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DEVELOPING A SOLAR HEATING SYSTEM FOR HEATING SWEET COLOUR PEPPER GREENHOUSE

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ABSTRACT

The objective of the present study was to evaluate the effect of solar heating system on the microclimatic conditions of sweet colour pepper greenhouse during winter season of 2009-2010. The use of solar energy system for greenhouse heating in winter and cold days helps to save fossil fuels and conserve green farm environment on the one hand, and on the other, enhances the quality of greenhouse products, reduces production costs and limits the release of greenhouse gases. Temperatures of inside and outside air, solar radiation flux incident, and air relative humidity of inside and outside for the last five years at nighttimes have been collected and used to calculate the total heat losses from the greenhouse. Using this data the solar collector area and collector configuration were calculated so that the optimal surface area of solar collectors was found to be 4 m^2 that adequate to heat the sweet colour pepper crop greenhouse. The thermal performance analysis was experimentally determined, by measuring the temperature increase at various water inlet temperatures and intensity of solar radiation, under clear sky conditions. A complete solar heating system (two solar collectors and storage tank) was utilised for heating 300 litres of water. The daily average overall thermal efficiencies of the solar collector and the storage system during the experimental period were 71.3% and 91.3%, respectively. Over a 181 days season the solar heating system collected 3813 kWh of energy or 70.5% of the total heat energy required to heat the greenhouse (27.234 kWh). This percentage could be increased by reducing heat losses from the greenhouse. Due to the microclimatic conditions of the greenhouse were at or around the desired level, the sweet colour pepper had have optimal vegetative growth rate, stem length, number of fruits being seated, and fresh yield. The total costs per square meter of greenhouse were L.E. 56.1.The fresh yield of sweet colour pepper was 5.931 kg/m^2, which sold by L.E. 80.1, consequently, the estimated return on capital was 42.8% per annum.

INTRODUCTION

Greenhouse development and expansion for off-season growing of vegetables and flowers since the first two-thirds of the twentieth century, have been based on plentiful and relatively low cost fuel. The greenhouse industry considered as one of the fastest growing agricultural sectors in Egypt, mainly because of its favorable climatic conditions during winter season. This sector creates important employment opportunities and benefit throughout the processing and marketing stages of greenhouse products. The industry is also very important for creating a demand for sub-sectors that provide inputs for greenhouse production such as seeds, organic fertilisers, bio-pesticides, glazing materials, and son on. The total greenhouse area has increased from 4.8 feddan in 1980 to more than 40,000 feddan in 2005, with 32,000 feddan plastic tunnels. This area is in operation for high cash crops production (sweet colour pepper, beans, cucumber, tomatoes, and cantaloupe).

Because of large heating loads and relatively high prices of fossil fuels (100-150$/barrel), alternative energy sources for greenhouse has gained utmost interest. Some of the important alternative sources of energy are; solar collectors, heat pumps, and thermal energy storage systems using phase change materials. As solar energy is available only during the daylight, its application requires efficient thermal energy storage systems. Therefore, the excess heat collected during the daylight is stored for later use at nighttime. Heating of a greenhouse is an essential requirement for proper growth and development of winter growing crops (Tiwari, 2003). Thermal heating of greenhouses have been studied by several researchers in employing different passive methods as well as active modes (Jain and Tiwari, 2003 ; Özturk and Bascetincelik, 2003 ; Abdellatif *et al*., 2007; Benli and Drmus, 2009 ; and Lu Aye *et al*., 2010). Among the active heating modes, a solar thermal system is one of the most practical and appropriate means for reducing the operating costs in a greenhouse. If heating pipes are galvanized or painted with aluminized paint, heat delivery rates will be approximately 15% less than from black pipe (ANSI/ASAE, 2003).

In this research work, emphasis has been given to solar thermal systems. Solar energy is non-polluting and offer significant protection of the environment. Therefore, solar thermal systems should be employed whenever possible in order to achieve a sustainable future. The solar energy collected by solar thermal systems is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at nighttime and/or cloudy days (Sayigh, 2001 ; Kalogirou, 2003).

The main objectives of the present study were: (1) to determine the actual surface area of solar collector suited for heating the greenhouse; (2) to evaluate the thermal performance analysis of solar heating system; and (3) to investigate the possibility of utilising the solar thermal system for heating the sweet colour pepper greenhouses during winter season of 2009-2010.

MATERIALS AND METHODS

1. Design

The climatic conditions of the northern delta of Egypt (data of the last five years) are associated as; the ambient air temperature at nighttimes during winter season lowered to 7.2ºC, optimal air temperature for vegetable crops 18ºC, overall heat loss coefficient for glazing material of fibreglass reinforced plastic 6.2 $W/m^2.{}^{o}K$, ambient air relative humidity 60%, and solar radiation 6.686 kWh/m^2. day. Under these conditions, the greenhouse with 32 m^2 floor surface areas (eaves height 3.25 m, gable height 1.02 m, rafter angle 27º, total width 4.0 m, total length 8.0 m, floor surface area 32 m^2, and volume 87.68 m^3) requires 300 litres storage tank of water at 60ºC or hotter are suited daily. A mathematical computer model was developed to determine the actual surface area of solar collectors required to provide hot water for heating greenhouse according to the total heat energy supplied. This requires 4 m^2 solar collector and a minimum flow rate of 12 litres per minute if the operating of solar heating is over a nine hours period. The heating operation over five months season from November to April (the end of heating operation depends on the atmospheric conditions in the particular year). The latitude and longitude angles of the site (University of Mansoura, Egypt) are respectively, 31.045°N and 31.365°E, and 19.45 m above the sea level. The meteorological data of site is given in Table (1).

Table (1): Meteorological details of site

Location	Mansoura University, Egypt
Latitude angle	31º 2' 42" N
Longitude angle	31º 21' 54" E
Experimental period	November 2009 to April 2010
Average annual sunshine hours	1209 h
Sunshine hours of experimental period	1600 h
Daily average solar radiation	7.351 kWh/m^2/day
Maximum daily solar radiation	9.180 kWh/m^2/day
Minimum daily solar radiation	1.805 kWh/m^2/day
Mean water temperature at the beginning of each day	25ºC

2. Solar collector area and arrangement

Two solar collectors, each having a surface area of 2.0 m^2, and constructed of copper pipes with a black absorbing surface, were connected with a 32.0 m^2 sweet colour pepper greenhouse (Fig.1). These solar collectors arranged in one bank with a series array. The solar heating system is of the "recycling flow system" i.e. the water is continually cycled through the solar collectors. The operating fluid (water) was continually pumped so as to pass through the solar collectors under clear sky conditions. After passing through the solar collectors, it was stored in a 300 liters insulated storage tank. The water pump was switched on and off manually on sunny days from 1st November 2009 until 20th April 2010. The flow rate of operating fluid (12 l/min.) was adjusted and controlled every day using a control valve and a measuring cylinder with stop clock.

The thermal performance analysis of the solar collectors was experimentally determined, by measuring the temperature increase at various water inlet temperatures, mass flow rate, and solar energy available under clear sky conditions. Using this data the solar collector area and configuration were calculated so that the water temperature at the end of day reached to over 60ºC when the solar radiation was a maximum. Under steady-state conditions, the overall thermal efficiency (η_o) can be measured and determined using the system analysis of Duffie and Beckman (1991) ; Kalogirou (2004) ; and ASHREA (2005) as follows:

$$\eta_o = \frac{F_R\ A_c\ [R\ (\tau\ \alpha) - U_o\ (T_{fi} - T_a)]}{R\ A_c} \times 100\ ,\ \% \qquad (1)$$

Where, F_R, A_c, R, $(\tau\alpha)$, U_o, T_{fi}, and T_a , respectively, are the heat removal factor, collectors surface area (m^2) , solar radiation on a tilted surface (W/m^2), optical efficiency, overall heat transfer coefficient (W/m^2. ºK), inlet water temperature (ºK) and ambient air temperature (ºK),. The normalized temperature rise (D_T) of the solar collector was computed from the following relation:-

$$D_T = \frac{T_{fi} - T_a}{R}, \quad °K\ m^2/W \qquad (2)$$

Fig. (1): Solar collectors array, the first one is 2.0 m high and 1.0 m wide giving a net surface area of 2.0 m^2, the second is 2.4 m high and 0.85 m wide giving a net surface area of 2.04 m^2.

3. Overall design and installation

The solar collectors were mounted individually on a movable frame outside the greenhouse at an optimum tilt angle and continually facing due south. The collectors were adjusted manually to change the orientation and tilt angle once each hour, so that at that time the angle of incidence of the surface of the solar collector and the sun's rays was set at zero. The site was protected from the prevailing north-westerly winds by the greenhouse, but was not shaded from the sun. The storage tank was equipped with supplementary electric heater (2.5 kW). The auxiliary heater was used when the stored solar energy was insufficient to provide the requirements of the heat energy supply. To provide and maintain positively a temperature of 16-18^{o}C at night time during cold winter months, the greenhouse was equipped with a heat exchanger using parallel flow system in order to utilize the stored energy from the storage tank for heating the indoor air of the greenhouse (Fig. 2). The heat exchanger was located on an iron stand to be above the floor surface by 35 cm (the coldest zone inside the greenhouse). The heated water from the insulated storage tank (heated by solar energy during the daylight) was pumped to be circulated through the heat exchanger. It was controlled by on-off controller to initiate heating at 16°C and interrupt it at 18°C (environmental control board with differential thermostat).

4. Measurements and data acquisition unit

The solar radiation, air temperature, air relative humidity, and wind speed and direction were measured and recorded using meteorological station, which installed just above the solar collectors and greenhouse. Disk solarimeters installed on the top frame of solar collectors in order to measure the solar radiation flux incident on a tilted surface. A 12 channel data-logger was also used for taking and storing reading from the different sensors (thermocouples type K) situated at different location of the solar collectors and the storage tank. Another data-logger was also used for taking and storing reading from the different sensors situated at different locations of the sweet colour pepper greenhouse. The recorded data were stored in the memory for output to a printer or to a computer for storage on disk. The time interval for data recording was 60 min with data acquisition every one minute for integrated measurements. The calibration of all sensors and the logger was completed successfully at the beginning of the experimental work.

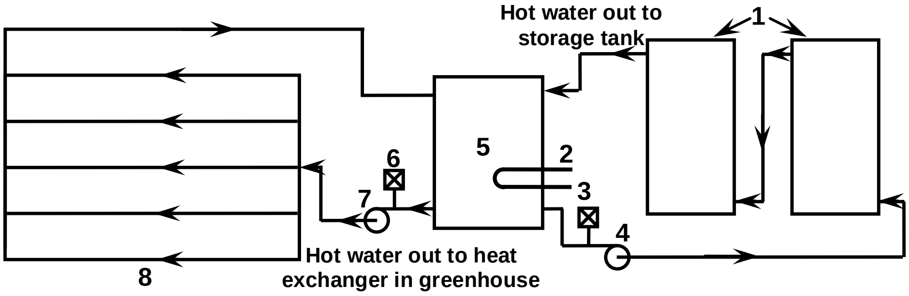

Fig. (2): Schematic diagram of solar heating system included; (1) solar collectors, (2) auxiliary electrical heater, (3) water flow control, (4) water pump for solar collectors, (5) storage tank, (6) flow control, (7) water pump for heating, and (8) heat exchanger.

5. Cultivation and Watering systems

Pots system was used as an agriculture system for sweet colour pepper. The greenhouse was equipped by 60 plastic pots, which arranged in five rows (each row having twelve pots). 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 48 cm dripper spacing throughout each row of plants inside the greenhouse. Two trays of sweet colour pepper seedlings (Bravo-Enze Zaden, C.V) were brought down from a nursery. Sixty five of seedlings with an average of six rear leaves were planted on the pots inside the greenhouse on 2nd October 2009.

RESULTS AND DISCUSSION

1. Thermal performance

The solar collectors have been operating satisfactorily for six months without malfunction, except for a small leaking in a rubber connection between the collectors and water pump after the water had reached to 60ºC. Water temperatures have been monitored for six months beginning in November 2009, and the monthly average solar energy contribution is shown in Fig. (3). During the experimental period, there were 1209 hours of bright sunshine of which 1025 hours (84.78%) were recorded and used in the thermal performance analysis and applications, slightly lower than average due to clouds. Although on day to day figures the correlation between sunshine hours and solar energy collected was poor, nevertheless the agreement was good on a monthly average basis (Fig. 3). The discrepancies between months arise due to number of bright sunshine hours, solar altitude angles, water temperature in the storage tank at the beginning of each day, and number of operating hours.

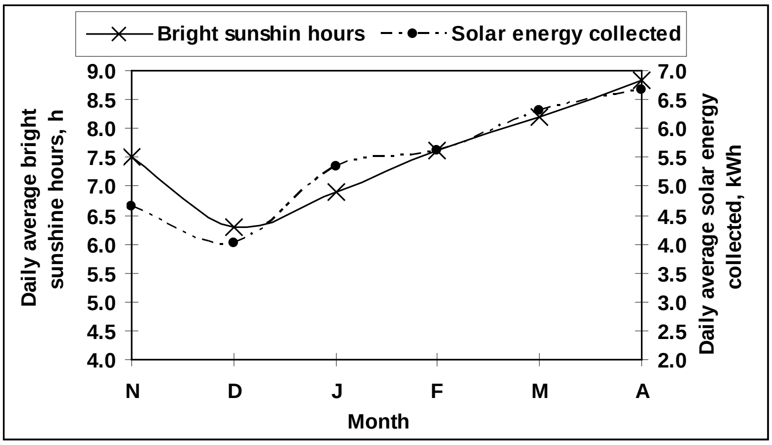

Fig. (3): Daily average solar energy collected by solar collectors and daily average sunshine hours during the experimental period.

The thermal performance analysis of the solar collectors is mainly determined by its overall thermal efficiency in converting solar energy into stored heat energy. A comparison between the daily average total solar radiation and total solar energy collected was executed (Fig. 4). The correlation between the solar energy collected (21.066 kWh) and the available solar radiation (29.405 kWh) was in agreement (91.03%) except that the solar collectors appear to be more efficient in February than in other months because the heat energy stored during daylight was consumed at nighttimes. This also due to the water temperature in the storage tank at the beginning of each day throughout the month was lower than the indoor air temperature. As the temperature difference between the absorber surface and the water passing through the solar collectors are increased, the heat transfer rate between the absorber surface and the water is increased. The regression analysis showed that the slope of the regression equation is almost equalled to the daily average overall thermal efficiency (71.25%) of the solar collectors during the experimental period (Fig.4).

The overall thermal efficiency is the ratio of the solar energy collected by the solar collectors to the solar energy available. The daily average overall thermal efficiency of the solar collectors during the experimental period was 71.64%, consequently, 28.36% of the solar energy available was lost. The overall thermal efficiency (η_o) was correlated with the normalized temperature rise (D_T) as shown in Fig. (5). It reveals a highly correlation ($r = 0.951$; $p > 0.001$) between these parameters.

2. Heat energy providing

During the 181 day heating season the solar collectors collected 3813 kWh. The daily average heat energy provided by the solar collectors during this period is given in Table (2), where it is compared with total heat energy requirements for providing and maintaining optimal level of indoor air temperature. During the heating period the useful solar energy collected was 21.066 kWh of which 19.200 kWh was stored in the storage tank and consumed during the heating period for both greenhouses. .It was provided 70.5% of the daily total heat energy required (27.234 kWh). The potential savings form solar power was not fully realized for three main reasons: firstly, little solar power was collected in the first two hours after sunrise and the last before sunset due to low solar altitude angle and water temperature in the storage tank. As the heat energy stored in the storage tank was not continually consumed at nighttimes, therefore at the beginning of some days more than two hours of sunshine were lost.

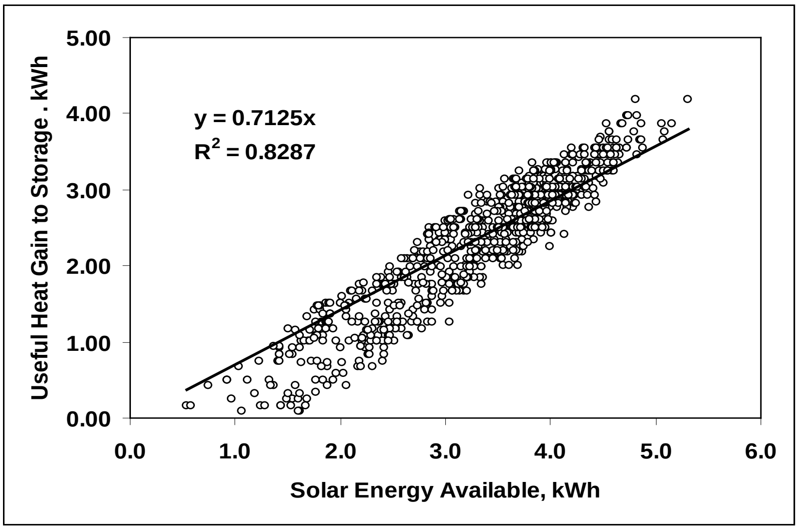

Fig. (4): Solar energy collected (useful to storage) versus solar energy available during the experimental period.

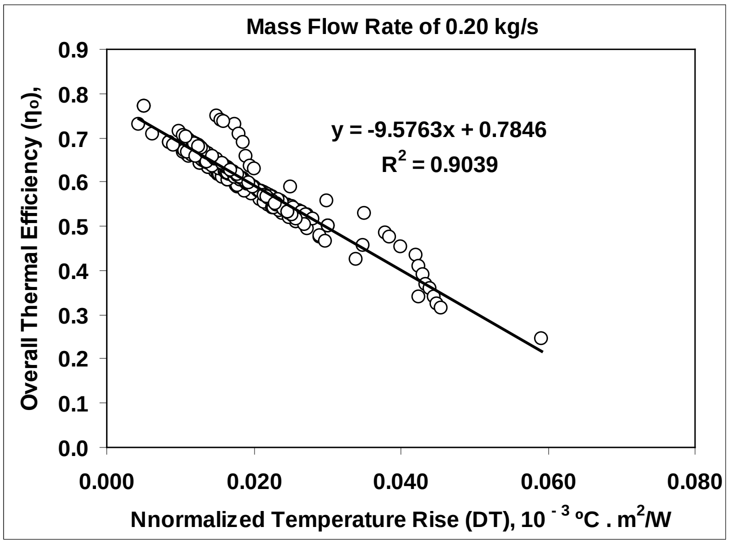

Fig. (5): Overall thermal efficiency versus normalized temperature rise during the experimental period

Secondly, throughout the heating season, the auxiliary electrical heater was switched on at the end of each day when the water temperature in the storage tank was lower than 60ºC. Therefore, some of this heat energy dissipated into the indoor air in spite of its temperature was higher than the set point temperature (18ºC). This point of action resulted in extra loss of heat energy from inside to the outside atmosphere. This heat energy was ignored in computing the percentage of heat energy supplied by the solar heating system. This loss can be eliminated by installing automatic control to switch on the auxiliary heater when the heat energy in the water tank is insufficient to provide the desired level temperature of indoor air.

Table (2): Daily average total heat energy normally required (kWh) during heating season (181 days).

Energy	**Heat energy, kWh per day**	**Providing of total, %**
Solar energy		
Total useful heat energy collected	21.066	-
Total heat energy stored in the storage tank	19.200	70.5
Electrical energy		
Total electrical energy used by water pump (4)	2.141	7.9
Total electrical energy used by water pump (7)	1.115	4.1
Total electrical energy used by electrical heater	4.778	17.5
Total energy actually used by greenhouse	27.234	100

Thirdly, during the coldest month (January) the outside air temperature at night times lowered to 7.3ºC for the majority of nights resulted in great amount of heat energy loss. As the heat energy supplied into the greenhouse reside in the task of adding heat at the rate at which it is lost, accordingly, there were 7.397 kWh of electrical energy added to the water in the storage tank during this month. Therefore, a movable thermal curtain should horizontally be spread at a height of 2.25 m above the floor surface at night times to reduce heat losses during this period. About 40% saving in heat energy supply can be achieved in this way. During the daylight, the thermal curtain can be withdrawn, but a 4% light loss due to the rolled-up material is produced (Critten and Bailet, 2002). A movable baffle should also be used to close the outside surface area of the cooling pads at the end of daylight to minimize the heat losses due to infiltration of cold air.

In spite of these heat energy losses solar power is providing a significant proportion of the total heat energy required for heating the greenhouse.

3. Microclimatic conditions

The air temperature inside the greenhouse was compared with the outside air temperature as an important measure of the effectiveness of heating system. The fluctuations of air temperature surrounding the crops play an important role for their growth rate, development, and productivity. Fluctuation changes in air temperature, caused by the on-off control board, were evidently observed inside the greenhouse. A temperature gradient developed along the centerline of greenhouse and its value varied with time during each heating cycle. The nightly average air temperature inside the greenhouse varied between 15.9°C and 19.2°C, whereas, the outside air temperature ranged from 10.5°C to 16.6°C.

The highest air temperature inside the greenhouse (18.2°C) during January month (coldest month) was recorded at 19.00h, just two hours after sunset. The air temperature (18.2°C) was gained from the heat energy stored during the daylight; therefore, the heating process was not used over this hour. The lowest air temperature inside the greenhouse (15.9°C) was also recorded during January month at 06.00h just prior to sunrise. The lowest air temperature inside the greenhouse occurred due to three reasons. Firstly, the majority of heat energy stored in the storage tank during daylight (from solar energy system) and supplementary heat energy added after that (from auxiliary electrical heater) was consumed during the heating cycles at night times. Secondly, the air temperature difference between the set point and the outside was 7.5°C, consequently greatest amount of heat energy was lost at that time. Thirdly, the fiberglass cover was able to keep the air temperature inside the greenhouse greater than that of the outside. Under these circumstances, the heating system provided a heating effect of 8.4°C.

The air relative humidity inside the greenhouse ranged from 61.3 to 75.8%, whereas the outside air relative humidity was in the range of 33.5 to 68.5%. The nightly average indoor air relative humidity was 71.7%. However, the nightly average outside air relative humidity was 54.5%. The cyclic variations in air relative humidity mainly occurred at the peak of the heating cycle in the greenhouse. The air relative humidity inside the greenhouse was decreased by 5.9% at the peak of each heating cycle, whereas at the end of the cooling down it was increased by 8.1%. Most protected cropping grow best within a fairly restricted range, typically 60% to 80% air relative humidity at night time for many varieties (Ozturk and Bascetincelik, 2003). High air relative humidity is the main response of pathogenic organisms. Most pathogenic spores cannot germinate at air relative humidity below 85%. Low air relative humidity increases the evaporation demand on the plant to the extent that moisture stress can occur, even when there is an ample supply of water to the roots. Normal plant growth inside the greenhouse generally occurs at air relative humidity ranged from 30 to 80% (Hanan, 1998).

Higher vapour pressure deficit means that, the air surrounding the plant has a higher capacity to hold water, stimulating water vapour transfer (transpiration) into the air in this low air relative humidity conditions. Lower vapour pressure deficit, on the other hand, means the air surrounding the plant is at or near saturation, so the air cannot accept moisture from the leaf in this high air relative humidity condition. The nightly average water vapour pressure deficit (VPD) during the experimental period was 0.58 kPa. When the air vapour pressure deficit is too low (VPD < 0.43 kPa) at air relative humidity too high (RH >85%) and air temperature very low (Ta < 15 °C), the water may condense out of the air onto leaves, fruits, and other plant parts. This can provide a medium for fungal growth and disease.

Under low VPD conditions, some plants may even exude water from their leaf cells in a process called guttation. When the plants are unable to evaporate water, excessive turgor pressure within the cells can cause splitting and cracking of fruits such as tomatoes. In cases where the VPD alternates between too high and too low, fruit quality can be adversely affected by 'shrink cracks' in the skin as the turgor; pressure alternately expands and contracts the water-filled cells in the fruit. This condition can significantly downgrade the quality of vegetable crops. Several studies (Pringer and Ling, 2004 ; Argus, 2009) that explored disease pathogen survival at different climate levels revealed two critical values of air vapour pressure deficit (0.20 – 0.43 kPa). The studies showed that fungal pathogens survive best below vapour pressure deficit of 0.43 kPa.

Due to the air temperature (16.4ºC), relative humidity (71.7%), and vapour pressure deficit (0.67 kPa) within the greenhouse were at or around the desired level particularly during the cold winter season, the sweet colour pepper plants were grown. The weekly averages increasing rate in number of leaves inside the greenhouse was 11.4 leaf/plant. 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. The weekly average stem length of sweet colour pepper plants was 5.9 cm. As the indoor air temperature is reduced lower than 15°C, slower growth rate, longer internodes, thinner xylem, and smaller rate of fruit set occurred. Due to these reasons discussed previously, the average number of fruits being seated on the plants was 19.4 fruit/plant. Therefore, the total fresh yield of sweet colour pepper crop was 188.8 kg (5.931 kg/m^2).

4. Economic considerations

The total annum costs included the three different items (greenhouse construction, solar heating system, and operating costs) were about L.E. 1795.4. However, the total costs per square meter of greenhouse were L.E. 56.1. The fresh yield of sweet colour pepper per square meter was

5.931 kg/m^2, which sold by L.E. 80.1. At the time, the estimated return on capital was 42.8% per annum. Since then power costs have risen and the system is achieving a return of about 64% can be obtained. The economic benefit of renewable energy utilization in agricultural applications is still marginal due to the unrealistically low price tariff for electricity power, as the government financially supporting this power. However, renewable energy systems can have a beneficial impact on the environmental, economic, and political issues of the world.

Conclussion

The primary objectives of this solar heating system are to increase the solar radiation converted into stored thermal energy and to investigate effective uses of that stored energy for heating sweet colour pepper greenhouse. A solar water heating system has been developed and installed on the roof of Agricultural Engineering Department, University of Mansoura, beside an experimentally greenhouse. The system has operated satisfactorily for over six months.

The solar collectors which are continuously orientated and tilted to maintain an incident solar angle of zero from sunrise to sunset will allow maximum values of both; the absorptance of the absorber surface and the transmittance of the glass cover to be reached. The overall thermal efficiency and heat losses are mainly affected by the water inlet temperature and ambient air temperature.

Over the period November 2009 to April 2010, the solar heating system collected 3813 kWh (13.73 GJ) of solar power. During the heating period the useful solar energy collected was 21.066 kWh of which 19.200 kWh was stored in the storage tank and consumed during the heating period for both greenhouses. It provided 70.5% of the power required by the greenhouse (27.234 kWh).

Due to the microclimatic circumstances within the adapted greenhouse were at or around the desired level during the daylight (26.8°C) and at night (16.4°C) particularly at the critical period (from 02.00 to 06.00h) during winter season, optimal vegetative growth rate, stem length, number of fruits being seated, and fresh yield were achieved. The nightly average vapour pressure deficit (0.58 kPa) was at the optimal level during the experimental period.

The economics of such a system remains marginal at present power prices in Egypt, although changes in power costs may drastically alter the situation.

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تطوير نظام تسخين شمسى لتدفئة بيت محمى للفلفل الألوان الحلو

صلاح مصطفى عبد اللطيف و يحيى عبد الشافى محمد
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يهدف هذا البحث إلى زيادة تحويل الإشعاع الشمسى لنظام التسخين الشمسى إلى طاقة حرارية مخزنه، وأيضاً دراسة تأثير إستخدام هذه الطاقة المخزنة لتدفئة بيت محمى للفلفل الألوان الحلو. تم تطوير نظام تسخين شمسى للماء مثبت بجوار بيت محمى تجريبى موجود فوق سطح قسم الهندسة الزراعية بجامعة المنصورة وتم تشغيله بشكل مرضى لفترة تتعدى الستة أشهر.

تم توجيه المجمعات الشمسية وتغيير زاوية الميل بإستمرار للمحافظة على زاوية سقوط شمسية صفر من الشروق وحتى الغروب حتى تسمح بالوصول إلى أقصى قيمة لكلاً من معامل إمتصاص السطح الماص ومعامل نفاذية الغطاء الزجاجى. وجد أن الكفاءة الحرارية الكلية والفواقد الحرارية تتأثر بشكل رئيسى بدرجة حرارة دخول الماء ودرجة حرارة الهواء الخارجى.

خلال الفترة من نوفمبر 2009 وحتى أبريل 2010 تم تجميع 3813 كيلووات.ساعة من الطاقة الشمسية (أى مايعادل 13.73 جيجا جول) بواسطة نظام التسخين الشمسى. وخلال فترة التسخين (الستة أشهر) أضاف نظام التسخين الشمسى 21.066 كيلووات .ساعة فى اليوم بمتوسط 70.5 % من متطلبات الطاقة الحرارية اللازمة للمحافظة على درجة حرارة هواء البيت المحمى عند أو حول المستوى الأمثل.

أدت الظروف المناخية داخل البيت المحمى والتى كانت عند أو حول المستوى المرغوب (درجات حرارة الهواء الداخلى 26.8°م نهاراً و 16.4°م ليلاً) خاصةً عند الفترة الحرجة (من الساعة 2 وحتى 6 ص) أثناء موسم الشتاء إلى تحقيق معدل نمو خضرى أمثل وكذلك طول السلميات وعدد الثمار التى عقدت وجودة المحصول، كما كان متوسط النقص فى الضغط البخارى أثناء الليل 0.67 كيلوباسكال والتى تعتبر عند المستوى الأمثل خلال فترة الليل. هذا وتظل إقتصاديات هذا النظام متماشية مع أسعار الطاقة الحالية فى مصر على الرغم من أن التغير فى تكاليف الطاقة يمكن أن يبدل الموقف بشدة.

قام بتحكيم البحث

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