THE ECONOMIC EFFICIENCY OF GEOTHERMAL HEATING SYSTEM IN SMALL-SCALE GREENHOUSE OPERATIONS IN BOSNIA AND HERZEGOVINA*

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Abstract

Greenhouse vegetable production offers many advantages over traditional open-field cultivation methods. These benefits include regulating and controlling growing conditions, leading to higher crop yields, year-round production, and increased resource allocation efficiency. Many studies demonstrate that heating systems improve production in greenhouses, leading to increased yields and improved economic profitability. However, similar research is lacking in Bosnia and Herzegovina, particularly in regions with a continental climate. Therefore, the main goal of this study was to evaluate the economic efficiency of vegetable production (lettuce, spring onion, tomato, and spinach) in a greenhouse equipped with an additional heating system compared to one without such a system. The experiment was conducted in two 100 m^2 greenhouses using identical cultivation technology. The results showed that the temperature in the two separate greenhouses was statistically significantly different in winter; however, the observed yields did not show a statistically significant difference. Unexpectedly, the economic results were contrary to expectations, with lower returns in the greenhouse with heating. The main reason is the higher costs associated with deprecation (1,238 BAM) and the geothermal pump's electricity consumption (700 BAM). In conclusion, through this research, it was found that the tested vegetable production using a geothermal heat pump is not economically justified. It is recommended to consider the use of such equipment under different conditions, such as larger greenhouse areas with improved insulation (double-layered plastic). Furthermore, it is recommended that similar experiments be conducted at this location to confirm or challenge the results obtained in this study.

Keywords: *economic efficiency, greenhouses, Bosnia and Herzegovina, geothermal heating system, continental climate*

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INTRODUCTION

Vegetable production in greenhouses offers several advantages over traditional outdoor production. These advantages include the ability to regulate growing conditions, which contributes to higher crop yields, overall production, and improved resource efficiency (Laktionov *et al*., 2020; Odhiambo *et al*., 2021; Zhao *et al*., 2022; Zhou *et al*., 2020). With the increase in the world population and the decrease in arable land, controlling conditions in greenhouses is essential to ensure safe food production (Kuswardhani *et al*., 2014). Greenhouses enable the application of intensive agricultural practices, such as irrigation and tillage operations, resulting in higher yields and more efficient production processes (Çanakcı & Akinci, 2006). Studies have also found that applying agrochemicals, both chemical and organic fertilisers, in greenhouse vegetable systems is higher than in open-field systems, contributing to higher yields in greenhouses (Yuan & Zhang, 2021). Furthermore, research indicates that greenhouse cultivation generally promotes better growth parameters, such as height and width extension, leaf number, leaf area, average leaf size, and total leaf dry mass compared to outdoor conditions (Zhang *et al*., 2021). Also, it encourages increased vegetable yields and promotes carbon accumulation in the soil, highlighting the benefits of vegetable production within greenhouses (Laktionov *et al*., 2018). Furthermore, the impact of heating on greenhouse yields has been a subject of interest. Samaranayake *et al.* (2020) analysed the seasonal effects on greenhouse energy consumption during crop production, emphasising the importance of environmental control in achieving higher yields. The profitability of greenhouse production can be related to the intensity of energy invested in production and the quality and volume of output products (Tong, 2024). Economic analyses show that greenhouse vegetable production is more profitable than outdoor production (Hao *et al*., 2009; Yajie, 2023).

Additionally, greenhouse heating systems can create optimal conditions for vegetable crops, increasing yields. Efficient greenhouse heating is essential for minimising production costs and creating optimal conditions for plant growth. Winter heating can account for a significant portion of greenhouse production costs, highlighting the need for sustainable heating solutions (Blanco *et al.*, 2013). Various heating systems have been studied to improve energy efficiency and reduce greenhouse production costs. Energy consumption for greenhouse heating can be substantial, indicating the importance of exploring efficient heating methods (Wang & Liang, 2006). Studies have also delved into optimising energy consumption and microclimate control in greenhouses. Optimised daily average temperatures in a greenhouse to minimise energy consumption, providing insights for decision-making in greenhouse heating (Shen *et al*., 2018).

Biomass heating systems in rural China demonstrate innovative approaches to meet heating and greenhouse demands sustainably (Huang *et al*., 2020). Bezari *et al.* (2020) focus on rock-bed heat storage systems to preserve thermal energy and respond to temperature variation in greenhouses, stating the importance of thermal storage during day and night-time for stable microclimates. Experimental studies of a geothermal heat pump's performance for greenhouse heating illustrated how low-enthalpy geothermal sources can be used to meet agricultural needs (Anifantis *et al*., 2016). Barbaresi *et al.* (2020) evaluated the efficiency of a geothermal heat pump system for greenhouse heating, underlining the importance of sustainable heating solutions.

In BiH, there is limited research on the profitability of greenhouse production (Becirovic *et al*., 2018; Čadro *et al.*, 2022)Given the higher yield potential per unit area and the increased safety of production, particularly in relation to climate change risks such as early spring heat waves followed by sudden temperature drops, this type of production could potentially offer solutions for many smallholder farmers in BiH.
However, studies that directly address the economic profitability of heating greenhouses for winter vegetable production remain scarce. This was the main reason for conducting this study at the Butmir experimental field, with the aim of evaluating the profitability of such systems under the continental climate conditions of BiH.

Ha1 – A statistically significant difference exists between the temperatures the heated and the control greenhouses achieved in the observed period.

Ha2 – There is a statistically significant difference in the realised yields in the heated and control greenhouses.

MATERIALS AND METHODS

In May 2020, two identical greenhouses, each covering an area of 100 m² (6.3 m x 16.0 m), were established side by side at the experimental site of the Faculty of Agriculture and Food Science at the University of Sarajevo, located in Butmir near Sarajevo.
Both greenhouses were constructed using materials and designs typical of those used by local farmers. However, one greenhouse was equipped with a geothermal heating system, while the other served as a control and was not heated. The installed geothermal heat pump (Ecoterm, Type 263, max power 3.2 kW) utilises soil heat collectors made of plastic pipes installed in trenches 120 cm deep and 60 cm wide. To meet the heating requirements for the 100 m² greenhouse, with a heating demand of 12 kW, three trenches, each 50 meters long, were dug for the earth collectors.
After analysing the heating capacity of the geothermal pump and the subsequent soil and air temperatures, the following operational protocol was implemented for the pump:
- The output temperature from the heat pump is set to 25°C.
- The geothermal pump operates simultaneously with an air fan.
- The pump is activated when the air temperature inside the greenhouse falls below 10°C.
- The pump is turned off when the temperature inside the greenhouse rises above 10°C.

The temperatures measured at 7:00, 14:00 and 21:00 hours are used to establish whether a statistically significant temperature difference was achieved with the help of heating in the two observed greenhouses.

The research was conducted on the following vegetable crops: lettuce, spring onion, tomato cv. Pink Rock, tomato cv. Mathias, and spinach during the period from November 2021 to April 2022. Data collection for the experiment was carried out directly on-site, where all data were entered into the CoboToolbox software. This software enabled data storage and partial analysis. The collected data include all material costs, such as planting material, fertiliser, protective equipment and other inputs, as well as detailed records of labor costs. These data made it possible to calculate the overall economic performance of the two greenhouses under study accurately. Product price trends during the season were determined based on monitoring average product prices during the research in several different markets, while selling prices for farmers were determined through a survey of five active producers of these products. Prices for consumed inputs were determined based on invoices submitted when purchasing inputs.

The gross margin (GM), a concept that covers variable costs, was used in the economic analysis. Specifically, the gross margin represents the difference between the achieved revenues and exclusively the variable costs (Kay *et al.*, 2015).

$$GM = \text{Revenue} - \text{Variable cost}$$

The concept of standard economic profit, which includes fixed costs, was also used. The following formula was used in this paper:

$$PROFIT = \text{Gross margin} - \text{Depreciation}$$

The study presents the expected revenues and costs for cultivating these crops on 25 and 100 square meters.

RESULTS AND DISCUSSION

Table 1 shows the vegetation period of all the crops grown during the experiment. The study demonstrates the impact of heated greenhouses on shortening the vegetation periods of various crops. Lettuce in heated greenhouses requires only 67 days, 49 days less than in unheated conditions. For spring onions, the vegetation period in the heated greenhouse was 30 days shorter than in the control. Spinach had a vegetation period of 52 days in heated greenhouses, significantly shorter by 50 to 130 days compared to unheated greenhouses in Bosnia and Herzegovina. For tomatoes, the difference in vegetation period between heated and unheated greenhouses was minimal, with only a seven-day reduction. Overall, heating significantly reduces vegetation, especially for lettuce, spring onions, and spinach. This shorter vegetative period in the heated greenhouse has allowed the growth of one more circle of production in the wintertime.

Table 1. Length of vegetation period of individual crops in control and heated greenhouses

Type of individual crops		Planting date	Harvesting date	Vegetation length in days
CONTROL	Lettuce	12.12.2020.	05.02.2021.	116
	Spring Onion	12.12.2020.	05.02.2021.	116
	Tomato Pink Rock	12.04.2021.	05.10.2021.	176
	Tomato Mathias	12.04.2021.	05.10.2021.	176
HEATED	Lettuce	12.10.2020.	18.12.2020.	67
	Spring Onion	12.10.2020.	05.01.2021.	85
	Spinach	05.01.2021.	25.03.2021.	52
	Tomato Pink Rock	05.04.2021.	05.10.2021.	169
	Tomato Mathias	05.04.2021.	05.10.2021.	169

Table 2 presents the average temperatures in two greenhouses, one heated and the other a control. Temperatures were measured at 7:00, 14:00 and 21:00 hours, and they were monitored from November to April. The table also includes the p-values of the test, showing where and during which period statistically significant differences in recorded temperatures occurred.

While significant differences were not observed at 14:00 h, except in January, statistically significant differences were achieved in temperatures measured at 7:00 and 21:00 h from November to February. No statistically significant differences in average temperatures were recorded in March and April.

Thus, we can state that the first hypothesis is partially confirmed, as statistically significant differences in recorded temperatures were observed in some cases within the two greenhouses. Overall, statistically significant differences were observed in 9 measurements out of 18 measurements. This allows us to conclude that the first hypothesis is partially confirmed.

Table 2. Average temperatures (in ºC) at 7:00, 14:00 and 21:00 h inside the control and heated greenhouse with statistical analysis of values using the t-test ($\alpha = 0.05$) with statistical analysis of mean values (t-test) greenhouses

Month/ Hour	07:00		14:00		21:00		p value - t test		
	Contr	Heate	Contr	Heate	Contr	Heate	07:0	14:0	21:0
Novemb	-0.5	3.9	15.9	16.6	2.4	6.1	0.005	0.650	0.001
Decemb	1.7	6.1	10.9	13.3	3.0	7.2	0.000	0.113	0.000
January	-1.0	2.7	7.9	10.8	0.5	4.1	0.001	0.008	0.000
Februar	-0.6	2.1	17.6	18.8	1.2	4.0	0.020	0.578	0.018
March	1.9	3.0	17.1	16.8	3.0	3.9	0.259	0.854	0.259
April	1.2	4.1	19.6	19.1	4.3	5.3	0.295	0.893	0.502

*** Differences between temperatures are statistically significant**

The most significant differences in achieved temperatures are observed in December and January, with January standing out particularly, as statistically significant differences in recorded temperatures appeared in all three time measurements.
Expected investments in greenhouse production without a geothermal pump in BiH are 2,639 BAM. Considering the years of amortisation, the annual depreciation would be 176 BAM. However, if there is a geothermal pump on greenhouses, depreciation would be eight times higher, and the total investment would be 21,211 BAM. As a result, the annual amortisation would be 1,415 BAM. From this, we can see that it is necessary to achieve a higher gross margin of 1,239 BAM in the heated greenhouse compared to the unheated greenhouse for the same final financial results.

Table 3. Type of investments in greenhouse production with and without a heating system

(in BAM)

Investments	**Greenhouse**	
	Control	**Heated**
Greenhouse with standard equipment	2,639	2,639
Installation of hot air distribution pipes		94
Hot air distribution pipe		156
Installation of geothermal heating systems		18,330
Total amount of investments	**2,639**	**21,218**
Number of years of depreciation	15	15
Annual amount of depreciation	**176**	**1,415**

Table 4 presents the average yields of different crops in two separate greenhouses. At first glance, it can be concluded that, except for onions, no statistically significant yields were achieved in the heated greenhouse. For onions, yields in the heated greenhouse reached 155 kg per 100 m² compared to 87 kg per 100 m² in the unheated greenhouse.

Table 4. Achieved yields in control and heated greenhouse on the Butmir experimental field on the area of 100 m^2 for the different crops

(in kg)

Type of crops	**Greenhouses**	
	Control	**Heated**
Lettuce	337	326
Onion	87	155
Tomato - Mathias	1,956	1,332
Tomato - Pink Rock	1,732	1,540
Spinach	-	315

When observing individual crops, no significant difference in lettuce yields was recorded between the two greenhouses. Contrary to expectations, the tomato yields for the Matias and Pink Rock varieties were lower in the heated greenhouse compared to the control greenhouse. This certainly represents a surprising outcome in the study. However, the significant difference in achieved yields can be explained by the fact that tomatoes in the heated greenhouse were planted seven days earlier, and during the flowering period, one night saw exceptionally low temperatures. This damaged the first flowers in the heated greenhouse, as the heating system was unable to compensate for the temperature difference between the outside and inside, thus failing to provide optimal conditions for the plants during this critical period. For this reason, the first harvest of tomatoes from the heated greenhouse yielded lower results compared to the unheated greenhouse. Also, fruit deformity (catfacing) was noted in the heated greenhouse during the first harvesting period. It is known that tomatoes are highly sensitive to heat stress, especially in the flowering phenophase (Sikes and Coffey, 1976). Exposure to suboptimal temperatures during flowering leads to deformed fruits that have little to no market value. One such disorder is "catface", a deformity that appears on tomato fruits when exposed to temperatures below 10°C during critical growth periods (Masarirambi *et al*., 2009). Catfacing is the abnormal development of plant tissue affecting the ovary or female sex organ (pistilate), which results in the flower, followed by the fruit development to become malformed. The exact cause of catfacing on tomatoes is uncertain and could be caused by any number of factors, but it seems to centre around unfavourable growing conditions. Temperatures below 10°C for several successive days when plants are immature - about three weeks before blooming - appear to coincide with tomato catfacing fruit deformity. However, all these results should be taken with caution, and a more reliable conclusion could be made through two or three additional years of research in the same region, using the same greenhouses under similar conditions.

The most significant difference in the production plan between the two observed greenhouses is that an additional production cycle could be conducted in the heated greenhouse during the winter months. This study achieved this by growing an extra crop of spinach. These facts, combined with increased yields of other crops, were expected to compensate for the difference in depreciation costs and electricity consumption in the heated greenhouse. The following tables show how successfully this was achieved.

During the experiment's design, it was expected that the significantly higher depreciation for the heated greenhouse would be compensated by the higher yields achieved within it and by the anticipated higher prices for products that would reach the market earlier than those arriving later from the control greenhouse. However, during the study year, no significant difference was observed in the prices of products based on the timing of their market availability.

Table 5. Achieved gross margin and profit in the control and heated greenhouse on the Butmir experimental field on an area of 25 m^2 for the different crops

(in BAM)

Description	**Greenhouses**	
	Control	**Heated**
Gross margin of individual crops		
Lettuce	221	106
Onion	-55	-149
Tomato - Mathias	708	380
Tomato - Pink Rock	838	675
Spinach	-	493
Total gross margin	**2,230**	**2,119**
Depreciation	176	1,415
Profit	**2,054**	**704**

Thus, not only were the expected higher yields not achieved in the heated greenhouse, but higher prices for these products were also not realised. For this reason, even the total gross margins were lower in the heated greenhouse. This indicates that the costs in the heated greenhouse are higher, while the expected benefits were not achieved. For this, the financial results in controlled greenhouses in this experiment were 2,054 BAM, contrary to 704 BAM in heated greenhouses. So, in this case, with those yields and prices, it could be said that an option without heating is better for the farmer economically.

Further, it has been analysed what would happen if the farmers included in the production plan only production lines with the highest gross margin in both greenhouses from this experiment. This will enable us to make predictions about the highest expected gross margin possible in both greenhouses under the given circumstances.

The results of this experiment demonstrate that onion production will not be considered an economically viable production option in either greenhouse.

For this reason, the optimal production plan for the control greenhouse includes the most cost-effective crop during winter and another crop during spring/summer. Consequently, for control greenhouse the selected crops are letuce and the Pink Rock tomato variety, which proved slightly more profitable and cost-effective than the Matias variety. Using a geothermal pump during the winter allowed two production cycles in heated greenhouses. Spinach and lettuce were selected for consideration. Although spinach proved to have a higher gross margin for cultivation during the winter period, it was decided to grow two different crops during the winter months instead of planting spinach twice to allow crop rotation.

Table 6: Expected gross margin and profit with recommended plan production in a greenhouse area of 100 m^2 Table

(in BAM)

Description	Greenhouse				
	Control		**Heated**		
	Lettuce	Tomato Pink Rock	Lettuce	Tomato Pink Rock	Spinach
REVENUES	**1,348**	**4,330**	**1,304**	**3,850**	**1,418**
COST					
Seedlings	120	225	120	225	5
Fertiliser	25	190	25	190	6
Pesticide	13	26	28	29	0
Mechanisation	20	30	20	30	20
Labour	218	394	174	530	92
Geothermal pump	0	0	426	13	262
Irrigation	20	20	20	20	10
Supporting material	24	60	24	60	12
Other costs	24	32	42	54	26
TOTAL COSTS	**464**	**977**	**880**	**1,152**	**432**
GROSS MARGIN	**884**	**3,353**	**424**	**2,698**	**986**
Total gross margin	**4,237**		**4,108**		
Depreciation	176		1,415		
PROFIT	**4,060**		**2,693**		

The gross margin in the control greenhouse from lettuce cultivation amounted to 884 BAM, while the gross margin from tomato cultivation was 3,353 BAM. The total gross margin for the control greenhouse was 4,237 BAM. After deducting depreciation costs, the total profit for this greenhouse could amount to 4,060 BAM.

The gross margin from lettuce cultivation in the heated greenhouse amounted to 424 BAM, half of the control greenhouse's. This was primarily due to the electricity costs for heating the greenhouse, which amounted to 426 BAM for lettuce alone. Therefore, the electricity consumption and heating of the greenhouse did not improve the economic viability of lettuce cultivation during the winter period. On the contrary, the results were twice as poor because the yields were similar, and the selling prices were identical for both greenhouses. The gross margin from Tomato cultivation in heated greenhouses amounts to 2,638 BAM per 100 m². This gross margin is also lower than that achieved in the control greenhouse. The tomato yields were lower in the heated greenhouse compared to the control greenhouse, and labor costs were slightly higher than in the control greenhouse. These two factors contributed to the lower gross margin in the heated greenhouse compared to the control one.

Spinach had a gross margin of 986 BAM, making it the crop with the highest gross margin among those cultivated in the winter period. The total gross margin for the heated greenhouse was 4,108 BAM. After deducting depreciation costs, the total profit was 2,693 BAM. This indicates that the profit achieved in the heated greenhouse, even with the use of a geothermal pump, was significantly lower than in the control greenhouse. Considering that the investments for the heated greenhouse were also much more significant and extensive than for the control greenhouse, it can be concluded that the economic viability and profitability, in this case, proved to be better in the control greenhouse than in the heated one.

CONCLUSION

The study demonstrated that geothermal heating in small-scale greenhouses under the continental climate conditions of Bosnia and Herzegovina offers certain agronomic advantages. Still, these benefits do not justify the high investment and depreciation costs during the observed season. Statistically significant temperature differences were observed between the heated and control greenhouses, particularly during winter's morning and evening hours, which has confirmed alternative hypothesis one. However, this temperature advantage did not translate into consistently higher yields, except in the case of onions. These results rejected the hypothesis of increased yields inside the heated greenhouse. Tomato yields were lower in the heated greenhouse due to temperature stress and fruit deformities caused by suboptimal conditions during the flowering phase. The economic analysis revealed that, despite the potential for an additional crop cycle, the overall profit from the heated greenhouse was lower than that of the control, primarily due to significantly higher depreciation and energy costs.

Therefore, the heated greenhouse was not economically viable under the current market and climate conditions. It is recommended that further research be conducted over multiple seasons to obtain more reliable and representative results.

The significant disadvantage in the experiment was the lack of a double foil in the outside walls of the greenhouse. Such a double foil could ensure better greenhouse insulation, a higher internal temperature, and lower electricity consumption. Furthermore, it is recommended that similar experiments be conducted at this location to confirm or challenge the results obtained in this experiment. As the BiH has few climate zones, comparing the results with the same or similar system in the Mediterranean climate type would be interesting.

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EKONOMSKA EFIKASNOST SISTEMA GEOTERMALNOG GRIJANJA U MALIM PLASTENICIMA U BOSNI I HERCEGOVINI

Sažetak

Proizvodnja povrća u plastenicima nudi mnoge prednosti u odnosu na tradicionalne metode uzgoja na otvorenom. Ove prednosti uključuju regulisanje i kontrolu uslova uzgoja, što dovodi do većih prinosa, proizvodnje tokom cijele godine i povećane efikasnosti raspodjele resursa. Mnoge studije pokazuju da sistemi grijanja poboljšavaju proizvodnju u plastenicima, što dovodi do povećanja prinosa i poboljšane ekonomske isplativosti. Međutim, slična istraživanja nedostaju u Bosni i Hercegovini, posebno u regijama s kontinentalnom klimom. Stoga je osnovni cilj ovog istraživanja bio da se ocijeni ekonomska efikasnost proizvodnje povrća (zelene salete, mladog luka, paradajza i špinata) u plasteniku opremljenom dodatnim sistemom grijanja u odnosu na onaj bez takvog sistema. Eksperiment je izveden u dva plastenika površine 100 m^2 po identičnoj tehnologiji uzgoja.Rezultati su pokazali da su tokom zimskog perioda temperaturne razlike između plastenika bile statistički značajno različite; međutim, posmatrani prinosi nisu pokazali statistički značajnu razliku. Ekonomski rezultati su bili suprotni očekivanjima, sa manjim pokrićima u plasteniku sa grijanjem. Glavni razlog su veći troškovi vezani za amortizaciju (1.238 BAM) i potrošnju električne energije geotermalne pumpe (700 BAM). Zaključno, ovo istraživanje je pokazalo da korištenje geotermalne pumpe nije ekonomski opravdano za proizvodnju povrća, te se preporučuje da se razmotri korištenje ove opreme i u drugim uslovima, kao što su veće površine plastenika s poboljšanom izolacijom (dvoslojna plastika). Nadalje, provođenje sličnih eksperimenata na ovoj lokaciji je potrebno nastaviti kako bi se potvrdili ili osporili rezultati dobiveni u ovom eksperimentu.

Ključne riječi: *ekonomska efikasnost, plastenici, Bosna i Hercegovina, geotermalna pumpa, kontinentalna klima*