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Effects of Different Heating Systems on Cucumber Yield in Greenhouses and Cost and Gas Volume Consumed in Varamin Region

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Abstract: This research was conducted to investigate the effects of three heating systems on cucumber yield, and cost and gas volume consumed in greenhouses located in Varamin region, Tehran province, Iran. Conventional heating systems used in the greenhouses are: central heating system (including boiler + hot water pipes), gas heater system (including double-walled tank + blower) and traditional furnace system (including ignition chamber + torch + pipes carrying a mixture of hot air and flammable gases). The study was carried out for two consecutive cucumber cultivation periods from January to June. Average values of crop yield, volume and cost of gas consumed were determined separately for each heating system. Results of the study indicated that the central heating system with the highest crop yield (295 t/ha), and the lowest volume (100,000 m^3/ha) and cost (840 USD/ha) of gas consumed was the best and most suitable heating system for greenhouses producing cucumbers in Varamin region and other regions with the same and similar climate as well as regions with active greenhouses in the cold season.

Key words: Greenhouse, heating systems, greenhouse cucumber, crop yield, gas consumed, Varamin, Iran.

1. Introduction

Greenhouse production, which was significantly expanded in recent years, requires more energy for the off-season production. The energy consumption in greenhouses accounts for almost one third of the production costs; thus, increasing the energy efficiency in greenhouse production is a priority for the researchers and the producers. The success in increasing the energy efficiency in greenhouse production provides an optimal use of valuable energy sources [1].

The advantages of controlled greenhouse cultivation conditions for the production of some vegetable crops (such as cucumber, tomato, eggplant and pepper) have made the study of optimal greenhouse management methods one of the priorities of the Fourth Iran Development Plan. Despite the benefits of greenhouse cultivation, high energy consumption in greenhouses, especially in the cold season, on one hand, and the elimination of subsidies for energy carriers, on the other hand, increase the cost of energy carriers, which reduces producer (greenhouse owner) income. If appropriate methods (such as selecting the suitable heating system) are not taken to increase energy efficiency in the greenhouse, only by increasing the price of the product, greenhouse cultivation of crops can be continued, which is not a scientific and economic solution [2].

According to one of the latest reports of the Statistics Center of Iran, in 2015, out of about 2.68 million hectares of gardens in the country (both fertile and infertile), about 8,000 ha, equivalent to 0.3%, are

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allocated to greenhouse crops, which is 100% fertile. Among them, the area under cultivation (of the total area of greenhouses) is 74.8% cucumbers, 7.4% tomatoes, 5.2% peppers, 1.7% eggplants, 4.3% vegetables, 3.8% strawberries, 0.5% medicinal plants and 2.3% other products. The highest cultivation area of greenhouse crops in the country belongs to Tehran province with 23.3%, Southern Kerman province with 19.1% and Yazd province with 17%. These three provinces together occupy 59.4% of the country's greenhouse area [2, 3].

The greenhouse production in 2015 was about 1.73 million tons, equivalent to 8.92% of 19.38 million tons' horticultural production. The share of cucumber production in 1.73 million tons of greenhouse production was 84.1%, followed by tomatoes (8.7%), peppers (3.1%), vegetables (1.9%), eggplant (1.1%), strawberries (0.8%), medicinal plants (0.2%) and other crops (0.1%). The highest greenhouse production in the country was carried out in Tehran province with 29.2%, followed by Yazd province with 22.1% and Kerman province with 17%. These provinces accounted up 68.3% of the total greenhouse production of Iran [2, 3].

According to the same statistics, Tehran province, with about 1,800 ha of greenhouses, which have been built mainly in Pakdasht, Varamin and Pishva counties, ranks the first in the country in terms of both size and development of greenhouses. The province also produces more than half a million tons of greenhouse products, ranking the first in the country in terms of greenhouse production. About 85% of the total area of greenhouses in Tehran province is allocated to greenhouse cucumber, about 10% to tomatoes and about 5% to peppers, eggplants, vegetables, strawberries, medicinal plants and other products [2].

De Cock and Van Lierde [4] analyzed energy consumption in Belgian greenhouses. They found that the amount of fuel consumed per square meter of greenhouse is more affected by the price of fuel and the temperature of the air outside the greenhouse. According to Dalgaard [5], agriculture seeks to develop methods of production that increase crop yields while reducing consumption of energy and fossil fuels. In this regard, Saye *et al*. [6] conducted a study to reduce the consumption of fossil fuels to zero. They studied a combination of greenhouses with a combination of low consumption, recycling and energy storage, and recommended the use of new building materials and the use of dehumidifiers and heat pumps.

In contrast to the conventional agriculture, which does not pay attention to energy consumption and only aims to increase crop yield, modern agricultural aims to promote the efficiency in energy consumption while increasing the crop yield. In addition, the modern agriculture seeks to conserve the natural resources for future generations by adapting the most favorable and sustainable use of energy resources and reducing the environmental impacts of inappropriate energy consumption [7].

Sherafati [8] studied energy efficiency indices of cucumber production in greenhouses in Tehran province and found that the total energy consumption for the production of greenhouse cucumber in Tehran province is equal to 6,612,592 MJ/ha, and 97.7% of this amount has been spent on heating greenhouses. Also, Mohammadi and Omid [9] in economic analysis and study of energy consumption and calculation of productivity in 43 greenhouses for greenhouse cucumber production in Tehran province, estimated energy consumption of 148,836.76 MJ/ha that diesel fuel (heating) consumption with 41.94% (62,422.14 MJ/ha) and chemical fertilizer with 19.69% (29,305.96 MJ/ha) had the highest share. Moreover, Taki *et al.* [10] in the analysis of energy efficiency in the production of greenhouse cucumber in Shahreza city in Isfahan province, found that fuel (heating) with 47% and water (irrigation) with 1.2% had the highest and lowest energy consumption, respectively.

Agha-Alikhani *et al*. [11] in comparing the type and amount of energy inputs and determining energy

efficiency in tomato production greenhouses in Hamadan province and Jiroft region showed that the total energy consumption for the production of greenhouse tomatoes in Hamadan province and Jiroft region was equal to 133,896 MJ/ha and 145,957 MJ/ha, respectively. The highest energy consumption among tomato production inputs in the two regions was related to fossil fuels (heating) and chemical fertilizers, respectively.

Rostami *et al.* [12] in their research by preparing a questionnaire and completing it through face-to-face interviews with local farmers studied energy indices for the production of non-greenhouse cucumber in Borujen city. The results of their research showed that the total amount of energy consumed in the production of non-greenhouse cucumber is 290.7 GJ/ha, which irrigation operations with 83.56% of the total energy consumption had the highest energy consumption.

The results of a study [13] compiled the data of 25 greenhouse units in Qazvin province indicated that the highest energy consumption in cucumber production was fuel (64,981 MJ/ha), followed by electricity (23,841 MJ/ha). Likewise, Momeni [1] in his research to evaluate the energy consumption indices of greenhouse cucumber production in the south of Kerman province, by preparing a questionnaire and completing it by referring to 30 greenhouses in six southern cities of Kerman province showed that the energy consumption for the production of greenhouse cucumber in the south of Kerman province is equal to 2,057,973 MJ/ha, of which 1,751,829 MJ/ha, i.e., 85.1% has been spent on greenhouse heating.

This research was conducted to study and compare the effects of different heating systems on cucumber yield in greenhouses and cost and gas volume consumed in Varamin region.

2. Materials and Methods

2.1 Heating Systems

The energy consumptions of three different conventional heating systems in greenhouse cucumber production were studied during two production seasons (from January to June 2018 and 2019) in Varamin region, Tehran province, Iran. The heating systems were central heating system contained boiler + hot water pipes (Fig. 1), gas heater system contained double-walled tank + blower (Fig. 2), and traditional furnace system contained ignition chamber + torch + pipes carrying a mixture of hot air and flammable gases (Fig. 3).

Fig. 1 Greenhouse with central heating system.

Fig. 2 Greenhouse with gas heater system.

Fig. 3 Greenhouse with traditional furnace system.

2.2 Research Method

Three metal greenhouse units produce greenhouse cucumber in Varamin region, Tehran province, Iran, which were approximately the same in terms of location, hall design, area, volume of greenhouse space and other parameters affecting heating energy consumption, but had three different types of conventional heating systems in the region that were selected. Average values of crop yield, volume and cost of gas consumed corresponding to each of these three heating systems during two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June) were separately determined, and by comparing the obtained results, the most efficient heating system was introduced.

2.3 Greenhouses

In addition to the location of greenhouses, the design, size, volume of greenhouse space and other parameters affecting energy consumption including structure, type

of cover, length, width of span, column height, height of greenhouses and other specifications of the greenhouses were also the same. The only difference between the greenhouses was the heating systems used. The specifications of greenhouses used in the study were shown in Table 1.

2.4 Measuring Crop Yield

To determine the yield of product (greenhouse cucumber), the necessary information was directly measured and the crop yield was determined.

2.5 Natural Gas Consumption Measurement

The fuel consumed in all heating systems is the natural gas. Necessary information to measure the gas consumption in each heating system was collected by a separate gas meter related to that greenhouse unit. It is worth mentioning that due to the considerable amount of gas consumed in the greenhouses of the region in the cold season, all gas meters, in addition to having a special seal, are located in the gas station of the complex, in such a way that only the reading officer of the National Gas Company has the opportunity to access the gas meters and record the relevant numbers and data. This issue, in addition to reassuring the National Gas Company of accurate calculation of the cost of gas consumed by customers (greenhouse owners), creates an important advantage that the recorded data related to the gas consumed of each heating system have the necessary accuracy and sufficient reliability to conduct this research.

2.6 Statistical Analysis

Due to the fact that the research project was similar to the mechanization index determination projects in terms of structure and did not have any treatment, it did not need a statistical design, analysis of variance, and comparison of means, and finally after determining the average values of crop yield, volume and cost of gas consumed corresponding to each of three heating systems, they had been compared and evaluated, and the most suitable heating system for greenhouses producing greenhouse cucumber and similar products (tomato, eggplant and pepper) in Varamin region and other regions with the same or similar climate, and also regions with active greenhouses in the cold season were introduced.

3. Results and Discussion

3.1 Crop Yield

Average crop yields in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June 2018 and 2019) under the influence of three conventional heating systems in greenhouses producing greenhouse cucumber in Varamin region, namely central heating system, gas heater system and traditional furnace system are shown in Table 2 and Fig. 4.

The highest cucumber yield (295 t/ha) was recorded in the greenhouse equipped with a central heating system, followed by the greenhouse equipped with a

Table 1 The specifications of all three greenhouse units used in this research.

Specifications	Description/Amount
Type of greenhouses	Metal units
Structure material	Galvanized steel
Type of cover	Plastic film
Length (m)	45.5
Width (m)	22.0
Height of columns (m)	3.0
Height of greenhouse (m)	4.7

Table 2 Mean values of crop yield, and volume and cost of gas consumed in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June) under the influence of three conventional heating systems in the greenhouses of Varamin region.

Heating system	Crop yield (t/ha)	Volume of gas consumed (1,000 m^3/ha)	Cost of gas consumed (USD/ha)
Central heating system	295	100	840
Gas heater system	274	409	1,800
Traditional furnace system	251	500	2,200

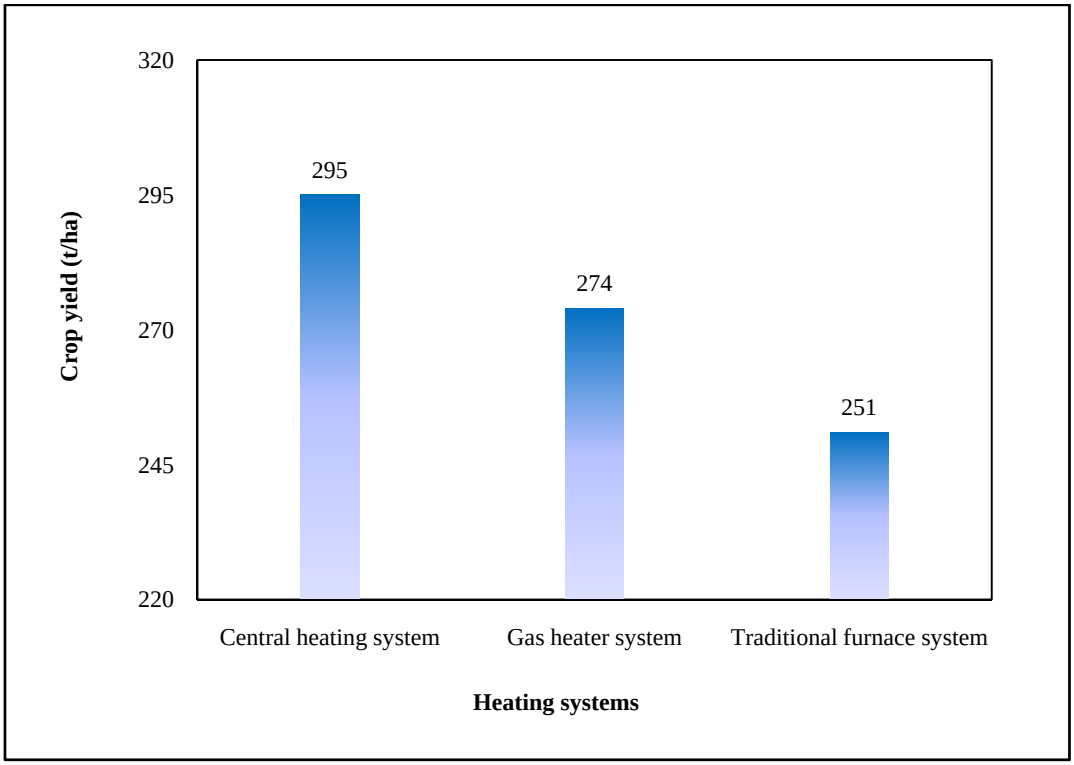

Fig. 4 Crop yield (mean values) in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June) under the influence of three conventional heating systems in the greenhouses of Varamin region.

gas heater system (274 t/ha) and the greenhouse with a traditional furnace system (251 t/ha).

Carefully in the results of crop yield, it can be seen that the use of central heating system in comparison with gas heater system, increases crop yield by 21 t/ha or 7.7% increase in crop yield, and the use of central heating system in comparison with traditional furnace system, increases crop yield by 44 t/ha or 17.5% increase in crop yield. In this regard, the use of gas heater system in comparison with traditional furnace system, increases crop yield by 23 t/ha or 9.2% increase in crop yield.

3.2 The Volume of Natural Gas Consumed in Greenhouse

Average volume of gas consumed in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June 2018 and 2019) under the influence of three conventional heating systems in greenhouses producing greenhouse cucumber in Varamin region, namely central heating system, gas heater system and traditional furnace system are shown in Table 2 and Fig. 5.

The lowest mean gas consumption was 100,000 m^3/ha recorded in the greenhouse equipped with a central heating system, while the highest mean gas consumption was 500,000 m^3/ha recorded in the greenhouse with a traditional furnace system. The mean gas consumption of the greenhouse equipped with a gas heater system was 409,000 m^3/ha.

Carefully in the results of volume of gas consumed, it can be seen that the use of central heating system in comparison with gas heater system, reduces the volume of gas consumed by 309,000 m^3/ha or 75.6% reduction in the volume of gas consumed and the use of central heating system in comparison with traditional furnace system, reduces the volume of gas consumed by 400,000 m^3/ha or 80% reduction in the volume of gas consumed. In this case, the use of gas heater system in comparison with traditional furnace system reduces the volume of gas consumed by 91,000 m^3/ha or 18.2% reduction in the volume of gas consumed.

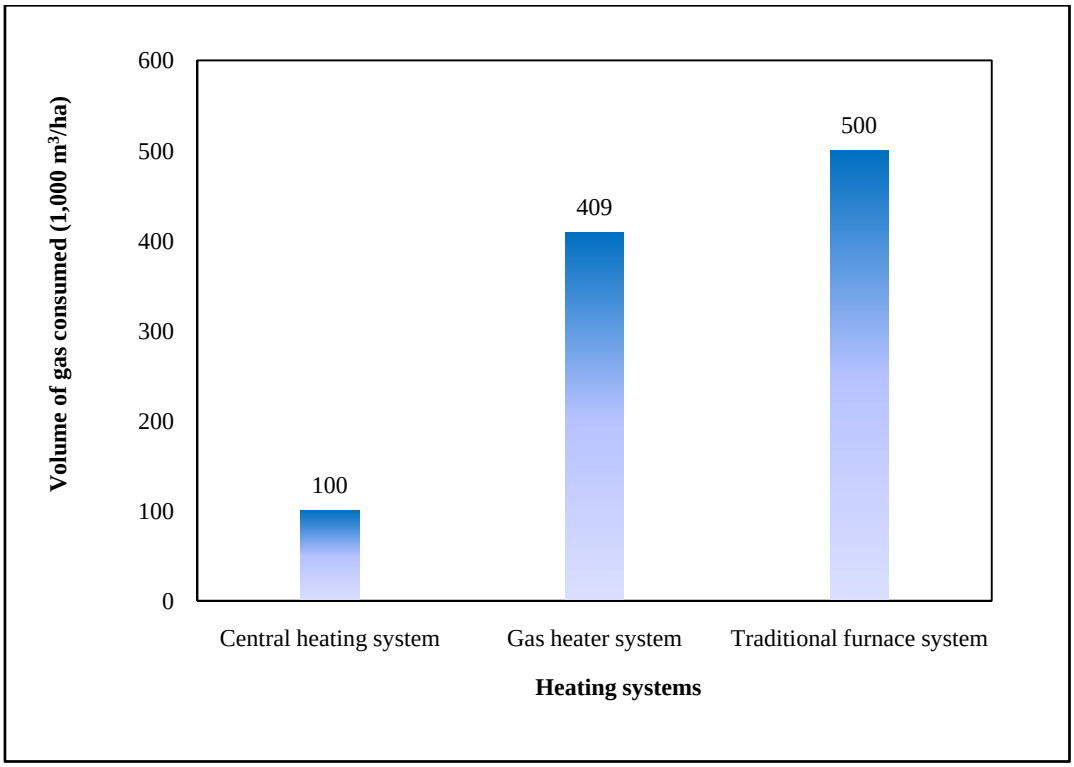

Fig. 5 Volume of gas consumed (mean values) in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June) under the influence of three conventional heating systems in the greenhouses of Varamin region.

3.3 The Cost of Natural Gas Consumed in Greenhouse

Average costs of natural gas consumed in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June 2018 and 2019) under the influence of three conventional heating systems in greenhouses producing greenhouse cucumber in Varamin region, namely central heating system, gas heater system and traditional furnace system are shown in Table 2 and Fig. 6.

The lowest mean gas cost (840 USD/ha) was in the greenhouse equipped with a central heating system and the highest mean gas cost (2,200 USD/ha) was in the greenhouse with a traditional furnace system. The mean gas cost of the greenhouse equipped with a gas heater system was 1,800 USD/ha that was very close to the greenhouse with a traditional furnace system.

Carefully in the results of cost of gas consumed, it can be seen that the use of central heating system in comparison with gas heater system reduces the cost of gas consumed by 960 USD/ha or 53.3% reduction in the cost of gas consumed and the use of central heating system in comparison with traditional furnace system, reduces the cost of gas consumed by 1,360 USD/ha or 61.8% reduction in the cost of gas consumed. In this regard, the use of gas heater system in comparison with traditional furnace system reduces the cost of gas consumed by 400 USD/ha or 18.2% reduction in the cost of gas consumed.

The results of crop yield, volume and cost of gas consumption in three greenhouses equipped with a central heating system, a gas heater system and a traditional furnace system confirm the findings of Dalgaard [5] who stated that agricultural production methods should increase crop yield while reducing

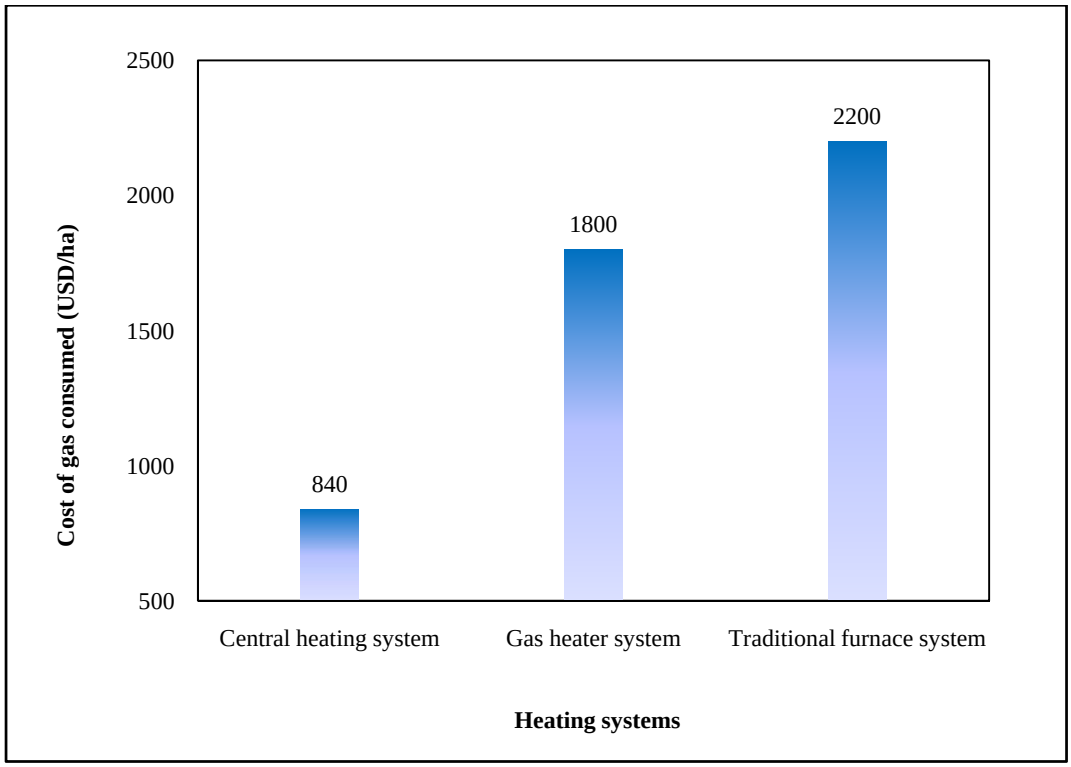

Fig. 6 Cost of gas consumed (mean values) in two consecutive periods of greenhouse cucumber cultivation in the cold season (from January to June) under the influence of three conventional heating systems in the greenhouses of Varamin region.

energy consumption. These results are also in line with Rezadoust [7] who stated that increasing crop yield regardless of energy consumption method has been outdated and the amount of production and crop yield can be measured based on energy efficiency and the most important goal and principles of modern agriculture are the optimal and sustainable use of energy resources in order to preserve these resources for future generations and reduce the environmental effects of excessive and inappropriate energy consumption.

4. Conclusions

It can be concluded that the central heating system with the highest crop yield (295 t/ha), and the lowest volume (100,000 m^3/ha) and cost (840 USD/ha) of gas consumed was the best and most suitable heating system.

5. Recommendations

(1) Issuance of construction and/or operation license for greenhouse units equipped with central heating system or newer and more advanced heating systems;

(2) Legal coercion of greenhouse units with traditional, old and inefficient heating systems to equip and use central heating system or newer and more advanced heating systems in the shortest possible time;

(3) Supportive policies such as tax exemptions and/or granting low-interest and interest-free banking facilities to encourage greenhouse owners to equip their greenhouse units with central heating systems or newer and more advanced heating systems;

(4) Incentive policies such as calculating the cost of gas consumed with special discounts for low-consumption subscribers, i.e., greenhouses equipped with efficient heating systems;

(5) Punitive policies such as calculating the cost of gas consumed with special penalties and progressive increase for high-consumption subscribers, i.e., greenhouses with inefficient heating systems.

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