according to the output of the controller, within the limits of a minimum of 1 min. and a maximum of 14 min. pause time.

Problems may arise as a result of the time delays and dead times in the return gully of the closed growing system, especially since in this test the concept of constant drain return is applied. This concept tries to keep the drain flow from the plants at a constant value, thus compensating for the uptake of the plants. In order to minimise the values of the dead times, a so-called Tichelmann layout of the water supply pipes is used (Gieling et al., 1995). The gullies with rootmats and small rockwool-seedling blocks and the return pit will add extra time delays. As a flow sensor for drain water, a tipping-bucket sensor (Fig. 1) is applied in the drain-pipe of a short starting gully with 5 plants. The starting gully is placed in-between the normal canopy of plants. The return flow from the short gully is kept constant by means of the applied control algorithm. The water supplied to the whole greenhouse, is according to the ratio between the total amount of plants in the greenhouse and the plants in the short gully.

A PI controller for water supply is designed according to the classic design method, using a unit step response (Fig. 3) and Bode plot design. A unit step function on the input brings the flow from 7.5 to 30 drain sensor pulses, as is shown by Fig. 3 curve 1. The response of the drain flow in supply system is shown by curve 2. Curve 3 shows the smoothed original response data. A second order response with dead time is fitted through the response data, resulting in curve 4. With the aid of the data of curve 4, a process transfers function $H_p$ was constructed as in Equation 1. A classic tuning procedure results in the P and I factors of the control algorithms, which keep the Gain Margin and the Phase Margin just within the prescribed limits. It results in a transfer $H_c$ (Eq. 2).

$$H_p(s) = \frac{K \cdot e^{-t_d \cdot s}}{(t_1 s + 1) \cdot (t_2 s + 1)} = \frac{12.9 \cdot e^{-75s}}{(90s + 1) \cdot (114s + 1)} \qquad (1)$$

$$H_c(s) = K \cdot \frac{t_i \cdot s + 1}{t_i \cdot s} = 0.07 \cdot \frac{120s + 1}{120s} \qquad (2)$$

## RESULTS AND DISCUSSION

### The Controlled Process

Figure 4a shows the flow response of the drain output on the controlled water supply. Curve 4b depicts the actuator activity (ON- and OFF-time). The evenly divided pattern of pulses from 400 till 1200 in curve 4a shows the response of the drain of the short gully on a water supply regime of 1 minute on-time and on average 5 minutes off-time. The first part of both curves depicts the overshoot of the start-up transient phenomena. In Fig. 5 the response is shown over a period of approx. 24 hours of the drain return. During this time, the drain of the short gully is kept at a constant level of 1.8 $l \cdot h^{-1}$. The data of Figure 5 starts at approx. 12:30 hours.

The ripple of the flow signal from the tipping-bucket flow meter is due to the ON-OFF switching of water supply. The surface of each peak is the total drain return of one ON-period of water supply. Evaporation and water uptake causes a high ripple frequency, from the start until 19:00 hours. Then from 19:00 hours and onwards the ripple shows a much lower frequency, indicating the lower water uptake and - as a consequence - less water supply due to the chosen strategy of constant drain returns.

The controller clearly tries to react on variations in water uptake and compensates for it. During the next period of high sun radiation the water supply - and hence the ripple frequency -

is higher again. Fig. 6 shows a drain flow of 1.2 $l \cdot h^{-1}$, where during each supply cycle the return flow from the start gully is averaged.

Figure 7 shows the data for radiation and flow of two consecutive days. Here, the radiation as function of time (Fig. 7-1) is shown in relation to the water supply as function of time (Fig. 7-2a) during the same period of time. In the second diagram (Fig. 7-2b) also the constant drain return (averaged over each supply cycle) is shown.

By keeping the drain return at a constant level, the controller automatically compensates for the water uptake by the plants. It increases the supplied amount when plant water uptake increases due to higher global radiation (and vice versa). Now, the value of the drain water flow can be chosen freely. It can be lowered in such a way, that only a minimal amount is supplied, but still all the plants in the greenhouse are receiving water. In this way, the amount of return water is minimised and thus the amount of recycled water, which has to be cleaned before being reused, is reduced. No harm to the plants is risked, since the controlled supply system will act almost instantaneously and will immediately compensate for any change in the returned amount of drain water, as is shown in Fig. 7 and 8.

The small delay between the radiation curve and the curve of water uptake by the plants (approx. 5-10 minutes) is not completely explained by the delayed reaction of the plants on changing radiation. Earlier research by Bruggink et al. (1988) and Van Ieperen (1997) confirms that radiation and water uptake only show negligible time delays. The time delays are better explained by the lingering time of the water in gullies, root mats and return pit.

The data of Fig. 7 were recorded on 4 - 5 of June 1997. The data of Fig. 8 were recorded in spring 1997 on 20 - 21 of May. Here, the average radiation is lower - and of much shorter duration at high level - than the radiation of June in Fig. 7. Nevertheless these lower radiation energies, the relation between radiation and water uptake stays the same.

## The Tipping-Bucket Flow Sensor

When the spoon of the tipping-bucket sensor is in the down position, problems may arise, since water will pass by the spoon without being counted. To overcome this problem, an interpolation table is constructed, where apparent spoon volumes connect to a value in a set of time intervals. When the time between two tipping-over pulses is in one of these intervals, the apparent spoon volume connected to this interval is used. Two methods of calibration for the instrument have been applied, using a measurement set up as in Fig. 9.

- The reservoir above the tipping spoon was filled with 1 litre of water. The pulse count was logged, whilst measuring the weight of the water leaving the instrument. Advantage: many calibration points. Disadvantage: needs a accurate weighing instrument (< 0.01 gram) and logging of weight and pulse count at the moment as the spoon is tipping over.
- Apply a constant known flow of water to the instrument and measure the time between pulses of the spoon. Repeat it for a number of known flows within the normal range of expected flow values. Advantage: can be simply done with available equipment and gives a lot of readings for one calibration point. Disadvantage: limited number of calibration points, which results in an approximation of the characteristics in a small part of the working range. The accuracy is never better than the accuracy of the known calibration flow.

The calibration procedures lead to an interpolation table that can be used in interpreting measuring data in-line with the data acquisition process (Table 1). The table provides an apparent spoon volume as function of the time between pulses from the tipping bucket, which corrects for the water that passes by the spoon. After installation of the tipping-bucket in the greenhouse and application of the calibration procedure in the data acquisition process, it showed that precise horizontal alignment of the instrument is hard to achieve. Applying a multiplication factor in addition to the interpolation table can compensate for the resulting error. After testing, this set up needed a multiplication factor of 0.984.

## CONCLUSIONS

Control of water supply by means of the method of constant drain return showed to be adequate to compensate the water uptake of ten rows of 37 plants each during several consecutive days. The drain flow can be chosen freely at a low value, giving rise to a reduction in the amount of water that has to be cleaned before being re-used, hence to a cost reduction. After calibration, the tipping-bucket sensor showed to be a reliable sensor for measuring the drain water flow.

## ACKNOWLEDGEMENTS

The authors wish to thank the EU Air III Research Program (CT93-1603), The Dutch Ministry of Agriculture, Nature Management and Fisheries and the IMAG-DLO institute for the sponsoring of this research.

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## Tables

Table 1. Time between pulses and apparent spoon volume as function of 5 actual flow values

| Actual flow [ml·min$^{-1}$] | 91.305 | 68.475 | 54.709 | 45.474 | 38.828 | 33.800 |
|---|---|---|---|---|---|---|
| Time between pulses [s] | 2.597 | 5.021 | 5.195 | 6.630 | 8.108 | 13.480 |
| App. spoon vol. [ml] | 4.565 | 4.565 | 4.559 | 4.547 | 4.530 | 4.507 |

## Figures

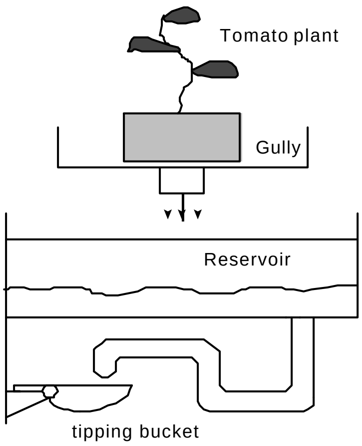

Fig. 1. Tipping-bucket sensor.

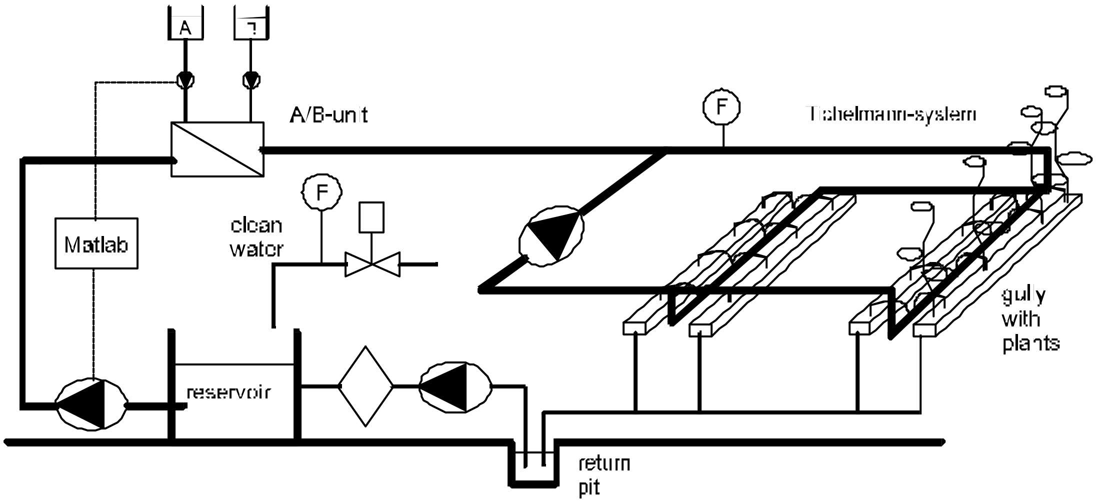

Fig.2. Layout of the controlled process.

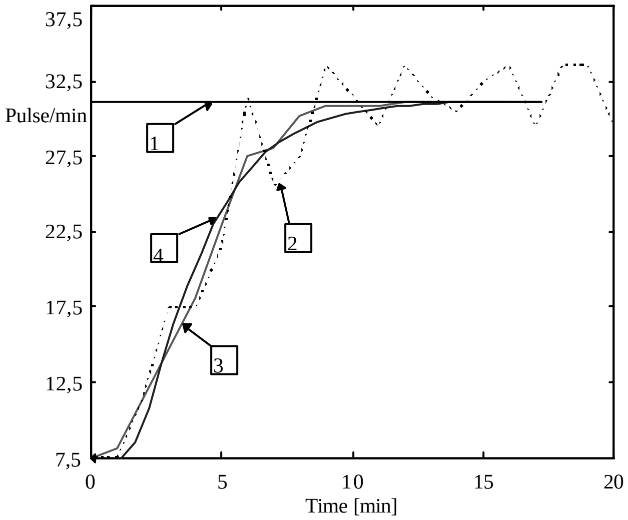

Fig. 3. Response of the drain flow on a unit step excitation on the water supply.

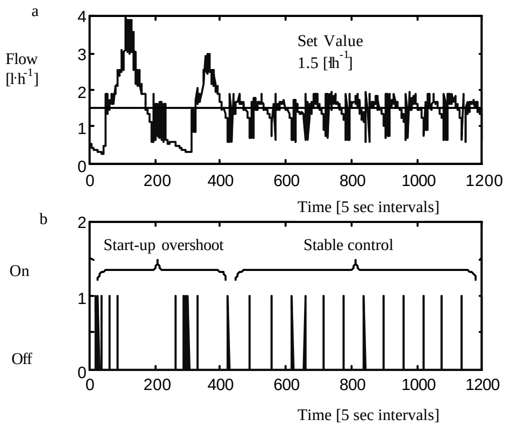

Fig. 4. Response of the controlled system during the first 100 min.

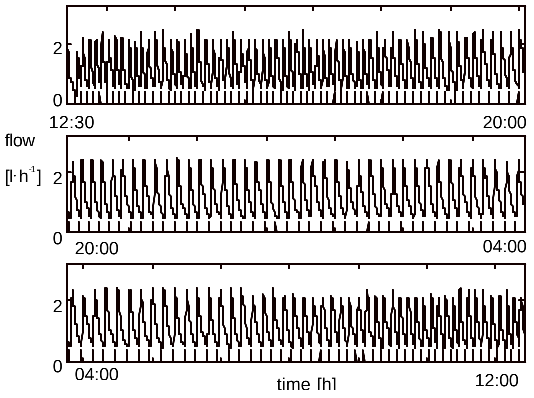

Fig. 5. Drain flow response of the controlled system

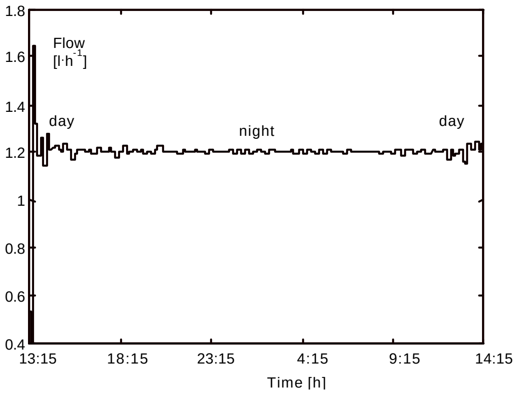

Fig. 6. Drain flow, where the return of each supply cycle is averaged.

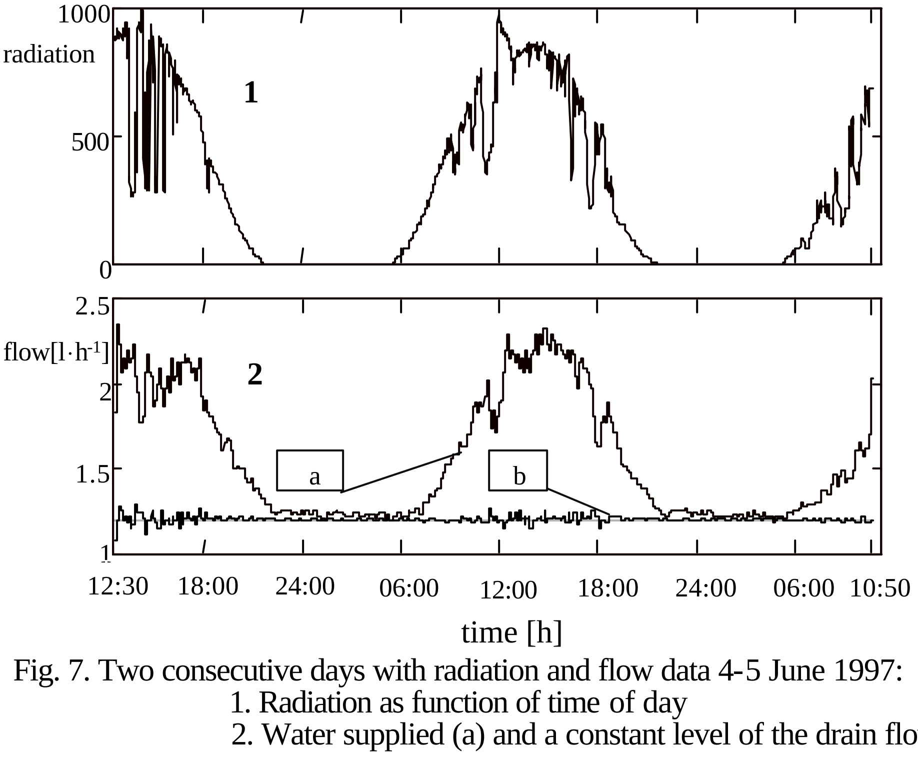

Fig. 7. Two consecutive days with radiation and flow data 4-5 June 1997:
1. Radiation as function of time of day
2. Water supplied (a) and a constant level of the drain flow (b).

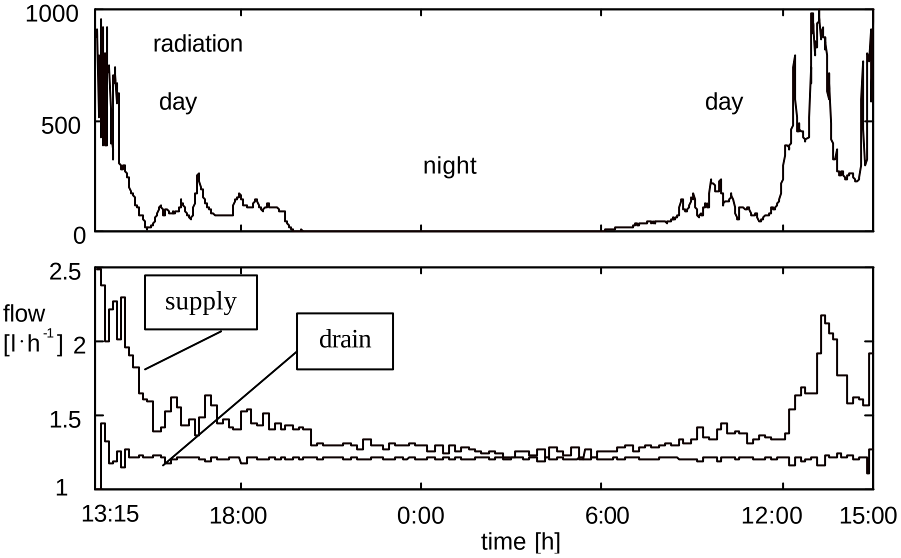

Fig. 8. Radiation and flow data recorded on 20-21 May 1997.

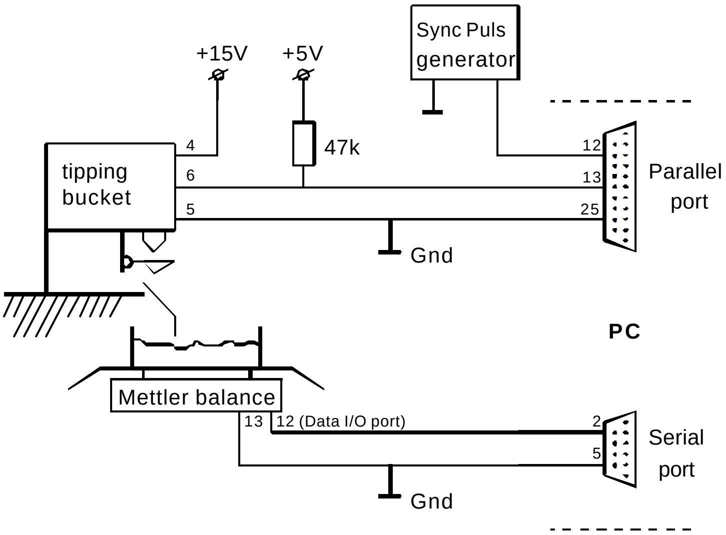

Fig. 9. Measurement set up for calibration of tipping bucket sensor.