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THE DESIGN AND TEST OF IN-VESSEL COMPOSTING UNIT FOR HEATING A PLASTIC HOUSE

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ABSTRACT

Efficiency of locally designed and constructed in-vessel composting unit for heating plastic house was investigated during winter seasons of 2014/2015 and 2015/2016 at the Central Laboratory for Agricultural Climate (CLAC), Dokki, Giza. Composting unit constructed of fear face wood for the outer body,irontubes for the heat exchanger (four stages square coil) with a passive-aeration system.Plastic low tunnel was used as sink for the harvested heat.For Both seasons, the highest compost temperature,70.1 and 73.2°C, were recorded after three days and maintainedat55°C during the second and the third week.The lowest temperature values were recorded during the fourth week. A total of 4363.313 and 4339.657 kJ kg^{-1} were harvested during first and second season; respectively. Harvested energy used to adjust heated tunnel temperature between 20 and 26°C, which is reflected on better tomato growth and yield compared to non heated tunnel. Pile inside the in-vessel unit present 26% of plastic househeating requirement.

Key_words: In vessel composting- compost heated plastic houses- temperature profile- produced heat energy- growth patterns- crop yield.

1. INTRODUCTION

Greenhouses are present all over the world. In 2016world greenhouse vegetable productionarea was 473,466 hectares (WGVPS, 2016). Philosophy of greenhouses industry is to provide required optimal conditions for growing vegetables crops on a year-round basis. Therefore,greenhouse interior climate is extremely important for continues food production. Moreover, it is crucial for greenhouse operation to remain interior temperature at the optimal level for cultivated vegetables especially during winter season.

Additional energy is required for heating greenhouses during the winter season, which comes from fossil fuels with more stress on the environment. Concerning this situation,Bot(2001) reported that this is not a sustainable practice and there is a need for greener alternatives. Lagerberg*et al.* (1999), stresses the essentiality of increasing level of sustainability in greenhouses. They provide the fuel green alternatives such as pumpingof compost heat to the greenhouse.

Compost heating as a new technology appearsfor the first time about 40 years ago. Pain and Pain (1972) was the first to use this new technology followed bySchuchardt (1984) andFulford (1986). Later on, Schonbeck(1998) reported that, the National Alchemy Institute conducted many research on several prototypes related to compost heated greenhouses between years of 1983 and 1989. Their results indicated that it's important to keep the compost pile away outside of the greenhouse. Such distance is essential for avoiding the harmful effects of ammonia and carbon dioxide that produced during the decomposition.

From the above mentioned, it’s importantto develop a system characterized by simplicityas well as environmental friendly suitable for greenhouse operationwhile no additional work required with a controlled compost process (Viel*et al*., 1987).

Several studies confirmed that, in-vessel composting should be a controlled process. In-vessel system allows shortening of mesophillic and/orthemophillicstagesas well as producing high quality product with low number of pathogens (Viel*et al*., 1987). In

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addition, vessel-composting system has an advantage in harvested heat because ofthe homogeneous in activity of microorganism inside the compost material. It also doesn't have a large temperature gradients found in other composting methods. More advantage for the in-vessel composing was reported by Ripley and Mackenzie (2008).

2. OBJECTIVE

Therefore, the main objective of this study is to design and testa local vessel that uses compostto produce heat.The specific objectives are as follow:

2.1 Plastic house objectives

a) To reduce the original volume of organic waste (mainly the rice straw) into a biologically stable product (compost).
b) To present a simple green renewable alternative source of energy to heat plastic houses during winter seasons.
c) To determinate amount of harvested heatproduced from the specific used compost formula.
d) To determine the exact amount of compost needed to heat a specific plastic house area.
e) To determine the quality of the final compost produced from the in-vessel unit.

2.2 Horticulture objectives

a) To evaluate efficiency of tested in-vessel composting unit in pumping heat inside the tested plastic tunnels.
b) 2-To evaluate the direct effect of the thermal stability on growth and productivity of tomato plants grown under heated tunnel.

3. MATERIALS AND METHODS

3.1 Site description

Current investigation was held atthe experimental farmyardat the Central Laboratory for Agricultural Climate (CLAC), during the winter seasons of 2014/2015 and 2015/2016.

3.2 Type and materials of the composting unit

Outer body of the composting unit was made of 18-millimeterfear face sheets. The wood was shaped in a horizontal rectangular shape. The four sides of the rectangular were constructed to the floor-face by hinges. The hinges make it possible tomove the four faces up,to closed, and down to open. A dimension of the in-vessel composting unit was 240cm length x120cm width x120cm height (Figure, 1).

3.3 Heat exchanger system

Four stages square coil, made of a galvanized iron tube (2 inches), were used in the design of the heat exchanger system to fit the shape of the composting unite.The total length of the coil was 16.30 meter with14.30meter efficient length. One "1/3 horse power" blower (220 Volt single phase) was used to blowing air through the coils of the exchanger system, with discharge air capacity 3300m^3/h. the added compost should completely cover the four square coil (Figure, 1).

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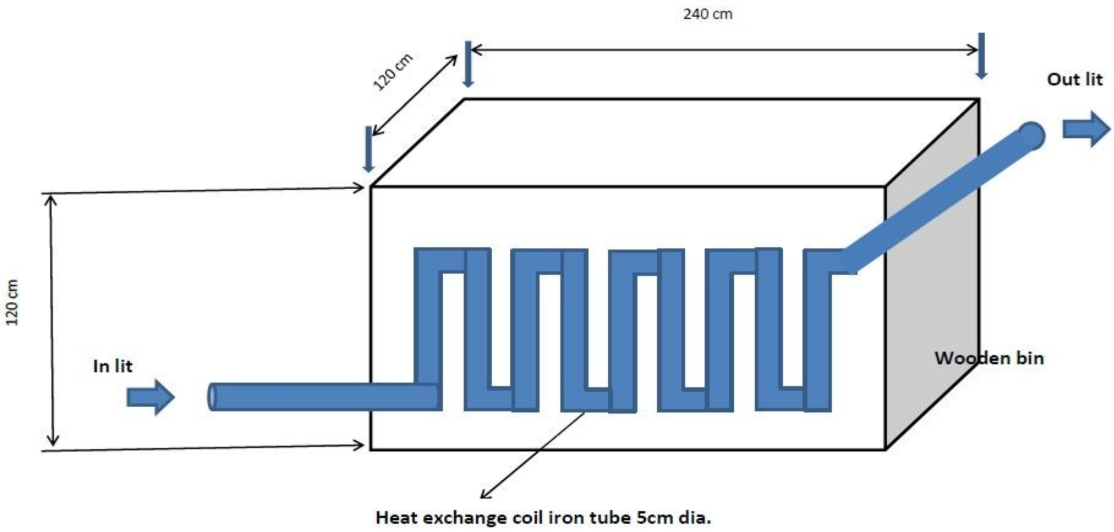

Figure (1): Heat exchanger system

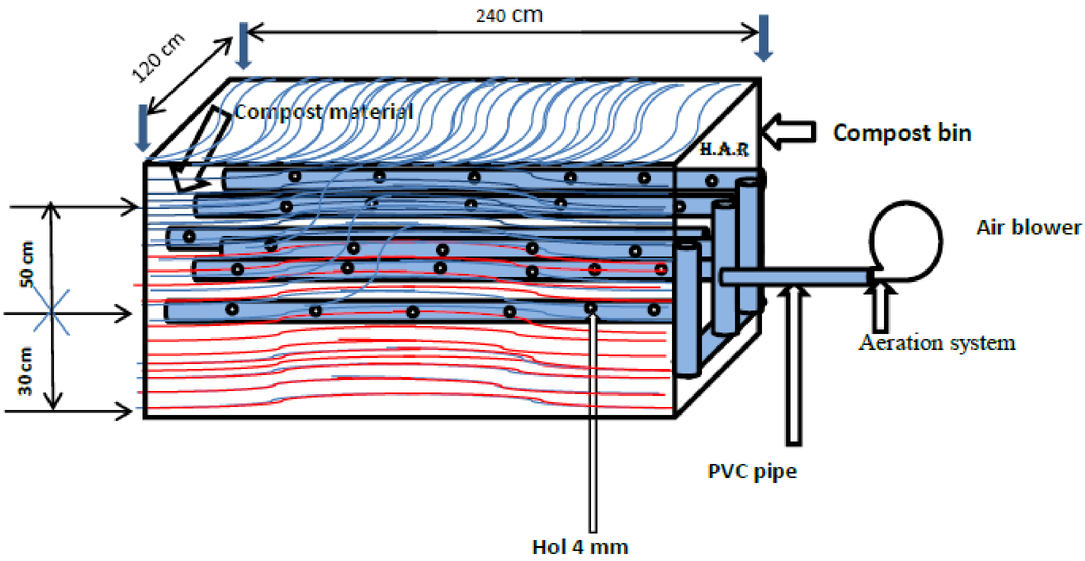

Figure (2): Aeration system

3.4 Aeration system

Passive-aeration system was constructed to aerate the composting tank. Perforated 50 mm PVC vertical pipes were arranged in two layers (50 cm space between them). Compost material is then loaded on top of the pipe networks.

Every vertical pipe at every layer was connected to one horizontal pipe from one end, and the other end is closed (Figure, 2).Every vertical pipe has 10 halls (each 4 mm diameter) to discharge air(0.0075 m^3/minute) with total discharge for total system 0.3m^3/h. Finally, horizontal pipes are connected to one outlet. The outlet of this network is connected to 1/3 horse blower (source of power 220 Volt single phase) for blowing air through the compost pile. The blower was connected to a timer to control time and frequency between air discharges.

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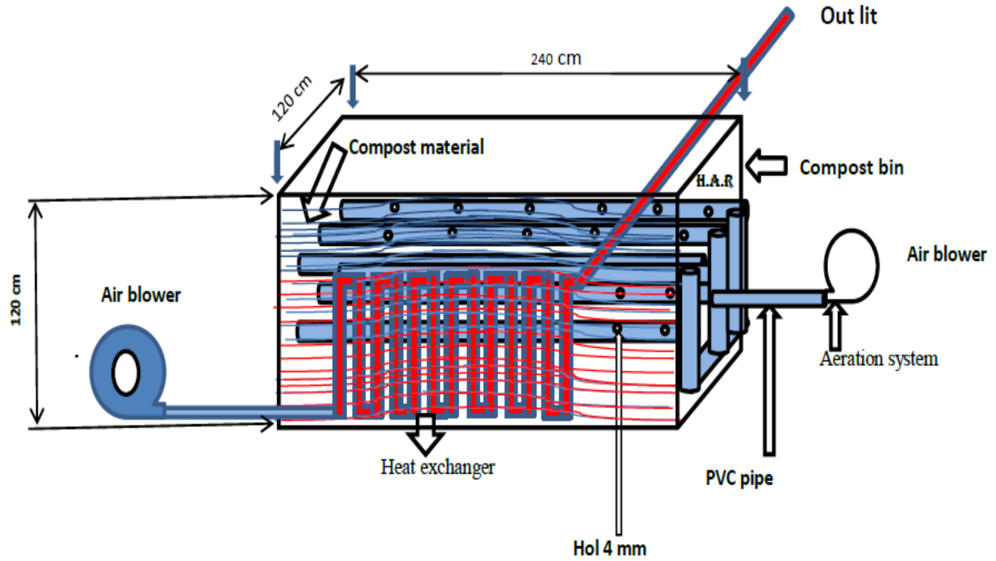

Figure (3): Composting unit

3.5 Compost preparation

In this work a formula proper to mushroom cultivation (*Agaricusbisporus*) was chosen (Zhanxi and Dongmei, 2008). The following table shows the formula of the raw materials:

Table (1): Types and weights of used raw materials adjusted by the formula for mushroom cultivation.

Raw materials	Basic formula (Kg)	Formula according to composter capacity (Kg)
Rice Straw	1500	136.4
Cattle Manure	1000	90.9
Ammonium Bicarbonate	30	2.7
Urea	10	0.9
Calcium Sulfate	20	1.8
Gypsum Powder	40	3.6
Calcium Carbonate	40	3.6
Lime	40	3.6

The straw was shredded to 2-4 inches using a cutting machine. The cattle manure was brought from livestock unit, collage of agriculture, Cairo University. All materials were weighted accurately according to the formulae. The yard was cleaned, settled and covered with a plastic sheet. The shredded straw was disseminated on the plastic sheet and fully pre wetted with 1% limewater. After disposal of excessive water, the adjusted material by the mushroom cultivation formula divided of four equal layers, each layer consists of: (1) rice straw (30 cm height),(2) cattle manure (3-5 cm height), (3) ammonium bicarbonate and (4) urea with continuous supply with water, and then the pile was covered with plastic sheet. The pile was turned over using turning machine (Tanta Motors, lnc.).After 4 days when the temperature reached it is peak value (70-75ºC), the following chemicals were added to regulate the water content, (calcium super phosphate, gypsum Powder, calcium carbonate and lime), and emit the exhausted gases (ABEMTC, 2011).

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3.6 Sampling and analysis

For monitoring quality and maturity stage of compost pile, a weekly sample were taken and analyzed.Compost pile temperature, pH, moisture content, extract colorand odor were considered as indicators for composting operation.

Once result of final analysis showed the desirable indicators, degraded compost material moved to windrow area where it was allowed todecompose for a further one week.

3.7 Temperature Profiles

Temperature values of compost inside the unit were recorded through the composting time for the two study seasons (15/12/2014 to 22/1/2015 and from 20/12/2015 to 28/1/2016). Temperaturesmeasured manually by adigital thermometer probe (model TP3001),that was placed into the compost inside the composting unit.

Resultswere recorded every12hours;throughout thecomposting process.The obtained temperature values were averaged in order to create the temperature profileforeach of the two seasons.

3.8 Energy value

Energy values were calculated for each of the two studied seasons using the method of (Holman, 1981; Ekinci*et al*., 2006) in composting systemsused equation (1) is as follow:

$$qp = m \times cp \times \Delta T \quad (1)$$

Where:
$qp$is heat energy leaving the system (kJ kg−1),
$m$is mass of product (kg),
$cp$is specific heat at a constantpressure (kJ kg−1K−1), and
ΔT is change in temperature.

3.9 Plastic house heating requirements calculation

Heating requirement for plastic house (9*60*3.25m) was calculated, using the following equation (2):

$$H = u\,A\,(ti - to) \quad (2)$$

Where:
H is heating requirement in BTU/hour,
u is a constant differ according to type of covering material,
A is area of plastic house in square feet,
tiis the interior temperature in °F, and
tois the outer temperature in °F.

The calculated heat requirements, together with calculated energy value from composting unit, were used to estimate the percentage ratio between plastic house area and area of compost pile.

3.10 Horticulture experiment

Polyethylenelow tunnel (1.0width x 0.60 heights x. 10.0 m length)wasused to examine the efficiency of harvested heat in cover the heat requirements for the plants grown inside.

For distribute the hot air inside in, the tunnel, one perforated polyethylene tube was fixedinside the tunnel at the top (Figure, 4). Such perforated tube was connected to the hot air outlet of the heat exchanger system. For temperature leveladjustmentinside the tunnel, a digital thermostatwas used to controlling time and frequency of heat exchanger blower on and off. Temperature level inside the tunnel adjusted to be between 20-26 °C.

For comparing temperature profile as well as performance of tomato plants, another low tunnel with the same dimensions was built beside the heated tunnel to use as control.

3.11 Plant material

Seedlings of tomato (*Solanumlycopersicum* cv. Super strain B) were transplanted in two rowsinside both tunnels, in 15th and 20thof December of 2014 and 2015; respectively, at a spacing of 0.5m between plants inside the same raw and0.5m between rows. Recommended doses of nutrients were applied before transplanting (extension bulletin no. 1294/2013). Tunnels were covered manually after transplanting.Soil set was irrigated using drip irrigation system.

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3.12 Recorded data

To determine plant growth indicators under both studied tunnels, data were recorded every 15 days (during the heating period) on number of leaves and plant fresh and dry weight. The total yields of tomato in both tunnel, were recorded.

In addition, air temperature inside each of the two tested tunnels was daily recorded by digital thermo/hygrometer Art.No.30.5000/30.5002 produced by TFA, Germany. Measurement was done every 12 hours.

3.13 Experimental design and statistical analysis

The experiment was designed using randomize complete plots design with three replicates.Obtained data were statistically analyzed using the analysis of variance methodaccording to Snedecor and Cochran, 1990. Level of probability at 5% was used to compare means of the treatments.

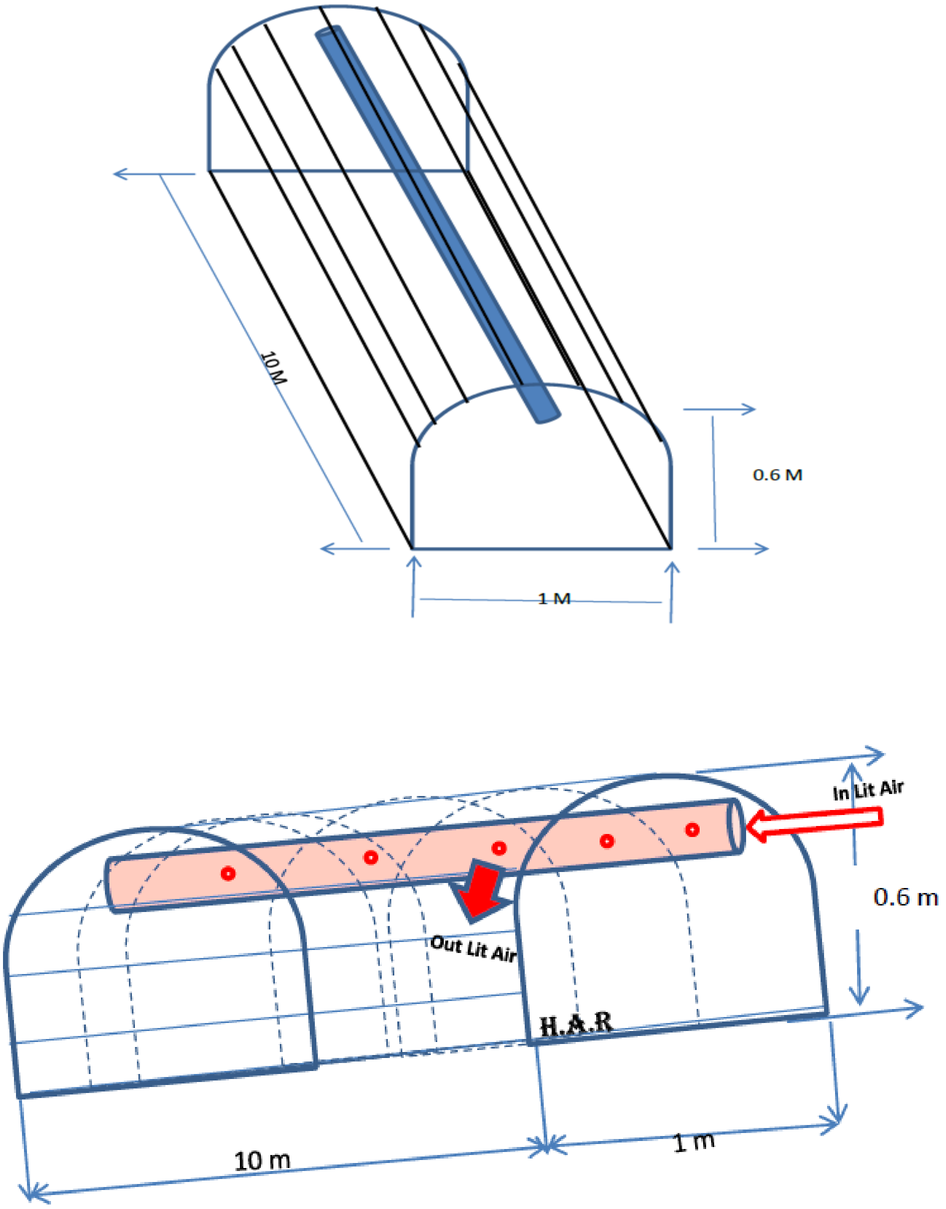

Figure (4): Heated tunnel

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4. RESULTS AND DISCUSSION

4.1 Temperature profile

4.1.1 ***Compost temperature:*** it's clear from Figure (5) that, by the end of the first day, temperature inside compostingtankrecorded45.7 and 47.4°C during first and second seasons, respectively.Temperature rapidly increased to the maximum value (70.1 and 73.2°C) in the third day. Later on,temperature gradually decreasedfrom the fourth day to the end of composting period to record55°C as a meantemperature during this period. Finally, mean temperatures reached the lowest degree (38.6 and 34°C) by the end of the composting period (Fig, 5). In this study, obtained compost temperature was similar to those observed by Ekinci*et al*. (2006) and Irvine *et al.* (2010).

Earlier, Keener *et al*. (2000)explain the temperature profile basis onthe activity of microorganisms and categorized the entire composting processinto two major phases.

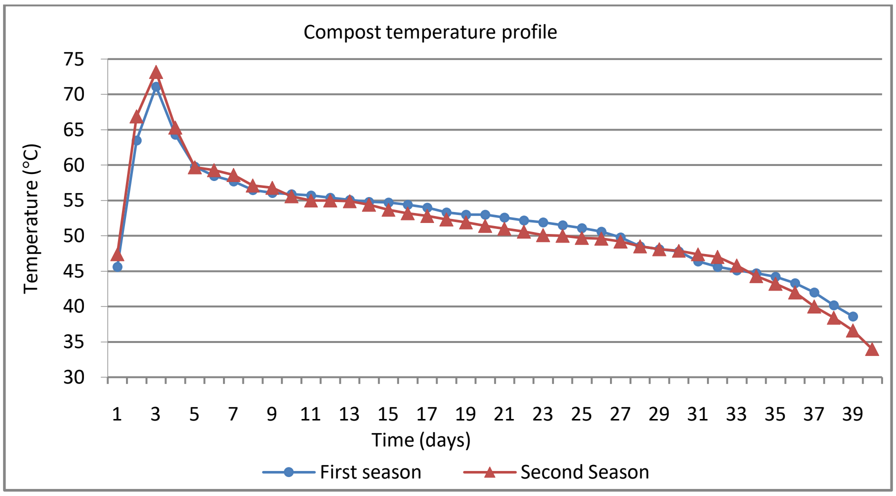

Figure (5): Compost temperature profile during seasons of 2014/2015 and 2015/2016.

4.1.2 ***Tunnels temperature:*** from Figure (6)it's obvious that, recorded maximum and minimum air temperature under the non-heated tunnel were relatively higher than the maximum and minimum temperature in the open air. Average temperatures inside non heated tunnels were about 2°C higher than the open air.

Concerning the thermal situation under the heated tunnel, both of maximum and minimum air temperatures were almost stable all over the heating period. This stability is a direct result ofpumping hot air, from composting tank to the tunnel controlledby a digital thermostat.

Comparing the thermal situation under both studied tunnels, it's concluded that temperatures were higher and more stable under the heated tunnel than the non-heated tunnel (Figure, 6).

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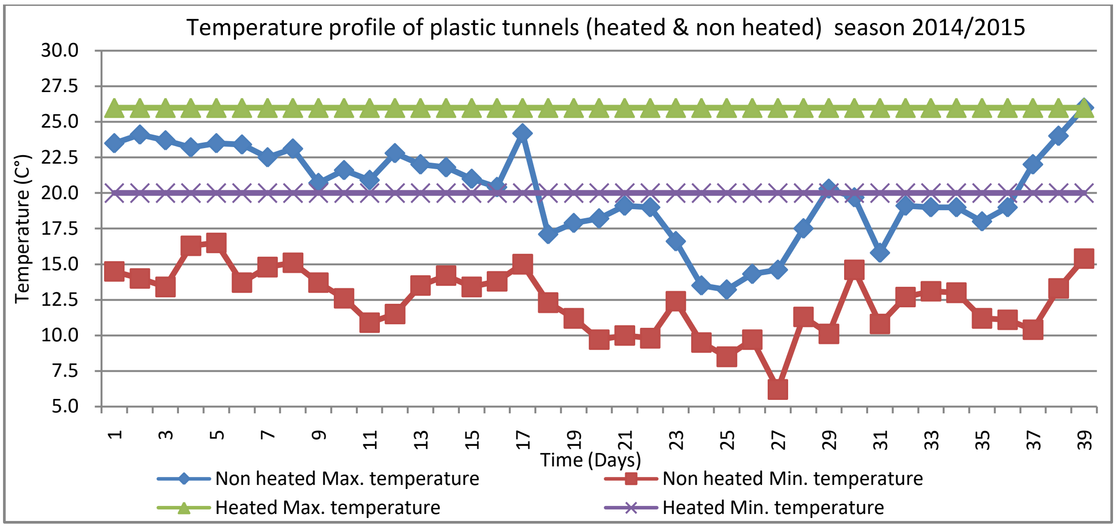

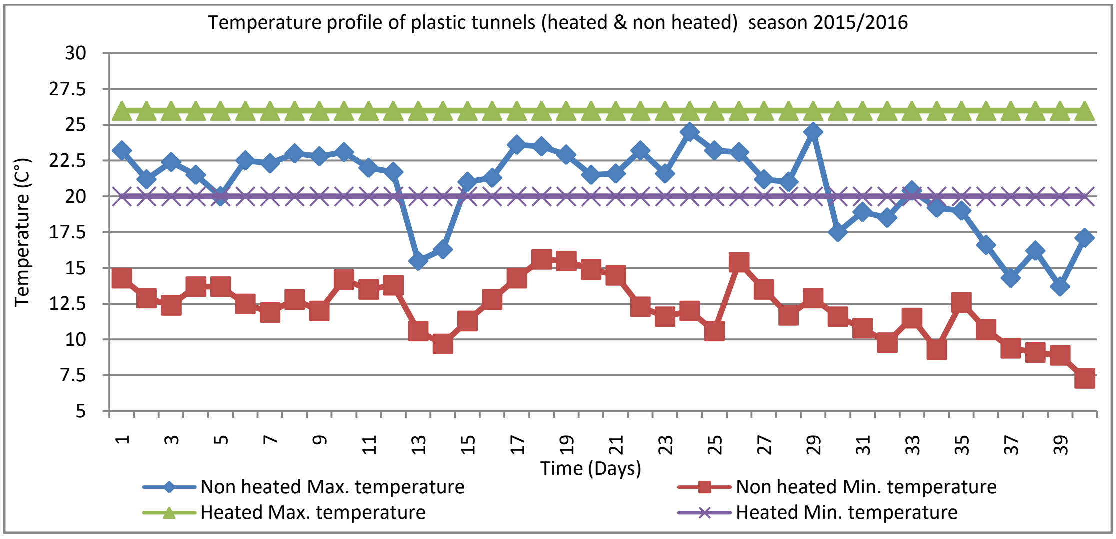

Figure (6): Maximum and minimum temperature inside the plastic tunnels (heated &non heated).

4.1.3 ***Energy values:*** both, of compost temperature (Figure,5) and harvested heat profiles (Figure,7) were used to calculate produced energy value. Calculated energy value from the studied system recorded 4363.313 and 4339.657 kJ kg^{-1}, in first and second season, respectively.

It's noticeable that comparing produced energy from different studies does not reflect any considerable indicator because of the different composting substrates, different conditions and differences in decomposition rates. The mentioned factors make it very difficult to do a fear comparison (Irvine *et al.* 2010)

4.2 Plastic house heating requirements

Calculationfor the plastic house heating requirement indicateda total 1150BTU/hour/9.3m^2.Employing the last mentioned value together with the harvested heat energy indicated that, for heating plastic housewith dimensions of 9x60x3.25m, composting tank needs to be 26.3% of the plastic house area.

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In a similar study, but on large scale, Adams (2005) suggests that for heating a vegetable production greenhouse, the area of the compost pile needs to be 27% of that of the greenhouse area. More clarification, for heating a9.3m^2 greenhouse the volume of the compost pile is require to be a 2.508 m^2 compost pile.

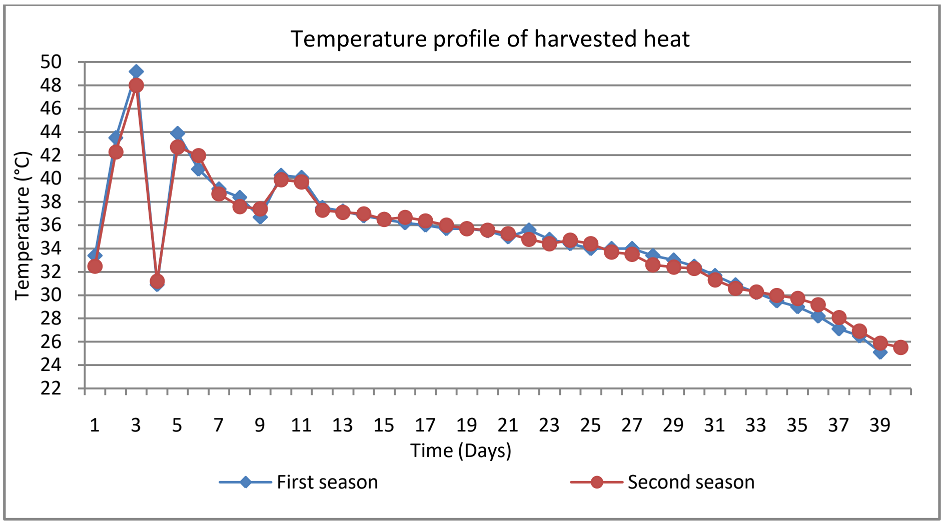

Figure (7): average temperatures of harvested heated air from the composting unite.

4.3 Quality of produced compost

Analysis of produced compost from studied composting unit indicated moisture content 64, Ph 7.2, C/N ratio 1/18.8, Ash%36.7, fibers 18, nitrogen % 1.36, phosphorus % 0.07 and potassium% 0.92. In addition it was odorless.

Comparing the analysis resultswith the desirable quality of matured compost by Wakchaure and Singh (2013), it is clear that produced compost in this study was typically similar to the range of good quality compost.

4.4 Tomato growth & yield indicators

From illustrated data in Table (2) it's concluded that, growth and yield of tomato plants grown under the heated tunnel, showed a significantly a better growth pattern as well as significant higher yield compared with those grown under the non heated tunnel (control). The last mentioned obtained result is confirmed during both studied seasons.

Table (2): response of tomato plants to the thermal situation under heated and non-heatedtunnel (control)

Character	Number of leaves			Plant fresh weight (g)			Plant dry weight(g)			Yield
2014/2015										
days	15	30	45	15	30	45	15	30	45	(kg/plant)
Heated	16.7	19.7	22.0	150.3	161.0	167.3	20.3	24.0	27.0	4.0
Control	12.3	16.7	18.3	147.0	150.7	159.7	16.7	19.0	22.0	3.2
L.S.D	0.97	1.69	1.95	2.24	3.51	3.89	4.24	2.92	2.92	0.54
2015/2016										
days	15	30	45	15	30	45	15	30	45	(kg/plant)
Heated	17.0	20.3	23.0	151.3	163.3	168.7	22.7	26.0	28.3	4.3
Control	12.7	16.3	19.7	148.3	152.0	161.3	19.7	21.3	22.7	3.4
L.S.D	0.97	1.69	2.58	2.92	1.07	5.15	1.86	0.97	5.15	0.49

5. CONCLUSION

- ❖ The thermal conditions under the heated tunnel reflected a better significant growth patterns for tomato plants compared to those under the non-heated tunnel.

- The composting unit was able to produce 4363.313 kJ $kg^{-1}$and 4339.657kJ kg^{-1}during first and second season; respectively. These amounts of harvested heat present 26% of the total heating requirements of plastic house with dimensions 9x60x3.25m. Moreover, employing this amount of energy was sufficiently enough to increase temperature of the heated tunnel by 2.5°Cup to 3.4°C above the temperature level inside the control tunnel.
- A good quality compost is produced inside the composting tank, odorless matured with desirable quality.

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