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ENERGY EFFICIENCY OF THE TOMATO OPEN FILED AND GREENHOUSE PRODUCTION SYSTEM

ENERGETSKA EFIKASNOST PROIZVODNJE PARADAJZA NA OTVORENOM POLJU I U OBJEKTIMA ZAŠTIĆENOG PROSTORA

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ABSTRACT

In this paper the influence of tomato production technology and greenhouse construction type on production energy efficiency was analysed. Influence of greenhouse construction on energy consumption was estimated for four different double plastic covered greenhouses: a tunnel type, covered with 180 µm PE UV IR outside folia, a gutter connected plastic covered greenhouse with 50 µm inner folia and 180 µm outside folia, a multi-span greenhouse with four bays with 50 µm inner folia and 180 µm outside folia and a multi-span greenhouse with thirteen bays were used. Specific energy input, energy output-input ratio and energy productivity were estimated. Results show that there are differences in the open field and greenhouse tomato production. The lowest energy input was measured for the open filed tomato production (18.02 MJ/m^2) while in greenhouses in average was 24.13 MJ/m^2. Concerning the greenhouses alone, the highest energy input was calculated in the case of tunnel structure, 26.87 MJ/m^2. The lowest yield was observed in the open filed tomato production (1.89 kg/m^2). The highest yield was achieved in the multi-span greenhouse with thirteen bays (6.08 kg/m^2). Analysis showed that tomato production technology influences the energy efficiency and that the type of greenhouse construction has a significant influence on the energy efficiency of the greenhouse tomato production.

Key words: *tomato, open field production, plastic covered greenhouses, energy, energy productivity.*

REZIME

U radu je prikazan uticaj tehnologije gajenja paradajza (otvoreno polje ili objekti zaštićenog prostora) na energetsku efikasnost. U tu svrhu praćena je njegova proizvodnja na otvorenom polju i u četiri tipa objekta i to objektu tunel tipa dimenzija 5,5 x 24 m pokrivenog 180 µm PE folijom, zatim u blok objektu sa dva bloka dimenzija 21 x 250 m sa 50 µm unutrašnjom i 180 µm spoljašnjom PE folijom, u blok objektu sa četiri bloka, dimenzija 4 x 8 x 51 m sa 50 µm unutrašnjom i 180 µm spoljašnjom PE folijom i u blok objektu sa trinaest blokova dimenzija 13 x 12 x 67,5 m sa 50 µm unutrašnjom i 180 µm spoljašnjom PE folijom. Na osnovu energetskog ouput-a i energetskog input-a, specifična potrošnja energije, energetski odnos i energetska produktivnost su određene. Rezultati pokazuju da postoje razlike u potrošnji energije u proizvodnji na otvorenom polju i u objektima zaštićenog prostora. Najniža potrošnja energije zabeležena je na otvorenom polju (18,02 MJ/m^2) dok je potrošnja energije u objektima zaštićenog prostora u proseku bila 24,13 MJ/m^2. Ako se međusobno uporede samo objekti zaštićenog prostora, najviše energije je utrošeno u objektu tunel tipa 26,87 MJ/m^2. Najniži prinos je ostvaren na otvorenom polju i iznosio je 1,89 kg/m^2 dok je najviši prinos zabeležen u blok objektu sa trinaest blokova (6,08 kg/m^2). Analiza potrošnje energije je pokazala da tehnologija gajenja paradajza utiče na energetsku efikasnost proizvodnje kao i da se izborom tipa objekta značajno može uticati na energetsku produktivnost proizvodnje.

Ključne reči: *paradajz, otvoreno polje, plastenici, energija, energetska produktivnost.*

INTRODUCTION

Greenhouse plant production is one of the most intensive parts of the agricultural production. It is intensive in the sense of yield (production) and in whole year production, but also in sense of the energy consumption, investments and costs (*Canakci and Akinci, 2006; Sethi and Sharma, 2007; Singh et al., 2007*). In order to reduce the costs and save the energy, various greenhouse constructions and different coverings are offered to the farmers (*Nelson, 2003; Hanan, 1998*). One of the biggest problems is in winter production when additional heating and light are needed (*Damjanovic et al., 2005; Enoch, 1978, Momirovic, 2003; Sethi and Sharma, 2007*). During that period construction and coverings fully show their qualities. One of the most common vegetables in Serbia is tomato. It is grown in greenhouses as well as in open field, and it can be found on the market most of the year. The most important growth factors for the tomato production are temperature and light (*Momirovic, 2003*). Optimal temperature during the vegetation period is 15-29 °C. Optimal soil temperature is 25 °C.The most common greenhouse structures in Serbia are tunnels covered with the double PE UV AD folia. However, lately there is a tendency of introducing gutter connected and multi-span greenhouses. This tendency is motivated by the fact that crop rotation is more viable in these structures (*Stevens, 1994*).

The aim of this paper was to estimate greenhouse energy consumption and the energy efficiency for the tomato production in order to see if and how the production technology influences the overall energy efficiency and to see how the different types of greenhouse construction can influence energy consumption for a given plant production.

MATERIAL AND METHOD

Influence of greenhouse construction on energy consumption was estimated for four different double plastic covered greenhouses. For the research a tunnel type, 5.5 x 24 m covered with 180 µm PE UV IR outside folia, a gutter connected plastic covered greenhouse 21 x 250 m and with 50 µm inner folia and 180 µm outside folia, a multi-span greenhouse 4 x 8 m wide and 51 m long with 50 µm inner folia and 180 µm outside folia and a multi-span greenhouse 13 x 12 m wide and 67.5 m long, with 50 µm inner folia and 180 µm outside folia were used. The parameter needed for the statistical analysis, was covering material /production surface ratio. For the tunnel structure this value was 1.91, for GH2 structure it was 1.62, for the GH3 type of construction it was 1.44 and for the GH4 type of construction it was 1.30. Tomato production was carried out in the season of 2009. Tomato was planted in April in the open filed as well as in the greenhouses. Influence of the production technology (whether to grow tomato in the open or in the greenhouses) was determined based on the energy consumption in the open field and greenhouse tomato production. The experiment was carried out at a private property near Novi Sad (Serbia) on 19°51E altitude and 45°20N latitude and at a private property near Jagodina (Serbia) on 21°16E altitude and 44°1N latitude. The method used for the energy efficiency analysis (*Ortiz-Cañavate, 1999; Đevic and Dimitrijevic, 2004; Hatirli et al., 2006; Ozkan et al., 2007; Mani et al., 2007; Khan and Singh, 1996; Canakci and Akinci, 2006; Bajkin et al., 2014*) is based on the energy input analysis (definition of direct and indirect energy inputs), calculation of the energy consumption for a given plant production and the energy efficiency. On the basis of tomato production output and the energy input, specific energy input, energy output-input ratio and energy productivity were estimated. The energy inputs were calculated by multiplying the material input with the referent energy equivalent. Energy equivalents for different material inputs as well as for the lettuce output were obtained from different sources (*Enoch, 1978; Ortiz-Canavate and Hernanz, 1999; Badger, 1999*). For the purpose of defining the production technology influence on the overall energy efficiency of the tomato production a 2^k statistical analysis was carried (*Dimitrijevic, 2010*). Statistical analysis, used for the greenhouse construction type influence on the energy efficiency, included the linear regression model. The parameter that was used to describe differences in constructions was the greenhouse covering / production surface ratio. The obtained data and the calculated values were imported in Microsoft Excel 2000 for the statistical analysis.

RESULTS AND DISCUSSION

A parameter that can be used to showed different values for the open field and different greenhouse constructions (Tab. 1). The lowest value was calculated for the open filed tomato production (0.72 MJ/m^2) and the highest for the tunnel greenhouse (26.87 MJ/m^2).

Table 1. Energy consumption for the open field and greenhouse tomato production

	Open field	Tunnel structure GH1	Gutter-connected structure GH2	Multi-span structure GH3	Multi-span structure GH4
	MJ	MJ	MJ	MJ	MJ
Direct energy inputs					
Diesel, l	47.8	189.29	3346.00		
Electricity, kWh	78.60	168.69	8971.50	2788.85	17994.17
Straw, kg			17294.00		
Indirect energy inputs					
Nutrients					
Nitrogen, kg	295.13	2000.55	49206.00	20251.08	135741.80
Phosphorus, kg	161.82	200.97	5702.90		
Potassium, kg	193.17	411.41	11198.00	8126.84	54010.88
Plant protection chemicals					
Pesticides, kg		5.97	115.42	280.59	1623.84
Fungicides, kg		24.84	299.92	784.76	3269.68
Water, m^3	90.72	203.67	8104.50	396.00	2223.00
Technical systems, h	2.35	7.84	67.91		
Human labor, h	211.68	333.20	10976.00	7389.20	28894.32
Total, MJ	1081.27	3546.43	115282.00	40017.32	243757.67
Total, MJ/m^2	**0.72**	**26.87**	**21.96**	**24.52**	**23.15**

The energy output was calculated based on the energy value for tomato and obtained yield (Tab.2). The highest yield was calculated for multi-span greenhouse GH4 (35.81 kg/m^2) and the lowest for the tunnel (17.00 kg/m^2).

Table 2. Tomato yield and energy output

	Yield, kg	Specific yield, kg/m^2	Energy output, MJ	Specific energy output, MJ/m^2
Open field	**1020.00**	17.00	816.00	13.60
Tunnel structure, GH1	2291.52	17.36	1833.22	13.89
Gutter-connected structure, GH2	129980.00	24.76	103984.00	19.81
Multi-span structure, GH3	51224.00	31.39	40979.00	25.11
Multi-span structure, GH4	377080.00	35.81	301664.00	28.65

Based on the measured energy inputs and the energy output, parameters for energy analysis were calculated (Tab. 3). It can be seen that different values were obtained for open field tomato production and tomato production in different greenhouse structures regarding the basic energy parameters. Lower values of the specific energy inputs were calculated for the gutter-connected and multi-span greenhouses while higher values for the energy ration and energy productivity were obtained in the multi-span greenhouses.

Table 3. Energy analysis for the open field and greenhouse tomato production

	Specific energy input, MJ/kg	Energy ratio	Energy productivity, kg/MJ
Open field	1.06	0.75	0.94
Tunnel, GH1	1.55	0.52	0.65
Gutter connected structure, GH2	0.89	0.90	1.13
Multi-span structure, GH3	0.78	1.02	1.28
Multi-span structure, GH4	0.65	1.23	1.55

It can be observed, in the table 3, that tunnel structure can not be recommended for the tomato production. This production technology has the highest specific energy input and the lowest energy ratio and energy productivity compared to all the other technologies. In order to evaluate whether the production technology and greenhouse construction type influence the energy parameters of the production, results from previous research were used. In this sense the 2^k statistical analysis was used. Energy parameters of the lettuce open field and greenhouse production, Tab. 4 *(Dimitrijević et al., 2011)* and tomato open filed and greenhouse production were used in the analysis. Table 4 shows the data needed for the 2^k statistical system. The same working tables were prepared for each type of greenhouse. Based on the Variance statistical analysis it was concluded that there are no significant differences in the energy parameters in case of the lettuce and tomato production in the open field and in the tunnel greenhouse construction. So, in the case of lettuce and tomato production it will not be significant if the production was in the open filed or in the greenhouses, concerning the specific energy input. The same results, concerning the energy inputs were obtained for all other greenhouses.

Table 4. Energy analysis for the open field and greenhouse lettuce production (Dimitrijević et al., 2011)

	Specific energy input, MJ/kg	Energy ratio	Energy productivity, kg/MJ
Open field	4.23	0.11	0.24
Tunnel, GH1	0.97	0.47	1.03
Gutter connected structure, GH2	0.63	0.73	1.59
Multi-span structure, GH3	0.58	0.79	1.73
Multi-span structure, GH4	0.54	0.85	1.85

Table 5. Working table for the analysis of production technology and greenhouse construction type influence on specific energy input

		Plant specie	
		Lettuce	Tomato
Production technology	Open filed	4.23	1.06
	Tunnel structure, GH1	0.97	1.55

In the case of energy ratio, the highest value was obtained in the case of tomato production in gutter connected greenhouse GH4 while the lowest was observed for the open filed lettuce production. It was observed that better results were obtained in the tomato greenhouse production compared to lettuce production. Statistical analysis showed that in case of greenhouse production the choice of plant specie and type of greenhouse production has a significant influence on energy ratio. Statistical analysis of the energy productivity showed that the choice of plant specie and type of greenhouse construction has a significant influence on energy productivity and if the greenhouse covering material / production surface ratio is 1.3 or less lettuce can not be recommended for production in these types of greenhouses. In this case tomato, like more intensive specie is recommended.

In order to see if the previously showed differences in energy parameters, in case of greenhouse production, are influenced by the greenhouse construction, statistical regression analysis was used. The covering material surface / production surface ratio was used as a parameter for describing the greenhouse construction *(Hanan, 1998)*. After importing these data in Microsoft Excel data analysis tool pack, Eqs. 4, 5 and 6 were obtained which describe relations between the calculated energy parameters and the greenhouse specific greenhouse volume.

In the case of energy input per kg of product the applied statistical method of linear regression showed that there is a strong correlation between specific energy input and greenhouse construction (92.74 %). Equation obtained (eq. 1) gives relation between these two parameters and shows that the decreasing of energy consumption should be expected with the greenhouses with the lower covering material surface / production surface ratio.

$$y = -1.3 + 1.48\ \mathrm{EI} \qquad (1)$$

If the energy ratio is analyzed it can be concluded that there is a strong correlation dependence between this parameter and greenhouse construction (98.6 %). The correlation coefficient was estimated to be significant. Regression equitation shows that energy ratio will be higher in conditions of greenhouse structures that have a lower covering material surface / production surface ratio (eq. 2).

$$y = 2.7 - 1.14\ \mathrm{ER} \qquad (2)$$

Similar results were obtained for the energy productivity. Analysis showed that there is a strong correlation between energy productivity and greenhouse type of construction (98.6 %). Regression equitation shows that energy productivity will be higher in conditions of greenhouse structures that have a lower covering material surface / production surface ratio (eq. 3).

$$y = 3.38 - 1.42\ \mathrm{EPx} \qquad (3)$$

Presented results lead to the conclusion that in the sense of lowering specific energy input and having energy productivity higher, greenhouse structures with lower covering material surface / production surface ration should be used. The reason for this kind of tendencies can be searched in the more uniform microclimatic conditions in the gutter connected and the multi-span greenhouse. Also, the tunnels in this area were more susceptible to wind and there were more damaged lettuce heads in the tunnels near the side walls.

The obtained results can be helpful in suggesting producers what kind of greenhouse structures should they use in order to have a better energy efficiency, energy productivity and lower energy input per kg of product.

CONCLUSION

In the study, the energy input and output for different production technologies and different greenhouse construction in the tomato production was analyzed. The specific energy consumption showed different values for different greenhouse constructions and in the open filed. Lowest value was obtained for the gutter-connected greenhouse and the highest for the multi-span greenhouse with the thirteen bays. Higher yield were obtained in the gutter and multi-span greenhouses compared to tunnel structures, due to better climatic conditions and better utilization of the fertilizer. The multi-span greenhouses also showed lower energy input per kg of product compared to the tunnel structure and the open field production.

Results on the joined influence of plant specie and production technology, show that energy parameters are influenced by these two parameters. This influence was significant in the case of energy ratio and energy productivity. Results show that in the case of having a greenhouse that has covering material / surface ratio that is 1.4 or less, lettuce can not be recommended for planting in the greenhouse. In this case tomato could be recommended as energy viable option. Larger greenhouse should not be “vested” on plant species like lettuce or spinach.

The linear regression models were estimated as significant and had shown that the greenhouse structure has a significant influence on energy input, energy efficiency and productivity. The results show that lower covering material surface / production surface ratio can influence a lower energy input per kg of product, higher energy ratio and better energy productivity. Additionally, it can be concluded that the energy efficiency can also be higher with gutter-connected and multi-span greenhouses.

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