GREENHOUSE HEATING AND VENTILATION CONTROL SYSTEM

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ABSTRACT

This research aims to study the effect of using the heating and ventilation system on the production and quality of tomato crop in winter season. Two different poly-greenhouse models were constructed at Al-Zahwiyyin, Egypt (ϕ= 30°15'N). It was equipped with heating and ventilation control system (treatment) and the other was a traditional greenhouse (control). Results of the experimental work show that the specific approach of heating and mechanical ventilation for tomato crop production enhances the rate of growth and increasing the fresh tomato yield by 57.69% comparing with control greenhouse. The quality of tomato crop of the treatment greenhouse can be noticed through the firmness and toughness value comparing with the control one. They were greater by 85% and 62.5%, respectively.

Keywords: Greenhouses, Heating system, Ventilation, Relative humidity

INTRODUCTION

Polyethylene greenhouses used in Egypt on an increasingly large scale for early production of warm-season vegetable, fruit and flowers. It is a good application of solar energy collection for space heating and plant production. Moreover, its productivity per unit area is greater than the field production, and its product quality is always the highest. However, in winter, supplementary heating is necessary at night and during periods of gray sky to maintain the required plant temperature. Also, proper manipulation of the moisture in the greenhouse air by use of heat and ventilation is necessary to reduce or prevent fungous diseases that cause great losses and cannot easily controlled with fungicides.

Generally, Climate control is of great importance for greenhouse production in order to achieve high yield and good quality crops that meet the demands of consumers, as well as for economical production.

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Temperature and relative humidity (RH) are two basic climatic parameters usually controlled by heating and ventilation equipment. It is more difficult to control RH than temperature because relative humidity not only relies on air exchange from the infiltration and ventilation, but also related to evaporation from growing media and transpiration of the plants. (Gao 2012)

Therefore, the present research is aimed to develop, construct, and test an experimental greenhouse that will be equipped with heating and ventilation control system to maintain optimum growing environment for tomato growth during winter season through the following specific objective:-

1- Connecting the greenhouse to an adequate heating system.
2- Supplying the designed system with environmental instruments to control the interior climate for plant growth under environmentally controlled high-yield conditions as well as offering an opportunity to reduce the electrical energy consumption.
3- Investigating the effect of adequate mechanical ventilation to adjust the relative humidity of air inside the constructed greenhouse.
4- Comparing the productivity of the designed system with a traditional greenhouse that has the same shape, dimensions, cover, and orientation with natural ventilation.

MATERIAL AND METHODS

1- Description of the greenhouses:-

Two identical gable-even-span greenhouses were designed, constructed and installed on the roof of a house at Al-Zahwiyyin village, Al-Qaliobia Governorate, Egypt (ϕ= 30°15′N). The construction was made of steel angle (1" x 1" x 3/16"). Each greenhouse was 4.0 m long and 3 m wide with a single gable at maximum height of 1 m, whilst the height of sidewall was 2 m. The greenhouse frame was covered using 0.1 mm thickness polyethylene sheet. It was oriented in north-south direction, one longitudinal side facing south and other facing north (Fig.1), and the roof was sloped at an angle 26.6°.

The first greenhouse was used to study and test the effect of heating the interior climate and mechanical ventilation on the growth and production of tomato crop. It was connected to an insulated storage tank of pure water, which was supplied with an electrical heater, through heat exchanger inside the greenhouse and small size pump to circulate the hot water in closed loop in order to transfer extra thermal energy to the interior climate for accelerating the growth of plants during winter season.

Storage tank

A galvanized steel tank, (100 liters capacity) filled with 60 liter of water was used. It has cylindrical shape, diameter of 0.46 m and height of 0.62 m. It was insulated using a glass wool insulation of 3 inches (76.200mm) thickness to reduce the thermal losses to the ambient. It was provided with an electrical heater (type R-T-M water heater- made in Italy) and a thermostat (single-pole 40-80 °C) to adjust the water temperature at about 60 °C. It had an outlet galvanized tube (3/4" diameter) (19.05mm) at the bottom which was connected to the intake-mouse of the pump, and input tube (3/4" diameter) at the top which was connected to the external outlet connection of the heat exchanger. The tubes were also insulated by 3 inches thickness glass wool.

Heat exchanger

Heat exchanger was made of galvanized pipes (3/4" diameter) and placed inside the greenhouse at 20 cm above the ground; It was used to transfer the heat from the working fluid (hot pure water) to the interior climate of the greenhouse to maintaine the required plant temperature. Two thermocouples (k type) were used to measure the inlet and outlet temperatures of heat exchanger.

Pump

An electrical rotary pump (0.5 HP, model QP-60, 21 l/min capacity, made in China) was used to circulate the working fluid.

Ventilation fan

A 40 cm diameter ventilation fan (FAD104 model, 200 m^3/h capacity, 1400 rpm, 145 W power) was used to exchange the air inside the greenhouse. The fan placed on the opposite side of the intake window (50 X 50 cm) of air (Ventilation shutter).

2- Instrumentation

a- Thermocouples (K-type) and a digital thermometer (DM6801A, made in China, - 50 °C to 1300 °C range, ± 0.3 % accuracy) were used to measure the following temperatures: the inlet and outlet temperatures of the heat exchanger, air in and outside the greenhouse.

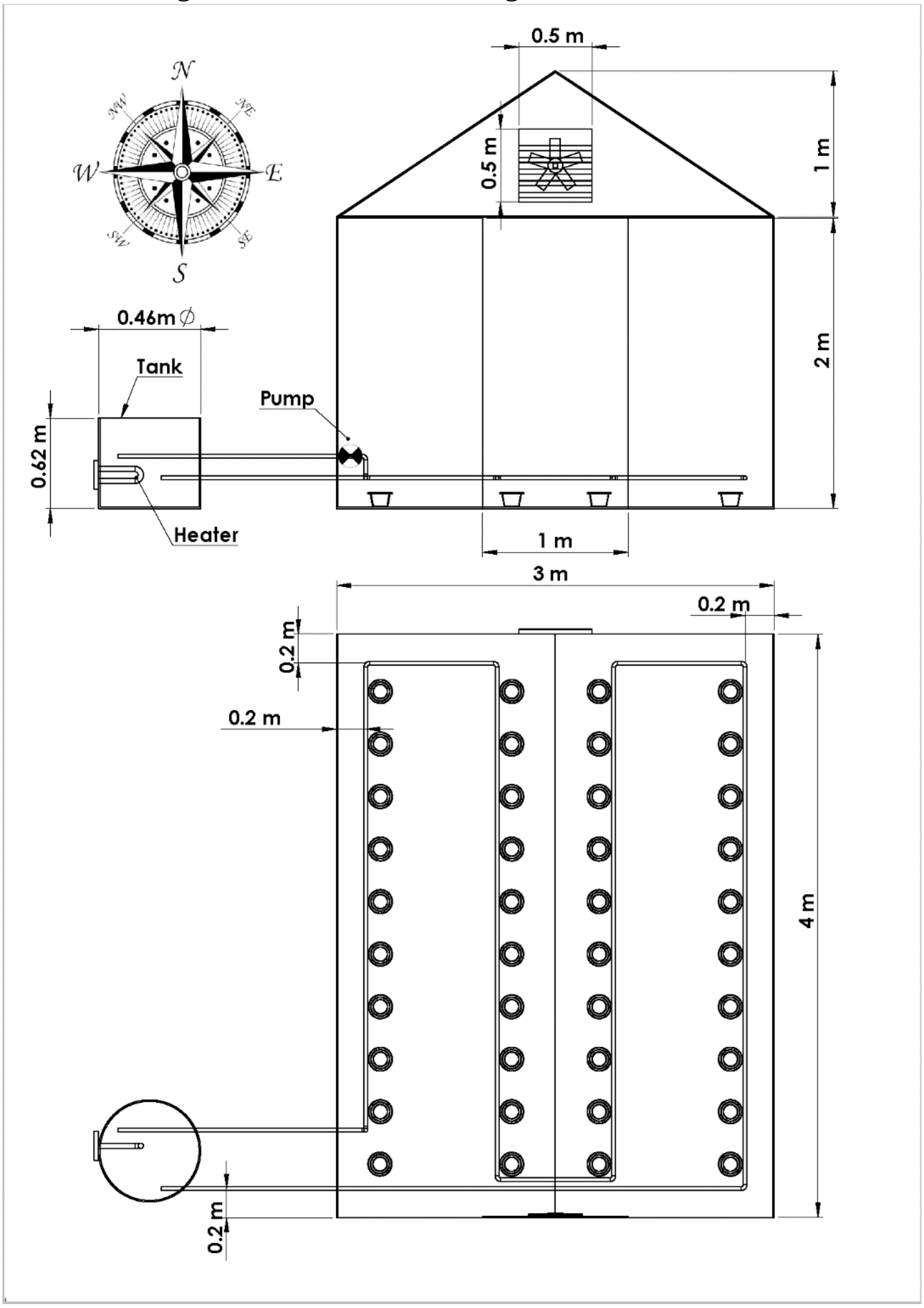

Fig.1: Schematic diagram showing the basic dimensions and component of the constructed greenhouse

b- Two electrical thermostats were used. The first one (10-60 °C range) was used to control the water pump operation. When the inside temperature of the greenhouse air is lower than 20 °C, the thermostat operates the pump until the air temperature reaches the desired plant temperature. The other one is to operate the exhaust fan if the greenhouse air temperature exceeds 28 °C.

c- Digital temperature and humidity meter (HTC2, 20-50 °C temperature range, 10% - 95% RH range, made in china) was used as a humidity-sensing device to measure the air humidity of the greenhouse and a humidistat (35%- 95% RH range ± 3.0%) was used to operate the exhaust fan of the ventilation system when the relative humidity exceeds 75%. It was necessary to use such device because on cold days of winter, especially at night, the ventilation fan would not be operated, it was adjusted to operate on the temperature rise (greater than 28 °C), and the RH could be increased (more than 75%) which may initiate some serious disease problems.

3- Heat losses from the greenhouse

a- Heat flow through the polyethylene

Heat flow through the greenhouse covering materials (walls and roof) during the heating season is represented the greatest losses with respect to the other energy losses from the greenhouse. It is generally related the temperature difference between the inside and outside temperature by the overall heat transfer coefficient as following

$$Q_c = U \times A \times (T_i - T_o)$$ (Ibrahim, 2000 and Abdel-Lattif, 1993)

Where

Q_c	:	Heat flow, J/s;
U	:	Overall heat transfer coefficient ,W/(m^2.°C) ;
A	:	Area of greenhouse wall and roof, m2;
T_i	:	Interior ambient air temperature, °C;
T_o	:	Exterior ambient air temperature, °C.

b- Energy loss via ventilation

Heat loss via ventilation (Q_v) is approximated as follows (Ibrahim, 2000)

$$Q_v = Q_{sv} + Q_{lv}$$

Where

Q_{sv} is the sensible heat losses via ventilation;

Q_{lv} is latent heat losses via ventilation;

$Q_{sv} = \dot{m} \times cp \times (T_{in} - T_o)$, J/s (Abdel-Lattif, 1993).

$Q_{lv} = E \times F \times Q_i = E \times F \times \tau \ I \ A_f$

Where

τ Transmittance of greenhouse covering (assumed 88%);

I Total solar radiation outside the greenhouse on horizontal surface (W/m^2), it was obtained from the weather station of the arid land and agricultural research and services center Faculty of Agriculture,Ain Shams University. ;

A_f Floor area of the greenhouse, (m^2) ;

T_{in} , T_o Inside and outside air temperature of greenhouse;

$\dot{m}$ Mass flow rate of air kg/s = M x ρ/3600, (Abdel-Lattif, 1993) ;

Where

M= greenhouse volume x air exchange rate per hour ,(m^3/ h) ;

ρ = air density(= 1.2 kg/m^3) ;

C_p = Air specific heat 1007 J/kg. °C;

E = Floor use factor—ratio of ground covered by plants to total ground area, (assumed 0.4) ;

F = Evapotranspiration to internal solar radiation (assumed 0.5).

c- Total losses

$$Q_{loss} = Q_c + Q_v$$

4- Heating system

Heating system delivers heat energy from boiler to the air of the greenhouse by circulating hot water through piping system of the heat exchanger, and the rate of heat transfer may be approximated by the equation

$$Q_{hl} = \dot{m}_w \times C_{p_w} \times (T_{exi} - T_{exo})$$

Where

Q_{hl} : the rate of heat transfer, J/s;

$\dot{m}_w$: Water mass flow rate, kg/s;

C_{p_w} : Water specific heat , (4190 J/kg.°C) ;

T_{exi} : Inlet temperature of the heat exchanger, °C;

T_{exo} : Outlet temperature of the heat exchanger, °C.

5- Mechanical ventilation

a- Determining ventilation volume rate

The ventilation volume rate may be calculated by the following equation

Air volume flow rate (m^3/h) = V_{gh} x AR

Where

Vgr : Greenhouse volume, m^3;

AR : Air exchange rate per hour 1 /h

In Winter AR = 2 1/h (Buffington et al., 2002).

b- Size of the intake vent

The following equation is used to determine the area of the air inlet

$$\text{Size of the intake vent} = \frac{\text{Air volumetric flow rate } (m^3/h)}{\text{Maximum air speed allowed } (m/h)}$$

Since air speed influences many factors that affect plant growth, such as transpiration, evaporation, leaf temperature, and carbon dioxide availability, the maximum air speed allowed through the vent was used to be 1.27 m/s (Abdel-Lattif, 1993 and Aldrish and Bartok, 1994).

6- Natural ventilation

Natural ventilation depends upon the ventilation opening area's and positions, to achieve the optimum air exchange in the greenhouse, the lateral wall opening and roof holes in the range (15- 30)% of the floor area of the greenhouse (Ibrahim, 2000).

7- Firmness value:-

The mechanical damage of tomatoes usually occurs as a result of careless handling at mechanical harvest, package, and transport (Li et al., 2013), therefore firmness values of tomatoes are the most important internal quality to retail marketing or using at home (Sirisomboon et al.,2012). It is defined as the ability of fruit to retain its original shape when exposed to external force and usually it is described by the fruit's force-deformation behavior. (Rajabipour, 1995 and BATU, 1998). Jackman *et al.* (1990) indicated that firmness of tomatoes has commonly been measured by flat-plate compression or by puncture of whole fruit and defined as either the force at failure or the ratio of force to deformation at failure.

In this study a number of tests are conducted under certain puncture force by specific point on the tomato fruit and the resulting force deformation curve is obtained using Tinius Olsen Benchtop Materials Testing machines with a plunger diameter (6.05 mm), then the firmness is determined as the following (Sirisomboon et al.,2012)

Average firmness = $\frac{\Delta F_r}{\Delta D_r}$, $(\frac{N}{mm})$

Where

ΔF_r Is the rapture force , (N) ;

ΔD_r Is deformation at the rapture point, (mm).

8- Toughness :-

Toughness is defined as the area under the complete force-deformation curve from the origin to the rapture point (N/mm)

Toughness $= \frac{1}{2} \times F_r \times D_r$ (Shafiee et al., 2008)

<u>Planting and harvesting time</u>

Each greenhouse was equipped by 40 pots (30 cm high and 25 cm diameter).

a- Planting time 1/1/2012

b- Flowering First date of the treatment greenhouse was 25/1/2012 and the control greenhouse was 7/2/2012.

c- Vegetating date of the treatment greenhouse was 6/2/2012 and the control greenhouse was 23/2/2012.

d- The first date of picked tomatoes of the treatment greenhouse was 14/3/2012 and the control greenhouse was 4/4/2012.

RESULTS AND DISCUSSION

1- Hourly variation of temperatures:

Fig. (2) illustrates the average hourly temperatures variation of the ambient and inside the treatment and control greenhouses. The results show that the temperatures of the air gradually increased with the time, which peaked at about 2:00 pm, then reduced towards the evening.

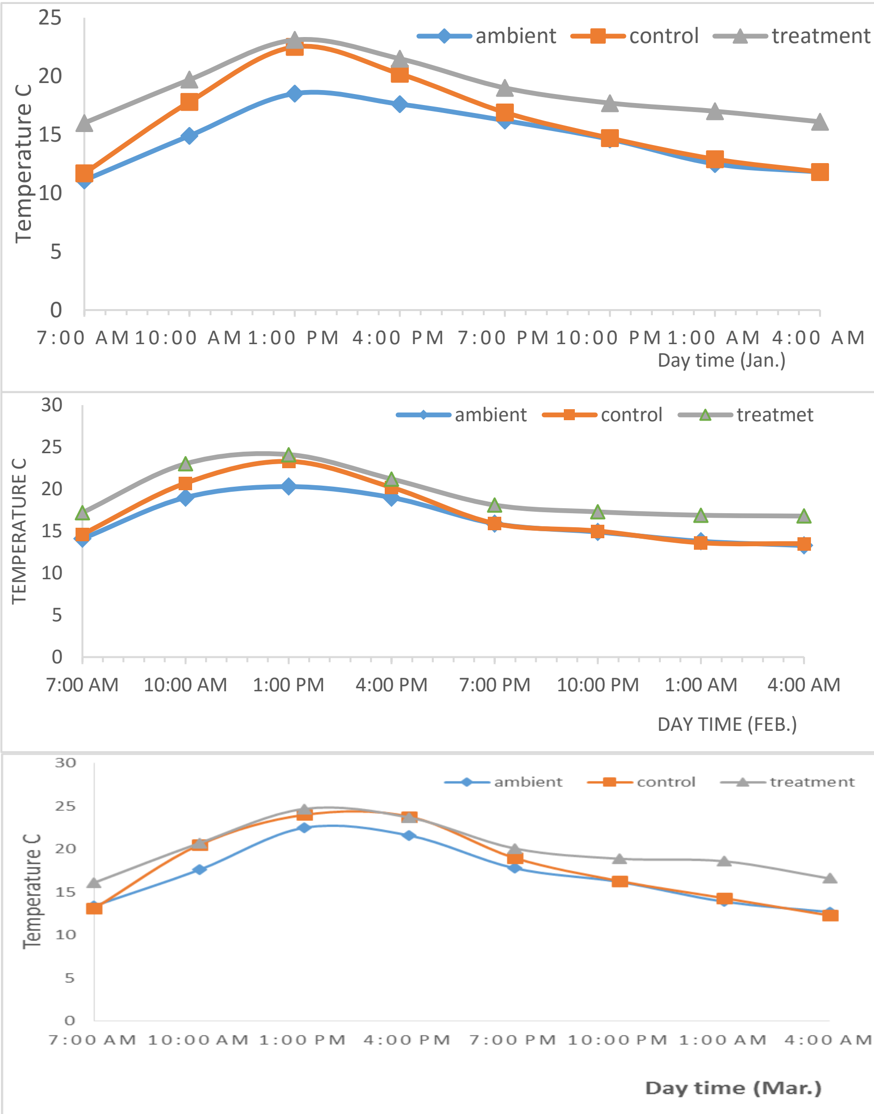

Fig. (2): The average air temperatures outside and inside the treatment and control greenhouses vs. time during (January to March).

The temperatures of the treatment greenhouse was higher than the control one, and of course the ambient temperature was the lowest. Also, at night and up to 4.0 AM the temperatures of the control greenhouse and the ambient were almost the same.

2- Relative humidity

Fig; (3) shows the hourly relative humidity variation of the greenhouse. It is clear that the relative humidity inside the greenhouses gradually decreased with time it reached to the minimum

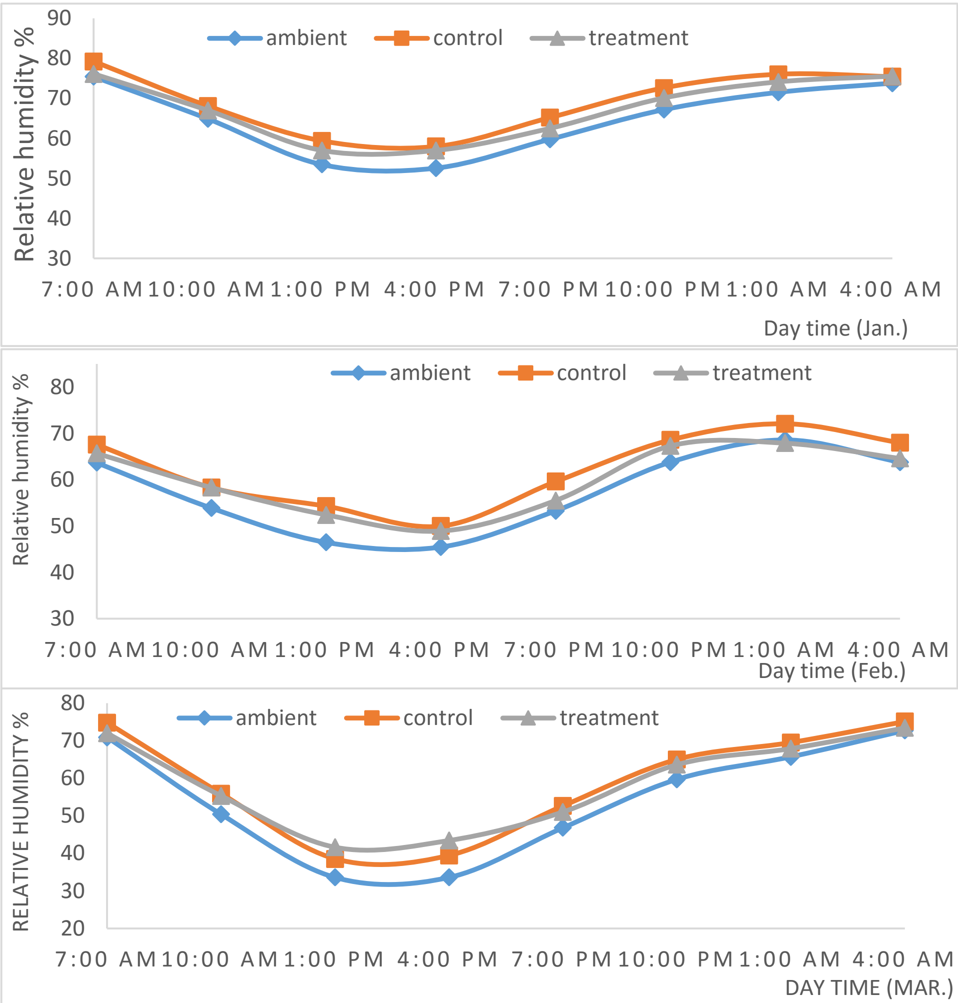

Fig. (3): Average air relative humidity outside and inside the treatment and control greenhouses vs. time during (January to March).

value at about 3 PM for all measurements then increased up to 4 AM. These results could be attributed to the fact that the level of the inside relative humidity is accompanied by the level of temperatures inside the greenhouses. The results has also show that the relative humidity of the control greenhouse is higher than the treatment one and there is slight increase in the relative humidity of the ambient comparing with the relative humidity of the control greenhouse.

3- Firmness

Figures (4), (5) and (6) represent the average firmness value of tomato fruits of the treatment and control greenhouses. It was 1.85 N/mm and 1.0 N/mm, respectively; this means that the firmness value of tomato fruits of the treatment greenhouse was greater by 85%.

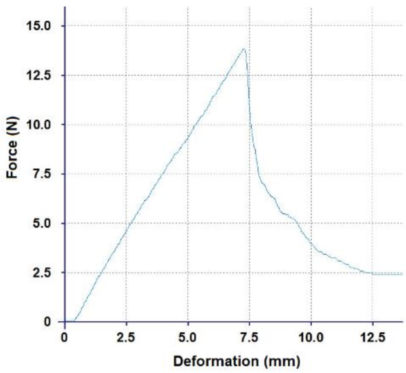

Fig. (4) Tomato's force-deformation behavior (treatment greenhouse)

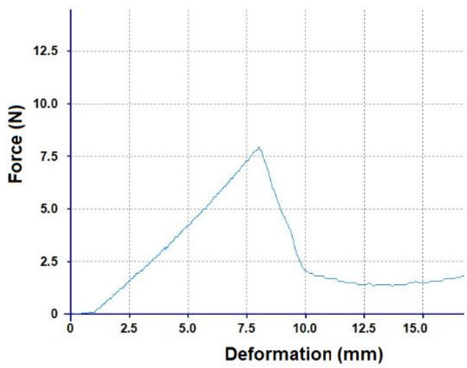

Fig. (5) Tomato's force-deformation behavior (control greenhouse)

4- Toughness

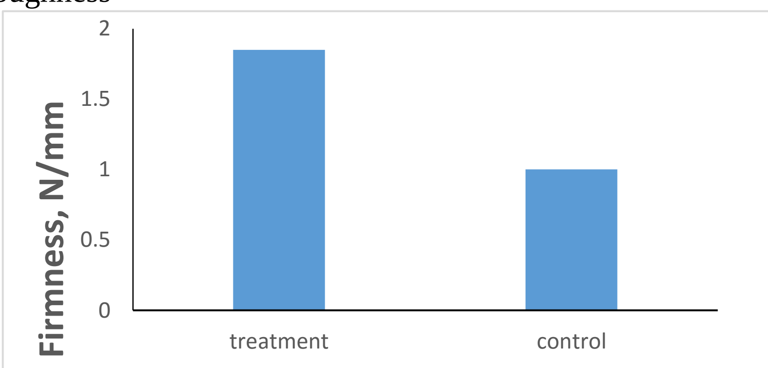

Fig. (6): Values of firmness of tomato fruits in treatment and control greenhouses.

Figs (4),(5) and (7) show the average toughness value of tomato fruits of the treatment and control greenhouses. It was 45.5 N.mm and 28 N.mm, respectively. This means that the percentage of increasing of toughness of tomato fruits was about 62.5%.

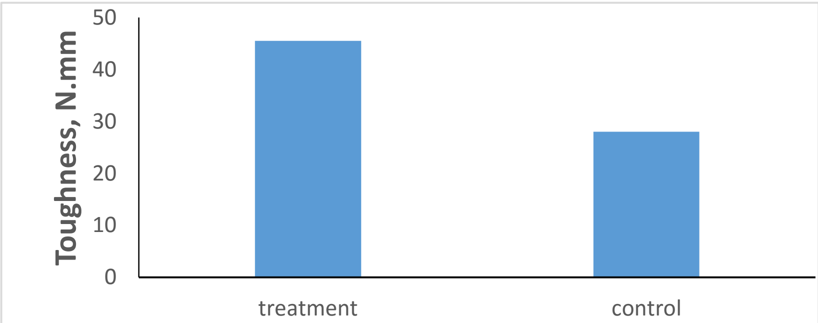

Fig. (7): Value of toughness of tomato fruits of the treatment and control greenhouses.

5- Heat losses through the greenhouse

Fig. (8) showed the results of the mean components (Q_v, Q_c) and Q_{total} of the greenhouse energy loses (treatment greenhouse) during the daytime of February 27, 2012. It can be noticed that, energy lost via ventilation increasing gradually from 7AM to 10 AM and decreasing before 1 PM to

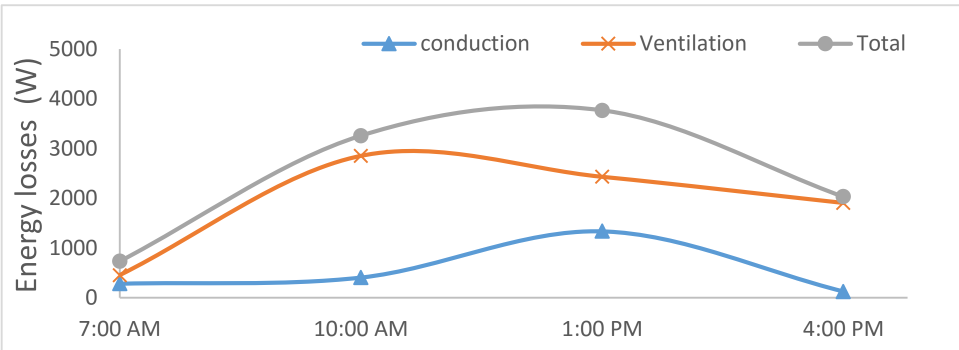

Fig.(8): Heat loss through the greenhouse.

4 PM but the heat flow through the polyethylene was approximately stable from 7 AM to 10 AM and began to increase gradually after 10 AM to 1 PM, then decreasing after 1 PM to 4 PM. Also, it be noticed that the greatest total losses of the energy from the greenhouses were at about 1.0 PM The reason of that is the air temperature difference between outside and inside greenhouse was maximum.

6- Effect of heat and ventilation on plant growth

Fis (9), (10), (11) and (12) show the effect of heat and mechanical ventilation on the average number of leaves, plant height, stem diameter and tomato production per plant during winter season of 2012. The obtained data show significant increase in all the above parameters in case of the treatment greenhouse as compared with the control greenhouse. Such increases were 28.98%, 22.21%, 28.75% and 57.69 %, respectively, at the end of the growth season.

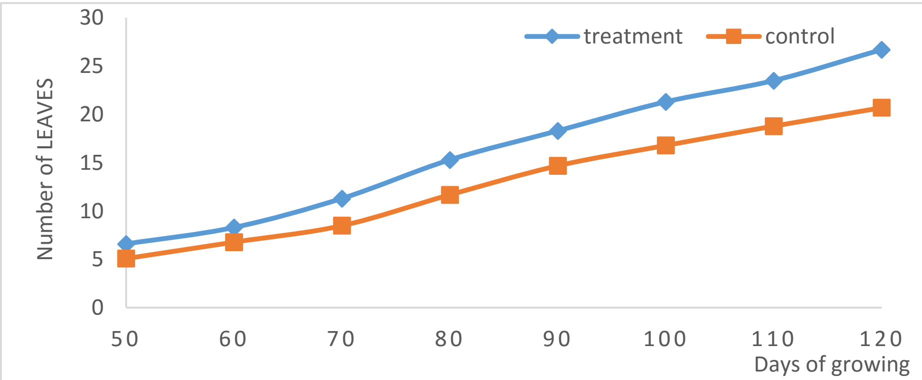

Fig. (9): The average variation in leaves number of the treatment and control greenhouses through growing season.

These increases may be due to control the interior climate (heat and RH) for plant growth under environmentally appropriate conditions, which help for (a) increasing the rate of nutrient absorption due to maintaining the optimum growth temperature; (b) forming a large number of leaves, which are necessary for photosynthesis process; and (c) increasing diameter and height of stem and consequently increasing the tomato production.

CONCLUSION

An experimental polyethylene greenhouse was constructed and equipped with heating and mechanical ventilation system to investigate the effect of air temperature and relative humidity on plant growth of early production of tomato crop during winter season of (2012) the designed system was supplied with environmental instruments to control the interior climate for high-yield conditions and it was compared with a traditional greenhouse the results showed an increase in number of leaves, stem height, stem diameter, tomato production, average value of firmness, and average value of toughness by 28.98%, 22.21%, 28.75% 57.69 % , 85%, and 62.5%, respectively.

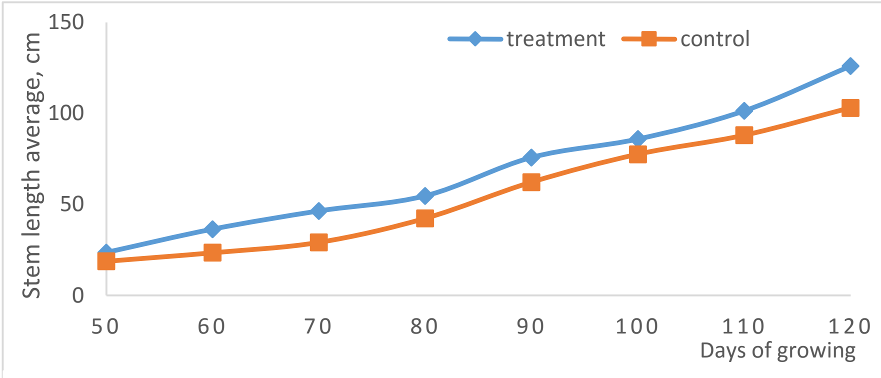

Fig. (10): The average variation in stem length of the treatment and control greenhouses through growing season.

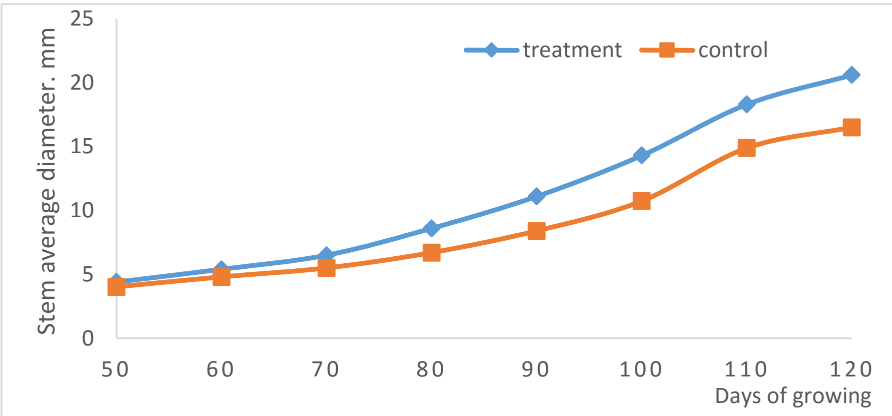

Fig.(11): The average variation in the stem diameter of the treatment and control greenhouses through growing season.

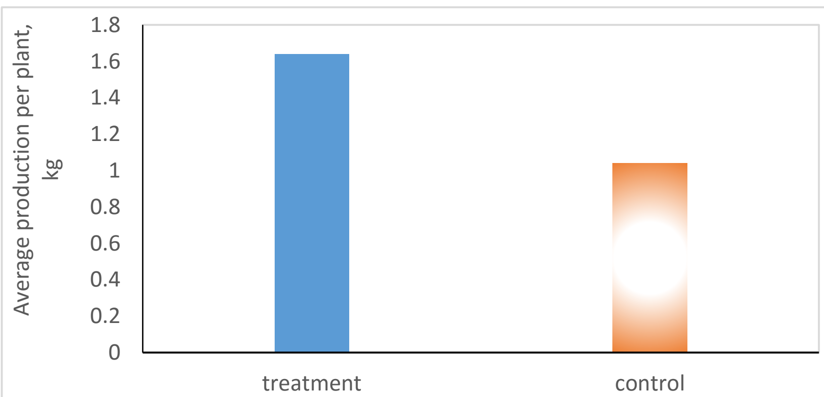

Fig. (12): The average production per plant of the treatment and control greenhouses at the end of growing season.

RECOMMENDATION

As a future work, it is recommended to use a solar heating system for substitution of stored solar energy for a significant portion of the electrical energy (that was used in this study, to heat the treatment greenhouse) in order to reduce the electrical consumption and save production cost.

المراجع العربية

إبراهيم محمد حلمي-٢٠٠٠.هندسة بيئة الصوب الزراعية.قسم الهندسة الزراعية-كلية الزراعية-جامعة الإسكندرية

صلاح عبد اللطيف-١٩٩٣.تصميم وتشغيل أنظمة الزراعة المحمية.قسم الهندسة الزراعية-كلية العلوم الزراعية والاغذية-جامعة الملك فيصل.

REFERENCES

Aldrish,A.R.and Bartok.W.J.(1994).greenhouse engineering. NRASE-33-3rd edition

BATU, A. (1998). Some factors affecting on determination and measurement of tomato firmness. Tr. J. of agriculture and forestry 22(1998) 411-418.

Buffington, D.E.; Bucklin, D.A.; Henley, R.W. and Mc Connell, D.B. (2002). Fans for greenhouses, institute of food and agriculture science, university of Florida AE-12

Gao,Z.(2012).Dehumidification of greenhouses in cold regions. Thesis, degree of, Sc, Uni. of Saskatchewan.

Jackman, R. L., A. G. Marangoni and Stanely, D. W. (1990). Measurement of tomato fruit firmness, Hort Science. 25(7):781-783.

Rajabipour,A.(1995).Effects of Ca, K and water table depth on tomato mechanical properties; PhD thesis, McGill Univ. MacDonald campus.

Shafiee, s; Motlag,A.M; Didar,R.A., and Minaee,s.(2008). Investigation the effect of skin on mechanical behavior of apple, journal of food technology 6(2):86-91, 2008.ISSN:1684-8426.

Sirisomboon,P. ; Tanaka,M. ; Kojima,T. and William,P. (2012). Nondestructive estimation of maturity and textural properties on tomato ‘momotaro’ by near infrared spectroscopy. Journal of Food Engineering 112 (2012) 218-226.

Li, Z.; Li,P.; and Liu, J. (2011), Physical and mechanical properties of tomato fruits as related to robot’s harvesting. Journal of food engineering 103 (2011) 170- 178.

الملخص العربي

نظام التحكم في التدفئة والتهوية للبيت المحمي

***شيماء عبد الفتاح ، *مبارك محمد مصطفى ،**
***محمود احمد النونو و **احمد محمد قاسم**

تستخدم الصوب الزراعية في مصر على نطاق واسع ومتزايد لإنتاج الخضراوات والفواكه ونباتات الزينة مبكراً، وتعتبر الصوب الزراعية أحد التطبيقات الجيدة لتجميع الطاقة الشمسية بغرض التدفئة وانتاج النباتات. علاوة على ذلك فان انتاجية وحدة المساحة للصوب أكبر من إنتاجية الحقل وجودة منتجاتها تكون دائما أفضل. ورغم ذلك فان الصوب تحتاج الى مصدر حرارة اضافي في فصل الشتاء خاصة اثناء الليل وخلال الفترات التي تكون فيها السماء ملبدة بالغيوم لإمداد النباتات باحتياجاتها الحرارية ولذا فمن الضروري التحكم في درجة حرارة ورطوبة الهواء اللازمة لأفضل نمو للنباتات داخل الصوبة عن طريق نظام للتدفئة والتهوية الميكانيكية مما يساعد أيضا على تقليل فرص اصابة النباتات بالأمراض الفطرية والتي تسبب خسائر فادحة للمزارع والتي يصعب مكافحتها عن طريق المبيدات.

إن التحكم في الظروف المناخية ذو اهمية كبيرة للإنتاج داخل الصوب لتحقيق اعلى انتاجية بأقل تكلفة وبأفضل جودة والتي يحتاجها السوق والمستهلك وتعد درجة الحرارة وكذلك الرطوبة من العوامل المناخية الاساسية التي يتم التحكم فيها من خلال نظامي التدفئة والتهوية، ولذا تم في هذا البحث تطوير، انشاء واختبار صوبة تجريبية مزودة بنظام للتحكم في التدفئة والتهوية لتوفير

الظروف المثلي لبيئة نمو نبات الطماطم اثناء فصل الشتاء من خلال: -

١- امداد الصوبة بنظام تدفئة مناسب من خلال دفع مائع تشغيل (ماء نقي) في دائرة مغلقة من خزان معزول مزود بسخان كهربائي الى مبادل حراري داخل الصوبة بواسطة مضخة.
٢- تزويد الصوبة بنظام للتهوية الميكانيكية لضبط الرطوبة النسبية داخل الصوبة.
٣- امداد النظام المصمم بأدوات للتحكم في المناخ الداخلي للصوبة (درجة حرارة ورطوبة نسبية) عن طريق ثرموستات وحساس للرطوبة لتوفير الظروف البيئية المناسبة للنبات.
٤- مقارنة إنتاجية الصوبة المصممة بصوبة تقليدية لها نفس المواصفات والتوجيه.

ويمكن تلخيص النتائج فيما يلي: زيادة عدد أوراق النباتات، طول النبات، قطر النبات، الانتاجية /نبات، ثبوت الثمرة (firmness)، صلابة الثمرة (toughness) بالصوبة المصممة عنها في الصوبة التقليدية بمقدار ٢٨,٩٨%، ٢٢,٢١%، ٢٨,٧٥%، ٥٧,٦٩%،٨٥%، ٦٢,٥% على التوالي. نوصى باستخدام نظام تسخين شمسي لإحلال الطاقة الشمسية المخزنة كجزء بدلا من الطاقة الكهربية.

***قسم الهندسة الزراعية -كليه الزراعة-جامعه عين شمس.**
****معهد بحوث الهندسة الزراعية.**