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The Feasibility of Underground Greenhouses Construction as an Action to Reduce Climate Change Impacts

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Abstract

The greenhouses, as a controlled area, are of special importance for the cultivation of horticultural products, and the use of this system is inevitable in many regions. One of the problems that threaten greenhouse production in recent years in many regions, especially in the colder climates, is the increase in fuel and electricity consumption, and the frequent replacement costs of the greenhouse covering. As a result, this study investigates the effectiveness of underground greenhouses as a basic method for mitigating and adapting climate change impacts in the Arak city climate. To perform this experiment, three greenhouse units were built at 0 meters below the ground level (SG1), 1.5 meters below the ground level (SG2) and 2.5 meters below the ground level (SG3). Then, for the cultivation of the crop, each greenhouse was divided into four parts (blocks or duplicates), and the cultivation of scaffolding cucumbers was carried out with a density of two plants per square meter. The growing operation was performed in the same way for all three greenhouses. Environmental factors, including temperature, relative humidity, and brightness were recorded at canopy height. The results revealed that the differences in temperature, relative humidity and radiation intensity in all three greenhouses were significant. Although, in the underground greenhouses there is more temperature stability and more relative humidity, the intensity of radiation is less. Also, the results of comparing the crop yield in the two seasons showed that the yield difference between SG1 and SG3 greenhouses was significant. However with SG2 greenhouse was not significant. The results showed 5 and 6.5 percent reduction in electricity and gas energy consumption in SG2 greenhouse, respectively. Also, results indicated 13.3 and 14.5 percent reduction in electricity and gas energy consumption in SG3 greenhouse, respectively. These figures indicate that 8.3 and 8 percent of electricity and gas energy are saved per depth of underground greenhouses. Therefore, using underground greenhouses for agricultural production, will reduce the pressure on the water-food-energy nexus and help in climate change mitigation.

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Introduction

The greenhouses, as a controlled area, are of special importance for the cultivation of horticultural products, and the use of this system is inevitable in many regions. On the other hand, the production and cultivation of greenhouse products, including the selection and construction of various types of greenhouse structures and crop production management, is one of the most specialized horticultural subgroups that require the use of knowledge and expertise in different fields.

Commercial production of greenhouse crops first began in Europe in the early years of the twentieth century, and expanded after World War II (Paradossi et al., 2004). With the invention of the greenhouse type and the use of tools and devices for the production and injection of carbon dioxide in the 1960s, many changes took place in this industry. Construction of greenhouses for off-season fruit and vegetable production, as well as ornamental plants, began in the United States and other European countries in the 17th century and has expanded in recent decades due to its unique features around the world (Goodarzi, 2020). Barzegar and Allahyari (2005), showed that standards for structural direction, heating system, cooling system, type of greenhouse cover, ventilation system, and type of structure could play an important role in the developmental or deterrent of greenhouse units. According to Hassani (2010), the main problems with greenhouse development in East Mazandaran, were the small number, small area, and the use of unfavorable ventilation, heating, and cooling systems. Tuzel and Leonardi (2009) in a study examined the problems of this industry in 17 Mediterranean countries. They studied greenhouses in terms of type, type of cover, type of production, technology and strategy. Momeni (2008) studied the effect of greenhouse height on energy consumption and cucumber yield in the Jiroft region, Iran. In the mentioned study, three greenhouses with the same length and width and diffrent height of 3.5, 4 and 4.5 meters, were examined. Their findings showed that, all three greenhouse units, were warmer than the ambient air outside. As a result, their relative humidity is lower than the outside environment. Also, despite the difference in temperature inside the greenhouses, there was no significant difference between the crop yield, number of fruits and number of spraying times. Their findings showed that increasing the height of the greenhouse makes the greenhouse more effective in controlling the effects of the surrounding environment. Basically, the purpose of constructing a greenhouse is to create a volume and space that are separated from the outside space by a cover so that it can control temperature, humidity, light, and other factors. Additionally, it protects plants from frost, windand snow. Therefore, the greenhouse structure must have minimum properties to withstand these factors (Momeni, 2008). In addition, one of the problems threatening greenhouse production in recent years, especially in the cold climates, is the increase in fuel and electricity costs. This is caused by frequent replacement of the cover due to wind damage. Therefore, it is necessary to study different ways to reduce fuel consumption and protect greenhouses from weather conditions. The cost of replacing the cover will be very high, which is besides the expected cost of reducing fuel consumption (Juaristi, 2013).One of the possible ways to reduce fuel costs and increase the stability of greenhouses is to use greenhouses below ground level. Few studies have been done on underground greenhouses around the world. Yaristi (2013), in a study at the University of Queretaro, Mexico, examined the use of thermal curtains and semi-buried greenhouses as an option for inactive control of climatic variables. This study concluded that semi-burying greenhouses and thermal curtains affect the variables studied, so that their combination can be a good option to keep the greenhouse temperature stable. Angmo et al. (2019), evaluated passive solar greenhouse for round the year vegetable cultivation in the trans-himalayan Ladakh region, India. Passive solar greenhouse structures such as Ladakhi greenhouse, trench, polytrench, polyench, polycarbonate, FRP and polynet have been designed and tested in the inhospitable environment of the trans–Himalaya. The results indicated that these greenhouses have some advantages. However, there is a need to improvise the greenhouse design to make it economically viable and technologically feasible to grow a variety of crops, especially during the winter months.

The increase in the consumption of fossil fuels by humans, especially after the industrial revolution, has caused an increase in the emission of greenhouse gases. This has caused climate change, global warming, shifting of seasons and aggravation of drought in the world, including Iran. This situation has not only caused the destruction of the environment, but has also made life more difficult for humans, while it is possible to reduce the effects of climate change by adopting solutions (Kolstad et al., 2014; Shukla et al., 2022). Climate change mitigation policies include the elimination of fossil fuels with a tendency towards "low carbon energy sources" such as renewable and nuclear energy, efficient use of energy, divestment from fossil fuels, subsidies for clean energy and so on (Eslamian et al., 2011; Kolstad et al., 2014; Shukla et al., 2022).

Considering the above discussion, the current study aims to investigate the effictiveness of underground greenhouses as a solution of reducing energy consumption and mitigating climate change impacts, creating a safer greenhouse structure, reducing the cost of construction and better management of greenhouses in the climate of Arak city in Iran.

Materials and Methods

Study Area

The Arak plain, located in Markazi province, Iran, is located at 49° 41´ E and 34° 05´ N. The mountains around Arak, the Miqan wetland and the Farahan plain have affected the climate of this region and have given it special features (Goodarzi, 2020). The western clouds and fronts lose most of their moisture in the fall and winter in the mountains of the western part of the region, and in winter the cold front occupies the Arak weather, which stays in the region for a long time due to the surrounding heights and the pressure of the Miqan wetland (Goodarzi, 2020). The duration of frost days varies from 65 to 120 days in different years. The climate of the Arak region based on the De Martonne and Amberger methods, is semi-arid and cold semi-arid, respectively. Also, the average annual rainfall is estimated about 307 mm, the average annual potential evaptranspiration 2035 mm and its average altitude is 1700 meters above sea level (Goodarzi, 2020).

In order to study the effect of greenhouse level on its microclimate, greenhouse durability, and crop yield, three greenhouse units with dimensions of 25×9 meters, were built at the Arak agricultural research station located in the Markazi Agricultural and Natural Resources Research and Education center, Arak, Iran. One unit of these greenhouses was constructed at the ground level surface (SG2), and the other two units at a depth of 1.5 meters from the ground surface (SG2), and 2.5 meters from the ground surface (SG3). For this purpose, after digging the ground and making the bed of the greenhouses to the desired depth, creating the necessary infrastructure along with the implementation of the foundation and leveling the floor, to further strengthen the greenhouses, earth walls to the ground level became stronger with building materials (brick and cement). Figure (2) shows the different stages of greenhouse construction. An anti-UV 8 polyethylene layer of 180 microns was applied to the greenhouses to protect them from UV rays. The aerial image of the location of the greenhouses is shown in Figure (1).

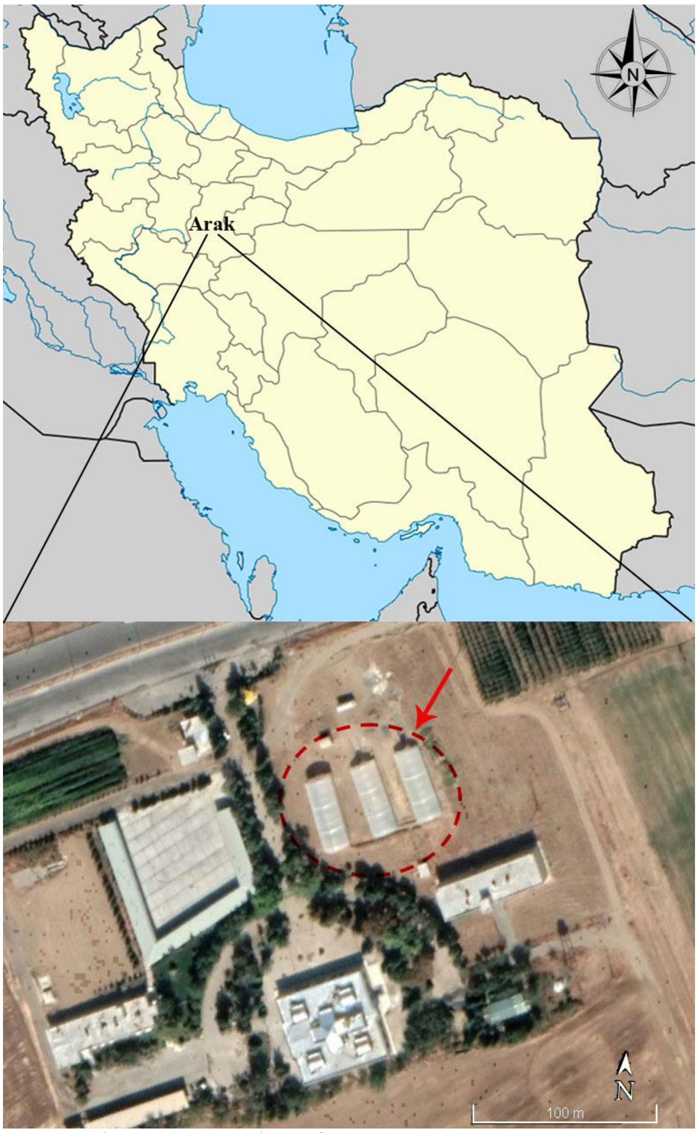

Figure 1. Location of the constructed greenhouses

After the construction of the greenhouses, three gas heaters were used to heat the greenhouses. During the cultivation experiment, each greenhouse was divided into four parts (blocks or duplicates) and scaffolding cucumbers were planted at two per square meter. The irrigation was done using the drip irrigation system for all three greenhouse units equally. Other cultivation operations were performed in the same way for all three greenhouses Environmental factors, including temperature, relative humidity, and light intensity were recorded in the greenhouse and at canopy height. The temperature outside the greenhouse was also recorded based on meteorological data from the weather station. Three digital data loggers were used to capture temperature, humidity, light intensity and radiation data. Furthermore, the energy consumption of the heaters was measured by three gas flow meters. The experiment was performed in the form of complete random blocks, and statistical comparison was implemented. Summer and winter cultivation was done after preparing the cultivation bed and installing sensors in all three greenhouses. Measured yield traits, including fruit number per plant, plant height, and fruit weights were compared using Duncan's test and compared with SPSS software.

Figure 2. Different stages of greenhouse construction

Results and Discussion

Statistical analysis for the mean values of temperature, relative humidity and light intensity in the greenhouses for two growing seasons is presented in table (1). As can be seen, the differences in temperature, relative humidity, and light intensity in the greenhouses are significant at a probability level of 1%. Accordingly, the average temperature difference between the SG1 and SG2 greenhouses, is about 1.1 degrees Celsius, and between the SG1 and SG3 greenhouses, is about 3 degrees Celsius. The difference in relative humidity between the SG1 and SG2 greenhouses is about 10.5% on average, and between the SG1 and SG3 greenhouses, is about 15.5%. Moreover, the difference in radiation intensity between the SG1 and SG2 greenhouses, is about 67 Lux on average, and between the SG1 and SG3 greenhouses, is about 148 Lux.

Figure (3)shows the trend of temperature changes recorded by the data logger in the three greenhouses. As can be seen, the range of temperature changes during the day and night in the SG3 greenhouse is less than in the SG2 and SG1 greenhouses. So that the maximum temperature difference in the SG1 and SG3 greenhouses, is about 12 degrees Celsius, and in the SG1 and SG2 greenhouses, is about 5 degrees Celsius. Furthermore, Figure (4) shows the trend of moisture changes recorded by the data logger in the three greenhouses. This trend indicates the lower relative humidity in the SG1 and SG2 greenhouses. In general, these conditions, while providing better conditions for plant growth, reduce the energy costs required for the cooling and ventilation system in the greenhouse.

Table 1. Comparison of temperature changes, relative humidity and light intensity in different greenhouses

parameter	Greenhouse Type		
	SG1	SG2	SG3
Temperature (^{0}C)	33.36^a	32.27^b	30.41^c
F value		98.2	
Sig.		0.00**	
Relative Humidity (%)	18.81^a	29.38^b	34.33^c
F value		373.5	
Sig.		0.00**	
Light Intensity (Lux)	682.9^a	615.6^b	534.5^c
F value		104.4	
Sig.		0.00**	

ns, * and **: no significant difference, significant at 5% probability level and significant at 1% probability level, respectively.
a, b and c: Classification of treatments based on comparison of means with Duncan's method (common letters have no significant differences)

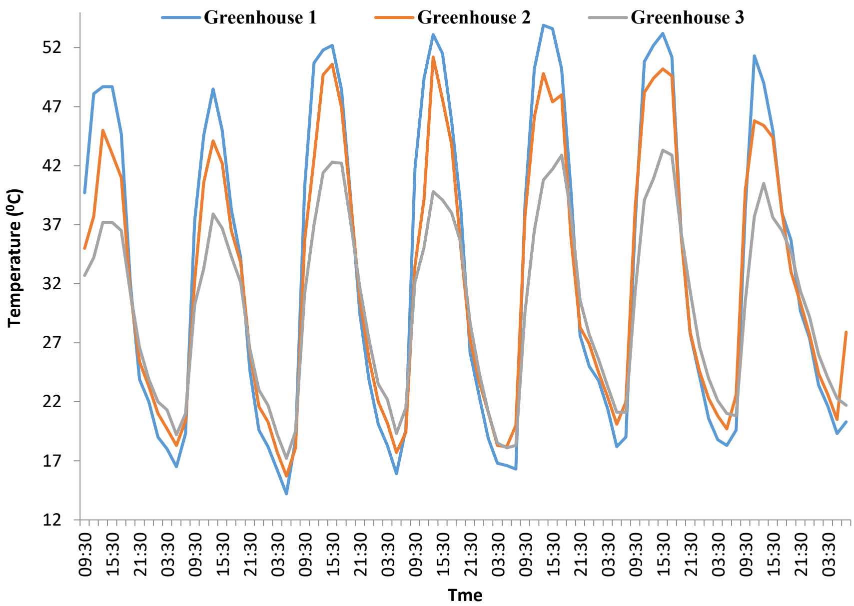

Figure 3. The temperature changes in the studied greenhouses

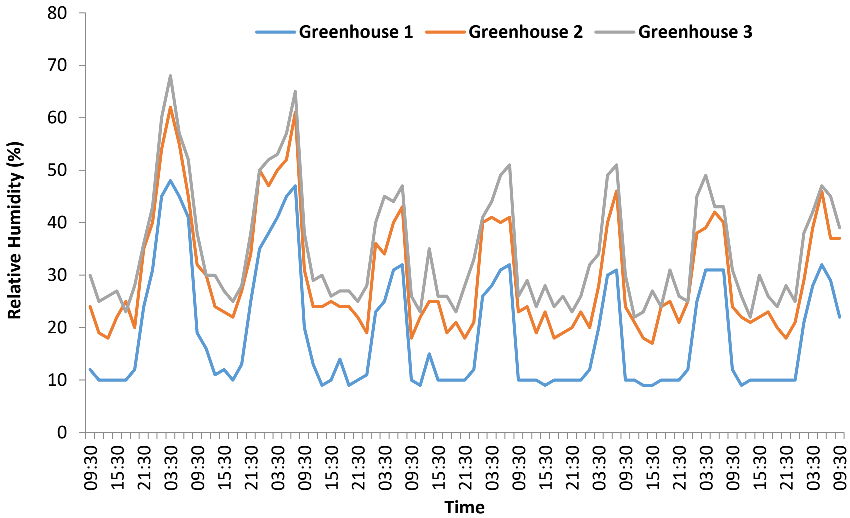

Figure 4. The relative humidity changes in the studied greenhouses

Figure (5) shows the changes in the light intensity measured during the day and night in the three studied greenhouses. This figure shows that the light intensity in the SG2 and SG3 greenhouses is lower than the SG1 greenhouse.

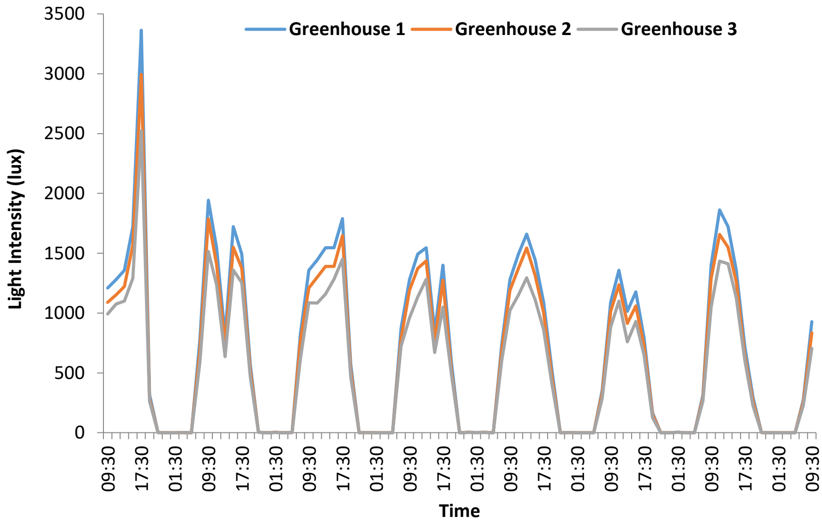

Figure 5. The light intensity changes in the studied greenhouses

Table (2) presents the results of the analysis of variance in summer and winter cultivation. Based on the results, it was found that the difference in crop yield in the three greenhouses in both growing seasons is significant. However, the difference in the yield in the SG1 and SG2 greenhouses, is not significant. Based on the results of Duncan's test, the yield in the SG1 and SG2 greenhouses, is in the same class. The difference in the number of fruits per plant in three greenhouses in both growing seasons was significant. However, the difference between the number of fruits per plant in the SG1 and SG2 greenhouses, was not significant. Based on the results of Duncan's test, the number of fruits per plant in the SG1 and SG2 greenhouses, is in one category. The results also showed that the difference in plant height in three greenhouses in both growing seasons was not noticeable.

Table (3) presents the results of the statistical comparison of energy consumption in the studied greenhouses. As can be seen, the difference in energy consumption between the three greenhouses was significant at the 1% probability level. According to the results, in the winter, on average the gas energy consumption in the SG2 greenhouse is about 6.5 percent less than the SG1 greenhouse. In addition, the SG3 greenhouse consumed around 14.5% less gas energy than the SG1 greenhouse. Therefore, the gas energy saved per depth of underground greenhouses was about 8 percent. Also, in the summer, the SG2 greenhouse's electricity consumption was about 5 percent lower than the SG1 greenhouse's. Furthermore, SG3's electricity consumption is 13.3 percent lower than SG1's. Consequently, electricity energy saved per depth of underground greenhouses was about 8.3 percent.

Food and energy production are highly water intensive actions. Therefore, using underground greenhouses for agricultural production will reduce the pressure on the water-food-energy nexus and help in climate change mitigation. Hence, there needs to be much more support for the development of less water-intensive renewable energy, such as using underground greenhouses, which has great potential as a long-term,

Table 2. Comparison of yield, number of fruits per plant and height of cucumber plant in different greenhouses

Growing Season	Parameter	Greenhouse Type		
		SG1	SG2	SG3
Summer	Single plant yield in each harvest (gr)	79.75[a]	78.25[a]	69.45[b]
	F value		5.825	
	Sig.		0.039*	
Winter	Single plant yield in each harvest (gr)	77.15[a]	76.57[a]	64.12[b]
	F value		10.82	
	Sig.		0.01*	
Summer	Number of fruits per plant per harvest	1.10[a]	0.91[a]	0.81[b]
	F value		11.19	
	Sig.		0.009**	
Winter	Number of fruits per plant per harvest	1.01[a]	0.95[a]	0.79[b]
	F value		15.55	
	Sig.		0.004**	
Summer	Plant height (cm)	140[a]	134[a]	139[a]
	F value		0.769	
	Sig.		0.504[ns]	
Winter	Plant height (cm)	138[a]	130[a]	135[a]
	F value		1.474	
	Sig.		0.302[ns]	

ns, * and **: no significant difference, significant at 5% probability level and significant at 1% probability level, respectively
a, b and c: Classification of treatments based on comparison of means with Duncan's method (common letters have no significant differences)

Table 3. Comparison of energy consumption changes in different greenhouses

Parameter	Greenhouse Type		
	SG1	SG2	SG3
Gas consumption (m^3/day)	60.7[a]	56.7[b]	51.9[c]
F value		2499	
Sig.		0.00**	
Electricity consumption (Kw/day)	6.4[a]	6.08[b]	5.55[c]
F value		235	
Sig.		0.00**	

ns, * and **: no significant difference, significant at 5% probability level and significant at 1% probability level, respectively
a, b and c: Classification of treatments based on comparison of means with Duncan's method (common letters have no significant differences)

climate independent resource that produces little or no greenhouse gases and does not consume water.

The results of this study showed that the insulation walls around the underground greenhouses reduce the level of contact with the air. This minimize the temperature loss, and the greenhouse environment remains cooler in summer and warmer in winter, which is consistent with the results of Angmo et al. (2019). Underground greenhouses increase and stabilize the temperature and relative humidity inside the greenhouse. This reduces the energy consumption, including the energy required for heating in the winter or cooling in the summer. In other words, because the floor of these greenhouses is lower than the ground level, the walls around the greenhouse act as an insulator and prevent energy loss. Furthermore, since the energy loss in the greenhouse increases with increasing wind speed, these greenhouses reduce the temperature loss caused by the wind in winter, which further reduces the consumption of heating energy, especially in windy regions.

Conclusion

This study evaluated the feasibility of

underground greenhouses as a measure of reducing climate change impacts. Based on the results, it was found that greenhouse 2 which is 1.5 meters below ground, is superior to the other two greenhouses. The results of this study showed that underground greenhouses cause better control of temperature and relative humidity and lead to a reduction in total energy consumption in the greenhouse. If these greenhouses are located, designed and built properly, there are several benefits to these greenhouses that distinguish them from conventional greenhouses, which are located at the ground level. Some advantages of these greenhouses are better temperature and humidity balance in the greenhouse environment, reduced cooling and heating energy consumption, greater greenhouse strength, and durability. As energy prices rise and greenhouse production uses more energy, one of the key challenges facing greenhouse management is the high energy consumption during the cold and warm seasons. As a result, strategies such as building greenhouses below ground level can significantly reduce greenhouse production costs and conserve energy. The main disadvantages and limitations of underground greenhouses is that the implementation of this type of greenhouse is more applicable to pre-drilled lands, existing holes, bad lands, deserted brick kilns, and in small areas of less than 500 square meters. The results of this study suggest that underground greenhouses can be constructed in cold and tropical regions and have various advantages.

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