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Original article

Utilizing biomass energy for improving summer squash greenhouse productivity during the winter season

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ABSTRACT

The objective of this present research is to use agricultural residues as a source of energy for heating greenhouses during winter seasons and sequestrating soil carbon dioxide through adding biochar to the soil media. To fulfill the objective of the research work, summer squash was transplanted in a constructed greenhouse and heated using an attached biomass-burning system. The performance of the attached biomass-burning system was experimentally studied under different agricultural residues (corn stalks, cotton stalks and okra stalks), heating fluids (water and oil) and air fan operating periods (10, 15 and 20 min/h). Results indicated that the biomass-burning system allowed increasing temperature and relative humidity inside the greenhouse up to 27.2 and 80 %, respectively. The maximum biomass-burning system efficiency of 81 % was achieved with the use of okra stalks as a source of energy and oil as a heating fluid side by side with adjusting the suction fan operating period at 15 min/h. Adding bio-charcoal to the soil media, enhanced the soil carbon, resulting in a total fresh yield of 3.7 and 2.9 kg/pot with a total number of leaves per plant of 55 and 47 leaves under conditions of with and without charcoal addition, respectively.

1. Introduction

The development of renewable energy as a primary global resource of clean energy is one of the main objectives of energy policies worldwide, which is the general framework of sustainable development (Aznar-Sánchez et al., 2020). Agriculture is one of the most important sectors, which is characterized by the greatest potential for sustainable economic development (Odeim et al., 2015). Protected cultivation supplies a good opportunity for high quality product production and guaranteed supply of huge amounts to improve quality production, increase harvesting period and expand the area of production. Therefore, greenhouses production has increased greatly in most countries. Greenhouse farming has demonstrated their efficiency in stepped up food production as a system of agricultural management (Gorjian et al, 2020).These systems provide a feasible alternative to food supplies that comprise one of the largest challenges faced in the twenty-first century by humankind.

A greenhouse is intended to protect plants against climatic hazards and to promote the growth of crops by creating climatic conditions more favorable than the local climate or to produce "out-of-season (Gorjian et al, 2020). In general, climate control is the most important for greenhouse production to achieve high yield and good quality crops that meet the demands of consumers and economical production. Temperature and relative humidity are two basic climatic parameters always controlled by heating. Temperature in a greenhouse without heating, can be below the optimum range for crops during cold winters especially at night (Zhang et al, 2020). Lack of heating has adverse effects on the

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quality and quantity of the products in a greenhouse. Temperature is also one of the most essential aspects affecting plant growth, including inside air temperature (Bai, 2007). As regards heat source, the heating system is one of the most important aspects in greenhouse industry that it can cover up to 70% of energy. It is observed that the inside air relative humidity is always larger than outside air relative humidity. The air relative humidity inside the greenhouses ranged from 68.0 to 80.0 % but the outside air relative humidity ranged from 40.2 to 67% (Heravi, 2013**).** Greenhouse heating is one of the most energy-efficient activities during winter. Increasing fossil fuel prices and their adverse effects on the environment and human health have forced farmers and researchers in the field of heating greenhouses to use alternative heating sources. Different renewable energy sources, such as biomass energy, geothermal and solar energy can be used in horticulture instead of the fossil fuels that are used up to now (Xu et al., 2014). It is clear that a heating effect of 3–8 °C is higher than the solar greenhouse without heating systems. As whole, biomass energy application is a bright future in the greenhouse heating system which meets the stability and economy requirements of the greenhouse system. (Zhang et al., 2016). Compared to Greenhouse without a heating system, the greenhouse biomass heating system is very affordable, with a 105% excess return rate for farmers per year (Huang et al., 2020). Carbon sequestration is an atmospheric carbon dioxide (CO2) sequestration and long-term storage process to prevent dangerous climate change. The application of biochar increases the crop yield through the improvement of soil physiochemical properties (Lehmann and Rondon, 2006). The carbon(C) in the biochar is long-term and biochar use is an effective way to improve soil C sequestration (Lehmann et al., 2009). Biochar is a solid material processed under oxygen-limited conditions from the thermochemical conversion of biomass (Laufer and Tomlinson, 2013). Bio-charcoal can be added to soils to improve soil quality, reduce the use of conventional fossil fuel-based fertilizers, and sequester carbon. However, variable applications, uncertain feedstock effects and original soil conditions offer a wide variety of costs, often, for a marginally improved yield from biochar addition. The need for more clarifying the application of biochar for different crop yields is important if widespread acceptance is to be gained as a soil modification (Filiberto and Gaunt, 2013).

In the cold winter the greenhouse air temperature without system of heating can fall just below the optimal range for plants especially in night. Based on the above mentioned, a suitable heating system is required to keep and provide the inner air temperature at the required level. There are many types of heating systems for greenhouses. The most common and cheapest system is the unit heater (Huang et al., 2020). Therefore, the main aim of the present research is to assess the feasibility of using the combustion of biomass for heating greenhouse, reduce greenhouse emissions through CO_2 sequestration. The main objectives of this study are constructing a greenhouse provided with a biomass-burning system for controlling climatic conditions and enhancing crop productivity. Optimizing some different operating parameters that affect the performance of the biomass-burning system (agricultural residues, heating fluids and air fan operating periods) during heating greenhouse. Investigating the effectiveness of bio charcoal addition (resulting from biomass burning) to the soil media to sequestrate carbon dioxide on the crop productivity compared to without addition (control).

2. Materials and methods

Experiments were carried out through the period from 1 December 2019 to 15 February 2020 at Faculty of Agriculture, Zagazig University, Zagazig city (300 2′N latitude and 31012′E longitude), Sharkia Governorate in Eastern Delta, Egypt. The agricultural residues used as a source of energy for heating greenhouses during winter seasons.

2.1. Experimental setup

2.1.1. The transplanted summer squash plants

The transplanted summer squash was planted in pots as an agriculture system in the greenhouse. The greenhouse was equipped with 55 plastic pots (30 cm diameter and 40 cm high) which were arranged in five rows (each row having 11 pots). The distance between rows was 80 cm and 40 cm between plants within a row. Sixty seedlings from summer squash with two leaves were planted inside the greenhouse.

2.1.2. The chemical composition of agricultural wastes

Agricultural residues of corn, cotton and okra stalks were collected from the farm to be used as a source of energy for heating the greenhouse. Chemical properties of the used agricultural residues were analyzed in the faculty of Veterinary, Zagazig University such as moisture content (MC), carbon (C), nitrogen (N), hydrogen (H), oxygen (O), ash and calorific value (CV) as illustrated in Table 1.

2.1.3. The constructed greenhouse

The greenhouse was constructed at a faculty of Agriculture, Zagazig University, Sharkia Governorate, Egypt. The greenhouse was 6 m in length, 4 m in width, 2 m eaves height and 2.4 m in ridge height. The greenhouse frame was covered by a polyethylene sheet with 150-μm thickness. The floor surface area was 24 m^2 and 1010.4 m^3 volume. The greenhouse was provided with a biomass-burning system for heating as shown in Fig. 1.

2.1.4. Biomass-burning system

The biomass-burning system was manufactured in a special workshop at Zagazig city, Sharkia Governorate, Egypt and constructed beside the greenhouse (Fig. 1. The biomass-burning system consisted mainly of a biomass burner, heat exchanger, heating fluid and suction fan as following:

2.1.4.1. Biomass burner. The biomass burner consisted of the burning chamber which was constructed from a galvanized iron sheet of 3 mm thickness. It was a cylindrical shape with dimensions of 100 cm length and 60 cm diameter. The burning chamber was surrounded by another tank with a diameter of 70 cm and insulated using glass wool. The biomass burner was provided with an inlet tube made of galvanized iron with a diameter of 4 in. at a height of 30 cm from the surface of the ground to enter the agricultural residues and another outlet tube with a diameter of 3 in. for the ash exit at a height of 10 cm from the surface of the ground. The unit was completely insulated with fiberglass to reduce the heat losses.

2.1.4.2. Heat exchanger. The biomass-heating system is provided with a heat exchanger on its side. The heat exchanger consisted of a stainless copper coil with a diameter of 0.5 in. and 16 m in length and connected with another heat exchanger inside the greenhouse at a height of 180 cm above the ground. One functional part of the heat energy generated from the combustion of the agricultural residues was absorbed by the heat exchanger copper coil inside the biomass burner and transferred to the other heat exchanger inside the greenhouse.

2.1.4.3. Heating fluid. Two heating fluids were used (water and waste engine car oil). Ordinary tap water was used as heating fluid inside a greenhouse. While the waste engine car oil was filtered to

Table 1
Chemical analysis of the used agricultural residues.

Agricultural residues	Characteristics							
	MC, %	H, %	C, %	O, %	N, %	Ash, %	CV, MJ/kg	
							HHV	LHV
Corn stalks	11.75	5.8	37.5	27.2	0.15	0.3	17.38	15.81
Cotton stalks	10.2	6.1	35.1	29.1	0.17	7.4	18.01	16.40
Okra stalks	9.8	7.9	28.25	25.4	0.14	8.4	19.30	17.20

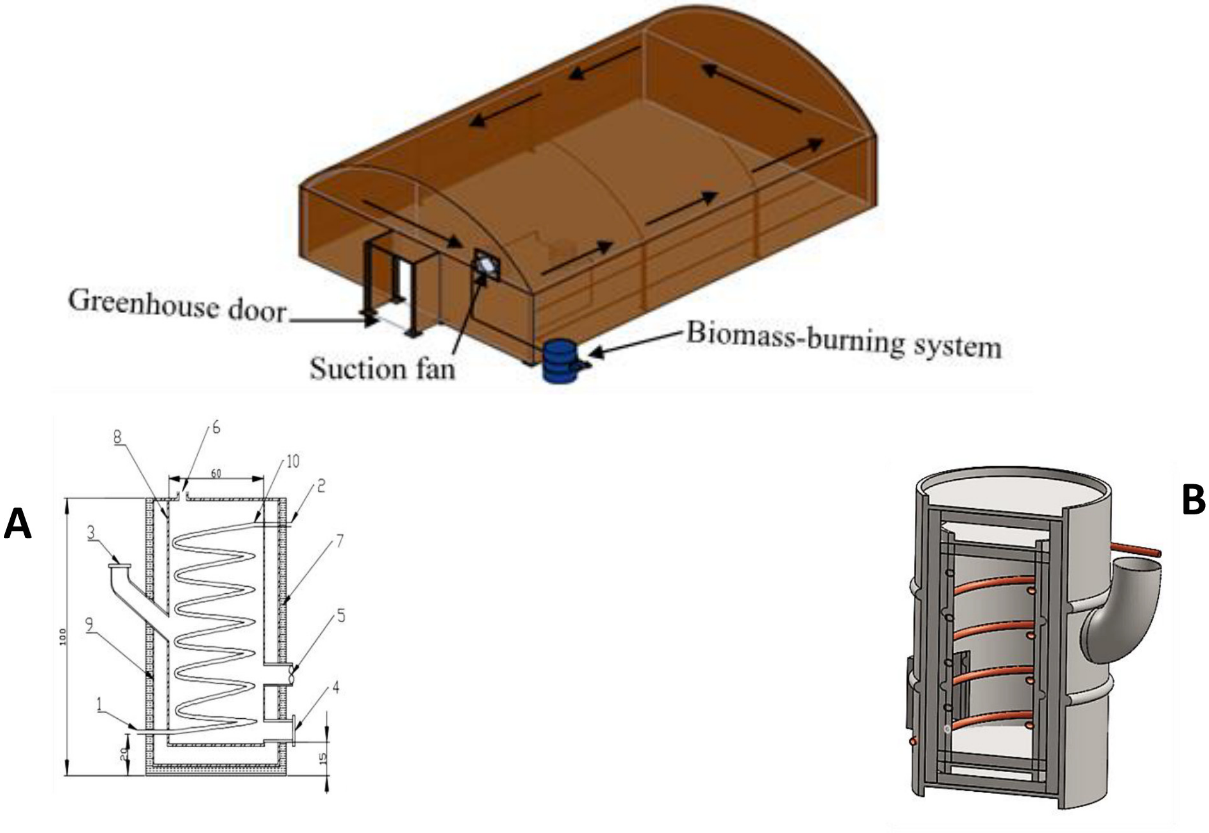


Fig. 1. Green House (A), The constructed biomass-burning system (B). All dimensions in, cm.

be used also as heating fluid inside a greenhouse. Heating fluid was pushed inside the heat exchanger of the biomass-burning system to raise fluid temperature, which pushed to the other heat exchanger inside the greenhouse as a closed system.

2.1.4.4. Suction fan. Hot air will rise to the top of greenhouse. Without circulation fans, this would lead to an extremely variable temperature distribution and CO distribution in the greenhouse. Suction air fan (DJF (a)-620(20), with 62 cm diameter, 1400 rpm and 370 W power was placed on the opposite side of the heat exchanger inside the greenhouse. The fresh outside air was drawn by the fan and pushed into the heat exchanger to keep the air inside the greenhouse moving continuously.

2.2. Experimental procedure

Experiments were carried out to assess the feasibility of using biomass combustion for heating greenhouse during winter seasons.

2.2.1. Experimental conditions

To fulfill the objective of this research work, three experimental groups were carried out taking into consideration some operating parameters as follow:

2.2.1.1. The first experiment. The first experiment was conducted to study the effect of air fan operating periods (10, 15 and 20 min/h) on the greenhouse thermal performance. During the first experiment, okra stalks as a source of energy for heating greenhouses and waste engine car oil as a heating fluid were used.

2.2.1.2. The second experiment. Based on the optimum condition of fan operating period obtained from the first experiment, the influence of different agricultural residues (corn, cotton and okra stalks) and different heating fluids (tap water and waste engine car oil) on the biomass-burning system efficiency were studied.

2.2.1.3. The third experiment. Depending on the two above mentioned experiments, the effect of adding biochar (resulting from biomass burning) to the soil on mitigating greenhouse gas emissions and crop productivity was studied compared to without addition (control). During the third experiment, the optimum fan operating period obtained from the first experiment was kept constant side by side with using okra stalks as a source of energy for heating greenhouses and waste engine car oil as a heating fluid were used.

Four kilograms of biomass residues were combusted inside the biomass-burning system twice a day. Two kilograms were combusted at 9 a.m. while the other two kilograms were combusted at 4p.m.

2.2.2. Measurements and determinations

The greenhouse, as well as the attached biomass-burning system was evaluated with taking into consideration the following indicators:

2.2.2.1. Temperature and relative humidity. Air temperature (T) and relative humidity (RH) were measured inside the greenhouse every hour during experiments. TENMARS TM-40x Series Anemometer (Tenmars Electronics Company, TAIPEI, TAIWAN) was used to measure temperature per hour provided with data logging capacity (99 records) with an accuracy ± 1 and relative humidity with an accuracy ± 3.5%. In addition, the fluid temperature at the entrance and fluid temperature inside the greenhouse were measured by 0.8 mm diameter of copper thermocouples. All thermocouples were connected to a digital millimeter.

2.2.2.2. Vapor pressure deficit. Vapor pressure deficit (VPD) is the difference between the pressure of the saturation vapor and the vapor pressure. VPD measures the pressure exerted by the vapor in the air and compares it to the theoretical saturation point of the air. This parameter can be used as an indicator to determine how close a closed-field environment is to saturation.

Vapor pressure was calculated according to Abtew and Melesse (2013) as:

$$VPD{=}\exp\left(6.41+0.0727\mathrm{T}^{-3}+10^{-4}\mathrm{T}^{2}+1.1810^{-6}\mathrm{T}^{3}-3.8610^{-9}\mathrm{T}^{4}\right)(1-\mathrm{RH}/100) \tag{1}$$

2.2.2.3. Heating calorific value. The calorific value (CV) means the energy content or the heat value of a material is expressed when it is burned in the air. The CV is usually measured in terms of the energy content per unit mass (MJ/kg). The energy content per unit mass (MJ/kg) is usually measured by CV. The fuel CV can be defined in two forms: a higher heating value (HHV) and lower heating value (LHV). The HHV is the overall energy content released when the fuel in the air is burned, including the latent heat in the water vapor. It thus represents the maximum energy that can be re-energized from a biomass source. according to Wazwaz et al. (2002) as follows:

$$HHV = 123.89(H) + 34.16(C) + 19.07(S) + 6.28(N) - 9.85(O) \tag{2}$$

The LHV is the appropriate value to use for the energy available for subsequent use and estimated according to Orel et al. (2002) as follows:

$$LHV = HHV - 2.453(9H + MC) \tag{3}$$

2.2.2.4. Heat energy losses from the greenhouse. Many factors affect heat energy losses such as frame, structure, covering materials, heating systems and orientation. The total heat losses from inside greenhouse to outside of the greenhouse can be estimated from the following equations:

$$Q_{Heat} = Q_{loss} \tag{4}$$

$$Q_{loss} = Q_{cl} + Q_{inf} \tag{5}$$

where: Q_{CL}The loss of heat via the conduction of concrete blocks and greenhouse glazing material. Conduction heat transfer was estimated according to Aldrich and Bartok (1994):

$$Q_{cl} = UA(T_{ai} - T_{ao}) \tag{6}$$

where: A: The surface area of the greenhouse (m^2), U: the overall heat transmission coefficient (6.8 $W/m^{2\circ}C$ for single film plastic), T_i: Temperature inside the greenhouse (°C), T_o: Temperature outside the greenhouse (°C).

Q_{inf}: Energy losses can be determined according to Sayigh (2001) as:

$$Q_{inf} = q_s + q_l \tag{7}$$

q_s: The sensible heat component, estimated according to Kalogirous (2003).

$$q_s = m_a C_{pa}(T_{ai} - T_{ao}) \tag{8}$$

where: m_a: The mass flow rate of cold air (kg/s), C_{pa}: The specific heat of air in J/ kg °C.

$$m_a = MN_F/3600 \tag{9}$$

where: M: Mass of air (kg), N_F: The air infiltration rate for cover (1.25).

The latent heat (q_l) Evaporation and transpiration is removed as water vapor. It is possible to calculate sensible heat transfer by Aldrich and Bartok (1994) as:

$$q_l = E \times F \times Q_i = E \times F \times \tau \times I \times A_f \tag{10}$$

where: E: Evapotranspiration to internal solar radiation (assumed 0.5), F: Floor use factor (ratio of ground covered by plants to the total ground area, assumed 0.4), τ : Transmittance of greenhouse covering (assumed 85%), I: Total solar radiation outside the greenhouse on a horizontal surface (W/m^2), A_f: Floor area of the greenhouse (m^2).

2.2.2.5. Biomass-burning system efficiency. The biomass-burning system efficiency is calculated as the ratio of energy output (heat energy gained) to the input energy (net heating value of biomass) according to Covarrubias and Romero (2007).

Heat energy gained from biomass burning system: is the amount of heat energy absorbed by fluid that passes through the heat exchanger located in the unit (Q_{fluid}) estimated by Sipila et al. (2008).

$$Q_{fluid} = m_{fluid} C_p (T_o - T_i) \tag{11}$$

where: m_{fluid}: Mass flow rate of operating fluid (kg/s), C_P: Specific heat of fluid (J /kg °C), T_o: Temperature of outlet fluid (°C), T_i: Temperature of outlet fluid (°C).

The heat absorbed by the air that pushes inside the unit (Q_{air}) that determined by Vamvuka and Tsoutsos (2002) as:

$$Q_{air} = m_a C_{pa}(T_{ha} - T_{ca}) \tag{12}$$

where: m_a: Mass flow rate of air (kg/s), C_{pa}: Specific heat of air (J/kg.°C), T_{ha}: The outlet temperature of air (°C), T_{ca}: The inlet temperature of air (°C).

The net heating value of biomass is the heat energy gained from the biomass-burning system in addition to the heat energy losses from the biomass burning system.

2.2.2.6. Soil carbon sequestration. Soil samples were collected and prepared for chemical analysis. Soil Carbon Sequestration (SCS, g C/pot) was calculated by the following equation:

$$SCS = (C_{tre} - C_{bef}) \times DW \tag{13}$$

where: C_{tre}: The soil C content of the treatment after cultivation (g C/kg dry soil), C_{bef}: The initial soil C content at the start of the experiment (60.3 g C/kg dry soil) and *DW*: The dry soil weight (kg/pot).

2.2.2.7. Greenhouse crop productivity. Greenhouse crop productivity was measured in terms of total fresh yield and number of leaves per plant

3. Results

3.1. Results of the first experiment

Results of the first experiment clarified the effect of air fan operating periods on the greenhouse performance so as to select the suitable period inside the greenhouse during the second and the third experiments. During the first experiment, okra stalks as a source of energy for heating greenhouses and waste engine car oil as a heating fluid were used.

The obtained data of the first experiment were discussed in terms of the following greenhouse thermal indicators:

3.1.1. Temperature inside and outside the greenhouse

Air temperature is greatly affecting the growth rate and productivity of crops inside the greenhouse. From this point of view, controlling air temperature is of great importance to protect crops inside the greenhouse against outside climatic hazards. For that, a heating system was attached to the greenhouse to provide better-controlled environment inside it than outside. Changes in the inside air temperature and outside the greenhouse under different fan operating periods using okra stalks as a source of energy and waste engine car oil as a heating fluid are shown in Fig. 2 as average values during the plant growth period.

Results showed that the outside air temperature is always lower than the inside air temperature. The obtained data clarified that the outside air temperature ranged between 11.6 and 17 °C. whereas the inside air temperature varied from 17 to 23, from 19.8 to 27 and from 20.5 to 28.5 °C under fan operating periods of 10, 15 and 20 min/h, respectively. This means that maximum air temperature values inside the greenhouse were very close at the fan operating periods of 15 and 20 min/h. So, a suction fan at 15 min/h is recommended to reduce the required energy, and approximately achieve the same increase in air temperature inside the greenhouse of 20 min/h fan operating period in the winter season.

It can be noticed that fan operating period of 10 min gave the worst-case relating to air temperature inside the greenhouse not only because of its low value but also due to the non-uniformity of air distribution. While the vice versa was noticed with 15 min/h fan operating period, which gave a reasonable increase in air temperature with high uniformity of distribution. This is due to the increase of the hot air movement by the fan inside the greenhouse.

3.1.2. Relative humidity inside and outside the greenhouse

Relating to relative humidity inside and outside the greenhouse, results showed that the relative humidity inside the greenhouse was higher than the outside as illustrated in Fig. 3. The relative humidity outside the greenhouse ranged from 40.2 to 64.6 %, whereas the inside relative humidity varied from 74.4 to 80, from 69.2 to 82 and 73 to 80.5 %, under circulation fan operating periods of 10, 15 and 20 min/h, respectively.

From the results, it was found that relative humidity decreased by increasing air temperature inside the greenhouse and relative humidity value was lower when the temperature achieved the peak value.

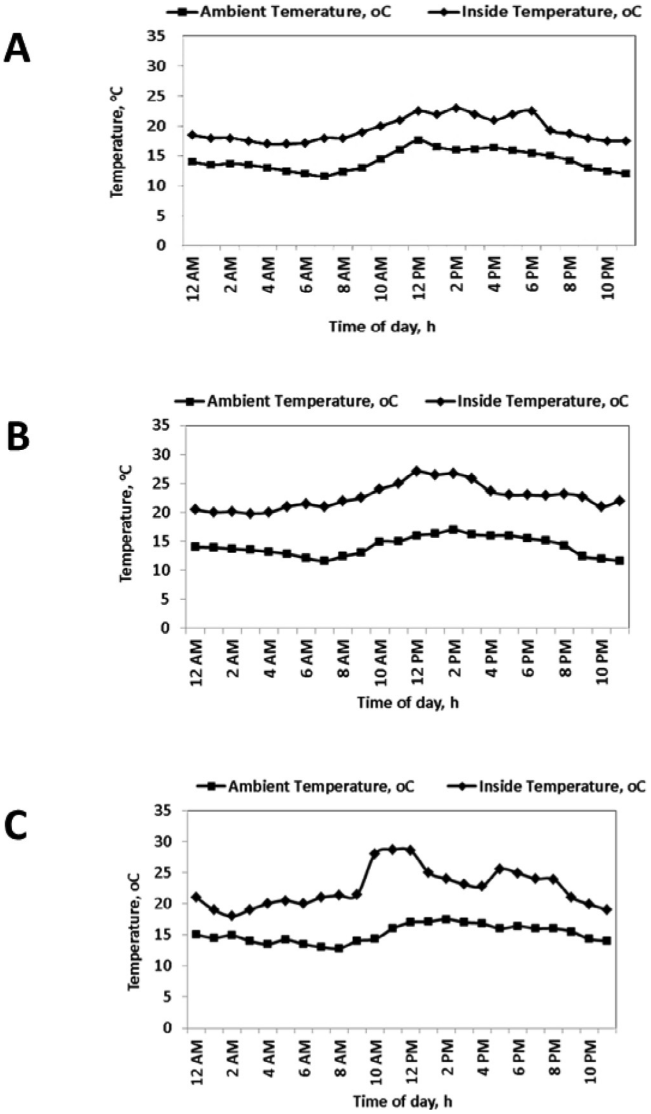


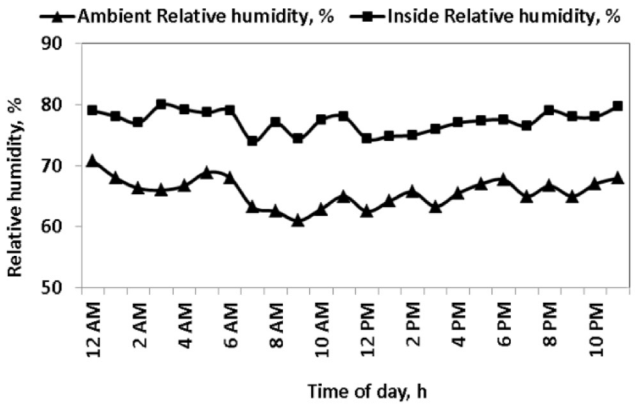
Fig. 2. Temperature variation inside and outside the greenhouse under different fan operating periods; Fan operating period of 10 min/h (A), Fan operating period of 15 min/h (B), Fan operating period of 20 min/h (C).

3.1.3. Vapor pressure deficit inside the greenhouse

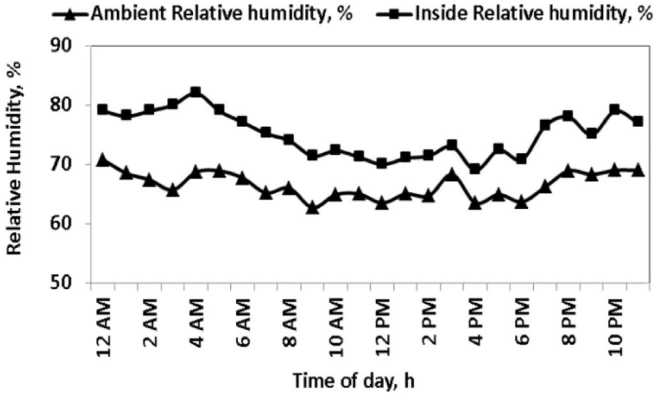
The hourly vapor pressure deficit (VPD) values inside the greenhouse are shown in Fig. 4. The results showed that the vapor pressure deficit increased with time of day and reached its maximum values as the inside air temperature increased and relative humidity decreased. The vapor pressure deficit values inside the greenhouse ranged from 0.43 to 0.67, from 0.4 to 0.65 and from 0.39 to 0.61 kPa under suction fan operating periods of 10, 15 and 20 min/h, respectively.

3.1.4. Heat energy losses from the greenhouse

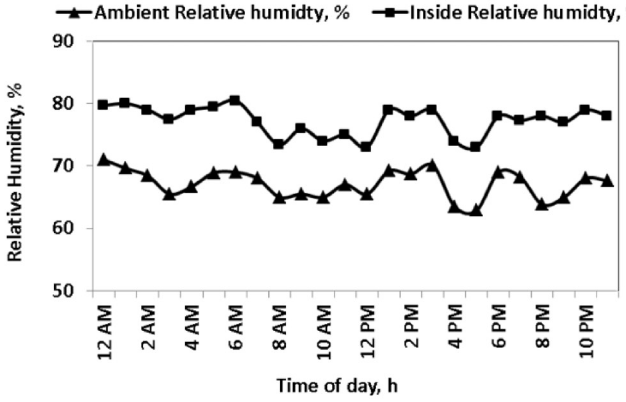
Fig. 5 showed the components of heat energy losses by conduction (Q_{cl}), heat energy losses (Q_{inf}) and total heat energy losses from the greenhouse (Q_t). Results show that the energy lost via conduction is much less than the heat lost by ventilation. The obtained data revealed that the maximum value of heat losses by conduction was 4.9 kW at 11p.m., while the minimum value was 1.9 kW at 10 a.m. This heat energy is lost because of the difference



a- Fan operating period of 10 min/h



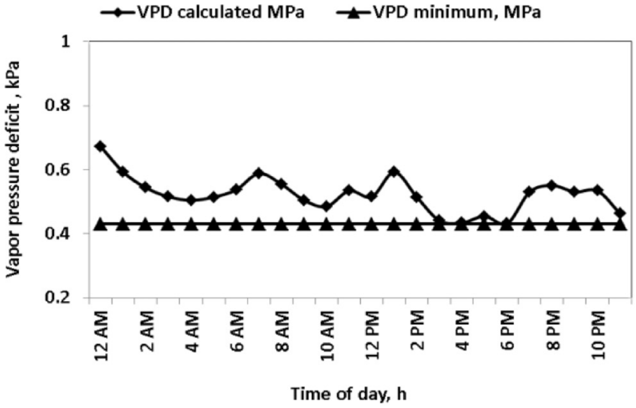
b- Fan operating period of 15 min/h



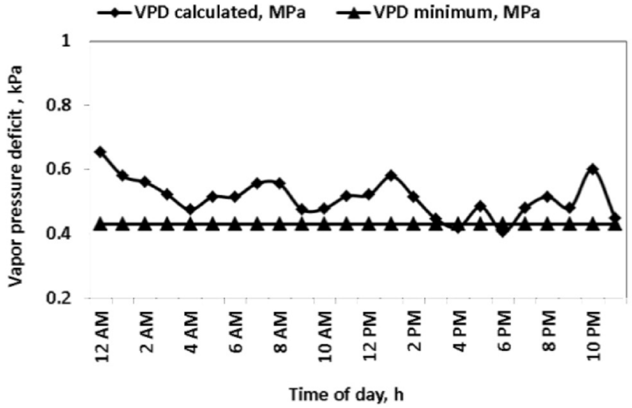
c- Fan operating period of 20 min/h

Fig. 3. Relative humidity variation inside and outside the greenhouse under different fan operating periods.

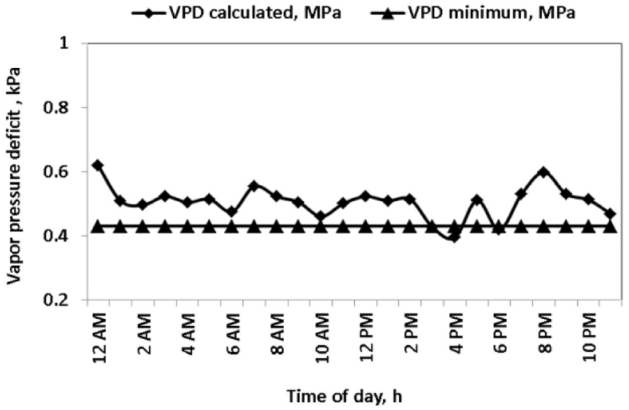
between the inside air temperature and outside temperature of the greenhouse. The maximum value of total heat losses from the greenhouse was 10.3 kW at 10p.m. when the inside and outside air temperatures were 22.7 °C and 14.4 °C, respectively.



a- Fan operating period of 10 min/h



b- Fan operating period of 15 min/h

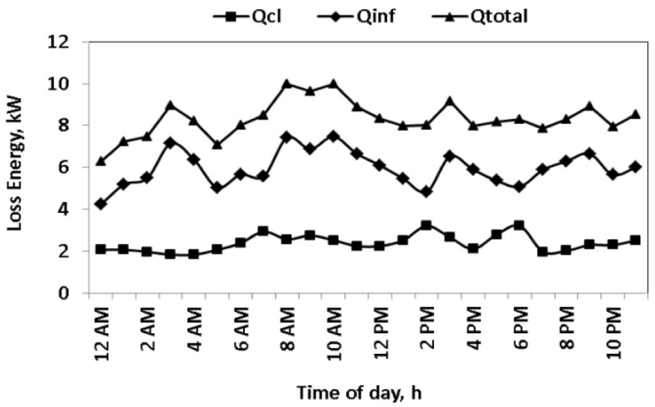


c- Fan operating period of 20 min/h

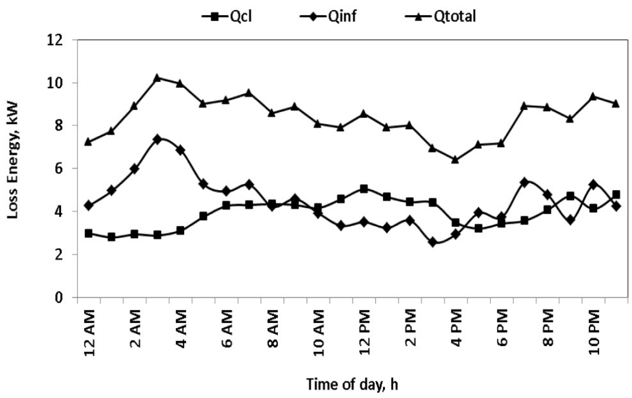
Fig. 4. Vapor pressure deficit under different fan operating periods.

3.2. Results of the second experiment

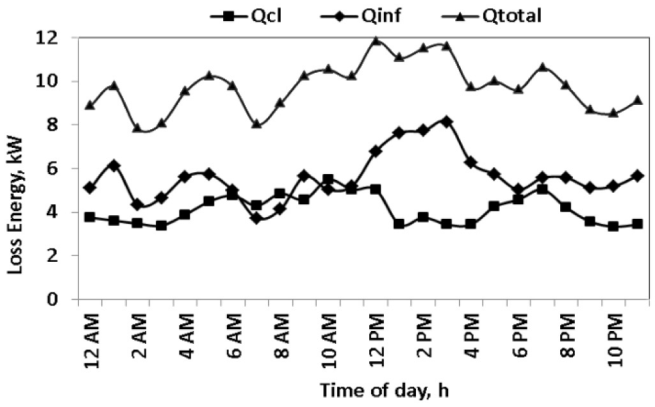
Based on the above greenhouse thermal performance from the first experiment, it was clear that running the suction fan through



a- Fan operating period of 10 min/h



b- Fan operating period of 15 min/h



c- Fan operating period of 20 min/h

Fig. 5. Heat energy losses from the greenhouse under different fan operating periods.

a period of 15 min/h provides sufficient conditions resulting in uniformity of air distribution inside the greenhouse. The second experiment is conducted to find out the suitable agricultural residues to be used as a source of energy side by side with the heating fluid that gave the highest system efficiency.

3.2.1. Biomass-burning system efficiency

Biomass-burning system efficiency versus different agricultural wastes and different heating fluids is shown in Fig. 6. The biomass-burning system efficiency decreased once the heat losses from the system increased. Heat losses from the biomass-burning system could be due to high moisture content in the used agricultural wastes, incomplete combustion, ash content and design of the biomass-burning system.

Relating to the effect of heating fluid on system efficiency, the same results showed that the biomass-burning system efficiency of waste engine car oil as a heating fluid was more than the efficiency of tap water as a heating fluid. The decrease in system efficiency with the use of water as a heating fluid is attributed to that the water evaporates easily and has very high latent heat for vaporization, which reducing efficiency. While the increase in system efficiency with the use of waste engine car oil as a heating fluid is due to the low specific heat of oil compared to water.

The biomass-burning efficiency values for cotton stalks, corn stalks and okra stalks were 73, 69 and 81 % with the use of waste engine car oil as heating fluid. These values were 65.5, 55 and 75 % with the use of tap water as a heating fluid under the same mentioned wastes, respectively. The maximum system efficiency was 81% % for orka stalks. This is due to the high heat energy gained that occurred during operating the burning system by orka stalks.

3.3. Results of the third experiment

Based on the two previous experiments, 15 min fan operating period with the use of okra stalks as a source of energy and waste engine car oil as a heating fluid gave the best greenhouse thermal performance in the winter season compared to the other treatments. In the third experiment, biochar was mixed with the potting media at a rate of 40 g/pot and compared to without addition to study the effects of adding biochar on productivity and CO_2 sequestration, trying to reduce greenhouse gas emissions that affect global temperature.

3.4. Greenhouse crop productivity

The results showed that existing of the biomass-burning system attached with the greenhouse with the benefit of adding biochar to the soil media enhanced the growth rate of summer squash crop where the total fresh yield of squash was 3.7 and 2.9 kg/pot, the total number of leaves per plant was 55 and 47 leaves under with and without biochar addition, respectively as clarified in Table 2.

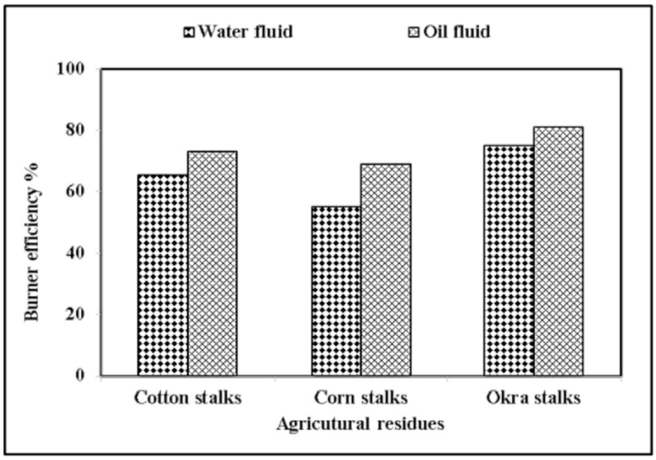


Fig. 6. Biomass-burning efficiency for different agricultural residues and heating fluids.

Biochar addition increased the crop yield by improving the physiochemical properties of soil according to Lehmann and Rondon (2006). In addition to fixing the carbon of residues as biochar, reduce the amount of carbon released to the atmosphere as recorded by Thakkar et al. (2016). Results indicated that the soil carbon (C) after cultivation increased with okra biochar (OC) addition. Soil Carbon Sequestration (SCS) values were 2.5 and 18.6 g C/pot for the control treatment (without biochar addition) and treated soil with biochar, respectively. The application of biochar is an effective way of promoting sequestration of soil carbon. Obtained results are in agreement with Koyama et al. (2016). So, it is recommended to add biochar (resulted from biomass burning) to the soil media for enhancing the soil fertility, crop yield and reducing CO_2 percentage.

4. Discussion

The development of renewable energy as a primary global resource of clean energy is one of the main objectives of energy policies worldwide, which, in the general framework of sustainable development. Agriculture is one of the most important sectors, which is characterized by the greatest potential for sustainable economic development (Odeim et al., 2015). Concerning the effect of agricultural wastes which combusted in the burning system on system efficiency, results revealed that the biomass-burning system efficiency for corn stalks was less than for cotton and okra stalks. This is due to its high moisture content in corn stalks that requires more heating energy to evaporate water. This result is compatible with Zhang et al. (2016) and.

The main goal of using greenhouse farming, as an agricultural management system, especially when provided with a heating system is to protect plants against climatic hazards and to promote the growth of crops by creating more favorable climatic conditions than the local climate or to produce "out-of-season.

The highest temperature value inside the greenhouse (recorded at 12p.m.) was 27.2 while the lowest temperature value (recorded at the last third of the night) was 17 under a fan operating period of 15 min/h. The acceptable temperatures inside the greenhouse at night were achieved because of the heat energy, which was added by the biomass-burning system during the daylight that consumed through the night (Lazaar et al. 2015; Ezzaeri et al., 2020).

Relative humidity has an opposite pattern from temperature. For most greenhouse crop varieties, a relative humidity range of between 60 and 90% was considered appropriate by ASABE (2015). This clarified the beneficial role of the attached biomass-burning system, which provides the optimum conditions of both temperature and relative humidity inside the greenhouse (Jamaludin et al. 2014). Additionally, the obtained results are in agreement with Hand (1988) who showed that between 0.3 and 1.0 kPa VPD, most greenhouse crops' growth and development is unaffected. It is important to know that when the air vapor pressure deficit is too low (VPD < 0.3 kPa), Water condenses on leaves and other components of the plant from the air. This can help fungal growth and diseases. While high VPD values (larger than 1.5 kPa), results in the rate of evaporation from the leaves can exceed the supply of water into the roots. This causes the stomata to be closed and, in addition to wilting, stunted plants and photosynthesis to slow or end. The obtained results revealed that existing of the biomass-burning system accompanied by 15 min/h suction fan operating period controlled the vapor pressure deficit to be in the safe region.

The results clarified that the highest amount of heat losses occurred in the first third of the night. This is because of increasing the temperature potential difference between the inside and outside air temperature of the greenhouse. This is in agreement with Sayigh (2001).

Table 2
Effect of okra biochar addition to the soil media on summer squash productivity

Treatment	Productivity, kg/pot	Total number of leaves per plant
Soil with biochar addition	3.7	55
Soil without adding biochar	2.9	47

5. Conclusion

The present study recommended the following: Utilizing biomass energy for heating greenhouses as it proved to be very promising method for better-controlled environment.

Providing the greenhouse with a biomass-burning system to control climatic conditions and enhancing crop production. Adjusting the fan operating period at 15 min/h to achieve a reasonable increase in air temperature with high uniformity of distribution inside the greenhouse. Using okra stalks as a source of energy for heating greenhouses because of their high thermal efficiency compared to the other agricultural wastes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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