On-line Acquisition of Plant Related and Environmental Parameters (Plant Monitoring) in Gerbera: Determining Plant Responses

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Abstract

For on-line plant monitoring equipment to be functional in commercial glasshouse horticulture, relations between sensor readings and plant responses on both the short (days) and long term (weeks) are required. For this reason, systems were installed to monitor rockwool grown gerbera plants on a minute-to-minute basis from July 2002 until April 2003. Data collected included, amongst others, crop transpiration from lysimeter data (2 m^2), canopy temperature using infrared sensors, rockwool water content, and greenhouse climatic parameters, such as global radiation and temperature. By combining data from lysimeter and water content, changes in crop fresh weight could be calculated on a daily basis. Both transpiration and daily fresh weight production were better related to light integral as measured inside the greenhouse, than outside the greenhouse. The contribution of heating pipes underneath the canopy to transpiration could be estimated with the system. From the relation between daily FW production and previous day light integral, a light use efficiency of ca. 10-g FW/MJ solar radiation as measured inside the greenhouse was calculated. Water use efficiency was on average 25 g FW/L. A 3-4 day drying cycle did not affect flower production. The results underline the importance of knowledge on the adaptation and tolerance of crops to stressful conditions, in order to be able to use plant monitoring under grower conditions effectively.

INTRODUCTION

On-line acquisition of plant-related and environmental parameters, in order to assess stressful circumstances to be used for controlling climate and irrigation under greenhouse climate conditions, has been proposed decades ago (e.g. Udink ten Cate et al. 1978; Hashimoto, 1979; Hopmans, 1981). The potential of the horticultural equivalent of an 'intensive care unit' was thought to be an attractive and logical development, since at present only indirect links exist between plant functioning and environmental conditions. Setpoints for greenhouse climate controllers are at best obtained from empirical experiments, which are 'valid only for the given circumstances'. Direct signals from plants in reaction on the conditions they are actually growing in, would in theory be a more direct controller than setpoints obtained from empirical/experimental studies.

However, the introduction of monitoring techniques based on plant related parameters in commercial horticulture as a means for e.g. a climate controller, has been slow for both sensor-related (1) and crop-related (2) factors.

1) Sensor related factors.

Preferably, sensors are accurate, show good repeatability and no drift or interactions with environmental parameters (e.g. temperature), require no maintenance and are nicely priced. Data reduction procedures by filtering 'odd' data should be implemented.

Besides, the use of the sensor should preferably require little labour for adjustments, which excludes the use of a number of methods with 'attached sensors' such as photosynthesis, stomatal conductivity or chlorophyll fluorescence.

Progress has been made on the technical side of some monitoring techniques. For

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instance, a FD sensor monitoring water content and pore water EC from measured permittivity and bulk-EC (Hilhorst, 1998; Baas and Straver, 2001), shows many of the desired characteristics and has been introduced into commercial practice for irrigation means by rockwool manufacturers in the Netherlands.

2) Crop related factors.

a) Variability, both in the environment and within the crop. Biological systems typically show large variation. Moreover, crops grow, which itself may alter variation and may cause difficulties in obtaining reliable plant parameters on an on-line basis over a prolonged time (weeks).

b) Lack of knowledge on the interpretation of the data. This is probably the most difficult problem to tackle. Is a signal/response a deviation from e.g. a diurnal variation, at which level of response is a process (irreversibly) affected, and, if a process is affected, does this relate with e.g. long-term yield and/or quality? These kinds of questions immediately rise when plant-monitoring equipment is used.

For this purpose, the aim of our research was to focus mainly on the aspects of signal response in relation to short and long-term crop performance. Therefore, two monitoring systems were installed in which different treatments with their corresponding plant and environment responses could be compared.

MATERIALS AND METHODS

In a computer controlled Venlo-type glasshouse (12 x 12.8 m) 6 beds of each 10-m long and 1.1 m width were positioned. Each bed consisted of 2 rows of tempex on which 1-m plastic gerbera containers were placed. Rockwool slabs (1 x 0.1 x 0.07 m) fitted in the containers and 5 gerbera plants (c.v. Serena) in propagation cubes were planted per container in week 24, 2002. Nutrient solution (2 dS/m) was applied with one dripper per plant and the drainage solution was recirculated. In two of the beds, weighing systems of 2 m^2 were placed in such a way that the plants were under near identical conditions to the rest of the crop. Each lysimeter system, which consisted of an aluminium frame, contained 4 containers (Fig. 1). The system was weighed continuously by 4 CELTRON LOC50 kg loadcells (resolution 2 g per loadcell). On the frame a 12-l drain tank was positioned on a CELTRON LOC30 kg loadcell (resolution 1.2-g); the drain solution was collected from the containers after irrigation and was removed automatically once a day. The loadcells were connected to a digital junction box (Leon engineering DJB-4) which logged to a PC. In this set-up transpiration was calculated on a minute-to-minute basis by ignoring differences in fresh weight (van Meurs and Stanghellini, 1992). For noise reduction, a 20-minute running average was used.

In each rockwool slab in the lysimeter, a frequency domain (FD) sensor (Delta-T WET sensor) was placed vertically between two propagation tubes. The FD sensors logged permittivity, EC and temperature in the slab. From the relation between permittivity and water content (%v/v), water content and weight of the rockwool slabs were calculated. The changes in the difference between total weight of the lysimeter system and the water volume in the rockwool in time were calculated as the changes in fresh weight (FW).

Other data collected on-line above the lysimeters were leaf temperature with infrared sensors (Apogee), global radiation (300-1100 nm) with a tube solarimeter (Delta T) and ventilated air temperature with a PT100 sensor.

Twice during the experiment a drying cycle was performed. On days 226-228 2002, no irrigation was given during the daytime; irrigation resumed from 8-12 p.m. During the drying cycle on days 280-284, 2002, no irrigation in the stress treatment were given at all.

The effect of switching the heating pipe of 50°C underneath the canopy on leaf temperature and transpiration was studied on day 7, 2003.

Flowers were harvested at marketable stage once a week during the experiment and number and weight was recorded.

RESULTS AND DISCUSSION

Fig. 2 is an example of typical results obtained with the system. At the onset of a day, all values were set to zero. Irrigation is visible from the weight differences and the water content data. From the minute-to-minute weight changes, (cumulative) transpiration and – in combination with water content data- FW change was calculated. Maximum FW change and transpiration were ca 0.1 and 4.4 kg/m^2.day, respectively, in summer conditions (daily light integral inside the greenhouse around 1000 J/cm^2). In winter conditions, with daily radiation integrals around 100-150 J/cm^2, FW change was at most 0.05 kg/m^2.day, and transpiration ca 0.6-1 kg/m^2.day. The relation between daily global radiation integral, measured inside the greenhouse at canopy level, and transpiration (Fig. 3) proved to be better (Fig. 3: r^2=0.89-0.91) than when measured outside the greenhouse (r^2=0.72-0.79). This may be attributed to the use of artificial lighting on the one side and to shading by screens at high light intensities on the other. Apart from the influence of heating, transpiration was well predicted (Fig. 4) within (a randomly selected) day, with the relation from Fig. 3. With the increased use of assimilation lighting and use of shading screens in glasshouse horticulture, light measurements at the canopy level therefore reflect transpiration better than light measured outside the greenhouse. However, transpiration models in commercial horticulture are until now based on outside radiation (e.g. de Graaf, 1988).

The effect of the 50^0C-heating pipe underneath the gerbera canopy was studied by switching it on or off (Fig. 5). On a day with relatively little transpiration (day 7, 2003; 1.5 kg/m^2) the effect of the heating pipe was clearly seen on both transpiration and leaf temperature. Compared to days with a comparable light integral (190 J/cm^2), constant heating increased transpiration by 15-25%.

Estimated differences in plant fresh weight were only used on a day to day basis. Variations in plant weight during the day (Fig. 1) due to differences in relative water content (e.g. van Ieperen, 1996) were considered rather unreliable, due to unsatisfying efforts to control the different temperature-effects on the loadcells. The relative constant temperature during the night allowed calculating day-to-day differences in plant weight however. This method is particularly sensitive to differences in water content, since a difference of 1% over a day is the equivalent of ca. 0.14 kg/m^2, which is more than the maximum daily FW change during the whole trial. The accuracy of the FD sensors, together with the apparent constant volume of the rockwool during the experiment allowed to assess FW changes, which were in the same order of magnitude as the result of a destructive harvest as measured at the end of the trial (data not shown).

FW change related to radiation integrals with a lag time of 1-6 days. For cucumber, also a lag time of several days upon changing radiation has been found, which was ascribed to light adaptation (Marcelis, 1992). Linearly through the origin, a ‘light use efficiency’ of 10-g FW/MJ is calculated. As for the transpiration, FW change related better to light integral inside the greenhouse (Fig. 6 left) than to outside light integral (Fig. 6 right). Not surprisingly, since the relation between transpiration and light integral was strong, a relation between transpiration and subsequent FW change was also found, although not as profound (r^2=0.53, not shown). From this relation, an average water use efficiency of 25 g FW/L was calculated, which is somewhat higher than the ca. 15 g FW/L as measured for roses (Baas, 2001).

The changes in FW, as determined by the day-to day changes, are cumulatively given (Fig. 7). The data are corrected for the weekly harvested flowers, and therefore show the total FW increase (including flowers). Since the data of the weekly harvested flowers are also shown in Fig. 7, it is clear that the growing crop (total FW - harvested FW) shows a decline after the summer period, and remains between 2-3 kg/m^2 in the period from the middle of October to march. This effect however does not significantly affect the (for growers most interesting) flower production; apparently older leaves die and the remaining amount of leaf material is sufficient to sustain a relative constant flower production for a prolonged time despite changing light conditions. Flower production (which takes approximately 6-9 weeks from initiation) was relatively well related to a six-week light integral (data not shown) and shows therefore a quite different reaction time than canopy fresh weight.

The dips in the growing curves correspond with water stress periods, which were applied in august, and in October. However, no effects on the subsequent flower production could be found. Apparently, flower initiation and development was unaffected by a period of water stress for a number of days. This finding underlines the plasticity or adaptation potential of the gerbera crop. It is clear that the setpoint for – a temporary – minimum water content can be low, without adverse effects on gerbera flower yield. Immediate response upon lowered water contents for the risk of yield decrease, is therefore not necessary. Other reasons for avoiding low water contents (e.g. irreversible drying of rockwool) might however be valid of course.

The results from the transpiration studies in relation to light integral, and of the other data given in Fig. 2 can be used in irrigation control. Studies like the effects of heating on transpiration (Fig. 5) can be used for climate or energy efficiency reasons. However, the results also demonstrate that short-term responses caused by e.g. a temporary stress period may not necessarily influence long-term yields. For use of plant monitoring as a stress diagnostic tool, more knowledge on – the limits of - adaptive processes of crops to adverse conditions remains the key to successful implementation of the speaking plant concept in commercial horticulture.

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Figures

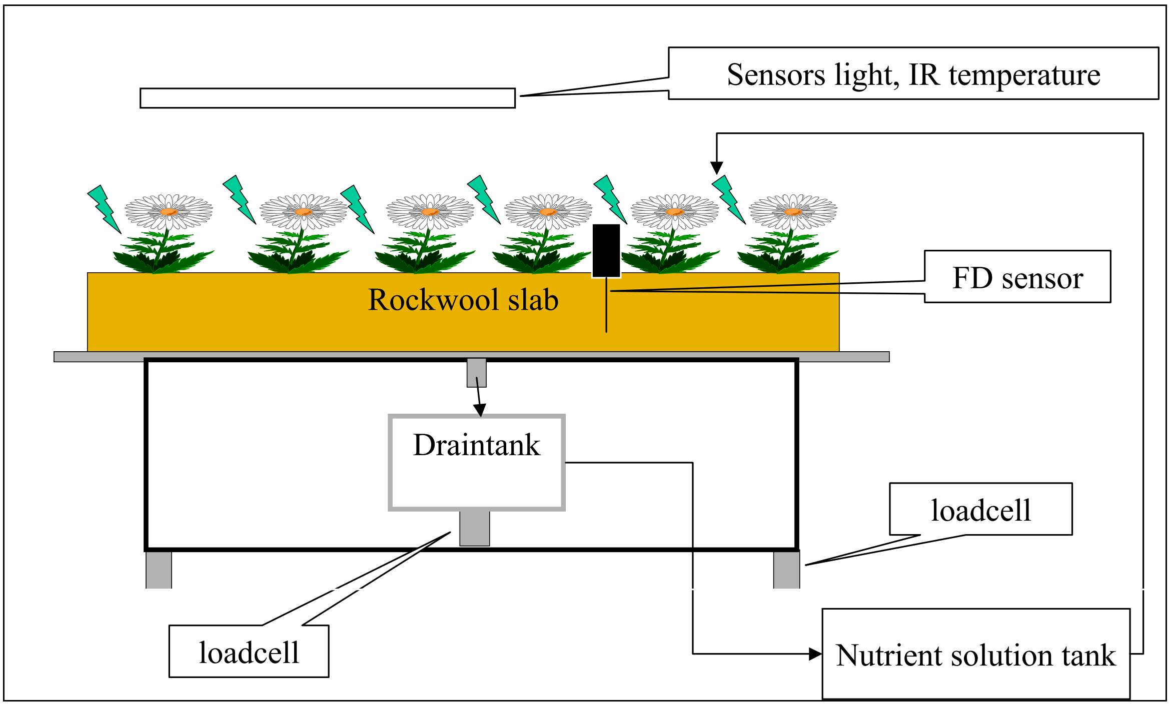

Fig 1. Schematic presentation of set-up of lysimeter and sensors in gerbera experiment.

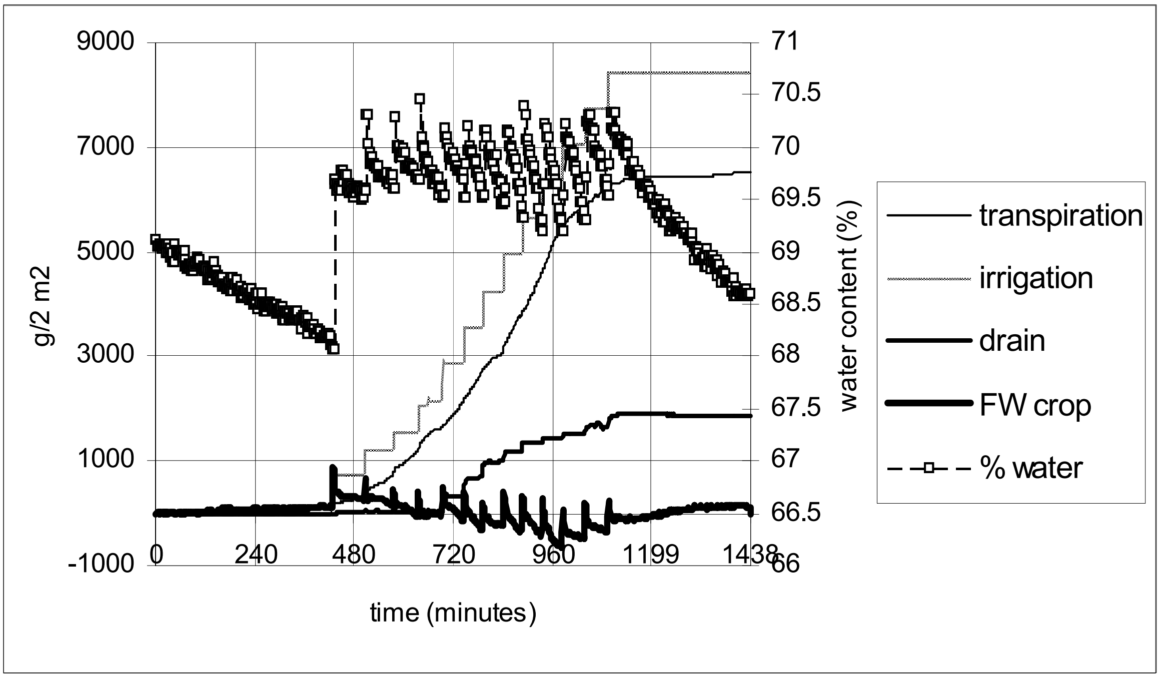

Fig. 2. Example of processed data (day 241, 2002) from lysimeter in combination with FD sensor.

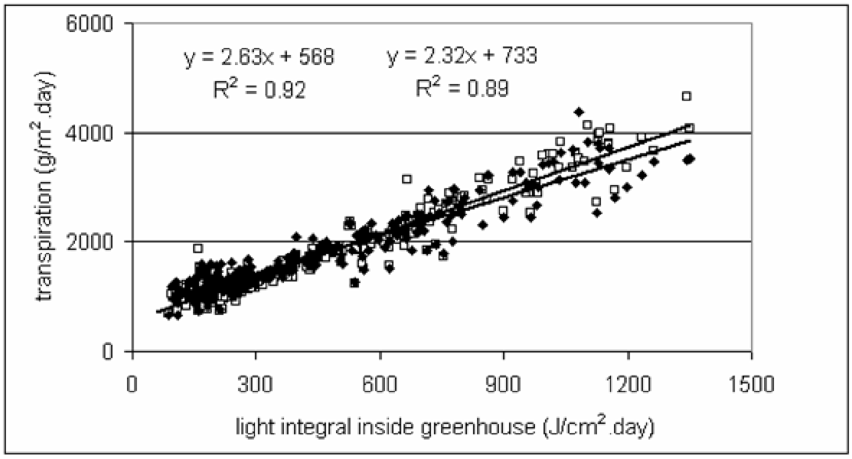

Fig. 3. Relation between light integral (global radiation) and realised transpiration in two lysimeters. Data from day 192, 2002 through day 112, 2003.

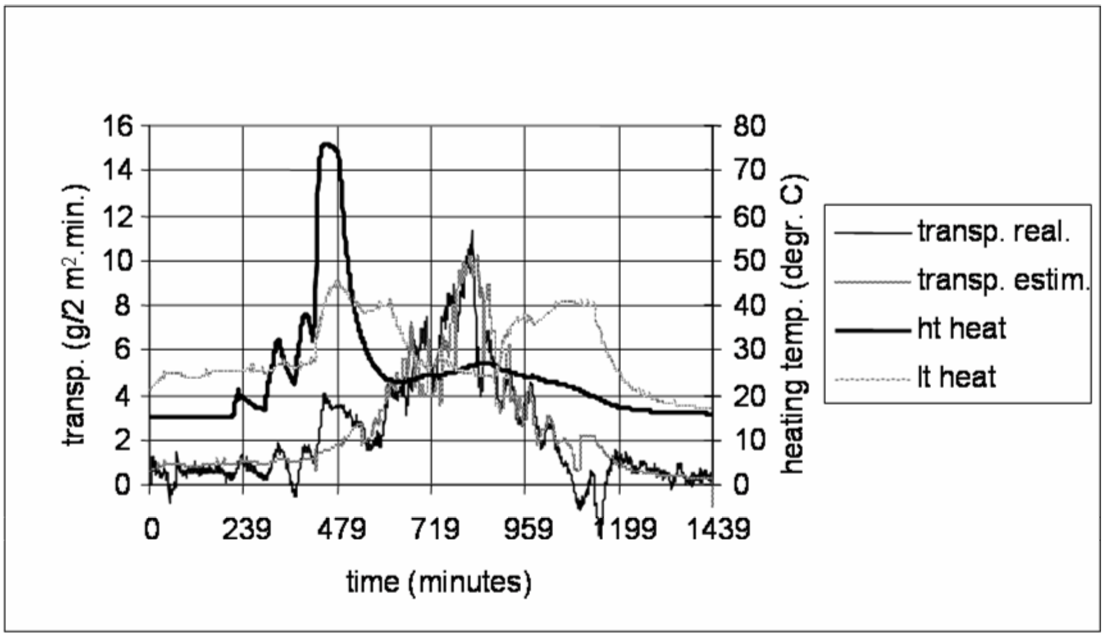

Fig 4. Estimated and realised transpiration (day 60, 2003). Temperature of heating pipes above (ht heat) and below (lt heat) the canopy is also given.

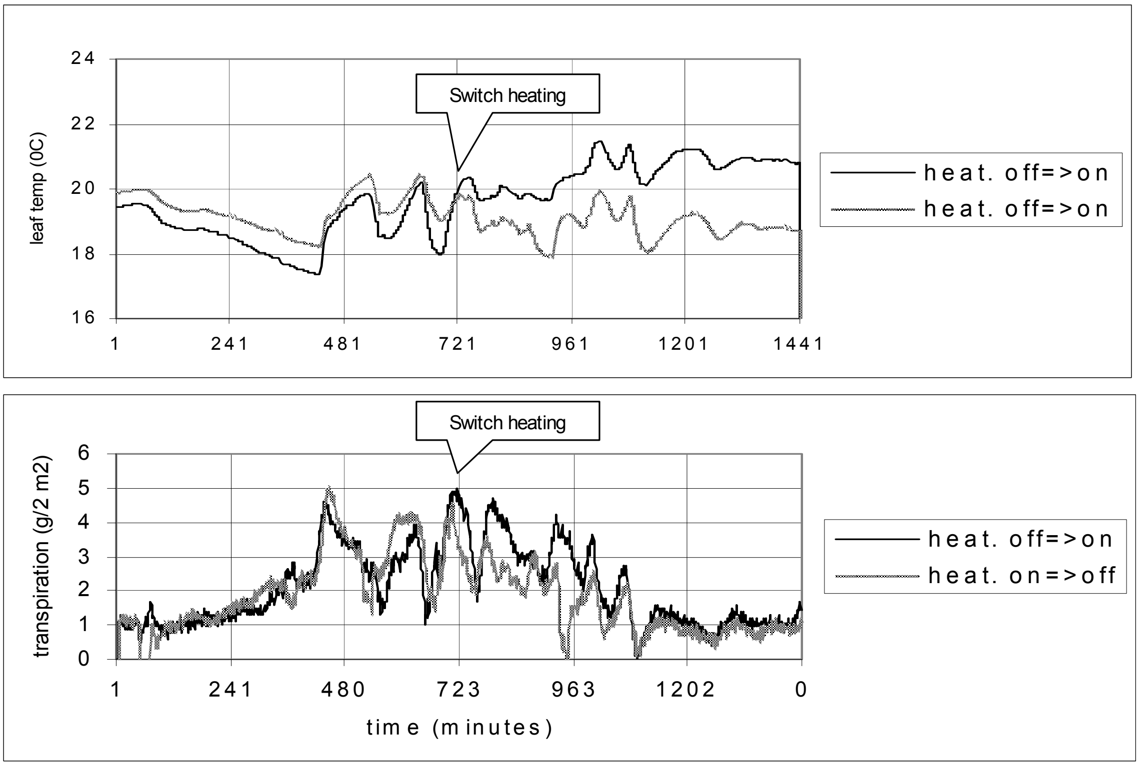

Fig. 5. Effect of switching on or off the heating pipes (50^{0}C) below the gerbera canopy on leaf temperature and transpiration (day 7 2003).

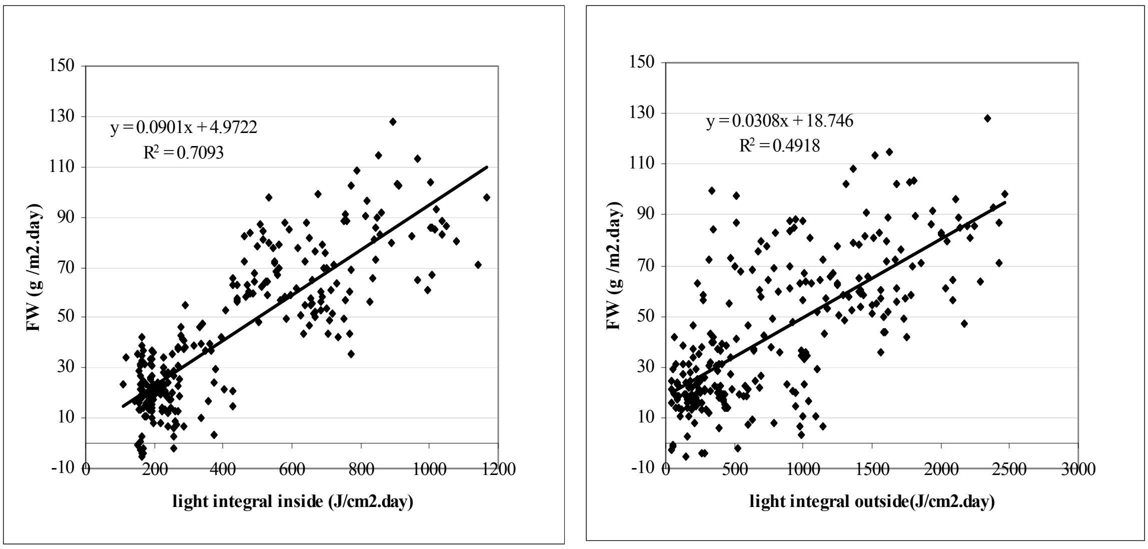

Fig. 6. Relation between daily FW production and previous day light integral, measured inside (left) and outside (right) the greenhouse (day 205 2002 – day 112 2003). Note: data are running average of 7 days.

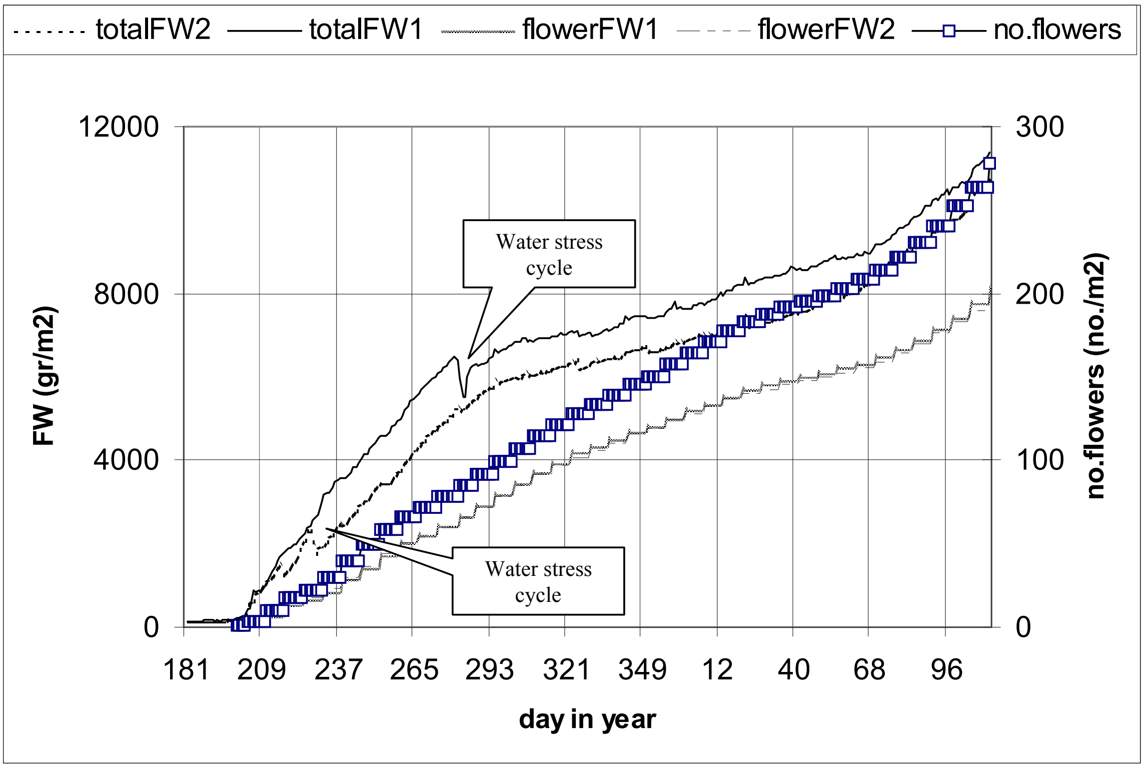

Fig. 7. Cumulative calculated FW production and gerbera flower production (from harvesting) from two lysimeters during the entire experiment.