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A Research On Determining The Efficiency Of Some Greenhouse Cooling Systems[1]

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Özet

Bazı Sera Soğutma Sistemlerinin Etkinliğinin Belirlenmesi Üzerine Bir Araştırma

Araştırma, 3 farklı soğutma sisteminin etkinliğinin belirlenmesi amacıyla yapılmıştır. Bu amaçla, 4 adet PE örtülü sera kullanılmıştır. Biri kontrol amaçlı bu seraların üzeri, tümünü kaplayacak şekilde % 30 gölgeleme yapılmıştır. Araştırmada en düşük sera içi sıcaklığı fan-ped soğutma sisteminde, en düşük bağıl nem ise soğuk hava üflemeli soğutma sisteminde elde edilmiştir. Tüm seralarda elde edilen sıcaklıklarla çevre sıcaklığı arasındaki ilişki önemli bulunmuştur.

Anahtar kelimeler: Sera, soğutma, fan-ped, sisleme sistemi.

Introduction

To meet the heat and light requirements of plants at the lowest cost, the greenhouses were covered with a transparent material that allowed sunlight to pass through it. Although this method has very important benefits during winter months when the ambient temperature and solar radiation levels are low, it causes an excessive increase in heat after the month of April. A healthy environment for plant production is only possible if this excess heat is prevented (5).

There are two methods by which excessive heat in the greenhouses may be prevented. The first one is by shading, which lessens both the amount of heat energy coming from the sun and its effect on the plants. The second one is by ventilation or cooling, which prevents excessive air and high plant temperatures by allowing for the release of a certain amount of heat (7). Good ventilation should provide an internal temperature as close as possible to the ambient temperature, especially during the cooler months (9).

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In order to be able to provide an internal temperature that is lower than the ambient temperature, it is necessary to release excess heat. This is done by cooling: evaporative cooling methods are the most economical.

The evaporative cooling system is more effective under conditions of high temperature and low relative humidity and, if used in conjunction with shading, sufficient cooling can be provided (8). In Montero et al.'s study (10), in an experimental greenhouse where evaporative cooling and fogging evaporative cooling were applied, 3 ^{0}C average and 5 ^{0}C lower maximum temperatures were obtained than in the control greenhouse. In principle, evaporative cooling under hot weather conditions is an operation in which latent heat is converted into sensible heat (6).

In the greenhouses, two systems of evaporative cooling were tried, fan-pad cooling and fogging (3).

Under desert climate conditions, the fogging system provided more uniform greenhouse internal temperatures and a better relative humidity than the fan-pad cooling system (8,1).

Material And Methods

For this research, four greenhouses were used, with identical equipment, apart from cooling systems (Table 1). Three different cooling systems were used in the greenhouses and the cooling was controlled by an automatic control system. A data measurement / recording system was also used. It was used an air blowing cooling system in greenhouse 1 and a spray-cooling system in greenhouse 2 and a fan-pad cooling system in greenhouse 4. Greenhouse 3 was the control.

Table 1. Technical Specifications of an Experimental Greenhouse.

Greenhouse's	**Explanations**
-Width / length/Gutter height/ Direction	6 / 12 / 2.25 meters/ North – South
-Construction	Tunnel roof – galvanised twist steel
-Covering material	UV added, 0.3 mm transparent PE
-Shading	30 % green coloured, knitting PE
-Irrigation system	Drip irrigation system
-Ventilation system	Continuous side ventilation

In the research, all four greenhouses were shaded in an equal ratio. The system of greenhouse 1 is installed outside the greenhouse and consists of an evaporative surface and room, fogging hoods and fan; the internal system consists of an air distribution tunnel (Fig. 1).

When the fan of Greenhouse 1 shown in figure 1 started to blow the air in room B into an air tunnel, a negative pressure was formed in the evaporation room. This negative pressure allowed external air to enter the evaporation room through evaporation surfaces and air inlets shown in A. During this operation, a negative pressure formed in the evaporation room and on internal parts of the evaporation surface. This accelerated the inlet of water through the air inlet tunnels, which transformed the water from a fine spray into a vapour in the evaporation room. At the same time, the influence of the sun's rays on the evaporation surface caused a very fast evaporation and carried a part of the energy from inside the unit to outside. The energy transportation and the fast evaporation in the evaporation room together decreased the air heat from outside. The cooled air was distributed into the greenhouse homogeneously by air tunnels.

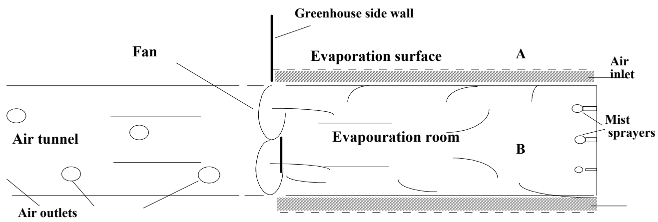

Figure 1. Air blowing cooling system.

In this research, in order to control the performance conditions of the cooling system, a room type thermostat measuring the greenhouses' internal temperatures were used, and it directed the current according to this temperature. The switches were controlled by time relays and contactors, which were regulated by the thermostat.

Two valves were installed to the outlets of the pressure tank. One valve gave pressured water to Greenhouse 1 and the second one to Greenhouse 2. When the air temperature measured in Greenhouse 1 exceeded 30 ^{0}C, the related fan started to work. When the greenhouse's internal temperature dropped below 28 ^{0}C, thermostat stopped the fan. When in use, Greenhouse 1's fan performed continuously and the valve stayed open for 5 seconds every 60 seconds.

In Greenhouse 4 when the air temperature exceeded 30 ^{0}C, the motor pump giving water to the pads of the fan-pad cooling system started to work and then stopped when the temperature dropped below 28 ^{0}C.

To reveal the efficiency of the cooling systems, features such as air temperature, relative humidity and solar radiation intensity values were stored on to a hard disk.

After installing shading and cooling systems for the greenhouses, the land was cultivated as necessary, and cucumbers were planted in the greenhouse on 2 nd July 2000. These were laid in double row spaces of

0.5/1.0 m and in each row at 0.5 m. When the plants had 4 or 5 leaves, two tension meters were established into 0-30 cm and 30-60 cm depth in each greenhouse to program the irrigation. At the same time, temperature/relative humidity/solar radiation intensity sensors were installed to 150 cm height outside and in the middle of the greenhouses. The performance of the cooling system and data measurement/ recording system was controlled for 20 days. Later, sensors were installed and programmed to measure and record the temperature, relative humidity and solar radiation intensity every 15 minutes starting 2 nd August 2000.

Data measurement and recording continued up to 26 th August 2000. To determine the activity of the cooling systems and to benefit from the values of solar radiation intensity and temperature measured outside, any values measured and recorded below 30 ^{0}C during the day and night were left out of the evaluation. The data was evaluated by variance analysis, regression analysis and LSD test statistics methods (11).

Results And Discussion

August 2000 was an extreme year because of its high temperatures when the research data were taken. During this period, when data were measured in the shade, the outside temperature changed from 29.9 ^{0}C to 42.5^{0}C, with an average temperature during daylight hours of 35.2 ^{0}C.

Except for shading, Greenhouse 2 was fogged at intervals, and the average temperature obtained was 31.4 ^{o}C; the maximum temperature was 44.9 ^{0}C. With this cooling system, while obtaining a lower air temperature than that outside, the maximum inside air temperature was higher. The fogging cooling system couldn't provide effective cooling when the relative humidity was high.

The cooling system in Greenhouse 1 blew the cooled air in the ext. unit into the greenhouse and gave lower temperatures than those outside from both an average temperature (32.8 ^{0}C) and a maximum (40.0 ^{0}C).

The lowest temperatures were obtained from the fan-pad cooling system in Greenhouse 4. In this greenhouse, the average temperature was 30.0 ^{0}C and the maximum was 39.3 ^{0}C. For the air-proof greenhouses, the most beneficial cooling was with the fan-pad cooling system.

During the period that the research data were collected, graphs from the daily average temperatures recorded inside and outside the greenhouses are given in fig. 2.

While the air temperature values of Greenhouse 3, the control, shaded-only greenhouse, were parallel to ambient temperature values, the air temperature values measured in Greenhouse 1 and 4 were similar and showed less dependence on ambient temperature values (fig. 2).

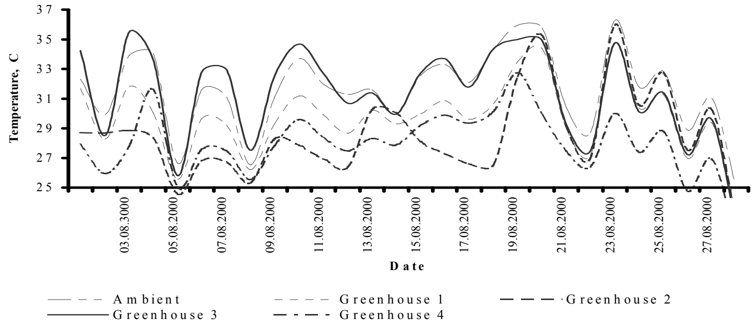

Figure 2. Daily average temperature measured inside and outside of the greenhouses.

A variation analysis was made by examining the difference of temperatures inside and outside the greenhouses (Tabl. 2).

Table 2. Variation Analysis Table of the Greenhouses' Internal and External Temperatures.

Variance source	**D. F.**	**S.T.**	**S.A.**	**F**
Total	3134	55531.19		
Between groups	4	13492.3	3373.075	251.1**
Error	3130	42038.89	13.43	

The probability of a difference arising between the internal and external greenhouses' temperature coincidentally is less then 1 % (Table 2). To examine the source of this difference, the results of the LSD test revealed that heat values measured in other greenhouses were different from the heat values measured outside of the greenhouses, except those values measured in the control Greenhouse 3. The cooling systems applied in Greenhouses 1, 2 and 4 provided lower internal air temperature than ambient temperature. Again, according to LSD results, all of the temperatures measured in the four greenhouses were different from one another. Whereas each of the cooling systems provided lower temperature than the control greenhouse, and also different greenhouses had different internal temperature values, the lowest temperature was provided by fan-pad cooling system.

During the period that the data were taken, while the other greenhouses' external relative humidity was 31 %, in Greenhouse 2, where the fogging system was used, this level was 69 %.

Of those greenhouses with a cooling system, the lowest average and the maximum relative humidity were measured in Greenhouse 1. A continuous opening of the ventilation in Greenhouse 1 prevented an excess increase in humidity. This was a conducive atmosphere for the fungus growth. The cooling system in Greenhouse 1 could provide the lowest temperature but, if the temperature was considered with the relative humidity, its activity was better than the other cooling systems.

The graph showing the daily average of the relative humidity values measured inside and outside the greenhouses was given in figure 3.

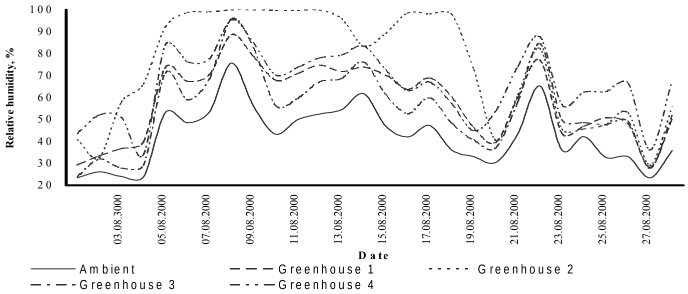

Figure 3. Daily average relative humidity measured inside and outside the greenhouses.

As seen in figure 3, the relative humidity values in all of the greenhouses were higher than outside. But the relative humidity in Greenhouse 2 where a fogging cooling system was applied was near to complete saturation. The relative humidity values measured in Greenhouse 1 were at lower levels than the others, except the control one.

To examine if there was any statistical difference between the relative humidity values recorded both inside and outside the greenhouses, a variation analysis was performed and the results were given in table 3.

Table 3. Variation Analysis Table of Relative Humidity Values.

Variance source	**D.F.**	**S.T.**	**S.A.**	**F**
Total	3134	1663631		
Between groups	4	501942	125485	338**
Error	3130	1.161.689	371	

As seen on table 3 the probability of a difference arising between the internal and external relative humidity values of the greenhouses coincidentally is less than 1 %. To examine the source of this difference, the results of the LSD test revealed that the average relative humidity values measured both inside and outside the greenhouses were different from one another.

In the research, to determine the relation between temperature and relative humidity values, a regression analysis was performed. Between the temperature values measured in Greenhouse 1 (t_1) and ambient external temperature (t_o) values,the following regression equation was obtained.

$$t_1 = 2.083 + 0.877 \cdot t_o, \qquad r^2 = 0.876$$

r^2 of the regression equation revealed that the external one on a large scale fixed the internal temperature in Greenhouse 1. A variance analysis results of the regression showed that the probability of this relation arising coincidentally was less than 1 %.

In the research, a spray-cooling system was applied in Greenhouse 2. The regression analysis resulted in a regression equation fixing the heat in Greenhouse 2 (t_2) dependent on ambient temperature as follows.

$$t_2 = 1.666 + 0.842 \cdot t_o, \qquad r^2 = 0.61$$

As seen in the equation, r^2 expressing the regression relation was lower than in Greenhouse 1. This reveals that the temperature in Greenhouse 2 was more independent from ambient temperature than Greenhouse 1. A variance analysis results of the regression showed that the probability of this relation arising coincidentally was less than 1 %.

In Greenhouse 4, a fan-pad cooling system, the most commonly used in our time, was used. The regression equation giving the relation between the temperatures values in Greenhouse 4 (t_4) and ambient temperature values as follows.

$$t_4 = 8.26 + 0.63 \cdot t_o, \qquad r^2 = 0.72$$

A variance analysis results of the regression showed that the probability of this relation arising coincidentally was less than 1 %.

Conclusion

According to variation analysis results;

1-The temperature values measured in all greenhouses were different from the ambient temperature values. The most effective cooling was obtained in Greenhouse 4 where the fan-pad cooling system was applied

2-Relative humidity values measured in all greenhouses were different from the ambient relative humidity values. The lowest relative humidity was obtained in the control greenhouse.

3-When the temperature and relative humidity were evaluated together, the cool air blowing system was most effective as it caused no excessive relative humidity increase. Its application is also easy as air-proofing is not essential.

4-The results obtained from the research showed that the cooling system used in Greenhouse 1 can be applied most easily to greenhouses in Turkey. In the system where the air is cooled outside the greenhouse, and delivered into it by distribution tunnels, the excess greenhouse internal relative humidity problem was not considered. Studies on increasing the vaporisation room activity in the system will provide great contributions to greenhouse growing abilities.

Summary

The aim of this research was to determine the efficiency of three different cooling systems. In order to accomplish this, four greenhouses were built, with 30 % of the buildings in the shade, and then covered with PE. One of the greenhouses served as a control. In the research, the lowest temperature was obtained using a fan-pad, and the lowest relative humidity was obtained using a cool air ventilation system. The regression relation between the temperatures obtained in all four greenhouses and the ambient temperature was also an important factor.

Key words: Greenhouse, cooling, fan-pad, misting system

References

1. Arbel, A., 1999. Performance of a Fog System for Cooling Greenhouses. J. of Agr. Engng. V. 72(2), p. 129-136, LONDON.
2. Arıcı, İ., Şimşek,E., Yazgan, S., Özgümüş, A., Şeniz, V., Özgür, M., Sivritepe, H.Ö., 1995. Seracılık. T.C. Ana. U. No: 865, Açıköğr. Fac., Y. No: 459, ESKİŞEHİR.
3. Bailey, B.J., 1991. The Environment in Evaporatively Cooled Greenhouse. Acta Horti., 287, p. 59-66, WAGENİNGEN.
4. Boulard, T., Baille, A., 1993. A Simple Greenhouse Climate Control Model Incorporating effects of Ventilation and Evaporative Cooling. Agri. and Forest Meteo., 65(1993), 145-157.
5. Çolak, A., Şahin, A., Balcı, A., 1995. Sera İçi Sıcaklığının Düşürülmesinde Sera Altı Toprağının Kullanılması Üzerinde Bir Araştırma, Ege U. Agr. Fac. Pub., Vol. 32, No: 1, Bornova-İZMİR.
6. Esmay, M.L., Dixon, J.E., 1986. Environmental Control for Agricultural Buildings. The AVI Publising Company, Inc. Westprot, CONNECTICUT.
7. Jewett, T.J., Sort, T.H., 1992. Computer Control of a Five-Stage Greenhouse Shading System. Amer. Soc. of Agric.l Eng., Vol. 35(2):March-April.
8. Luchow, K., von Zabeltitz., C., 1992. Investigation of a Spray Cooling System in a Plastic-Film Greenhouse, J. Agric. Engng. Res., v. 52(1), p. 1-10, LONDON.
9. Mistriotis, A., Bot, G.P.A., Picuno, P., Scarascia-Mugnozza, G., 1997. Analysis of the Efficiency of Greenhouse Ventilation Using Computational Fluid Dynamics. Agric. and Forest Meteo. 85(1997), 217-228.
10. Montero, J.I., Anton, A., Biel, C., Franquet, A., 1990. Cooling of Greenhouses with Compressed Air Fogging Nozzles. Act. Hrt.,v.281,p.199-209, WAGENINGEN.
11. Yurtsever, N., 1984. Deneysel İstatistik Metodları. TC. Tar. Or. ve Köy. Bkn., Köy Hiz. Gen. Mdr. Yay., Yay. no. 121, Teknik yayın no. 56, ANKARA.
12. Teitel,M., Shklyar,A., Segal,I. And Barak,M.,1996. Effects of Nonsteady Hot-water Green-house Heating on Heat Transfer and Microclimate, J.of Agric. Engng. Res., v.65, p.297 – 304.