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ENHANCEMENT OF PLASTIC GREENHOUSE COVERING SYSTEMS IN HOT ARID CLIMATE

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ABSTRACT

This study deals with the effect of using two layers of polyethylene tightly fixed together along the frame elements of the walls and the roof, the space between the films was inflated at a pressure of 50 Pa, on, the effectiveness of evaporative cooling system during hot period, energy transport characteristics during cold period, and most relative vegetative growth parameters and production of egg-plant crop under eastern province climatic conditions of Saudi Arabia. These parameters were studied and compared with the commonly used double layers (without air gap) covering method. The results of this experimental work show that the greatest values of cooling effect (16.60°C) and effectiveness of evaporative cooling system (81.5%) were achieved inside the greenhouses covered with double layers of polyethylene with 9 cm air gap (G1), whereas, the effectiveness of cooling system (76.2%) occurred inside the greenhouse covered by double layers of polyethylene without air gap (G2). Consequently, Greenhouse 1 increased the effectiveness of cooling system by 5.3%. At nighttime the heat flux at the soil surface normally contributes heat energy to the greenhouse air, by releasing heat energy stored from the absorption of solar radiation at the floor surface on the previous daylight. Inside the greenhouse heat is transferred from the floor surface to the inside air by natural convection and thermal radiation emits from the floor or a uniform horizontal canopy surface of egg-plant. The hourly averages solar radiation recorded outside and inside the two greenhouses was 563.8, 273.8, and 300.7 Wm^{-2}, consequently, the effective reflectance, absorption, and transmittance of the covering methods was on the average 48.56% and 53.34%, respectively. The air temperatures within the two greenhouses were at or around the desired level particularly in the greenhouse 1. Thus, the egg-plants were grown well during the experimental period. Moreover, the greenhouse 1, on the average, increased the rate of vegetative growth by 30.30% and fresh yield of egg-plant crop by 32.68%.

Keywords: Greenhouse, polyethylene cover, egg-plant

INTRODUCTION

Greenhouses are essential requirement to produce different crops in Saudi Arabia during summer and winter seasons. It can provide and maintain a desired level of environment (air temperature and relative humidity) that will result in improving crop growth and production. The prolongation of optimal growing season conditions by the operation of the greenhouse throughout the year is worthwhile for the following reasons; regular exports to keep the demands of the market supplies, maximized use of the installation, increased annual fresh yield per unit area, and increased profitability. In spite of this in most Arabic countries greenhouses such as a practice is limited because the cooling methods used (mainly natural or forced ventilation) are not provided the optimal conditions, particularly during the hot-humid summer months.

Thus, a greenhouse is essentially equipped with some environmental modifications such as heating, ventilating and cooling systems. Greenhouse plant production is one of the most intensive parts of the agricultural production (Djevic and Dimitrijevic, 2009).

A good greenhouse will provide a suitable level of transmission of solar radiation and a maximum insulation within an economic perspective. This could be satisfied by the use of transparent double-layered of polyethylene covers as a covering material. Insulation can be improved by the use of covering materials with a layered structure containing air layers (Swinkels *et al*., 2001).

Greenhouse industry in Saudi Arabia has been revolutionized by using both expensive and inexpensive transparent materials which can be supported on relatively heavy and light structures. The use of controlled environment agriculture (where the growth and development of plants is controlled by regulation of ambient conditions such as light, air temperature, air relative humidity, and soil nutrients) has been suggested for commercial greenhouse crop production since it could promise increased yields, better quality, and production stability of high value crop precise. The required maintenance of the growth environment makes input energy costs as a major consideration in the development of this agricultural technology (Al-Amri, 2000). Greenhouse ventilation is a necessary process to remove solar radiation heat, to control the level of relative humidity, and to replenish carbon dioxide that plants consume during the daylight hours in the process of photosynthesis (Al-Helal, 2007).

Greenhouses, by their inherent nature, are large energy consumers). As energy conservation schemes for greenhouses are implemented and greenhouse crops become more competitive with imports, profit margins should be restored, and new greenhouse construction will regain momentum. Designers will be called upon to produce new energy efficient designs compatible with energy conservation systems and changing cultural practices and crop varieties (Yang *et al*., 1995 ; Chiasson, 2006). Greenhouses provide better environmental conditions for plant growth and productivity. The important environmental factors affecting plant growth are temperature, relative humidity, light level, and carbon dioxide (Elsner *et al*., 2000 ; Al-Ayedh and Al-Doghairi, 2004).

Climate is a major factor influencing both the structural and the functional characteristics of greenhouses. The design of a greenhouse aims at exploiting the external climatic conditions for improving the indoor microclimate. For this reason, the overall greenhouse design is strongly influenced by the climate and the latitude of the location (Elsner *et al*., 2000). The increase of air temperature inside the greenhouse above the prevailing high outdoor air temperature in the tropical lowlands will stress the greenhouse crop. Lowering the air temperature is a major concern for tropical greenhouse climate management. This can be realised by: (1) reducing irradiative heat load; (2) removing excess heat through air exchange; and (3) increasing the fraction of energy partitioned into latent heat (Luo *et al*., 2005).

Polyethylene as a greenhouse covering material is low in cost, light weight, easy to apply. Unfortunately, it also has a high light transmittance and thermal conductivity. A polyethylene film is one of the most common greenhouse covering materials in Saudi Arabia. However, polyethylene films as a greenhouses covering materials with its transparent characteristics that transmits visible light (04–0.7 µm), which is the main source of energy for photosynthesis. Furthermore, it is susceptible to mechanical failure due to harsh conditions of high temperature, solar radiation, and wind. A serious problem with the greenhouse polyethylene cover is the short lifetime, especially in harsh weather conditions such as high temperature, high solar intensity, and dust, all of which are common in arid regions as occurs in central region, Saudi Arabia. The daily maximum temperature reaches as high as 45 C, and the amount of solar radiation exceeds 1000 W/m^2 (Alhamdan and Al-Helal, 2009).

The radiation transmission through a covering material is affected by several factors including: type of covering material, dirtiness, dust deposition, and changes in color caused by aging, location, and incident angle of the radiation. Another factor which determines the transmittance of a greenhouse covering is the presence of condensate on the interior surface of the materials. Temperature of the greenhouse cover is an essential parameter needed for any analysis of energy transfer in the greenhouse. Measuring the correct value is difficult due to the transparency of the covering materials and the effects of solar and thermal radiation and air movement on the cover surface (Abdel-Ghany *et al*. 2006).

Therefore, the main goal of this study is to investigate the effect of covering methods on thermal performance and energy transport characteristics in greenhouses under local climatic conditions, and their effect on the most relative vegetative growth parameters. Specific objectives are to: (a) compare the traditional covering method (double layers of polyethylene) with (double layers – separated with air gap - of polyethylene), (b) study the effect of covering method on the mechanisms of heat transfer for each case, and (c) study the effect of covering method on the most relative vegetative growth parameters and productivity.

MATERIALS AND METHODS

Gable-Even-Span Single Greenhouses

The experimental work was carried out during winter months of 2010-2011(from 15th September 2010 till 25th April 2011) in two similar gable-even-span single greenhouses, E-W orientated, and located at the Agricultural and Veterinary Research Station of King Faisal University, Saudi Arabia. They were utilized to grow and produce egg-plants under two different microclimatic conditions. The geometric characteristics of each greenhouse are as follows: eave height, 3.16 m, height of each side wall, 2.0 m, rafter angle, 30º, rafter length, 2.31 m, gable height, 1.16 m, width, 4.0 m, length 8.0 m, floor surface area, 32.0 m^2, and volume, 82.6 m^3 (Fig. 1). The structural frame of the two experimental greenhouses was formed from hot dipped galvanized pipes (38.1 mm diameter) with excellent anti-corrosion. The two greenhouses (G1 and G2) were covered using two different methods of glazing. The first greenhouse (G1) was covered using two layers of polyethylene sheet (150 µm thick as an inner layer and 200 µm thick as an outer layer) with air gab of 9 cm which inflated by air once every week at a pressure of 50 Pa. In this way, the insulating performance and the resistance of the structure to wind load may be enhanced. The other greenhouse (G2) was covered using double layer of polyethylene sheet as well as the first greenhouse but without air gab. The greenhouse facility used in this research work was covered with ratio of cover surface area (73.6 m^2) to the total floor surface area (32.0 m^2) of 2.3. To increase and maintain the durability of the structural frame and polyethylene cover, twenty tensile galvanized wires (2 mm diameter) were tied and fixed throughout the rafters and vertical bars in each side of the plastic greenhouses. The height of each side wall was 2.00 m. The straight-side wall pipes were strongly connected to the concrete foundations in order to transfer gravity, uplift and overturning loads such as those from the crop, suspended equipment, and wind loads safely to the ground.

Ventilation and cooling systems

Ambient air was forced through 7.20 m^2 face area of 10 cm thick cooling cross-fluted cellulose pads situated on the western end (side toward the prevailing winds). These cellulose pads permit 75 m^3/min. air flow rate. After crossing the pads, air stream traveled 8.0 m before being exhausted by two extracting fans located on the opposite side wall (eastern end). Each fan generates air flow rate of 3,630 m^3/h, under 2.5 mm of static pressure. A PVC pipe (12.7 mm diameter) was suspended immediately above the cooling pads. Holes were drilled each 5 cm long throughout the length of PVC pipe, and the end of this pipe was capped. To spread the water uniformly before it drops onto the cooling pads, a baffle was placed above the water pipe. A water sump was situated under the pads to collect the water and return it into the water tank (600 liters), from which it could be recycled to the cellulose pads by means of the submersible water pump. In order to bring the cold air onto the plants throughout the growth period, the cooling pads were located 20 cm above the ground surface of the greenhouse. The extracting fans were automatically operated using a differential thermostat. They switched on when the ambient air temperature inside the greenhouse was equal or greater than 25°C, and switched off when the interior ambient air temperature was lower than 25°C. The cooling process by ventilation was mostly used when the air temperature outside the greenhouse was lower than 20ºC. However, when it was higher than 20ºC, the evaporative cooling system operated. In order to prevent the accumulation of salt on the cellulose pads (mean reason of pad damage), potable water was usually used in the evaporative cooling system.

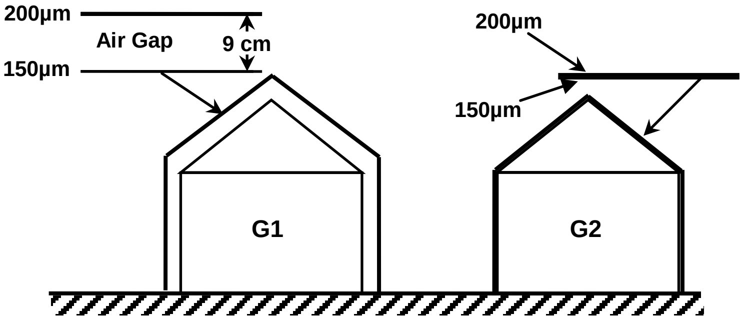

Fig. (1): Schematic diagram of two different covering methods:
(a) double layers of polyethylene with 9 cm inflated air gap, (b) double layer of polyethylene without air gap.

Watering System

A drip irrigation system was functioned for watering the egg-plants throughout the experimental work. A 2 m^3 PVC water supply tank, cylindrical in form (175 cm high, and 125 cm diameter) was located outside the greenhouses on 1.0 m above the ground surface in order to provide adequate hydrostatic pressure for maximum use rate of water. Twenty six drippers (long-bath GR, 4-litre/h discharge) were uniformly and alternative distributed with 30 cm dripper spacing throughout each row of plants inside the greenhouses.

Measurements and Data Acquisition Unit

The solar radiation, air temperature, air relative humidity, and wind speed and its direction outside the greenhouses were measured and recorded using a meteorological station installed just beside the greenhouses. Two disk solarimeters were located just above the canopy of egg-plants inside the two greenhouses. Wet and dry bulb air temperatures, temperature of the greenhouse cover, temperature of the soil surface at 5 cm deep, and relative humidity inside the two greenhouses were measured and recorded throughout the experimental work using data-logger (Onset Computer, Bourne, MA) with a manufacturer stated accuracy of ±0.35°C. The humidity ratio of the inside air in the mid-height and near the cover was obtained from psychrometric computer program in terms of dry and wet bulb temperatures. The temperature and relative humidity sensors were placed in multi-plate radiation shields (Hobo-RS3 Solar Radiation Shield) to protect them from error-producing by solar radiation and precipitation. It was found that a vertical temperature gradient existed inside the greenhouse. In order examine this effect in some detail a profile mast was constructed, on which were mounted 10 thermocouples, spaced at equal intervals, thus enabling the temperature to be measured at vertical intervals of 20 cm. It was found that the mean temperature of the inside air occurred at a height of 1.4 m slightly below the mid-height of the greenhouse. For the purpose of this analysis it was assumed that the inside air was at a uniform temperature with the value as measured in this position. The temperatures of several leaves at different locations inside the greenhouses were also measured using an infrared thermometer (Everett, WA 98203, USA). The recorded data were stored in the memory for output to a printer or to a computer file to store on disk. The time interval for data recording was 5 min with data acquisition every one minute for integrated measurements. The calibration of all sensors and the logger were completed successfully at the beginning of the experimental work.

Methods

Environmental parameters are generally recognized to have a major impact on the production of protected cropping. These parameters have been included ambient air temperature, air relative humidity, light, air movement, solar radiation intensity as well as number of plants per unit area. Reducing air temperatures is one of the main problems facing greenhouse management during daylight even in winter season such as in Saudi Arabia, in order to minimize the difference between maximum (during daylight) and minimum (at night) air temperatures.

Nocturnal heat energy balance during winter season:

The heat energy supplying to the greenhouse during nighttime can be determined according to the fact that adding heat energy must at the rate at which it is lost. The steady-state energy balance can be computed using the following equations (Zhang *et al*., 2002 ; Ozturk and Bascetincelink, 2003 and ASHREA, 2005):-

$$q_{supply} - q_{loss} + q_{gain} = 0$$
(1)

$$q_{supply} = q_{loss} - q_{gain}$$
(2

The heat energy supplying (q_{supply}) arises when there is a positive difference between heat losses (q_{loss}) and heat energy gains (q_{gain}). Due to the experimental work was executed throughout seven months (from Sept. 2010 to April 2011), there is no heat energy supplied. Therefore, the steady-state heat energy balance can be expressed as:

$$q_{loss} = q_{gain} \text{ ,} \qquad (3)$$

An illustrative, but highly simplified, derivation begins with the steady-state heat losses. The total heat losses from the inside to outside of the greenhouse can be computed from the following equation:-

$$q_{loss} = q_{cl} + q_{inf} \text{ ,} \quad \text{Watt} \qquad (4)$$

Where, q_{cl}, is the combination heat losses (by conduction, convection, and radiation) through the concrete blocks and the glazing materials of the greenhouse. It can be estimated from the following equation:-

$$q_{cl} = U_o A (T_{ai} - T_{ao}) \quad \text{,Watt} \qquad (5)$$

Where, U_o, is the overall heat transfer coefficient for each section of the greenhouse, A, surface area of each section, and Tai and T_{ao} ,respectively, are the inside and outside air temperatures of the greenhouse. The heat losses due to air infiltration through the structure (q_{inf}) from outside (cold air) to inside of the greenhouse (warm air) can be computed by considering that the total exchange is the sum of sensible and latent heat energy exchanges.

$$q_{inf} = m_a [C_{pa} (T_{ai} - T_{ao}) + h_{fg} (W_{ai} - W_{ao})], \text{ Watt} \qquad (6)$$

Where, m_a and C_{pa}, respectively, are the mass flow rate of cold air and specific heat of cold air, h_{fg} is the latent heat of vaporization of water, W_{ai} and W_{ao} are the inside and outside humidity ratios of the greenhouse, respectively.

The total rate of heat energy transferred (by natural convection, $q_{conv.}$ and radiation, $q_{rad.}$) from the concrete floor surface area (q_{gain}) and gained by the inside air can be computed from the following equation:-

$$q_{gain} = q_{conv.} + q_{rad.} \quad , \quad \text{Watt} \qquad (7)$$

The convection heat transfer from the bare floor surface to the inside air of the greenhouse can be estimated from the following formula:-

$$q_{conv.} = h_g \; A_g \; (T_g - T_{ai}) \quad , \quad \text{Watt} \qquad (8)$$

The value of the convection heat transfer coefficient (h_g) is given by

$$h_g = 1.4\,(T_g - T_{ai})^{1/3}, \quad \text{W m}^{-2}\,{}^{o}\text{K}^{-1}$$

Where, h_g, is the convective heat transfer coefficient between floor surface and internal air, A_g, and T_g, respectively, are the ground surface area, and the ground surface temperature. The radiation heat transfer from the ground surface to the interior air of the greenhouse can be calculated from the following equation:-

$$q_{rad.} = \varepsilon_g \; A_g \; \sigma \left(T_g^4 - T_{ai}^4\right) \quad , \quad \text{Watt} \qquad (9)$$

Where, ε_g, is the emissivity factor of the floor surface, and σ, is the Stefan-Boltzmann constant. Data were measured and stored in microcomputer files and statistically analyzed using Excel program. Once a computer model is tested and found to be accurate, it can be used to predict the results which could otherwise be obtained with extensive and costly experimentation.

For the duration of the experimental work (seven months), the leaves number of egg-plants, the stem length, and the total fresh yield of egg-plant crop will monitored and compared between the treatments. Statistical analysis will be used in order to compare the treatments and to clarify the effect of different treatments on the egg-plant crop. Egg-plant seeds (ALZAIN F1, N.V., Holland) were planted in the nursery on 10th August 2010, and transplanted in the greenhouses at four real leaves on 15th September 2010.

In the hot climate period of the Eastern Province of Saudi Arabia, evaporative cooling systems have been commonly employed to reduce the interior ambient air temperature of greenhouses. Evaporative cooling system efficiency (η) is normally defined as (ASHRAE, 2005):

$$\eta = \frac{T_{odb} - T_{idb}}{T_{odb} - T_{owb}} \times 100 \quad , \quad (\%) \qquad (10)$$

or

$$\eta = \frac{T_{dd}}{T_{wd}} \times 100 \quad , \quad (\%) \qquad (11)$$

Where, T_{odb} and T_{idb}, are the dry-bulb air temperatures of outside and inside, respectively (°C), T_{owb}, is the wet-bulb temperature of outside air (°C), T_{dd}, is the cooling effect (°C), and, T_{wd}, is the wet-bulb depression.

RESULTS AND DISCUSSION

During the experimental work, the two greenhouses operated satisfactorily for seven months without malfunction. Table (2) shows the daily average climatic conditions outside and inside the two greenhouses throughout the five warm months (September, October, November, March, and April), together with the contribution to heat removed due to evaporative cooling system. The air relative humidity in the two greenhouses during the daytime ranged from 48.2% to 59.4% and from 42.5% to 55.8%, respectively, whereas, the outside relative humidity was in the range 28.5– 69.3%. Most protected cropping grow best within a fairly restricted range, typically 40% to 70% relative humidity for many species (Nelson, 1996 ; Ozturk and Bascetincelik, 2003). Low humidity increases the evaporative demand on the plant to the extent that moisture stress can occur, even when there is an ample supply of water to the roots system.

The water loss from the plant and add to the inside air is often determined by; the difference in water vapor concentration between inside the leaf and outside, and by the resistance to movement of water molecules from inside the leaf to outside. The resistance varies according to the length of the path which water molecules must traverse, and the size of the stomata opening. As the leaf temperature is reduced due to evaporative cooling, the internal vapor pressure of the leaf is lowered and thus the water loss from the plant is less, and vice versa. With fan-pad cooling system, lowering of the dry-bulb temperature will generally raise the air relative humidity. Furthermore, water is always being added to the air in the greenhouse from transpiring plants and evaporating water from cooling system.

The solar radiation entering the greenhouse is often utilized to evaporate free water from the leaf, rather than raising leaf temperature and increasing water loss from the plant into inside air. When a non-saturated air comes in contact with free moisture and the two are thermal isolated from outside heat source, there is a transfer of mass and heat. Because of the vapor pressure of the free water surface is higher than that of the unsaturated air, water transfers in response to the differential. The transfer involves a change of state from liquid to vapor, requiring heat of vaporization. In spite of the pad face air velocity of fan-pad cooling system used with the two greenhouses was on the average 1.8 m/s, the air relative humidity inside G1 was greater than that in G2. This may be due to high intensity of solar radiation flux incident inside G2 as compared with G1 owing to the air space between the double layers of cover absorbs significant amount of solar radiation. Due to all the reasons discussed above, the air relative humidity in G2 was lower than that in G1 by 8.1%.

The effectiveness of the cross-fluted pads as a cooling media was experimentally examined from September 2010 to Aril 2011. Cooling capacity is dependent upon the volume of air flow and the saturation efficiency. Saturation efficiency is in turn depend strongly upon such factors as; length of cooling operation period, air velocity through the pad, water temperature in the cooling system, water flow rate through the cooling media, and intensity of solar radiation. The daily average effectiveness of the fan-pad cooling system inside the two greenhouses (G1 and G2) during the experimental period, respectively, was on the average 71.64% and 64.16%. Accordingly, the cooling system of G1 was on the average more efficient than the cooling system of G2 by 7.48% due to the intensity of solar radiation and consequently the thermal trapping occurred inside G1 was lower than that in G2. As a result, the air temperature difference between the air removed from the greenhouse and just left the cooling pads was lower than that in G2.

The effectiveness of fan-pad cooling system varied from time to time, from day to another, and during the experimental period, according to the air relative humidity and dry-bulb air temperature outside the greenhouses. As the exterior air relative humidity is decreased lower than 30%, more cooling effect is achieved making the cooling system more efficient. Substantial temperature decreases were obtained when the air relative humidity recorded outside was less than 30% and outside air temperature exceeded 35°C. Therefore, the two cooling systems achieved a cooling effect ranged between 16.6 to 1.7°C at air relative humidity ranged from 28.6 – 72.5%, respectively.

Table (2): Daily Average air relative humidity (RH), ambient air temperature (T_{odb}), wet-bulb temperature (T_{owb}) outside the Greenhouses, wet-bulb depression (T_{wd}), inside air temperatures (T_{idb}), cooling effect (T_{dd}), and effectiveness of evaporative cooling system (η).

Month	House	R.H., %	T_{odb}, °C	T_{owb}, °C	T_{wd}, °C	T_{idb}, °C	T_{dd}, °C	η, %
Sept., 2010	G1	42.5	40.3	28.7	11.6	32.1	7.6	65.5
	G2					33.5	6.8	58.6
Oct., 2010	G1	39.3	38.6	26.6	12.0	30.3	8.3	69.2
	G2					31.4	7.2	60.0
Nov., 2010	G1	35.3	35.8	23.4	12.4	27.1	8.7	70.2
	G2					28.0	7.8	62.9
March, 2011	G1	33.2	33.5	21.2	12.3	24.5	9.0	73.2
	G2					25.3	8.2	66.7
April, 2011	G1	30.6	39.5	24.9	14.6	27.8	11.7	80.1
	G2					28.9	10.6	69.9
Mean	G1	36.18	37.54	24.96	12.58	28.36	9.06	71.64
	G2					29.42	8.12	64.16

Cooling effect (degree of cooling) and consequently evaporative cooling efficiency was strongly dependent upon the wet-bulb depression that mainly affected by air relative humidity and water temperature in the cooling system. Therefore, the greatest value of cooling effect for G1 and G2 (16.6°C and 14.8°C, respectively) and cooling efficiencies (81.5% and 76.2%, respectively) were achieved with the greatest value of wet-bulb depression (20.5°C) and lowest value of air relative humidity (28.6%). Whereas, the lowest value of cooling effect for G1 and G2 (2.0°C and 1.7°C, respectively) and cooling efficiencies (57.1% and 48.6%, respectively) were recognized with the lowest value of wet-bulb depression (3.5) and greatest value of air relative humidity (72.5%). To determine and examine the best model which can be used to correlate cold air temperature just leaving the pad cooling system (T_{dd}) in G1 and G2, and wet-bulb depression (T_{wd}) all the obtained data were used in regression analysis and plotted in Fig. (2). Regression analysis revealed a highly significant linear relationship between these parameter. The linear regression equations for the best fit were:-

$$\mathbf{T_{dd}\ (G1) = 0.799073\ (T_{wd})} \qquad \mathbf{(12)}$$

$$\mathbf{T_{dd}\ (G2) = 0.700778\ (T_{wd})} \qquad \mathbf{(13)}$$

Nocturnal heat energy balance during the three months of winter season (December, January, and February) was determined according to the heat flux at the soil surface. At nighttime this normally contributes heat energy to the greenhouse air, by releasing heat energy stored from the absorption of solar radiation at the floor surface on the previous daylight. Inside the greenhouse heat is transferred from the floor surface to the inside air by natural convection and thermal radiation emits from the floor or a uniform horizontal canopy surface of egg-plant. Table (3) reveals the microclimatic conditions for each greenhouse, together with the contributions to the heat energy input to the greenhouses from the heat stored in the soil.

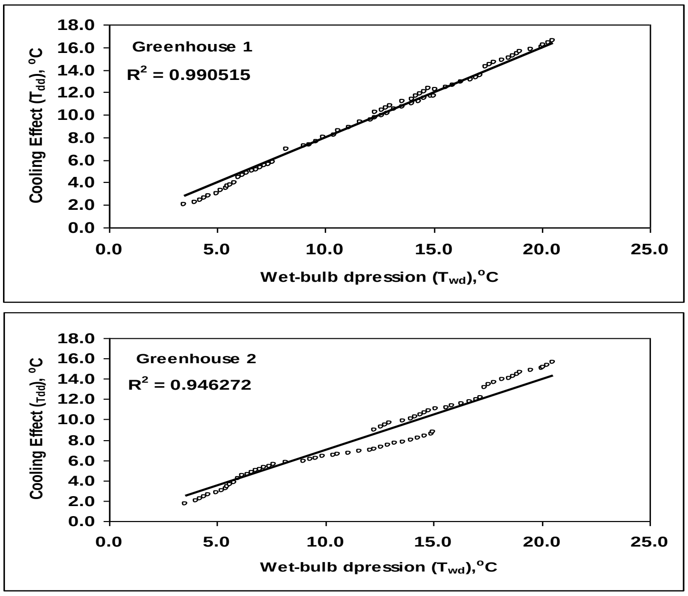

Fig. (2): Cooling effect of the evaporative cooling system versus wet-bulb depression during the experimental period

Table (3): Solar radiation flux incident outside (Ro) and inside (Ri) the two greenhouses, and air temperatures outside (Tao) and inside (Tai) the greenhouses during the winter months

Month	**Solar radiation, W/m²**			**Air temperature, ºC**		
	SRo	**SRi (G1)**	**SRi (G2)**	**Tao**	**Tai (G1)**	**Tai (G2)**
December	477.3	231.8	254.6	14.7	17.4	16.8
January	565.2	274.5	301.5	15.4	16.9	16.1
February	648.9	315.1	346.1	16.7	18.5	17.8
Mean	563.8	273.8	300.7	15.6	17.6	16.9

Actual solar radiation data recorded outside (R_o) and inside (R_i) on a clear day ranged from near zero to about 1000 Wm^{-2}. The lowest values during the experimental period were in the range 55-110 Wm^{-2} which occurred just after sunrise and prior to sunset. They varied from day to another and during the month according to the sky cover (clouds), solar altitude angle, and solar incident angle. The actual solar radiation recorded inside the two greenhouses was lower than that outside, due to the reflectance, absorption, and transmittance factors of the two different covering methods as shown in Fig. (3). The hourly averages solar radiation recorded outside and inside the two greenhouses was 563.8, 273.8, and 300.7 Wm^{-2}, consequently, the effective reflectance, absorption, and transmittance of the covering methods was on the average 48.56% and 53.34%, respectively.

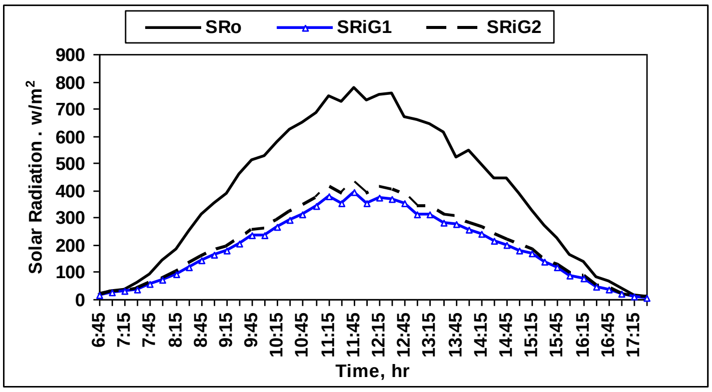

Fig. (3): Relationship between solar radiation flux incident outside and inside the two greenhouses.

To determine and examine the best model which can be used to correlate solar radiation flux incident inside (Ri) the two greenhouses (G1 and G2), and solar radiation flux incident outside the greenhouses (Ro) all the obtained data were used in regression analysis and plotted in Fig. (4). Regression analysis revealed a highly significant linear relationship between these parameter. The linear regression equations for the best fit were:-

$$Ri\ (G1) = 0.4856\ (Ro) \qquad (14)$$

$$Ri\ (G2) = 0.5334\ (Ro) \qquad (15)$$

The two slopes of the linear regression equations represent the effective reflectance, absorption, and transmittance of the covering methods of the two greenhouses. Due to the covering method of greenhouse 1 has an inflated air gap of 9 cm thick, thereby leading to a greater amount of solar radiation absorbed and reflected, and the rest was transmitted through the cover. As can be seen Fig. (3), the value of the internal solar radiation (Ri) shows the greatest response to difference in transparency of the covering methods.

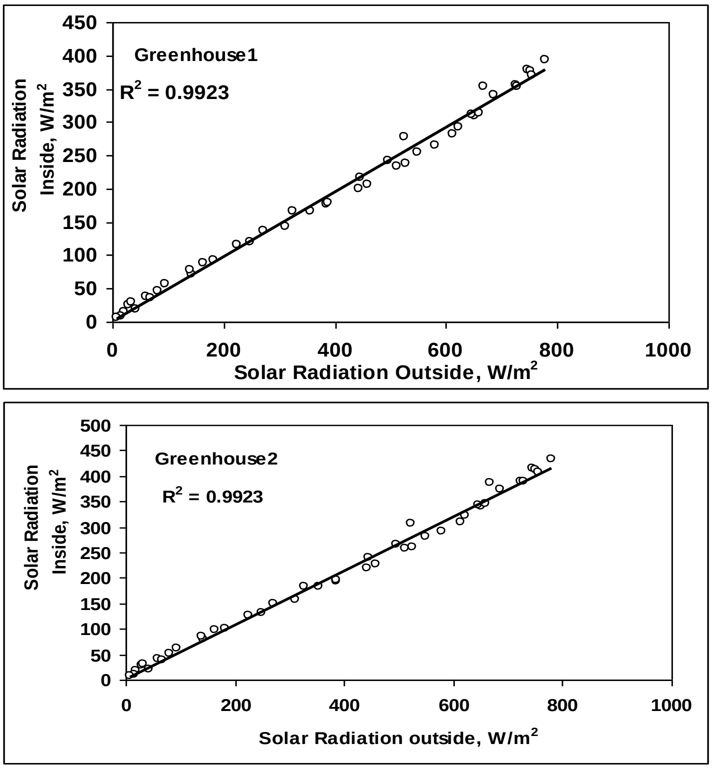

Fig. (4): Solar radiation flux incident inside the two greenhouses versus solar radiation flux outside.

The principal effect of greenhouses glazing methods is to provide thermal resistance that reduces the overall rate of heat transfer to the surroundings. Most undesirable heat loss from a greenhouse occurs by long-wave radiation, conduction and convection, and by infiltration. The total heat losses from the two greenhouses increased gradually with time from 20.00h until they reached the maximum values at 06.00h due to reduction in the outside air temperature. The hourly averages heat energy loss from the two greenhouses (G1 and G2) at nighttime during the coldest month was 1.530 and 1.798 kWh, respectively. Consequently, the polyethylene cover (double layer without air gap) increased the heat loss by 17.52% as compared with the polyethylene cover with air gap). The main source of the sandy soil floor surface temperature was the solar energy absorbed during the daylight. An overnight decrease in the floor temperature was observed inside the two greenhouses due to conduction, convection and radiation heat transfers between the floor and the inside air. At nighttime the heat energy gained from the floor was gradually decreased with time during the experimental period, as the surface temperature of the floor was reduced. Therefore, the greatest heat energy gained from the floor of the two greenhouses, respectively, was 1.692 and 1.704 kWh which achieved at the beginning of each night during the experimental period, whereas, the lowest heat energy gained (0.340 and 0.333 kWh, respectively) occurred at the end of each night. The amount of heat energy supplied to keep the air temperature at a desired level was approximately equal to the heat energy lost from the two greenhouses. To determine and examine the best model which can be used to correlate heat energy loss (Q_{loss}) from the two greenhouses (G1 and G2), and heat energy gained from the floor surface (Q_{gain}) all the obtained data were used in regression analysis and plotted in Fig. (5). Regression analysis revealed a highly significant linear relationship between these parameter. The linear regression equations for the best fit were:-

$$\mathbf{Q_{loss}\ (G1) = 0.9872\ (Q_{gain})} \qquad \mathbf{(16)}$$

$$\mathbf{Q_{loss}\ (G2) = 1.0324\ (Q_{lgain})} \qquad \mathbf{(17)}$$

Due to the air temperatures within the two greenhouses were at or around the desired level particularly in the greenhouse 1, the egg-plants were grown well during the experimental period. The weekly averages increasing rate in number of leaves inside the two greenhouses (G1 and G2), respectively, were 2.92 and 2.24 leaf/plant. This variation may be attributed to the reaction rates of various metabolic processes, absorption rate of nutrient elements, and release of water by root system, which strongly affected by the microclimatic conditions, particularly the air temperature and relative humidity within the two greenhouses. As the number of leaves is increased, the green surface area is increased, and the biochemical reactions are thus increased making the photosynthesis process more active. This in agreement with the data published by Nelson (1996)

The weekly averages stem length of egg-plants for the two greenhouses were 5.16 and 3.96 cm/week, respectively. Consequently, the covering method of greenhouse 1 increased the growth rate of egg-plants on the average by 30.30% as compared with greenhouse 2. As the air temperature surrounding the plants is reduced lower than 14°C, slower growth rate, longer internodes, thinner xylem, and smaller rate of fruit set occurred. Due to the reasons discussed previously, the number of fruits being seated on the plants within the two greenhouses was on the average 28.1 and 21.6 fruits per plant, respectively. Therefore, the total fresh yield of egg-plant crop for the two greenhouses, respectively, was 209.5 and 157.9 kg. Consequently, the greenhouse 1 was found to be on average 51.6 kg (32.68%) more productive than the greenhouse 2 as shown in Fig. (6).

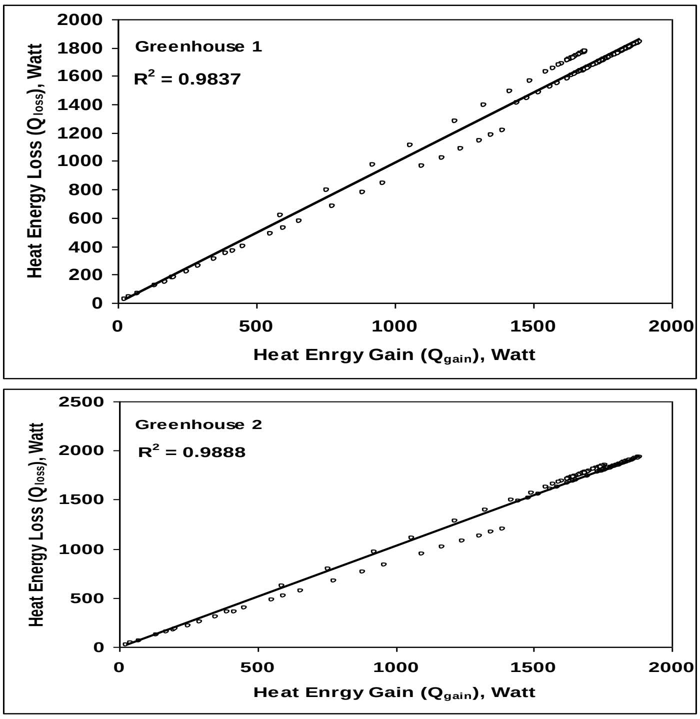

Fig. (5): Heat energy loss from the greenhouses versus heat energy gained.

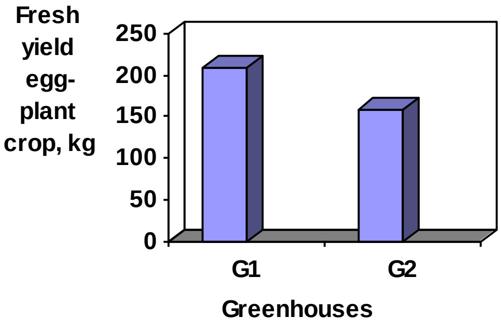

Fig. (6): Total fresh yield of egg-plant crop for the two greenhouses during the experimental period.

CONCLUSIONS

The effect of using double layers of polyethylene with air gap on the effectiveness of evaporative cooling system and heat energy transport characteristics and most relative vegetative growth parameters and production of the egg-plant crop under eastern province climatic condition were studied and compared with the commonly used double layers (without air gap) covering method. The results of this experimental work show that during the hot period (5 months) the greatest values of cooling effect (16.60°C) and effectiveness of evaporative cooling system (81.5%) were achieved inside the greenhouse covered by double layers of polyethylene with 9 cm air gap (G1), whereas, the effectiveness of cooling system (68.18%) recognized inside the greenhouse covered by double layers of polyethylene without air gap (G2). The daily average effectiveness of the fan-pad cooling system inside the two greenhouses (G1 and G2) during the experimental period, respectively, was on the average 71.64% and 64.16%. Accordingly, the cooling system of G1 was on the average more efficient than the cooling system of G2 by 7.48% due to the intensity of solar radiation and consequently the thermal trapping occurred inside G1 was lower than that in G2. As a result, the air temperature difference between the air removed from the greenhouse and just left the cooling pads was lower than that in G2. Nocturnal heat energy balance during the three months of winter season (December, January, and February) was determined according to the heat flux at the soil surface. At nighttime this normally contributes heat energy to the greenhouse air, by releasing heat energy stored from the absorption of solar radiation at the floor surface on the previous daylight. Inside the greenhouse heat is transferred from the floor surface to the inside air by natural convection and thermal radiation emits from the floor or a uniform horizontal canopy surface of egg-plant. . At nighttime the heat energy gained from the floor was gradually decreased with time during the experimental period, as the surface temperature of the floor was reduced. Therefore, the greatest heat energy gained from the floor of the two greenhouses, respectively, was 1.692 and 1.704 kWh which achieved at the beginning of each night during the experimental period, whereas, the lowest heat energy gained (0.340 and 0.333 kWh, respectively) occurred at the end of each night. The amount of heat energy supplied to keep the air temperature at a desired level was approximately equal to the heat energy lost from the two greenhouses. The inflated air in the gap between the two layers in greenhouse 1 was functioned as a thermal resistance at nighttime that reduced the overall rate of heat transfer to the surroundings. Most undesirable heat loss from a greenhouse occurs by long-wave radiation, conduction and convection, and by infiltration. Therefore, the hourly averages heat energy loss from the two greenhouses (G1 and G2) at nighttime during the coldest month was 1.530 and 1.798 kWh, respectively. The number of fruits being seated on the plants within the two greenhouses was on the average 28.1 and 21.6 fruits per plant, respectively. Therefore, the total fresh yield of egg-plant crop for the two greenhouses, respectively, was 209.5 and 157.9 kg. Consequently, the greenhouse 1 was found to be on average 51.6 kg (32.68%) more productive than the greenhouse 2

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تحسين نظم تغطية البيوت المحمية بالبلاستيك فى المناخ الحار والجاف

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تهدف هذه الدراسة إلى مقارنة بيتين محميين مغطيين بطبقتين من البلاستيك (البوليإثيلين) أحدهما يحتوى على فراغ سمكه ٩ سم تم ملئه بالهواء لتعمل هذه الطبقة كمادة عازلة للحرارة أثناء الليل فى موسم الشتاء وأيضاً تعمل فى اشهر الصيف على تخفيف حمل التسخين الطبيعى من الأشعة الشمسية. أبعاد كل بيت كان ٤ × ٨ × ١٦.٣م مع مساحة أرض مقدارها ٣٢م^{٢}. تم تزويد كل بيت بنظام كامل للتبريد بالتبخير (مروحة سحب مع وسائد تبريد سيليلوزية) بغرض إزاحة الحرارة الزائدة عن المستوى المرغوب أثناء ساعات النهار وأعتمد البيتين فى التدفئة أثناء الليل على الطاقة الحرارية التى يمكن لهواء كل بيت إكتسابها بالحمل والإشعاع من الطاقة الحرارية المختزنة بسطح التربة والناتجة من الأشعة الشمسية الساقطة على التربة داخل البيتين أثناء ساعات النهار. أوضحت النتائج المتحصل عليها أن كفاءة نظام التبريد بالتبخير كانت ٧١.٦٤% و ٦٤.١٦% للبيت الأول والثانى على التوالى مما يوضح أن البيت المحمى المغطى بطبقتين من البولى إثيلين مع وجود فراغ مملوء بالهواء أدى إلى تحسين كفاء نظام التبريد بالتبخير بنسبة ٧.٤٨% مقارنة بالبيت الآخر. كما أوضحت النتائج المتحصل عليها أن الفراغ المملوء بالهواء (البيت الأول) أدى إلى تقليل معامل إنتقال الحرارة الكلى من سقف وجوانب البيت المحمى مما ترتب عليه تقليل الفواقد الحرارية أثناء ساعات الليل فى الثلاثة أشهر الباردة (ديسمبر ويناير وفبراير) مقارنة بالبيت الثانى. حيث أن الفواقد الحرارية بالبيت البيت كانت أكبر من البيت الأول بنسبة ١٧.٥٢%. نتيجة لأن درجة حرارة الهواء والرطوبة النسبية داخل البيتين كانت عند أو حول المستوى الأمثل لمحصول الباذنجان خاصة بالبيت الأول فإن معدل النمو والتزهير وعقد الثمار كانوا بصورة مرضية مما ترتب عليه تحقيق إنتاج بلغ فى المتوسط ٢٠٩.٥ و ١٥٧.٩ كجم للبيت الأول والثانى على التوالى، بالتالى فإن نظام التغطية للبيت الأول قد أدى إلى زيادة الإنتاج الطازج من الباذنجان بنسبة ٣٢.٦٨% مقارنة بالبيت الأول.

قام بتحكيم البحث

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