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Full Length Research Paper

The efficiency of fan-pad cooling system in greenhouse and building up of internal greenhouse temperature map

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During summer periods, high temperature values that are being formed in greenhouses can greatly influence the efficiency of production workers and also decrease the productivity of plants grown there. A greenhouse production without the cooling systems can be sustained at the desirable level by imposing summer restrictions in the areas with warm climate, and by starting cooling in the areas with cold climate. A statement can be made regarding both utility and efficiency of fan-pad cooling systems that they tend to go up in the areas with low relative air humidity. The present study has been carried out in order to either prove or disprove this statement. We have attempted to create a map of internal greenhouse temperature distribution via determining the system's efficiency. As a result of this study, it was determined that since air temperature and relative humidity in the air tend to decrease during summer months by using fan-pad cooling system, temperatures in the greenhouse can be consequently lowered down to 10-12°C. Statistical analysis revealed remarkable differences ($p<0.01$) between the temperatures at various points in greenhouses observed.

Key words: Cooling system, fan-pad, greenhouse, temperature.

INTRODUCTION

The most important advantage of greenhouse production is keeping the environmental and climatic conditions under control. One of the most important climatic factors is the control of greenhouse temperatures. For plants grown in greenhouses, there are various seasonal temperature needs for each plant. In the controlled production environment, the temperatures required by each plant are controlled seasonally. The temperature increase becomes main problem in the greenhouses since glass or plastic cover materials are used in their design compared to walls in other structures which block the penetration of both light and heat. Various technological improvement methods allow for keeping the internal greenhouse temperature under control.

Harzadin (1986) stated that in order to obtain a sustainable plant production in greenhouses, the suitable environmental conditions during summertime should be maintained by cooling the greenhouses using different precautions. These environmental conditions can be maintained by keeping the internal greenhouse temperature and humidity within certain limits, as well as by maintaining necessary ventilation, cooling and shading in the summer season (Aydincioglu, 2004).

Seginer (1980) stated that control of the greenhouse air can be usually maintained by restricting the temperature which is the most critical parameter. Besides, such parameters as CO_2 and relative humidity are just as much important and should be also controlled in an ideal system.

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In order to continue the production process in the summer, required suitable conditions for each plant should be maintained. One of the most important tools for greenhouse cooling is the regulation of the transpiration phenomenon (Seginer et al., 2000). The transpiration occurring in plant leaves should not reach the stress level of plants. The regular cooling provides a satisfactory control for the transpiration (Anonymous, 2003). Stanghellini (1987) carried out a study which found proof to the idea that the transpiration in plants is the most important factor that is needed to be controlled in greenhouses. According to Bucklin et al. (1993), one of the methods lowering the air temperature by increasing the water vapor contents is called evaporative cooling.

As a result of studies published by Ozturk (2004), the fan-pad cooling systems can be used effectively in order to keep the internal greenhouse temperatures and relative humidity at the desired levels in the geographic areas with very hot summer months. It has been stated that they work better in the areas with low relative humidity since the efficiency of the system is somewhat a product of the relative humidity of the environment. Despite the fact that the wind speed tends to be higher in open areas during summer months, it is considered an irregular parameter and cannot be controlled. However, the greenhouse cooling can be done with fans which are considered to be a controllable and economically justifiable way of doing it (Li, 2007).

The fan-pad cooling systems which are properly designed and utilized can boost up the efficiency level in greenhouses to 85%. When the external moisture indications reach 50% level and the temperature raises up to 32℃, a vapor cooling system can lower temperature down to 24℃ (Yagcioglu, 2005).

Davies (2005) determined the efficiency of fan-pad system in greenhouse with tomatoes, peppers and cucumbers. He emphasized that fan-pad greenhouse cooling systems bring the internal temperatures down to 15℃, and this system has a better cooling efficiency at 5℃ level while compared with other systems.

In yet another study, Kittas et al. (2003) succeeded to keep the internal greenhouse temperature at 28℃ level by using fan-pad cooling system. By calculating the system efficiency to become 80%, they obtained a 10℃ decrease with respect to the external temperature. The moisture content in the environment is an important point in determining efficiency of cooling with using fan-pad systems. The lower the moisture contents in the area, the higher is the performance we can get from the fan-pad system.

Fuchs et al. (2006) examined the effect of fan-pad systems on transpiration of rose plants. They carried out cooling both by fan-pads and only by pads. With respect to the cooling realized only by fan-pad systems, the plant temperatures could be effectively decreased for 2℃, and internal greenhouse temperatures decreased by 15℃ compared with the external temperatures.

The goal of this study was to build up a temperature distribution map showing the efficiency of greenhouse fan-pad cooling system and to determine the critical levels of effectiveness of the system's usage.

MATERIALS AND METHODS

The greenhouse used in this study was built up as a triangular roof block system covered with one layer of glass. Both pads and fans were assembled in perpendicular positions to its end side. The roof air-conditioning was automatic in the greenhouse, however when the fan-pad system was not in operation, the windows had been kept open for the air condition and thus natural ventilation had been maintained. The greenhouse had three pads made of boards with 2.5x1.6 m^2 dimensions and two fans (1700 RPM with 0.55 kW of power).

Both temperatures and moisture in the greenhouse were regularly measured throughout the growing season. These measurements were obtained by HOBO devices. The HOBO-measured temperatures inside the greenhouse were recorded every 30 min. In order to accomplish this, six HOBO devices were positioned in the greenhouse with six temperature sensors connected to them. Outside temperature is taken from where has set up in the region climatic station. The temperature measurements were taken at 12 points in the greenhouse (Figure 1). The obtained temperature values were averaged up at 30 min increments, and the results were evaluated by using MS-Excel program. Then the results were presented using the graph charts. The internal greenhouse temperatures distribution was mapped using Surfer 8.0 software (Anonymous, 2008).

The following method of calculation of cooling system performance was used (Bottcher et al., 1989; Baytorun, 1995; Ozturk and Bascetincelik, 2002; Liao and Chiu, 2002; Yagcioglu, 2005; Sabeh et al., 2006):

$$n = \frac{T_{odb} - T_{cdb}}{T_{odb} - T_{owb}} x100$$

Where n = efficiency of evaporative cooling (%); T_{odb} = external air temperature (℃); T_{cdb} = cooling pad air temperature (℃); and T_{owb} = external air temperature (wet bulb) (℃).

The reason for using such method of cooling was to let plants in the greenhouse reach the temperatures that they need with controlled environment. Since the cooling processes in the greenhouse requires inputs not only of labor, but of energy as well, it follows that more energy must be needed to get the cooling reach the lower temperature levels compared to those ones outside. Although the temperature decreases are beyond those of the actual temperatures that are optimal for the plant, the results are that more energy is going to be consumed. That, in its own turn, affects the economic benefits of the greenhouse plant production as a whole.

In this study, the tomato plants were grown in pots. Both maximum and minimum required temperature values are shown in Table 1 (Hochmuth, 2001). The graphs drawn by sensor indications from three different locations were used to evaluate the temperature distribution in the greenhouse and the efficiency of the system at every greenhouse checking point. The temperature distributions based on indications of three sensors located in front of the fan (a), as well as of three sensors located in the middle of the greenhouse (b) and three sensors located in front of the cooling pad was investigated by using those graphs. The basic statistics were calculated relative to temperature data belonging to 50 daily averages

Table 1. Maximum and minimum temperature requirements for tomato plants.

Plant	Minimum temp. (℃)	Daily optimum temp. (℃)		Maximum temp. (℃)
		Minimum	Maximum	
Tomato	17	27	29	32

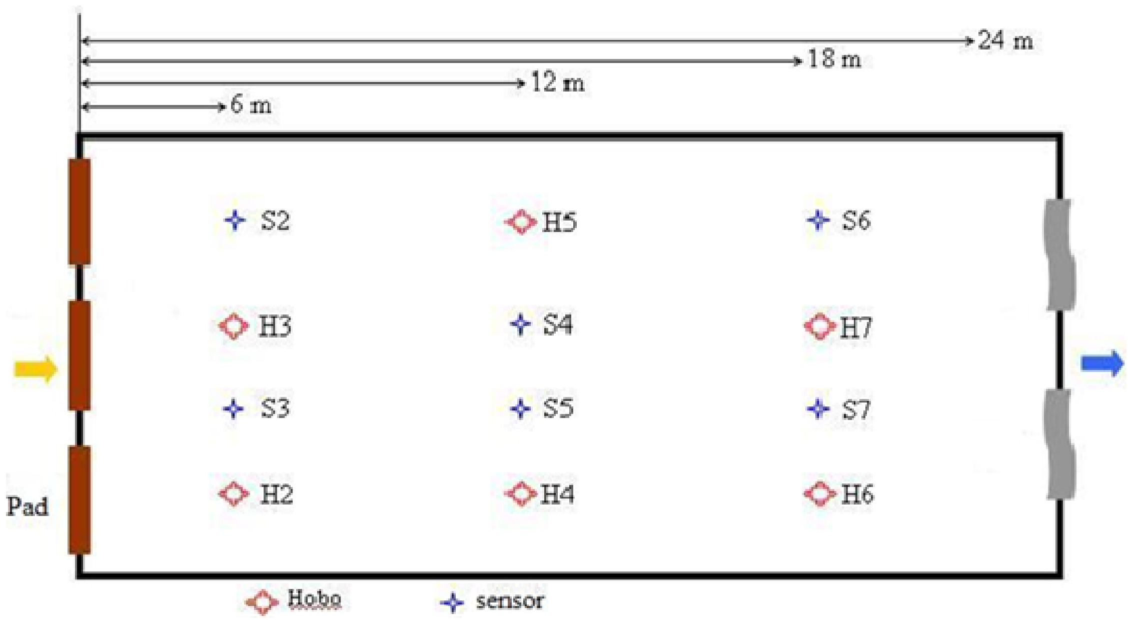

Figure 1. The location of sensors in the greenhouse.

measured at selected points, while using Kruskal-Wallis test. Kruskal-Wallis test, two or more groups independent from each other on the dependent variable distribution between the two measurements against the “whether there is a difference test” was used for the purpose. Multiple comparisons were furnished by using Bonferroni-Dunn method (Sheskin, 2000).

RESULTS AND DISCUSSION

In order to examine the temperature variations in the greenhouse during the growing season, randomized dates were selected and the system’s activity and cooling performance on these days were examined. Tomato seedlings were planted at the end of May and the fruits were grown around at the end of July. After end of July, it was going to be a problem for the plants to bear fruits at temperatures above 30℃ (Hochmuth, 2001). Fan-pad systems began to operate at 01:00 p.m. and were turned off at 04:00 p.m. The reason for this is that in fan-pad systems, the inner greenhouse temperature distribution displays a great variety. According to Ugurlu and Kara (1998), when the external temperature reaches maximum throughout the time interval between 02:00 p.m. and 04:00 p.m., the psychrometric features of the air passing through the pad must also be taken into account so that the cooling performance of the pads can be determined.

The temperature variations represented in Figure 2 show the continuous increase while the system is in operation. After the system operation is over, the temperature measurements at 02:00 p.m indicate a 13℃ decrease (as far as the internal temperature is concerned). Various temperature measurements at every point in greenhouse show the lack of similarity in temperature distributions. It has been observed that the temperature values go up as we move away from the pads.

There are regions in which cooling with fan-pad system seems to work out the most efficiently: those are the ones with low relative humidity values. As shown in Figure 3, the outer relative humidity value reached about 20% at 01:30 p.m. on July 26, 2007. The system, which started operating at 12:30 p.m., was turned off at 04:30 p.m. At 02:00 p.m., when the external temperature was 35℃, the temperature in front of the fan was measured as 27℃ indicating a dropdown of 8℃. The temperature taken by the sensors in the center line was measured as 28℃ level, showing a comparative decrease of 7℃. The temperature indicated by sensors located in front of the pad was measured as 22℃, showing a decrease of 13℃ as compared with the external temperature.

The lowest temperature indication was observed with

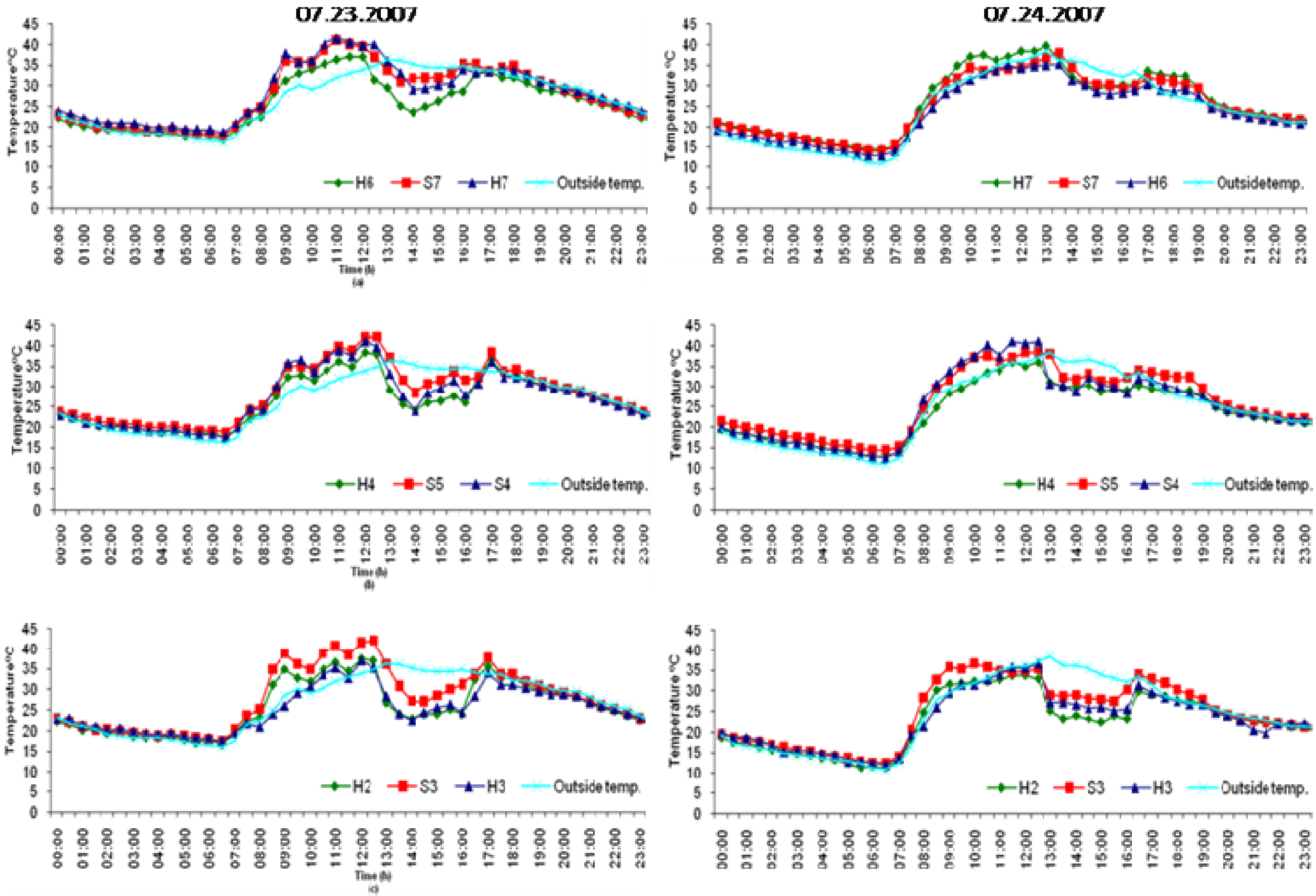

Figure 2. Hourly temperature variations as indicated by sensors (a) in front of the fan, (b) in the center line, (c) in front of the pad, on July 23, 2007 and on July 24, 2007.

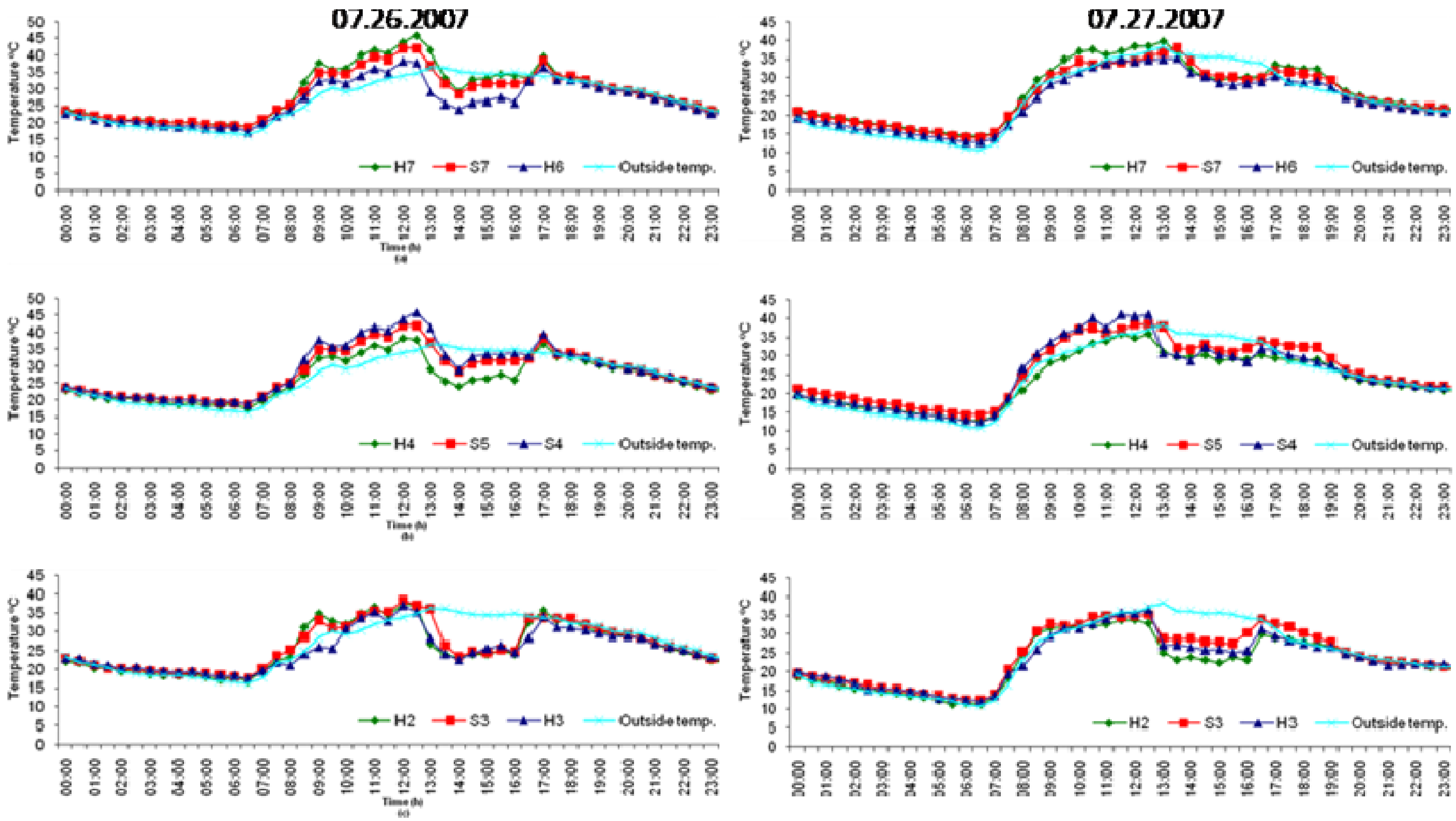

Figure 3. Hourly temperature changes of the sensors **(a)** in front of the fan, **(b)** in the center line, **(c)** in front of the pad; on July 26, 2007, when the outer relative humidity is the lowest and a day later (on July 27, 2007).

the sensors located in front of the pad. The reason for this can be explained by increase in the extent of air heat coming into the greenhouse from the pads as you move yourself towards the fans.

On July 28, 2007, the fan-pad system was not operating. When the temperature variations inside the greenhouse (Figure 4) were examined on that day, it was observed that the temperature measurements showed lower indications as a result of ventilation due to the pad openings located on the short axis oriented in westward direction in comparison with other checkpoints in the greenhouse. The temperature increase in the southern part of the greenhouse was measured to be higher than in the other points due to sun radiation. When the system was turned off, the temperatures in the greenhouse went above the

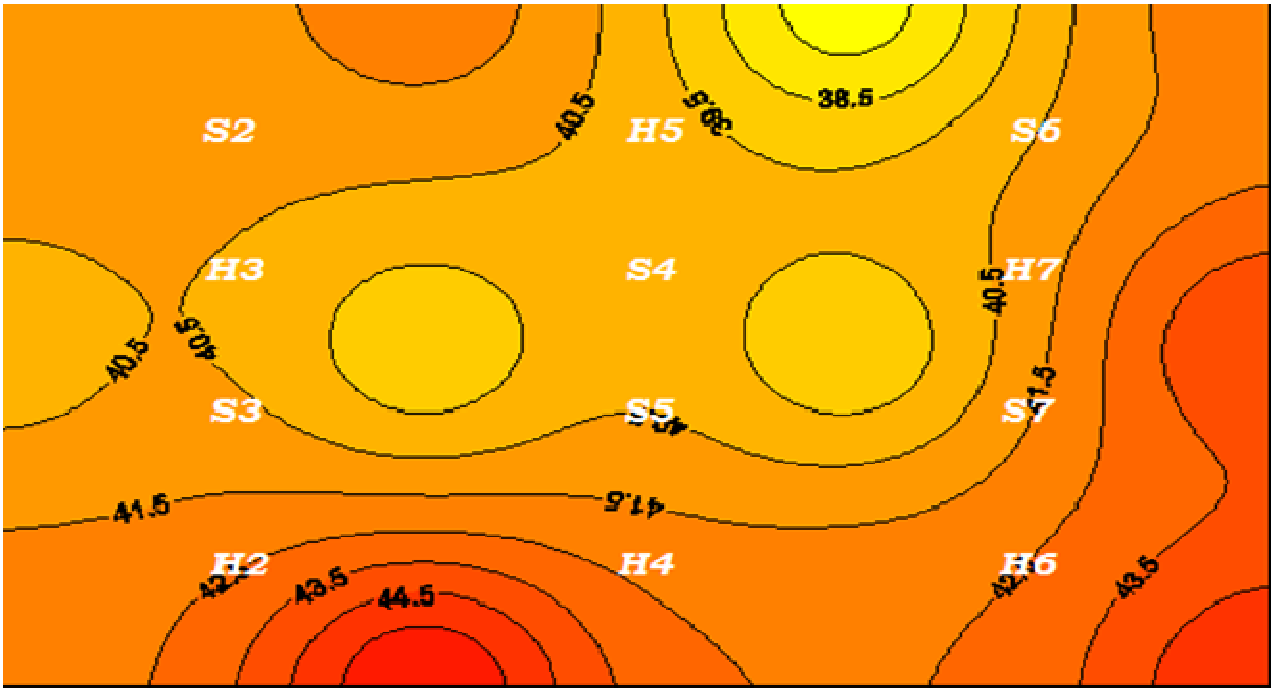

Figure 4. The temperature map inside the greenhouse on July 28, 2007 at 02:00 p.m. when the system was not operating.

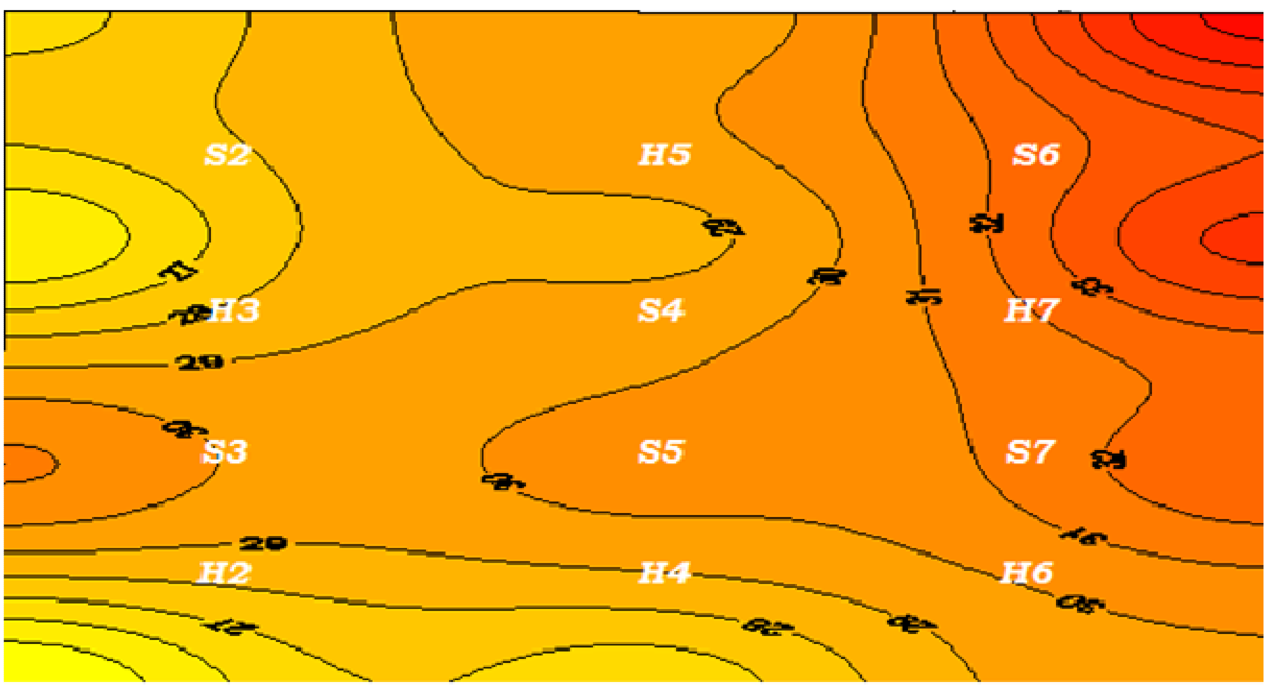

Figure 5. Temperature map inside the greenhouse on July 29, 2007 at 02:00 p.m.

maximum on tomato plants; thus the optimum conditions could not be maintained.

On July 29, 2007, the natural ventilation openings inside the greenhouse were closed, the air impermeability was maintained as the whole system was in operation (Figure 5). It was determined that the temperature values measured in the greenhouse on that date were 8°C lower compared with external temperature (particularly in front

Table 2. Statistics of 50 day averages measured at 02:00 p.m. as a function of temperature values.

Place	N	Mean	SE Mean	St.Dev	CoefVar	Minimum	Maximum
H2	50	29.135	0.700	4.947	16.98	15.230	41.990
S3	50	34.198	0.556	3.928	11.49	27.120	48.490
H3	50	27.374	0.886	6.262	22.88	14.470	38.770
S4	50	30.90	1.02	7.20	23.31	15.62	43.91
H4	50	26.201	0.932	6.590	25.15	13.320	40.130
S5	50	31.697	0.845	5.974	18.85	16.760	43.420
H5	50	27.618	0.790	5.588	20.23	16.000	40.130
S2	50	27.827	0.610	4.314	15.50	16.760	37.000
S6	50	37.601	0.681	4.812	12.80	28.700	48.490
H6	50	29.25	1.02	7.18	24.55	14.85	41.05
S7	50	32.017	0.848	5.994	18.72	17.140	42.940
H7	50	34.84	1.06	7.48	21.47	15.23	45.89

of the pad). During the fruiting period of tomatoes, the temperature values were above 30°C which was an unsuitable condition for tomatoes. The maximum temperature value for tomato plants was measured, however, only in front of the pad.

While the relative humidity kept at 30% level, according to the published results of the research by Erdogan (1994) in Cukurova delta region, and five fans were operated in the greenhouse, a dropdown of 8.3°C in the inner greenhouse temperature occurred (in com-parison with the outer temperature). When two fans were operated, the temperature variation reached a span of 3°C. Since the temperature variation in the case with five fans was greater than in the case with two fans, the degree of efficiency of the whole system seemed to be greater than in case of five fans. In the study quoted above, when the external moisture percentage reached 30%, the temperature variation reached 10°C level; when the moisture reached 95% level, the temperature variation was found to be sustaining at 0°C level.

In our study, humidity reached its lowest level on 07.26.2007. During the hours of the system's operation, a 10°C temperature decrease was observed with respect to external environmental temperature. The efficiency of the system was calculated as 80% on this day when outside humidity was the lowest.

The cooling efficiency of the system in the study of Ozturk (2004) carried out in venlo-type glass greenhouse reached its lowest value of 32.4% at 08:00 a.m. and its highest value of 76.6% at 02:00 p.m. During the experimentation period, the efficiency of fan-pad system was calculated as 53.3%. Incidentally, Giacomelli (1993) stated that the efficiency of moisturizing cooling system ranges between 40 and 70%. In addition, Arbel et al. (1999) made a comparison between fogging and fan-pad systems under the similar conditions. He found that both temperature and relative humidity distributions in the greenhouse with fogging system were smoothened out and the efficiency of fan-pad system came up to 75%. Moreover, Albright (1989), declared that the efficiency of cooling system may reach as high as 80% value.

The introductory statistics, which show the dependency of cooling efficiency (based on 50-day averages measured at 02:00 p.m. at certain points in the greenhouse) as a function of temperature values, were presented in Table 2.

Kruskal-Wallis test was used in order to analyze the temperature values measured at 12 points in the greenhouse and to figure out the statistically significant differences between the average indications for those points (provided the prerequisite of homogeneity of variations is met). Multiple comparisons were performed by using Bonferroni-Dunn method. In determining the validity of linear relation between the points at which temperature measurements were taken, correlation coefficients were calculated and correlation matrix was determined. As a result of Kruskal-Wallis test, statistically important differences between rank averages of the areas were found at $p<0.01$.

When correlation coefficients matrix that was calculated and presented in Table 3 was looked at, the correlation coefficient between H2 and S3 points was 0.663 and statistically important ($P<0.01$). Thus the positive relation between the two regions was obtained. It was observed that when the temperature measurement in one of the points tended to increase, the other one also tended to increase. The correlation coefficient between H6 point and S5 point was equal to 0.326 and it was statistically important ($P<0.05$). The relation between two points was negative: in other words, when one of them tended to increase, the other one tended to decrease.

Conclusion

One of the important problems in the evaporative cooling

Table 3. Differences between rank averages of areas

	H2	S3	H3	S4	H4	S5	H5	S2	S6	H6	S7
S3	0,663**	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
H3	0,521**	0,472**		-------	-------	-------	-------	-------	-------	-------	-------
S4	0,477**	0,419**	0,963**		-------	-------	-------	-------	-------	-------	-------
H4	0,317*	-------	0,497**	0,470**	-------	-------	-------	-------	-------	-------	-------
S5	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
H5	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
S2	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
S6	0,558**	0,741**	0,413**	0,369**	-------	0,477**	-------	-------	-------	-------	-------
H6	0,410**	0,371**	0,889**	0,879**	0,412**	-0,326*	-------	-------	-------	-------	-------
S7	0,459**	0,423**	0.939**	0,964**	0,467**	-------	-------	-------	0,418**	0,823**	-------
H7	0,467**	0,378**	0,905**	0,910**	0,446**	-------	-------	-------	-------	0,829**	0,933**

** P<0,01 * P<0,05

systems is the difference in humidity values between entry and exit points of the greenhouse. As a result of this research, great differences were found between the temperatures in front of the pad and the temperatures in the center and in front of the fans. While the temperature decrease value measured right in front of the pad was equivalent to approximately 13℃, it was 8ºC at the mid-point and 7ºC in front of the fan.

According to Ozturk (2004), the most important evidence against application of fan-pad cooling systems lays the fact that the distance between fan and pad is going to cause a significant temperature difference. He also stated that there are mainly five factors that affect the temperature along the length of the greenhouse. Those are: ventilation speed, transpiration of greenhouse plants, evaporation from the soil, shading system, water evaporation from the pad and permeability constant of the cover material by the heat.

Ozturk (2004), emphasized the importance of temperature values at the plant level, and stated that when the air speed in the greenhouse runs at the lower level, the air temperature rapidly goes up. By calculating the air speed gradients of the fans used to increase the air speed in the greenhouse, he found that fans should be adequate for the respective greenhouse area. At the same time, the absorber fans located at the center of the greenhouse can be provided to remove the hot air forming in the greenhouse.

During our study period, the fan-pad system was in operation in the afternoon hours. As the measurements showed, the temperature inside the greenhouse used to increase rapidly after ten o'clock in the morning and reach above the optimal temperature values needed by the plants. In order to create a controllable agricultural production environment, the fan-pad system must be operated before the temperature reaches the limiting value in order to prevent plant stress.

As a result of our study, it has been determined that if the greenhouses use fan-pad cooling systems, the temperature distribution in the greenhouses show such variations that can affect the production. As observed from the temperature maps, it looks inevitable that the temperature increases demonstrate different values at different points of the greenhouse and that they result in various differences occurring in the development of the same greenhouse produce at different point locations in the greenhouse.

Thus, what really the temperature maps are helpful for is to find out how to optimize the operation times of the fan-pad system in the greenhouse where tomatoes and other plants with similar temperature requirements are grown so that their production can be increased in the summer when the humidity levels are low.

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