Efficient Cooling of Strawberries: from Model Calculation to Implementation in a Commercial Greenhouse

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Abstract

Growing strawberries in autumn and spring crop cycle in greenhouses requires a start in the first week of August. Light intensity in this period ensures a good quality of crop with enough flower capacity for the spring crop cycle. A disadvantage of this early start is the almost non controllability of the start of harvest in autumn. An early start of harvest results in low prices and a low production. To control this, cooling of the greenhouse is required. Using a greenhouse climate model the effects on greenhouse climate of a number of cooling methods such as mechanical cooling, misting, misting with forced ventilation and insulation of the greenhouse soil were calculated. The most promising solutions were implemented in a greenhouse with four sections of a commercial grower. One section was used as reference. All sections were equipped with a misting system and vertical fans to improve air movement around the crop. The model predicted that the best solution was mechanical cooling in combination with insulation of the soil. Results of the autumn crop showed good agreement of the model calculations with the measured data. A reduction in growing degree hours of more than 10% by beginning of November was achieved. Night time temperature dropped up to 4°C compared with the reference. The start of the harvest was delayed by 10 days. Initially, a higher average fruit weight was achieved, but the overall production was not influenced. The overall energy use of the different treatments was reduced by 30% compared to the standard due to the use of several energy saving techniques.

INTRODUCTION

A strawberry plant may contain several developmental stages at the same time. In autumn, during the harvest, new flower buds for the spring crop cycle are already formed. Growers presume that this process of bud formation is stimulated by low night temperatures in the greenhouse. The theory is that cooled plants will spread flowering and production, so that finally more assimilates are available both for the fruits in the autumn crop and for the development of flower buds for the next spring cycle. Our hypothesis is that energy can be saved in the crop cycle by an earlier planting in the beginning of August, under the condition that cooling can control the temperature (De Zwart, 2004; Maaswinkel, 2008). Cooling at night in August and September could reduce plant development and production speed, but such plants have profited from the extra light during the first days in the greenhouse. The optimal temperature regime for this process, based on light sum – temperature sum, is 13.4+0.2°C per 100 J/cm^2 global radiation (Van Laarhoven, 2009). In practice growers define the desired night temperature in August-September at 9°C, a level which in August and the first half of September almost never will be reached (Vroegop, 2007). In 2008, a grower introduced a mechanical cooling system in his greenhouse in order to lower greenhouse temperature and spread the production. The results were disappointing since the drop in night temperature was only a few degrees Celsius and the reduction in degrees hours was small. In this paper we describe the process that led us to an improved cooling system and a reduced energy use in the growing of a strawberry crop.

MATERIALS AND METHODS

Dynamic Climate Model

Model calculations of greenhouse climate and energy consumption were carried out with the KASPRO model (De Zwart, 1996). The dynamic simulation model KASPRO can simulate a full-scale virtual greenhouse based on the construction elements, greenhouse equipment as heating, cooling and misting, different covering materials and their properties (transmission, reflection, emission), set points for inside climate and the outside climate of a given location. Output are several climate parameters, such as air temperature, relative humidity, CO_2-concentration and energy consumption. The model is based on the computation of relevant heat and mass balances. Greenhouse climate is controlled by a replica of commercially available climate controllers. The Venlo glass-greenhouse of the grower, with a trellis bar of 8 m carrying two roofs of 4 m, was assumed with a distance between two trellis of 5 m for all calculations. Four glass panes of 1.25 m are in between two trellis bars. A standard transparent (LS 10-ultra-plus) screen was installed inside the greenhouse. The strawberry crop was planted on August 5th and stopped June 10th next year. Climate set points were according to practice of the grower. The goal of these calculations was to find a system to achieve the "ideal" temperatures according to the hypothesis. Beside mechanical cooling, also other methods were considered (Jongschaap, 2009). The most promising methods were evaluated and compared with a reference that was based on the next generation greenhouse cultivation method, meaning reduction of energy consumption by increase of insulation and the exchange of creating air movement around the plant by fans instead of heating pipes. This means no use of minimum pipe temperature.

The Innovation Process

A group of eight experts from different fields (strawberry growers, crop scientists, climate specialists, technicians) was formed and held several discussion sessions at the farm of top strawberry grower Marcel Dings in Belfeld, the Netherlands. Together they defined common goals and described the ideal strawberry climate for a top production with reduced energy demand. In an iterative process, the effect of different technical systems for cooling and climate control in a strawberry crop were calculated with the KASPRO model and discussed with the group. Floor insulation and forced side wall ventilation had to be introduced into the model. The model calculations were carried out with mechanical cooling with or without floor insulation, several thicknesses of floor insulation, misting and forced ventilation, and were compared with a reference. The model calculations provided us with detailed predictions on the performance of these systems on greenhouse climate. Finally, the most promising systems were tested in an experimental setup at a commercial farm.

Experimental Setup

The experiment was carried out in an existing commercially used Venlo-type greenhouse of 8400 m^2 in Belfeld, The Netherlands (51.19° N, 6.8° E). The greenhouse was already divided into two compartments (called 5 and 6, Table 1) with separate control of heating, ventilation, horizontal screening and misting. For this research project we improved the existing compartmentalization and created four sections with movable vertical screens. Compartment 5 was divided into sections 1 and 2; compartment 6 was divided into sections 3 and 4 (Fig. 1). The climate, temperature, heating, ventilation and use of energy screens could only be controlled from sections 1 and 3. Therefore, section 2 follows 1 and section 4 follows 3, even if for example section 2 needed heating and section 1 needed ventilation. At night, when cooling was needed, the vertical screens were down but for maintenance and harvest during daytime the screens could be opened. All sections were supplied with a misting system with a capacity of 300 ml/m^2/h and vertical Airco Breeze fans from Hoogendoorn, one per 220 m^2 (www.aircokas.com). Section 1 is the reference. In section 2 the control of the misting system is adapted for use during night. In combination with four fans with a capacity of 8000 m^3/h each in this section the misting can continue. Even after sunset with low heat load this system can be used. Evaporation of water will reduce the greenhouse air temperature. The use of forced ventilation is introduced while with small temperature differences or even a negative temperature difference between in- and outside, the natural ventilation is significantly reduced even because at this time of the day in general the wind speed is reduced as well. In this setup a forced ventilation flow of about 15 m^3/m^2/h could be achieved. Sections 3 and 4 were provided with coolers, one per 100 m^2 ,with an out flow temperature of about 13°C and a cooling capacity of about 200 W/m^2. In section 3 the cooled air was distributed through plastic tubes, but in section 4 the cooled air was not distributed. In section 3, the soil was additionally covered with 40 mm thick blue Styrofoam floor insulation plates (Roofmate SL-A, Dow Chemical) with a thermal resistance (RD) of 1.15 m^2 K/W (Fig. 2).

Measurements

Each section was provided with a set of sensors containing of three measuring boxes with air temperature, humidity, plant temperature camera and a PAR sensor. The boxes were distributed in height: one up to 0.5 m above crop level, one at crop level and one up to 0.5 m below crop level. Sections 1 and 3 were also provided with an electronic CO_2 measurement. Energy use of the heating system was calculated from the difference of inlet and return water temperature (Verveer, 1995). The cooling energy was calculated from the flow and temperature difference of inlet and return water. Climate and control parameters as use of the misting system, windows windward and leeward side opening, horizontal screen and side wall fans, set points of heating, ventilation and humidity control were on 5 min base logged via the Hoogendoorn climate controller and uploaded to a Letsgrow web portal (www.letsgrow.com). Floor temperature was separately measured with an additional logging device at a depth of 4 cm. In section 3 this was done below the insulation plates. Each section was provided with three fields of 10 plants each. These plants were sorted on view as equal as possible, but the existing huge morphological variation in the plant material could not be reduced. Start of flowering, number of flowers and fruits per plant were measured weekly; at harvest the amount of fruits, fruit weight and the Brix content were also measured weekly. Grow degrees hours were calculated by summarizing per hour over the cropping cycle the degrees of average hourly greenhouse air temperature above 4.5°C.

RESULTS AND DISCUSSION

Model Calculations

The KASPRO model calculated a significant year round effect of floor insulation on day and night temperature. It appeared that insulation would increase energy consumption, especially in autumn and spring when the soil is heated in the day time and releases this heat at night. The calculations also showed that an ideal system layout (a guaranteed night temperature of 9°C) was only possible with a huge and expensive mechanical cooling capacity. Three possible systems emerged as second best options. Each of these systems were able to control the climate according to the temperature regime of the hypotheses. The use of a misting system could reduce the need for ventilation during day time and increase the CO_2 level, while the greenhouse air temperature hardly increased. From this we concluded that cooling at night was not necessary to reach the “ideal” twenty-four hours temperature regime. The calculations showed an increase of heating energy use when floor insulation was introduced. Floor insulation decreased the heat capacity of the greenhouse. In late autumn and in spring during daytime, the temperature of the greenhouse will increase faster and the start of ventilation on temperature will be earlier. But also, cooling of the greenhouse will lead to an earlier start of the heating. Finally, our calculations led us to three options which were tested in an experimental set up with a reference in a commercial greenhouse, as described in the experimental setup above.

Climate

During daytime, the misting decreases the greenhouse air temperature in all compartments up to 2 to 3°C below the outside air temperature (Fig. 3A). In sections 2, 3 and 4, the mechanical cooling devices were switched on at about 19:30 and quickly reduce the greenhouse temperature. In section 4 (without floor insulation) a few hours of cooling activity results in a temperature difference between inside and outside of 5°C. In section 3 (with floor insulation) a temperature difference reached up to 8°C, whereas in the reference only a difference of 1°C occurred. The system in compartment 2 (with misting and forced sidewall ventilation) was able to reduce the greenhouse air temperature with 2.5°C. Thus, all the developed systems allowed us to cool down greenhouse air temperature well below the outside temperature. Between 3:30 and 4:00 the systems were switched off in order to slowly increase the greenhouse air- and plant-temperature to at least outside air temperature. This was necessary to avoid condensation on fruits during daytime. The average temperature differences from 20:00-03:00 between inside and outside air for sections 1-4 were 0, 1.2, 6.7 and 3.7°C respectively. The twenty-four hours average temperature in section 3 was about 3°C lower than in the reference. In section 2, misting can continue till around 02:00. When misting was stopped, an immediate increase of the air temperature up to the level of reference compartment occurs (Fig. 3A). Average twenty-four hours greenhouse air temperature of the four sections from August 11th till January 5th shows that at night section 3 had in average a decrease in temperature of 1.5°C (Fig. 3B). Reference section 1 was the warmest; not only through the absence of cooling devices, but also because the location of this section in the greenhouse complex was known to be about 0.1-0.3°C warmer. One month after start of the crop cycle the amount of degrees hours in section 3 was reduced by more than 11% compared to reference (Table 2). Because the floor insulation could not be removed, the amount of degrees hours decreased through the whole Autumn. At winter stop (January 8th) the number of degrees hours in section 3 was still 8% behind the reference whereas the other cooled section showed smaller differences (Table 2). Differences in use of the misting system between compartment 5 and compartment 6 (Table 1) were caused by differences between the compartments, mainly caused by orientation of the greenhouse (Fig. 1). In spring the cooling systems were not used (Table 1), but still there was a difference in degrees hours, caused by the heating and ventilation system of section 1. While section 2 for ventilation was controlled by section 1 and section 1 requested more ventilation, in section 2 the ventilation was started too early according to the temperature of section 2 meaning a decrease in degrees hours of section 2 compared with section one. As predicted by the model calculations, the floor insulation decreased the heat capacity of the greenhouse. Due to the floor insulation, section 3 cooled down faster. The average greenhouse temperature in section 3 was closer to the set point heating (9°C) then the other sections (Fig. 3B).

Energy

The early start in first week of August became profitable in January. Other growers with comparable crops and greenhouses had started later, but in these crops the flower buds were not fully developed after the last harvest in December. Therefore, they had to continue the heating for (in some cases) a few weeks till January 20th. The energy saving by the earlier start of the crop cycle is calculated at 2 to 2.5 m^3/m^2. The use of minimum pipe heating could be decreased by the use of vertical fans to create air movement around the plants and so reducing humidity around the crop. Finally it was possible to finish autumn and spring crop with a total energy use of about 14 m^3/m^2 (Table 2). Reference companies use about 20 m^3/m^2 as a standard. The combination of misting, a start in early August, the use of vertical fans and the limited use of minimum pipe temperature all contributed to this significant or large reduction in energy use. Section 3, with mechanical cooling and floor insulation, used most energy as predicted by the model calculations (Table 2). The use of the cooling systems during the crop cycle was limited. In conclusion, our prior model calculations and discussions with the focus group proved to be useful in choosing the treatments. The reduction of the energy demand, however, was mainly caused by the lay-out of the greenhouse and the limited use of the minimum pipe.

Crop

The strawberry plants ('Elsanta') were planted August 10 and 11th. In spite of the big differences in greenhouse climate established, we did not create clear differences in plant development and production (Table 2). Where cooling was applied, initially a slower plant development, a later start of the harvest and a higher fruit weight was found, but in the end these differences disappeared (data not shown). The high morphological variability between individual plants perhaps obscured these effects. Although the cooling treatment led to an initial delay in production, we did not succeeded in spreading the harvest, but the development of degrees hours was delayed in section 3 and 4 (Table 2). Because the clear effect of cooling on the greenhouse climate, we expect that it should be possible to start even earlier with the crop cycle. We estimate that cooling allows for a week earlier start, provided that cooling ensures a slower plant development. By starting earlier it could then be possible to have a slower start, spread the production, produce more dry matter and reach a higher production level.

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Tables

Table 1. The use of cooling equipment in the four treatments (all in hours, for misting this indicates valve opening time) in autumn crop (A) and spring crop (S).

Compartment	Section	Misting		Misting at night		Coolers		Side wall fans	
		A	S	A	S	A	S	A	S
5	1	134	182						
5	2	134	182	11	0			257	0
6	3	141	215			180	0		
6	4	141	215			180	0		

Table 2. The development of degrees hours and energy use for cooling and heating and the production in the four treatments in the first month of the autumn crop, the full autumn crop (A), spring crop (S) and the complete crop cycle (Total).

Section	Degrees hours (°C)			Energy use (MJ/m^2)						Production (kg/m^2)		
				Cooling			Heating					
	08/10-09/11	A	S	A	S	Total	A	S	Total	A	S	Total
1	11534	38381	36138				184	210	394	5.2	9.3	14.5
2	11342	37433	34238				218	220	438	5.4	9.6	15.0
3	10224	35328	34332	34	-	34	240	220	460	5.4	9.2	14.6
4	11082	37185	35581	43	-	43	197	216	413	5.4	9.6	14.9

Figures

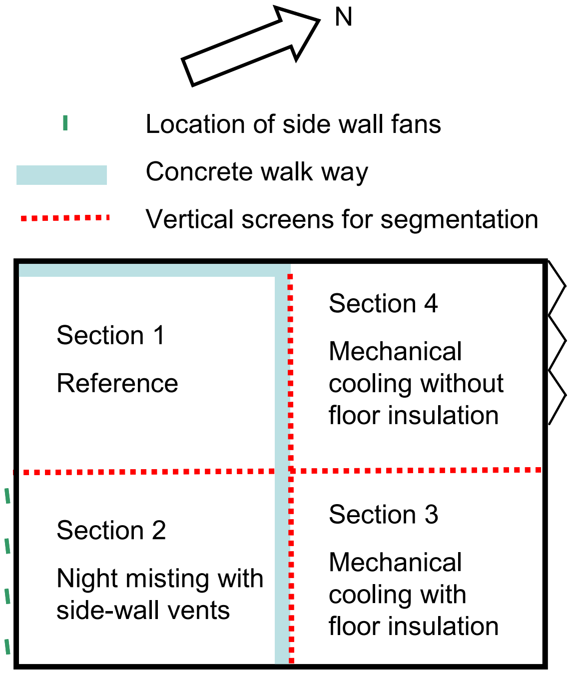

Fig. 1. Greenhouse treatments.

Fig. 2. Cooler in section 3 with insulation plates.

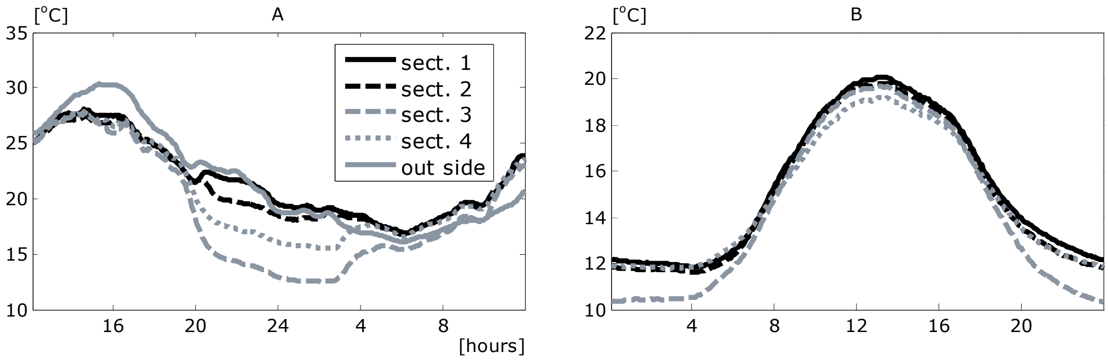

Fig. 3. Outside and greenhouse air temperature in four sections from August 24tn 12:00 till August 25th 12:00 (A) and twenty four hours average of greenhouse air temperature in the four sections from August 11th till January 5th (B).