J.Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 6 (5): 667 - 685, 2015

EFFECT OF EXTERNALLY MOUNTED SHADING SCREEN ON MICROCLIMATIC CONDITIONS OF GREENHOUSE CANTALOUPE CROP EQUIPPED WITH EVAPORATIVE COOLING SYSTEM

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ABSTRACT

The aim of this experimental work was to investigate the effect of two different types of cooling pads with and without externally mounted shading screen on growth, development, productivity, and fruit quality of cantaloupe crop. Two similar gable-even-span greenhouses were utilized at EL-Sabahia Horticultural Research Station (latitude and longitude angles, respectively, are 31.22ºN and 30.50°E, and 3.00 m mean altitude underneath the sea level), Alexandria, to grow and produce cantaloupe crop during summer of two successive growing seasons (2009 and 2010). Each greenhouse was equipped with complete evaporative cooling system based on cooling pads and extracting fans and shaded using shading screens mounted externally to reduce solar radiation inside the greenhouse and consequently increase the effectiveness of evaporative cooling systems. Two different cooling pads (one of locally available materials (LPM), and the other of cross-fluted cellulose pads (CCP) were functioned with shading to cool the two greenhouses. The obtained data revealed that, the indoor air temperatures of the shaded greenhouse were lower than the greenhouse without shading. The maximum indoor air temperatures without operating the evaporative cooling system reached to 37.8 and 41.9^{o}C for the shaded and not-shaded greenhouses, respectively. The hourly average indoor air temperatures when operating the two evaporative cooling systems with two different cooling pads (LPM and CCP), respectively, were 28.4 and 27.3 ^{o}C. The maximum indoor air temperatures for the two greenhouses when operating the evaporative cooling systems with and without shading screen were 28.5 and 31.4ºC, respectively. The maximum indoor temperatures were 29.75 and 28.85 ^{o}C, while, the hourly average indoor air temperatures were 27.50 and 26.37 ^{o}C for the two greenhouses with operating evaporative cooling system and shading screens, respectively. The obtained results also showed that, the hourly average vapour pressure deficit (VPD) of the indoor air during daylight times for the two greenhouses with shading screen was 1.458 and 1.480 kPa, consequently the cantaloupe plants were not heat stressed under these levels of VPD (danger level > 2.0 kPa). Utilizing the evaporative cooling systems for the two greenhouses with shading screens have had the same effect on the growth, development, productivity of fresh yield, and quality of fruit characteristics.

INTRODUCTION

Air cooling is desirable in many Mediterranean greenhouses in order to prevent plant stress and produce crops of marketable quality. Various technical equipment can efficiently contribute to maintain greenhouse indoor air temperature and relative humidity at acceptable levels during warm periods; but adequate models may be necessary to estimate the cooling loads and adequate manage such climate control equipment (Kittas et al., 2003). Forced greenhouse crops are an ever more common means of cultivation worldwide. Surface area dedicated to such crops at 700,000 ha, 150,000 of which are located in the Mediterranean basin (Franco et al., 2014). High spring-summer temperatures in the Mediterranean basin make evaporative cooling systems necessary. Excess heat causes indoor temperature to become hotter than the desired level resulting in detrimental effects to crop growth and production (Montero, 2006). The evaporative cooling of greenhouses is based on the evaporation of water in the mass of warm incoming air, thus allowing a decrease in air temperature and increase in relative humidity, (Kittas et al., 2003, Montero, 2006, Farmahini et al., 2012 and Jamaludin et al., 2014). The air saturation efficiency of the pad-fan system is greater than that of the fog system (Katsoulas et al., 2009), it is also cheaper (Sethi and Sharma, 2007) and it consumes less water and energy (López et al., 2012).

The packing material in the cooling chamber is the key element in the heat and mass transfer process, as it fulfills two important functions; it provides a large contact surface for the mixing of the water and air flows, while at the same time ensuring that the transfer process takes as short time as possible. As a result, the amount of water evaporated increases and the temperature of the non-saturated air decreases (Franco et al., 2011). This material usually consists of a plastic grid, though it may also be composed of corrugated cellulose pads, vegetable fibers found locally (Gunhan et al., 2007, Ahmed et al., 2011 and Jain and Hindoliya, 2011), such as wood chips, coconut fiber, *etc.*, or porous inorganic material (Gunhan et al., 2007) such as perlite, volcanic rock, *etc.* These materials are placed in such a way as to ensure that they present the maximum possible transfer surface and the minimum resistance to the passage of the airflow. Malli et al (2011) tested experimentally the thermal performances for three different cellulose Pad thicknesses, such as 75, 100 and 150 mm.

Helmy et al. (2013) tested three different pad materials namely; Se’d, Purdy and Samar with roof thin water film inside the combined system at 15 cm pad thickness and 0.45 m s^{-1} pad face air velocity. They found that the daily average cooling efficiencies of 88.4, 83.1 and 79.6% were achieved for Se’d, Purdy and Samar, respectively. Kittas et al. (2001a) investigated the influence of greenhouse ventilation regime on the microclimate and energy portioning of a rose canopy during summer conditions. They reported that, the sensible and latent heat profiles were observed along a large greenhouse, and, in order to explain their results, they proposed a model, which simulates the indoor air temperature distribution of the enclosure. Recently, Mehmet and Hasan (2015) stated that the hourly mean cooling effect and cooling efficiency calculated for fan-pad system were determined to be 6.96ºC and 76.8%, respectively.

Abdel-Rahman (2006) tested two greenhouses equipped with horizontal evaporative cooling pad, one with a long wheat straw and the other with an aspen fiber. The indoor air temperature reduction due to the evaporative cooling materials was ranged between 5 to 10^{o}C. The cooling efficiencies were varied between 45 and 75 % for both materials. Youssef et al., (2015) developed an evaporative cooling unit (CU) and tested against the traditional evaporative cooling (F-P). The average air temperature entering the greenhouse was approximately 7.1 and 6.8 ºC lower than the outside air temperature for CU and F-P systems, respectively. The indoor air relative humidity of greenhouse with cooling unit (CU) system was higher than that with evaporative cooling (F-P). The hourly average indoor air relative humidity for the CU and F-P was 69.0 and 61.8%. Consequently, the cooling unit (CU) increased the indoor air relative humidity by 12.38%. The hourly averages cooling efficiency of cooling unit (CU) in the first and second days were 77.55% and 74.79%, respectively, while they were 72.97% and 70.19% for the same days for F-P system. Consequently, the CU system was in an average more efficient than the F-P system by 6.29% and 6.58%. The total yield of tomato crop per plant was 6.24 and 5.48 kg for the CU and F-P systems, respectively. The CU system increased tomato yield per plant by 13.82% over the F-P system.

Roof shading and natural ventilation are the most common techniques. Shading screens mounted externally or internally, may be used to reduce solar radiation inside the greenhouse but the effective temperature reduction is not really proportional to the shading rate. Kittas et al. (2001a) showed that externally mounted black polyethylene films were less than 50% effective in reducing energy and temperature gains compared to their commercially given values, while white shading cloths were only slightly more effective. Ventilation reduces greenhouse overheating, but it may even enhance the risk of water stress because it often increases plant transpiration. Kittas et al. (2001b) reported that high ventilation rates were not, a priori, the best solution for alleviating crop stress in greenhouses during summer conditions. Evaporative cooling with roof shading substantially improves the microclimatic conditions of greenhouses. It can be done by spraying water droplets in a naturally ventilated building (by low or high pressure fog systems) or by forcing ambient air through wet cooling pads. Both produce a temperature drop with an absolute humidity rise in the greenhouse, which contributes to decrease the vapour pressure deficit and moderate the transpiration demand (Katsoulas et al., 2009).

The main disadvantage of evaporative cooling system (pad-fan system) is the creation of large temperature gradients inside the greenhouse, from cooling pads on one side to extracting fans on the opposite side. The amplitude of such gradients is affected by many factors, and only a numerical model can predict it value (Kittas et at., 2003). Efficient application of shading can be a useful component of effective ventilation/cooling strategy (GMPro-April 2011). The entry of excessive solar radiation is prevented using shade nets or thermal screens placed on the roof and or side walls. Shading is also done using paints, but the problem is that they get washed away during rains. Shade is a very important factor in reducing leaf and air temperature because it absorbs some of the solar radiation entering the greenhouse during summer (Al-Helal and Al-Musalam, 2003; Kittas et al., 2003; and Willits, 2003). Bartzanas and Kittas (2005) mentioned that the main disadvantage of fan and pad systems is the lack of uniformity of the climatic conditions, which are characterized by rising temperature and falling humidity along the length of the structure and in the airflow direction. To overcome these problems fan and pad systems are usually combined with shading.

Muskmelons are warm-season crops that grow best at air temperatures between 18 and 24°C. Temperatures above 35°C or below 10°C will slow the growth and maturation of the crop, (Jett, 2006). A better understanding of the effect of the temperature on the development would estimate the number of nodes on the main stem, the start of fruit set and harvest. However, these responses to temperature can vary depending on the genotypes or growth stages (Baker and Reddy, 2001). Bouzo and Küchen (2012) found differences in the melon cultivars development in response to temperature.

The aim of the present work is to investigate: 1) effect of only using shading screen on the indoor air temperature of greenhouse, 2) the cooling efficiency for the two different cooling pads, 3) effect of combining the shading screens with the evaporative cooling on reducing the indoor air temperature of greenhouses, and 4) effect of microclimatic conditions on growth, development, productivity, and fruit quality of cantaloupe crop.

MATERIALS AND METHODS

Materials

Greenhouses

Two identical gable-even-span greenhouses were utilized at EL-Sabahia Horticultural Research Station (latitude and longitude angles, respectively, are 31.22 ºN and 30.50 °E, and 3.00 m mean altitude underneath the sea level), Alexandria Governorate, to grow and produce cantaloupe crop during summer of two following growing seasons (2009 and 2010). The geometric characteristics of each greenhouse are as follows: eaves height 2.93 m, height of each side wall 2 m, rafter angle 25^o, width 4 m, length 8 m, floor surface area 32 m^2, and volume 78.922 m^3. The two greenhouses (G1 and G2) are covered using single layer of polyethylene sheet (PE) of 150 µm. The greenhouse facility used in this research work was covered with the ratio of cover surface area to the total greenhouse surface area of 2.603. To increase and maintain the durability of structural frame and polyethylene cover, twenty tensile galvanized wires (2 mm diameter) are tied and fixed throughout the rafters and vertical bars in each side of the plastic greenhouses.

Ventilating and Cooling Systems

One of the most efficient ways to reduce the difference between the indoor and outdoor air temperatures is to improve ventilation system. Natural or passive ventilation system uses very little external energy as opposed to active or forced ventilation system, but it increase the complexity of greenhouse structures and makes climate control more difficult. Therefore, the mechanical ventilation system (extracting fans) is employed during this research work. The two greenhouses are equipped with a complete evaporative cooling system based on cooling pads and extracting fans. Two different cooling pad materials are functioned during the experimental work. The first greenhouse (G1) is used cooling pads of cross-fluted cellulose material (CCP), and the other greenhouse (G2) is provided with locally pad materials (LPM). This type of cooling pads is made of rice straw, cotton threads, and spongy luffa slice and packed with layers of rice straw and tied by cotton threads until reached a thickness of 10 cm. It was reinforced from outside with metallic screen. To permit adequate air speed through the cooling pads, steel springs are passed throughout the pads. Slices of spongy luffa (act as a filter) were situated on the top and bottom of each cooling pad unit to prevent falling of rice straw in the water tank. The LPM cooling pad sited in three parallelogram frames. Each frame having a gross dimensions of 1.0 m long, 0.6 m high, and 0.1 m thick as shown in Fig.(1).

The gross dimensions of two different cooling pads are 3.0 x 0.6 x 0.1 m with cooling face area of 1.8 m^2. Each greenhouse is equipped with one extracting fan (single speed, direct driven, 60 cm diameter and 8000 m^3/h discharge) and located on the opposite side of cooling pads. A polyvinyl chloride pipe (PVC) 25.4 mm diameter and 3.0 m long is suspended immediately above the cooling pads. Holes are drilled in a line about 5 cm apart along the top side of PVC pipe, and the end of this pipe is capped. A baffle is placed above the water pipe to prevent any leaking of water from the cooling system. Sump (gutter) is situated underneath the cooling pads to collect the water and return it into the water tank (100 litres capacity) from which it can be recycled to the cooling pads by a submersible water pump (0.5 hp). To improve the effectiveness of evaporative cooling system and reduce the intensity of solar radiation inside the greenhouse, the two greenhouses are externally covered with blanket net 60% light transmission as revealed in Fig. (2).

a- cross-fluted cellulose pad (CCP)

b- Locally pad material (LPM)

Fig. (1): Two different cooling pads.

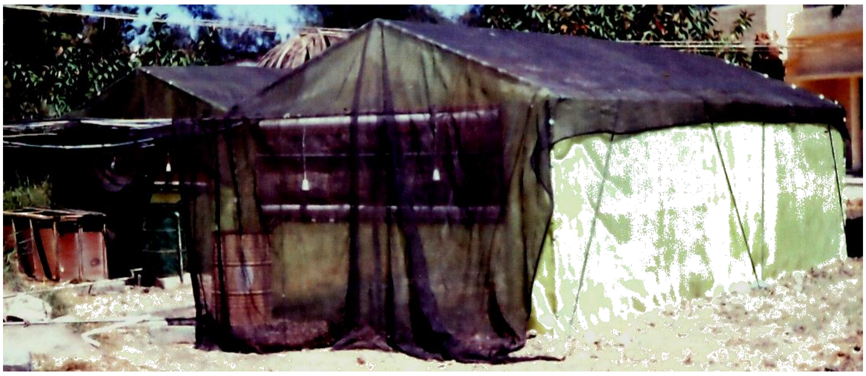

Fig (2). The two greenhouses covered with blanket net 60% to reduce the solar radiation incident.

Germination of cantaloupe seeds, cultivation and watering systems

Soil mix-media for germinating cantaloupe seeds consisted of peat-moss and vermiculite was used. The peat-moss was manipulated and enriched by adding little amount of chemical fertilizer (20 cm^3 of Maxim 3.5% as a disinfectant substance, 50 g Mr. Ally, 10 g Razomar, 20 g of Newtrical complex, 20 g of Humic acid, and 1 kg of Agricultural sulphur). Two vegetative trays (84 growth blocks) were used to germinate the seeds of cantaloupe. The tray blocks were full by soil mix- media, and 168 seeds (hybrid Yatherb 22, cv.) were directly planted for the first growing season on 11^{th} of March 2009 and on 14^{th} of March 2010 for the second growing season and situated inside the nursery. After one week the cantaloupe seedlings were raised in the vegetative trays with germination percentage of 95%. Cantaloupe seedlings at four expanded leaves instance were transported from the nursery into the greenhouse location on 1^{st} and 4^{th} of April for the first and second growing seasons, respectively.

Pots system was used as an agriculture system for cantaloupe crop. Each greenhouse was equipped with 72 plastic pots (30 cm diameter and 30 cm high), which arranged in six rows (each row having twelve pots) for a plant population density of 2.25 plants per square meter. Seventy two seedlings of cantaloupe were selected and manually transplanted inside each greenhouse in the late afternoon to minimize transplant shock. Humic acid (Granules) by the rate of 0.25 gram/liter were placed in each hole of seedlings just prior to transplanting to provide and enhance the growth of root system and to guard against insect attack. Drip irrigation system was used for watering pots of the crop. A 200 liters scaled plastic water supply tank was located inside the greenhouse on 1 m above the ground surface in order to provide adequate hydrostatic pressure for maximum use rate of water. Twelve drippers (long-bath GR 4 liter/hr discharge) were uniformly alternative distributed with 50 cm dripper spacing throughout each row of plants inside the two greenhouses. Measurements on plants were taken throughout the growth period (plant length, growth rate, flowering rate, fruit set rate, fresh yield). The experimental design used during this research work was a complete random design with three replicates (CRD), each replicate contained two rows.

Measurements and Data Acquisition Unit

Instrumentation

The meteorological data from a meteorological station (5 KUE SKH 2013) were used to measure solar radiation flux incident on a horizontal surface (Pyranometer), dry-bulb air temperature (ventilated thermistor), wind speed and its direction (cup anemometer and wind vane), and air relative humidity (hygrometer). These sensors were connected to a data-logger system in order to test, display, and record the data during the experimental period. Sixteen sensors (Thermocouple type K) were arranged inside the two greenhouses to measure the air temperatures at different locations, with five minutes intervals and the hourly average was recorded using a data-logger. Microclimate variables within the two greenhouses (G1 and G2) were measured These microclimate variables included the solar radiation flux incident above the canopy of cantaloupe plants (at a height of about 2.0 m), dry-bulb air temperatures, air relative humidity, using solarimeters (Pyranometer-Kipp and Zohne, Australia), thermograph (type omega, CT 485 B), and hygrometer, respectively.The electrical power consumption by fans and water pumps was measured and recorded using two electric meters. Wet-bulb temperature inside the greenhouse was measured using four sensors distributed evenly around the cooling pads. These sensors were connected to an analog/Digital card attached to the computer to test, display, and record the data throughout the experimental work.

Methods

Experimental procedure and data analysis for cantaloupe crop

The experiments were executed in experimental greenhouses during summer season of two successive growing periods (2009 and 2010). Two identical gable-even-span greenhouses (each having a floor surface area of 32 m^2) were functioned to grow and produce cantaloupe during a short growing season from April until June 2009 (first season) and from April to June 2010. The two greenhouses (G1, and G2) were equipped with a complete evaporative cooling system with different cooling pad materials. To investigate and examined the effect of shading material and different pad materials on the microclimatic conditions of the two greenhouses, the following studying and testing were executed:

1- One greenhouse was shaded while the other one kept without shading.
2- Two cooling pad materials CCP and LPM were operated without shading.
3- Evaporative cooling system using cooling pads of LPM was operated with shading while, the cooling pads CCP was operated without shading.
4- Evaporative cooling system using cooling pads of CCP was operated with shading, whereas the LPM was operated without shading.
5- Two cooling pads (CCS and LPM) were operated with shading the two greenhouses.

The air temperature inside the two greenhouses, at a height of 1.8 m above the floor level was automatically controlled at daylight-time by an ON-OFF controller (two differential thermostats) to start working of ventilation process at 28°C and interrupt it at 26°C (normal agricultural practices used for commercial sweet melon production were practiced as used in the area).

Vegetative data:

Data were measured and recorded on all the grown plants inside the two greenhouses as follows:

1-Vegetative measurements; plant length (cm), number of branches.

2-Fresh yield and its components; average fruit number per plant; average fruit weight (kg) and total fresh yield per plant (kg).

3-Fruit characteristics; flesh thickness (%) was calculated as the ratio between flesh thickness and fruit diameter; placenta hardness which was rated from 1 to 10, 1 denoted the juicy placenta tissues and 10 is the hard placenta; netting degree was rating from 1 to 10, 1 denoted the extreme smooth fruit skin and 10 the heavily rough fruit; total soluble solids (T.S.S) % determined using the Zeiss hand refractometer.

Effectiveness of evaporative cooling system

The efficiency of evaporative cooling system is namely associated with the cooling effect, wet-bulb depression, rate of heat transfer from air to water, and water consumption in evaporation process. The cooling efficiency (η, %) can be computed in terms of the cooling effect (denominator) and the wet-bulb depression (numerator) using the following equation (Kittas et al., 2003; ASHRAE, 2005):

$$\eta = \frac{T_{out} - T_{evp}}{T_{out} - T_{out-wb}} \times 100 \quad , \quad \% \qquad (1)$$

Where, T_{out}, is the outdoor air temperature in ºC, T_{evp}, is the cooled air just leaving the cooling pads in ºC, and, $T_{out\text{-}wb}$, is the wet-bulb air temperature of the outdoor in ºC. To express the synergistic effects of indoor dry-bulb air temperature ($T_{ai,\ db}$) and indoor dew-point air temperature ($T_{ai,\ dp}$), vapour pressure deficit of the indoor air (VPD_{air}) was functioned and computed according to the following equation (ASHREA, 2005):

$$VPD_{air} = P_{ws} \times (1 - RH), \quad kPa \qquad (2)$$

Where, P_{ws}, is the saturation vapour pressure at ($T_{ai,\ db}$) in kPa, and, RH, is the indoor air relative humidity in decimal. For $0^o \leq T_{ai,\ db} \leq 200^oC$, P_{ws} can be calculated from the following equation (ASHREA, 2005):

$$P_{ws} = \exp\left[C_1/T + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 \ln(T)\right] \qquad (3)$$

Where, T, is the dry-bulb temperature in Kelvin, and the constants are as follows:

C_1 = - 5.8002206 E + 03	,	C_2 = 1.3914993 E + 00
C_3 = - 4.8640239 E – 02	,	C_4 = 4.1764768 E – 05
C_5 = - 1.4452093 E – 08	,	C_6 = 6.5459673 E + 00

Statistical Analysis:

The analysis of variance, (Complete Random Design) was used to analyze the obtained data as outlined by Snedecor and Cochran (1980). Comparisons among the means of different treatments were executed, using

Duncan's multiple range test procedure at p = 0.05 level of significance, as illustrated by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Temperature is one of the most crucial environmental factors influencing plant growth, development, and productivity, especially in protected cultivation. There are various methods for cooling greenhouses, among them evaporative cooling and shading. They were utilized to investigate their effects on microclimatic conditions of the greenhouses. The experiments were carried out during two growing summer seasons of 2009 and 2010 and the averages of three successive days with similar macroclimatic conditions were selected for the representation in this study.

The main factors affecting microclimatic conditions of greenhouse are the intensity of solar radiation, the indoor air temperature, and relative humidity. The intensity of solar radiation outside the greenhouses during the experimental period for the three following days is illustrated in Fig. (3). The outdoor air temperatures and relative humidity for the same period are also shown in Fig. (4).

Effectiveness of shading

The hourly average outdoor and indoor air temperatures of the two greenhouses (one with shading screen and the other without shading) during the three successive days are showed in Fig. (5). It clearly showed that, the average temperatures of both greenhouses were higher than the ambient air temperatures for most of the day. It also, revealed that the indoor air temperatures of the shaded greenhouse was lower than that the greenhouse without shading. The maximum indoor air temperatures reached to 37.8 and 41.9^{o}C for the greenhouses with and without shading screens, respectively. Reduction percentage of indoor air temperature due to shading screen was 9.78%. This obtained result is in agreement with the data published by Hatem et al. (2007) as they found that the indoor air temperature of the greenhouse without shading screen is higher than that the shaded greenhouse particularly at the period from 12.00 pm to 4:00 pm. Under shading condition, the air temperature was mainly reduced by 3 - 5^{o}C.

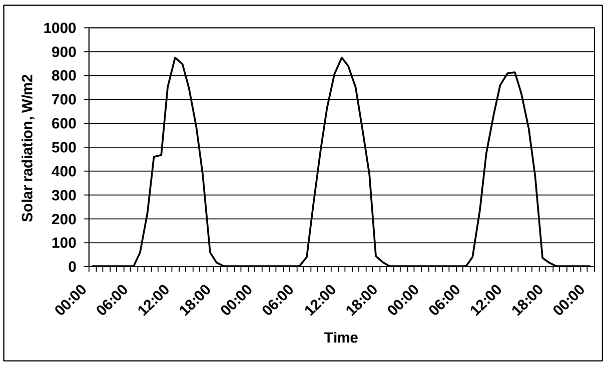

Fig. (3): Intensity of solar radiation outside the two greenhouses for the three successive days.

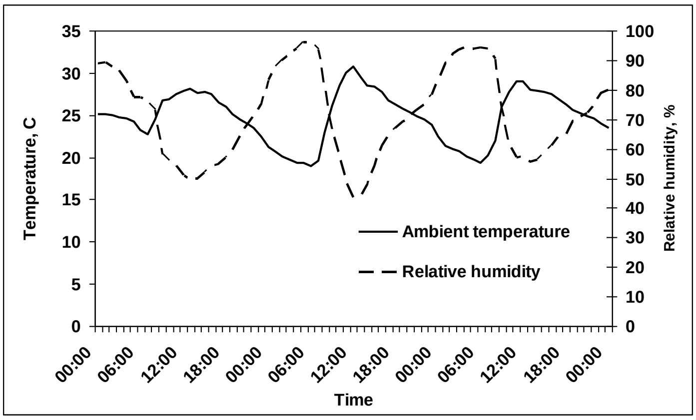

Fig. (4): Hourly averages outdoor air temperature and relative humidity for the three following days.

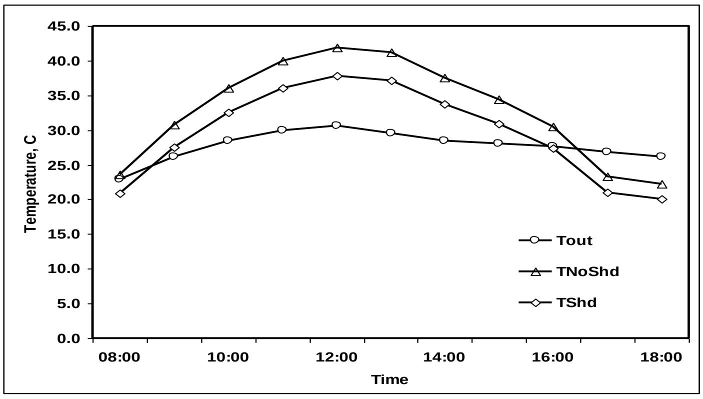

Fig. (5): Effect of shading on the indoor air temperatures of the two greenhouses.

Effectiveness of the two different cooling pads

The evaporative cooling systems using two different cooling pads were operated without shading to investigate and examine the effectiveness of the two cooling pads. The effect of the two different cooling pad materials on the indoor air temperatures of the two greenhouses is illustrated in Fig. (6). The indoor air temperatures of the greenhouse used the LPM were slightly higher than that of the greenhouse with CCP. The hourly average indoor air temperatures of the two greenhouses with two different cooling pads (CCP and LPM) were 27.3 and 28.4^{o}C, respectively. The hourly average increase in the indoor air temperature due to using the LPM was 1.1^{o}C. The hourly average differences in the indoor air temperature between the two different cooling pads were ranged between 0.9 to 1.2^{o}C. The differences in the air temperature between the outdoor and indoor of the greenhouse with CCP were ranged from 0.7 to 1.5^{o}C while, they were ranged between 0.9 to 2.7^{o}C for the greenhouse with LPM. These obtained data are in agreement with that published by Yakout (2006) who found that the differences in air temperature between outdoor and indoor of greenhouse with LPM were 2.3, 3.0, 4.1, 3.5, and 2.5°C during April, May, June, July, and August, respectively, meanwhile, these differences for the greenhouse with CCP at the same period were 0.7, 1.8, 2.0, 1.5, and 1.3°C, respectively. These results are also in agreement with that published by Oz et al., (2009) when they determined that indoor air temperature in the greenhouse tend to decrease during summer months by using fan-pad cooling system, the indoor air temperatures of the greenhouse were lowered to 10-12°C.

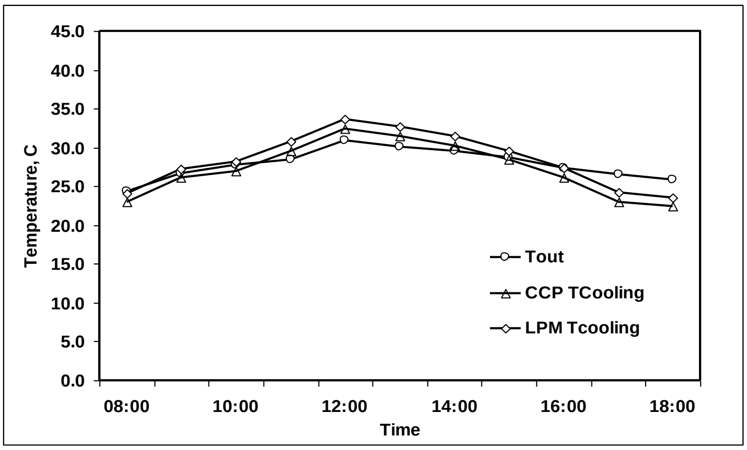

Fig. (6): Effect of the two different cooling pads on the indoor air temperatures of the two greenhouses.

Effectiveness of operating the two evaporative cooling systems with externally shading the greenhouse using cooling pad of LPM

The two evaporative cooling systems were operated while the greenhouse with cooling pad of LPM was externally shaded. The obtained results are plotted in Fig. (7). It clearly showed that the evaporative cooling system used the cooling pad of LPM was more efficient in cooling the indoor air of greenhouse than the other greenhouse used cooling pad of CCP without shading. The maximum indoor air temperatures for the cooling pads LPM and CCP were 29.5 and 31.4°C with an hourly averages 26.2 and 27.3°C, respectively. This means that externally shading screen of the greenhouse with the local pad materials (LPM) enhanced the cooling effect of the evaporative cooling system over the other system used Cellulose cooling pad (CCP).

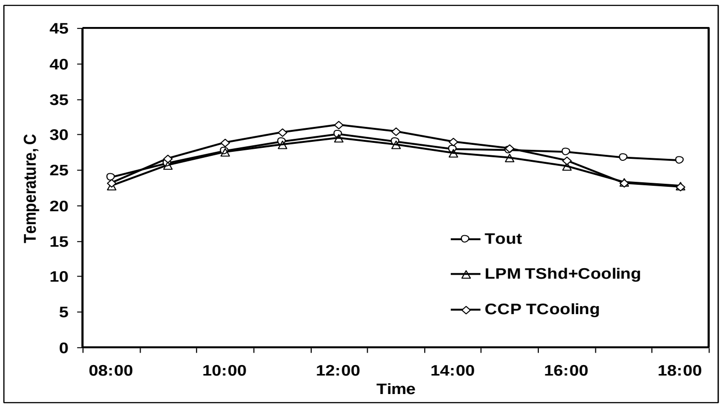

Fig. (7): Indoor air temperatures of the two greenhouses as affected by operating the evaporative cooling systems with externally shading greenhouse used LPM.

Effectiveness of operating the two evaporative cooling systems with externally shading the greenhouse using cooling pad of CCP

The two evaporative cooling systems were operated while the greenhouse with cooling pad of CCP was externally shaded. The obtained data are plotted in Fig. (8). The maximum indoor air temperatures of the two greenhouses using two different cooling pads (LPM without shading and CCP with shading screen) were 33.6 and 29.7^{o}C with an hourly averages 28.6 and 25.8^{o}C, respectively. This means that the cooling pad CCP with externally shading screen lowered the indoor air temperatures than that the other cooling pad without shading screen.

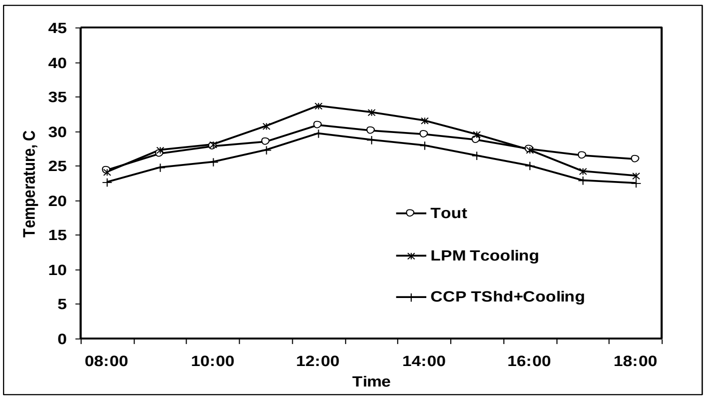

Fig. (8): Indoor air temperatures of the two greenhouses as affected by operating the evaporative cooling systems with externally shading greenhouse used CCP.

Effectiveness of operating the two evaporative cooling systems with externally shading the two greenhouses

The two evaporative cooling systems were operated while the two greenhouses were externally shaded. The outdoor and indoor air temperatures of the two greenhouses during this experimental period are plotted in Fig. (9). The maximum indoor air temperatures for the two greenhouses using cooling pads of LPM and CCP were 29.75 and 28.85^{o}C with an hourly averages 27.50 and 26.37 ^{o}C, respectively.

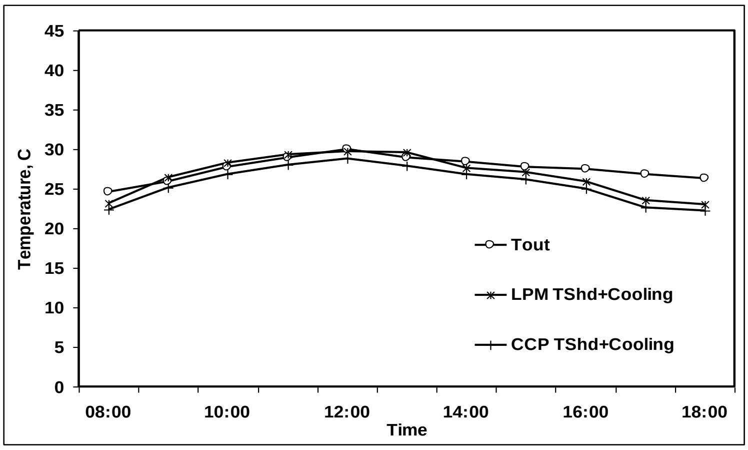

Fig. (9): Effect of shading screens on the effectiveness of the two evaporative cooling systems on the indoor air temperatures of greenhouses.

Measured indoor air temperatures of greenhouse against that calculated

A study state mathematical simulation model was developed and used to validate the predicted indoor air temperatures with that measured during the experimental period. The mathematical equations of the model were previously published by Yakout (2006), Youssef (2007), and Youssef et al. (2015). The model was utilized to predict the indoor air temperature of greenhouse in a typical experimental period. The obtained results are plotted in Fig. (10). It clearly revealed that the evaporative cooling system was intermittently operated from 9:30 AM till 11:00 AM then it was operated continuously from 11:00 till 14:30 PM, then it operated intermittently again till 17:30 PM when it was turn off. The continuously operation of the evaporative cooling system at noon could be attributed to the highly intensity of solar radiation flux incident. The maximum indoor air temperatures of the two greenhouses equipped with evaporative cooling systems and externally shaded were not increased than 29.0^{o}C while without evaporative cooling systems and shading screens increased to 41.0^{o}C. These obtained results are in agreement with that published by Kittas et al. (2003) when they reported that the evaporative cooling system based on pad-fan system was able to keep the indoor air temperature of below 28°C in all circumstances. This level of indoor air temperature is recommended by Ayres, (2014) when showed that the optimum germination temperature for melon crop is between 25-28°C and night temperature not lower than 18°C. Optimum growth temperatures during daylight-time are between 24-30°C and at nighttime are between 18-20°C.

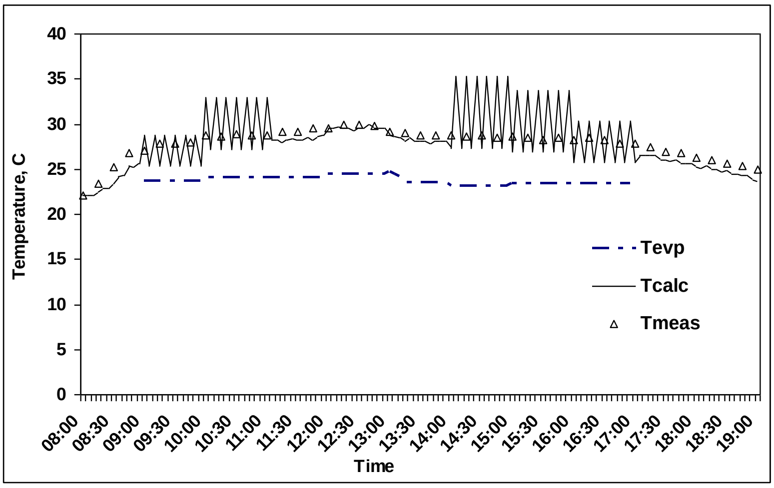

Fig. (10): Predicted and measured indoor air temperatures of greenhouse during the experimental period.

Vapour pressure deficit during daylight-time

The vapour pressure deficit (VPD) values for the two greenhouses externally shaded with black screens (60% transmissivity) were daily computed. The weight mean values for the two greenhouses (CCP and LPM), respectively, were 1.480 and 1.458 kPa according to the data measured and listed in Table (1). The vapour pressure deficit (VPD) values during the experimental period showed that the cantaloupe plants were not stressed as the indoor environmental conditions were comfortable for all plants. When the vapour pressure deficit values increased above 2.0 kPa, heat stress occurred and reduced rates of growth, development, and productivity of cantaloupe crop.

Effect of the two evaporative cooling systems on the yield and fruit quality of cantaloupe crop

Vegetative growth

The vegetative growth for cantaloupe crop included; plant length, number of branches per plant and fruit maturity during the experimental period are summarized and listed in Table (2). It clearly indicates that the vegetative growth for the greenhouse (G1) was higher than that in greenhouse (G2) during the two growing seasons. However, there were no significant differences in both seasons. While, there was significant difference for average fruit maturity in the first season. They were taken 77.0 and 80.0 days for the two greenhouses, respectively. This finding could be attributed to the microclimatic conditions of the two greenhouses resulting in earlier fruit maturation as mentioned by Pardossi et al. (2000). It is clear that the effect of utilizing the two cooling pad materials with externally shading screens have had the same effect on the vegetative growth characteristics for the two greenhouses whereas they have the ability to keep the indoor air temperatures at and around the optimal recommended level.

Table (1): Indoor and outdoor environmental conditions measured during study period.

Parameters	CCP greenhouse			
	Max.	**Min.**	**Mean**	**SD**
Indoor air temperature, ºC	28.85	22.65	26.37	±1.90
Outdoor air temperature, ºC	30.0	25.90	28.01	±1.24
Indoor air relative humidity, %	68.64	49.75	57.36	±7.05
Outdoor air relative humidity, %	59.0	32.0	42.78	±9.34
Effectiveness of evaporative cooling system	79.25	49.44	65.67	±10.51
Vapour pressure deficit, kPa	1.928	0.855	1.480	±0.375
Parameters	**LPM greenhouse**			
	Max.	**Min.**	**Mean**	**SD**
Indoor air temperature, ºC	29.75	23.55	27.50	±2. 03
Outdoor air temperature, ºC	30.0	25.90	28.01	± 1.24
Indoor air relative humidity, %	71.49	53.24	60.67	±6.51
Outdoor air relative humidity, %	59.0	32.0	42.78	± 9.34
Effectiveness of evaporative cooling system	72.98	45.14	61.02	±9.83
Vapour pressure deficit, kPa	1.878	0.927	1.458	±0.371

Table (2): Average vegetative growth characters in both greenhouses during 2009 and 2010 seasons.

Greenhouse	2009 season			2010 season		
	Plant length (cm)	**No. of branches /plant**	**Fruit maturity (days)**	**Plant length (cm)**	**No. of branches /plant**	**Fruit maturity (days)**
G1	188.0[a]	4.83[a]	80.0[b]	179.7[a]	3.80[a]	78.67[a]
G2	182.0[a]	4.67[a]	77.0[a]	176.7[a]	3.63[a]	76.67[a]

Values with the same alphabetical letter, in a comparable group of means do not differ significantly according to Duncan's Multiple Range test at 0.05 level of significance

Fresh yield productivity

The number of fruits per plant, average fruit weight and fruit fresh yield are summarized and listed in Table (3). The number of fruits per plant and average fruit fresh yield per plant for greenhouse (G1) was higher than that for greenhouse (G2) however; the differences between the two greenhouse was no significant during the two growing seasons. On the other hand, the average fruit weight or greenhouse (G1) was lower than that for the greenhouse (G2) during the two growing seasons. The obtained results are in agreement with the data published by Perry and Wehner (1990) when they reported that increasing the fruit loads on the plant negatively affect on fruit growth rate and weight.

Table (3): Average fruit yield and yield components in both greenhouses during 2009 and 2010 seasons.

Greenhouse	2009 season			2010 season		
	No. of fruits/ plant	Average fruit weight (kg)	Average fruit yield/ plant (kg)	No. of fruits/ plant	Average fruit weight (kg)	Average fruit yield/ plant (kg)
G1	5.5[a]	0.757[a]	4.16[a]	5.33[a]	0.770[a]	4.10[a]
G2	5.0[a]	0.807[a]	4.04[a]	4.67[a]	0.840[a]	3.92[a]

Values with the same alphabetical letter, in a comparable group of means do not differ significantly according to Duncan's Multiple Range test at 0.05 level of significance

Fruit quality characters

Data for the flesh thickness, placenta hardness, netted degree, T.S.S%, fruit moisture content% and sugar content are listed in Table (4). The data listed in the table clearly revealed that there were no significant differences among these characteristics during the two growing seasons for the two greenhouses (G1 and G2) On the other hand, placenta hardness showed a little difference in the second season. The data indicated that both evaporative cooling systems with externally shading screens have had the same performance in keeping the microclimatic conditions of the two greenhouses at and around the optimal recommended levels during summer season so there were no significant differences in the studied parameters in both greenhouses.

Table (4): Average fruit quality characteristics in both greenhouses during growing seasons of 2009 and 2010 seasons.

Greenhouse	Flesh thickness (%)	Placenta hardness	Netted degree	T.S.S. (%)	Fruit moisture (%)	Sugar content (mg/100 gm F.W)
2009 season						
G1	64.0[a]	10.0[a]	9.8[a]	12.67[a]	93.67[a]	2.83[a]
G2	60.3[a]	9.9[a]	9.4[a]	11.67[a]	93.33[a]	2.73[a]
2010 season						
G1	63.7[a]	10.0[a]	9.9[a]	12.8[a]	93.0[a]	2.70[a]
G2	64.0 a	9.87[b]	9.8[a]	12.5[a]	92.3[a]	2.73[a]

Values with the same alphabetical letter, in a comparable group of means do not differ significantly according to Duncan's Multiple Range test at 0.05 level of significance

CONCLUSION

Ultimately, to improve the cooling performance of LPM, (locally pad materials) and minimize the total costs of the cooling process, the greenhouse could be shaded to provide and maintain the microclimatic conditions at the recommended temperature levels as the greenhouse equipped with cooling pads of cellulose plates.

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تأثير تثبيت شبك تظليل خارجي على مناخ صوبة نبات الكنتالوب المزودة بنظام تبريد تبخيري

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أجريت هذه التجربة بمحطة بحوث البساتين بالصبحية ، الإسكندرية، خلال موسمي الصيف لسنتي 2009 ، 2010. جهزت كل صوبة بنظام تبريد تبخيري لتبريد الصوبة باستخدام وسادتين مختلفتين، الأولي من مواد مصنعة محلياً (قش الأرز – لوف) والأخرى وسادة السيلليلوز التجارية. وتم اختبار أداء نظامي التبريد منفردا، ثم مع تظليل الصوبة لكل نظام علي حده، ثم مع تظليل الصوبتين معاً. ثم تم تشغيل نظامي التبريد مع تظليل كلا الصوبتين لاختبار أداء نبات الكنتالوب من حيث الصفات الخضرية ، والمحصول وجودة الثمار الناتجة وكانت أهم النتائج المتحصل عليها:-

1- عند دراسة تأثير التظليل فقط على درجة حرارة الصوبة، كانت درجة حرارة الصوبة المظللة أقل من الصوبة الغير مظللة، وصلت أقصى درجة حرارة للصوبة المظللة والغير مظللة 37,8 و 41,9 درجة مئوية، على الترتيب.
2- عند تشغيل نظامي التبريد بدون تظليل، كانت درجات حرارة المتوسطة للصوبة المبردة بوسادة قش الأرز (محلية الصنع) ووسادة السيلليلوز28,4 و 27,3 درجة مئوية، على الترتيب.
3- عند تشغيل نظامي التبريد مع تظليل صوبة وسادة قش الأرز، كانت أقصى درجة حرارة لصوبة وسادة قش الأرز ووسادة السيلليلوز 29,26 و 31,36 درجة مئوية، على الترتيب.
4- عند تشغيل نظامي التبريد مع تظليل صوبة وسادة السيلليلوز، كانت أقصى درجة حرارة لصوبة وسادة قش الأرز ووسادة السيلليلوز 33,63 و 29,66 درجة مئوية، على الترتيب.
5- عند تشغيل نظامي التبريد مع تظليل كلا الصوبتين، كانت أقصى درجة حرارة لصوبة وسادة قش الأرز ووسادة السيلليلوز 29,75 و 28,85 درجة مئوية، على الترتيب.
6- كان لاستخدام نظامي التبريد مع التظليل خلال موسمي التجربة تأثير متساوي على إنتاجية الكنتالوب وجودة الثمار لكلا الصوبتين لقدرتهما على المحافظة علي درجة حرارة هواء الصوب في الحدود الموصي بها ولم تكن هناك فروق معنوية للصفات المدروسة.

ويتبين هذه الدراسة أنه يمكن الاعتماد على الوسادة المصنعة من مواد محلية (قش الأرز – لوف) مع تظليل الصوبة بشبك التظليل (بنفاذية للضوء 60 %) للحصول على كفاءة تبريد من نظام التبريد التبخيري بالصوبة تعادل تقريبا تبريد وسادة السيلليلوز المستوردة.