Steering of Fogging: Control of Humidity, Temperature or Transpiration?

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Abstract

Fogging systems are increasingly used to cool greenhouses and prevent water stress. More recently, fogging systems are applied also in relatively low radiation environments (such as The Netherlands), for a better control of product quality than whitewashing and to reduce need for natural ventilation – thus allowing for higher CO_2 concentrations to be maintained in the greenhouse. Most commonly the steering of such systems is done by setting an upper limit to the deficit of specific humidity that, whenever exceeded, triggers the fogging system. In both cases, however, one may wonder whether static and pre-fixed set points are the most effective choice.

In the experiment presented in this paper, fogging and venting were controlled with the purpose of steering crop transpiration. The desired transpiration rate was the input of an algorithm that calculated on-line the required humidity and air temperature set points in view of the current weather factors. The set points were then the input of a standard P-controller that calculated vent opening and time of operation of the fogging system. In this paper, the resulting climate and actuator control operations are discussed and compared with a similar greenhouse controlled in a traditional fashion. The study concluded that a desired crop transpiration rate (an all-round indicator of crop well-being) could be used to select dynamic set points for the climate control in a greenhouse equipped with a fogging system.

INTRODUCTION

The management of humidity has two purposes: maintaining crop transpiration within boundaries and preventing condensation on the crop. With respect to transpiration: too low and too high rates may result in local Ca deficiencies; in addition, a high rate – not matched by water uptake – results in turgor loss, partial stomatal closure and loss of assimilation. Condensation is known to increase incidence of pathologies such as mildew and botrytis (Köhl et al., 2007). In a traditional greenhouse both aims are combined in set-points for humidity (a maximum relative humidity or a minimum humidity deficit) whose crossing triggers procedures combining ventilation and heating, estimated to result in some 20% of the energy consumption of Dutch greenhouse (Bakker, 1991). There is little that can be done in a traditional greenhouse about too high transpiration, except shading or whitewashing, which obviously lower assimilation.

Fogging systems are a very effective tool to prevent water stress. Most commonly the steering of such systems is done by setting an upper limit to a measure of the deficit of humidity that, whenever exceeded, triggers the fogging system. The underlying assumption is that the deficit of humidity is a good indicator of potential evaporation, and limiting the deficit is equivalent to limit crop transpiration. It is known, however, that the same deficit of humidity can results in quite different potential evaporations, depending on other climate factors, particularly solar radiation, so that one may wonder whether static, pre-fixed set points are the most effective choice. Since they have become relatively cheap, high-pressure fogging systems are applied also in fairly low radiation environments (such as The Netherlands), for a better control of product quality than whitewashing and to reduce need for natural ventilation, thus allowing for higher CO_2 concentrations to be maintained in the greenhouse. The so-called semi-conditioned greenhouses (venting, heating, fogging and cooling, sometimes coupled to thermal

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storage) make it possible to control independently the temperature and humidity, which is not possible in more traditional greenhouses.

In the lack of a relevant body of knowledge, growers apply the steering criteria and set points they know. In view of the need of applying water resources in the most effective way possible and as the productivity in such greenhouses has not grown so as to pay back the additional investment that is required, there is an increasing awareness that such advanced systems should aim at the direct control of growth related processes and be based on simple indicators of plant welfare (Dieleman, 2008). This, together with the increasing energy prices, has spawned the need in particular for a fresh look at humidity, the purpose(s) of controlling it and to which extent our knowledge about its effect in plant processes has been conditioned by the constraints to its management in a natural system.

In this perspective, this study had a "fresh look" at data obtained from a series of experiments that was performed to test the hypothesis that lowering the transpiration rate could mitigate the yield loss caused by high salinity. This was proven and has been reported extensively (Li and Stanghellini, 2001; Li et al., 2001, 2002, 2004) and has been implicitly confirmed by Romero Aranda et al. (2002). Central to the experiment was a "transpiration control", an algorithm that constantly maintained crop transpiration to 65% of the rate in an identical compartment, using the opening of the roof ventilators and fogging as sole actuators. This paper describes how this was implemented and discusses the results in terms of climate attained and control of actuators, in order to show how a desired crop transpiration rate (an all-round indicator of crop well-being) could be used to select dynamic set points for the climate control.

MATERIALS AND METHODS

The experiments were performed in two identical compartments (300 m^2 each) of a multi-span Venlo glasshouse (Wageningen, the Netherlands, 52° N), where round tomato crops were grown in rock-wool, with a plant density of 2.2 m^{-2} and grown according to standard Dutch cultural practice. The greenhouses were equipped with a hot-water heating system and natural ventilation through alternate zenith opening on both sides of the ridge. One of the two compartments (the low-transpiration one, LT) was equipped with a high-pressure fogging system, with a constant capacity 0.17 L m^{-2} h^{-1}. The experiments were designed as split-plots, the subplots (half of each compartment) being the salinity treatment. So, there were two re-circulating nutrient solutions, each supplied to two halves of a compartment. A drain fraction around 70% and continuous recirculation for two hours after 2 a.m. were meant to prevent accumulation of salts in the slabs, which was indeed avoided. The transpiration control algorithm was implemented in the greenhouse climate control system and performed at two-minute intervals, 24 hours a day with the following procedure:

1. Reference transpiration rate was calculated through the model of Stanghellini (1987) – as implemented by Stanghellini and Van Meurs (1992) – as a function of current solar radiation (or lack thereof, at night), humidity and temperature in the reference compartment (high transpiration, HT) and an estimated Leaf Area Index (LAI). Solar radiation available for the crop was estimated from the weather station data, through the measured mean transmittance of the compartment.
2. The same model was inverted, to calculate the combinations of specific humidity deficit and temperature that would yield a transpiration rate which is 65% of the reference, under the same solar radiation (or lack thereof) and LAI.
3. Among those combinations, the one was selected that least modified the air temperature (with respect to the reference), under the constraint that the relative humidity, R.H., would not exceed 95%. The selection criterion was in view of the well known effects of temperature on crop growth and development and the constraint on R.H. aimed at eschewing mould pathologies (which never appeared).
4. A proportional (P) controller aimed first at attaining the desired humidity deficit through the control of the ventilators. When this was not enough, then it calculated the required operation time of the fogging system.

5. If necessary, the heating system was activated by a P-controller, as in the reference compartment.

To prevent differences in potential assimilation, CO_2 concentration in the LT compartment was made to be equal to the other one, which was controlled to 700 and 400 ppm, with closed and open vents, respectively. All climate and actuators data were logged by the greenhouse climate control system and saved at two-minute intervals. Transpiration was monitored by the following means: 8 plants on trays, supported by a frame resting on electronic weighing balances (60 kg full scale, 0.1 g nominal accuracy) one in the reference compartment and one in each salinity treatment in the low-transpiration compartment. Irrigation flow to each subplot was monitored through pulse flow meters with an accuracy of 0.5 litres. Drain of all subplots was collected separately in small tanks hence it was pumped back – through flow meters of the same kind – into the corresponding irrigation tank, by pumps triggered by floaters. For additional checks, a drain gauge (tipping spoon) measured drain flow, EC and pH from 8 plants in each subplot. In addition, the water use for refilling the two nutrient solution tanks (compound water use of the two equal salinity treatments in the two compartments) was metered as well. With hindsight, so many cross checks were not unnecessarily cautious, since all methods were rather prone to failure. The weighing balances could not be fully trusted while the fogging was on, and the two hours of continuous recirculation (and other incidents) caused leakages in some instances.

RESULTS AND DISCUSSION

Nevertheless, enough valid water use and transpiration data were collected to support the conclusion that the transpiration control achieved what it was meant to do (Fig. 1). As shown by Li et al. (2001), no effect was ever observed on the dry matter production or on plant development. There was a trend of more fresh weight production in the low transpiration compartment, that progressed from small and non-significant at EC = 2 dS m^{-1} to large and highly significant at EC = 9 dS m^{-1}.

How the "transpiration control" translated in terms of actuators is shown in Figure 2, displaying climate and actuator data during a sunny day. In the HT compartment, the humidity control caused a combination of minimal venting (C) and heating (D) in the hours before sunrise, whereas in the LT compartment vents were open more shortly and heating was applied for a shorter time and to a lower pipe temperature. The ventilation was much less during the whole day (C), though dynamic set points for temperature and deficit of humidity resulted in more variability in ventilation. A higher air temperature was allowed in the morning and afternoon (D) in the LT compartment. The steering of the fogging (A) was more variable than it would be if it were solely based on one variable, such as humidity or radiation (C). The capacity of the system was too limited to deliver the desired humidity (B) in such a sunny day, in spite of the almost continuous operation between noon and 5 p.m., which explains why the measured transpiration was slightly higher than the desired level (Fig. 1). The daily daytime and night-time average climate in the two greenhouses, for two experiments lasting nearly a whole year, is displayed in Figure 3. We may infer that the same productivity was attained in spite of significant differences in humidity management (mean humidity difference 1.3 g/kg) and, to a lower extent, temperature (mean difference 1.5 and 0.8ºC for the 1st and 2nd experiment, respectively).

CONCLUSION

The use of a complex indicator of plant well-being, such as the potential transpiration, allows for dynamic set points for climate actuators to be derived. This may reduce energy costs for humidity control and it may also reduce the need for ventilation (making possible increased CO_2 concentrations).

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Figures

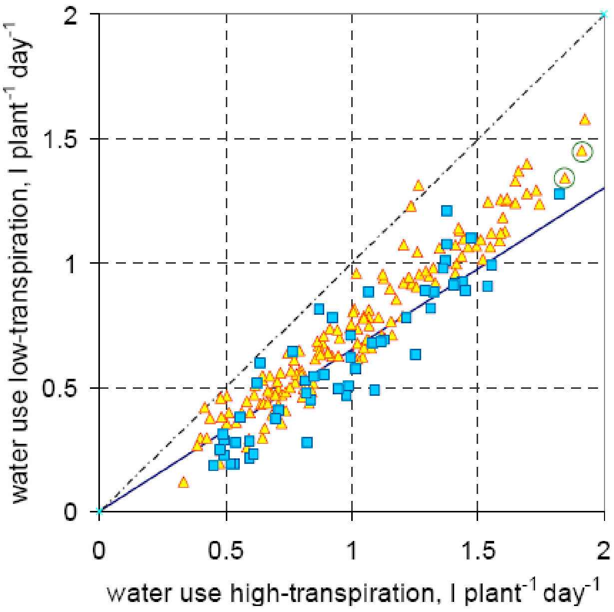

Fig. 1. Water use (liters per plant per day) measured in the low-transpiration compartment v water use of the same EC treatment, measured in the reference, years 1996 and 1997. Squares indicate a root zone salinity of 2 dS m^{-1} and triangles of 9 dS m^{-1}, two different experiments. The thick line indicates the target trend of the transpiration controller. The two circled triangles refer to the day discussed in Figure 2.

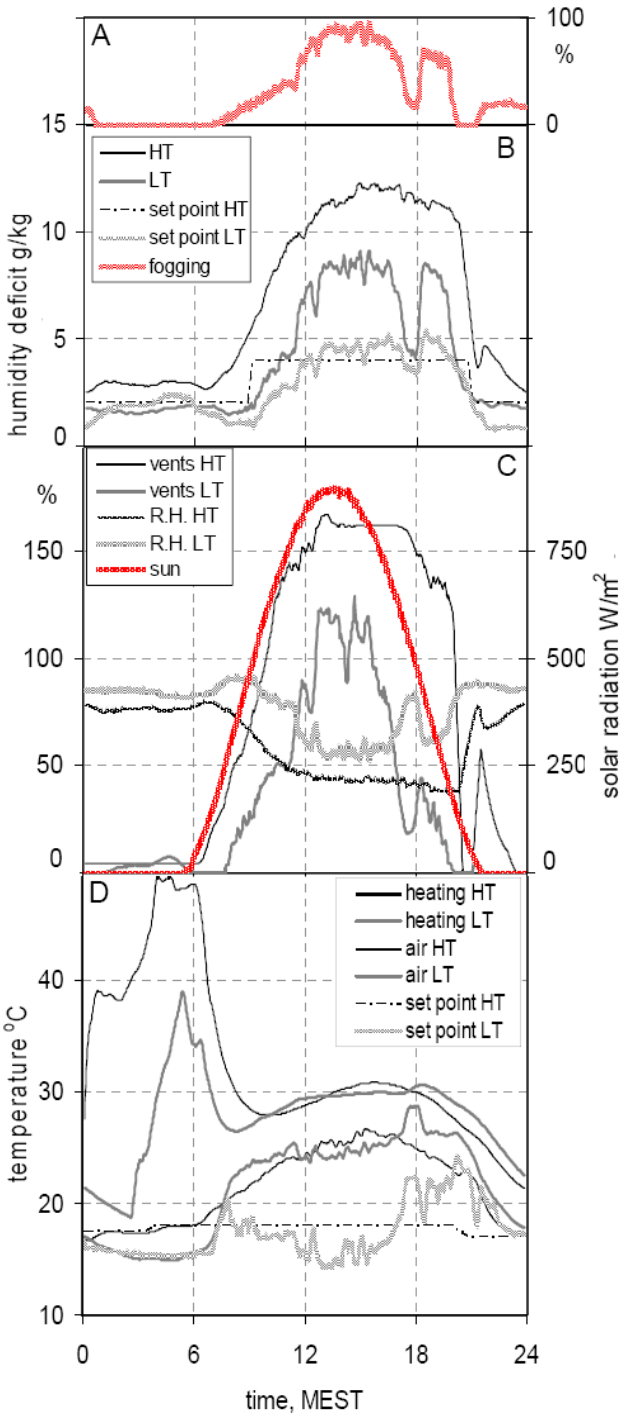

Fig. 2. Set points, actuators and climate in the two compartments (HT = high and LT = low transpiration, respectively), June 3rd, 1997, a sunny day. A) operation of the fogging system, % of time, at least 16 seconds without operation were left each 2-min cycle; B) measured specific humidity deficit and its "set point". Set point in HT is minimum, in LT is used for P-control of venting and/or duration of fogging; C) solar radiation, relative humidity and vents opening, sum of both sides in % of the maximum opening; D) temperatures: "heating" is pipe temperature; "air" is measured, the set point in HT is the heating set point for air temperature, in LT it is used for P-control of both heating and ventilation.

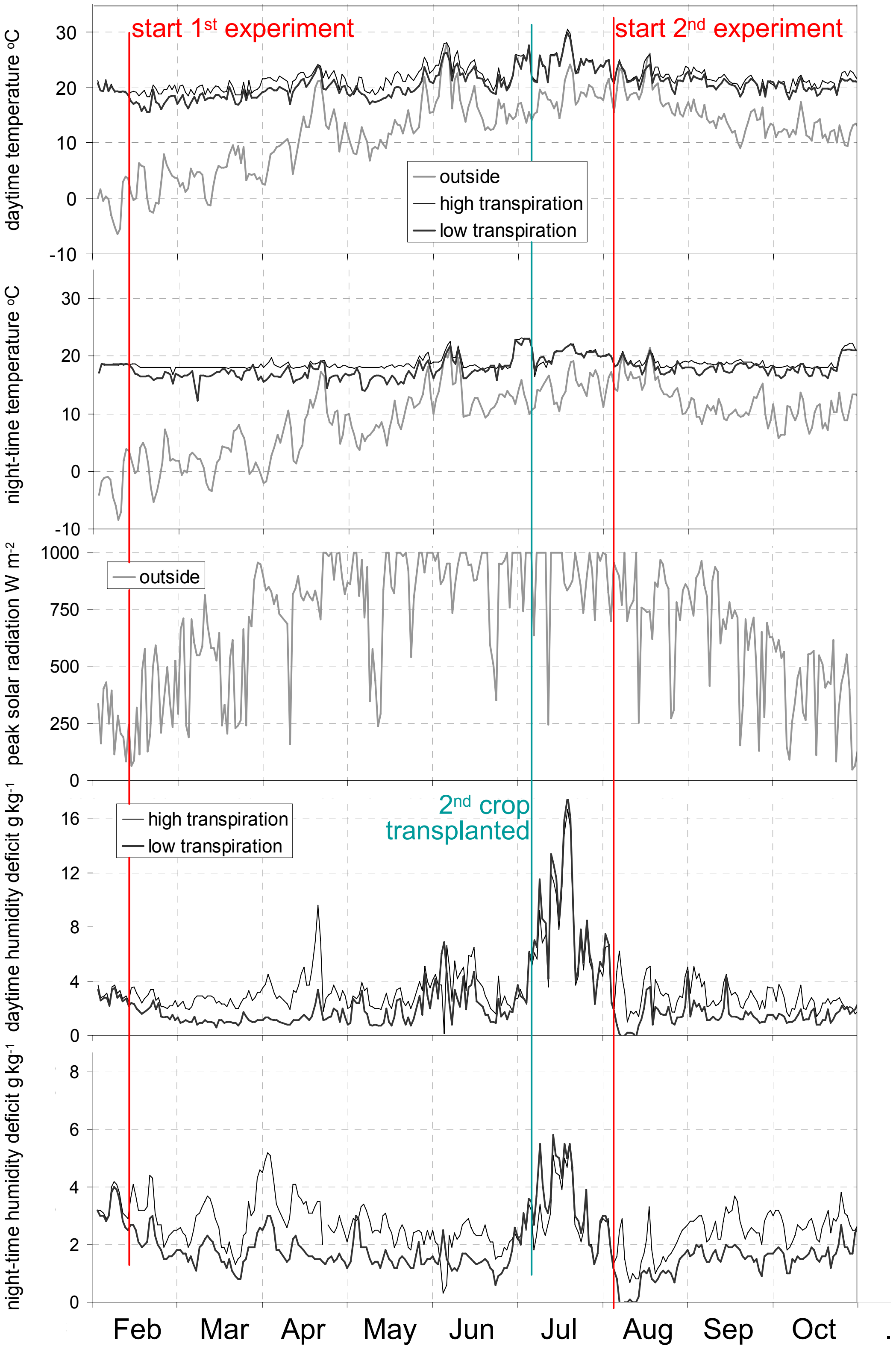

Fig. 3. Average ambient climate data in the two greenhouses, for two subsequent crops, 1996. The first crop had been transplanted on Dec. 15th, 1995. The peaks in humidity deficit in July are due to the coincidence of sunny weather and a very young crop.