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ENERGY EFFICIENCY OF THE MINERAL FERTILIZER APPLICATION IN CROP PRODUCTION

ENERGETSKA EFIKASNOST APLIKACIJE MINERALNIH ĐUBRIVA U PROIZVODNJI RATARSKIH KULTURA

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ABSTRACT

The efficiency of primary agricultural production is under constant analysis relative to energy, economy and ecology. Notwithstanding technological innovations in agricultural production, engineers and researchers are still seeking to create a production system that would render the primary agricultural production more energy efficient and ecologically sustainable.

The purpose of this paper is to examine the energy consumption and efficiency of crop production with an emphasis on the importance of mineral fertilizers and their influence on the overall energy consumption. The results obtained indicate that mineral fertilizers claim a share of the total energy consumption in crop production ranging from 40.53 % in sunflowers to 55.19 % in maize. A statistically significant correlation was found between the energy inputs for fertilizers and crop yields. The regression analysis performed showed a positive correlation between the energy inputs for fertilizers and yields in all the crops considered, with the exception of wheat.

Key words: *mineral fertilizers, crop production, energy consumption, energy efficiency*

REZIME

Efikasnost primarne poljoprivredne proizvodnje je predmet konstantnih analiza, kako energetskih tako i ekonomskih i ekoloških. Bez obzira na tehničko unapređenje proizvodnje, i dalje se traže proizvodni i tehnološko-tehnički sistemi koji će dati energetski efikasniju i ekološki održivu primarnu biljnu proizvodnju.

U radu je prikazan bilans potrošnje energije u proizvodnji ratarskih kultura i skrenuta je pažnja na mineralna đubriva. Potrošnja energije je praćena u proizvodnji pšenice, kukuruza, semenskog suncokreta, šećerne repe i soje, tokom tri proizvodne sezone. Data je analiza potrošnje energije kroz sve postupke manipulacije mineralnim đubrivima do i od imanja pa do same aplikacije na parceli. Analizirana je zavisnost ukupnih energetskih inputa i prinosa i korelacija utroška mineralnog đubriva i outputa.

Rezultati istraživanja pokazuju da mineralna đubriva, u energeskom bilansu ratarske proizvodnje, učestvuju sa 40,52% (semenski suncokret) pa do 55,19% (kukuruz). Najintenzivniji utrošak energije po jedinici površine zabeležen je u proizvodnji šećerne repe, 27848,9 MJ ha^{-1} dok je najmanje energije utrošeno kod soje, 11371,28 MJ ha^{-1}. Proizvodnja šećerne repe je energetski najproduktivnija (1,58 kg MJ^{-1}). Najviše energije, kod manipulacije i aplikacije đubriva, je utrošeno u proizvodnji pšenice, 14,54 MJ ha^{-1}, a najmanje u proizvodnji soje, 3,23 MJ ha^{-1}. Statistička analiza je pokazala da postoji korelacija između energije utrošene preko đubriva i samog prinosa ratarskih kultura. Funcionalna veza između inputa putem đubriva i prinosa je jaka u svim slučajevima osim kod soje. Regresione jednačine pokazuju pozitivnu zavisnost između prinosa i uložene energije preko đubriva, osim u slučaju pšenice i semenskog kukuruza.

Ključne reči: *mineralna đubriva, ratarska proizvodnja, energetski bilnas, energetska efikasnost.*

INTRODUCTION

Ecological, economic and energy efficiency are the principal requirements of sustainable agriculture. The energy consumption in agriculture has increased in recent years due to booming population growth, limited supply of arable land and the need for higher living standards (*Erdal et al., 2007*). The share of energy consumed in agriculture is considered very large, ranging up to 5 % of the total energy consumption in some countries (*Lupu and Lupu, 2000; Malnou et al., 2008*).

Fertilizing is one of the cultural practices that greatly affect crop production (60-70 %). Modern agricultural production cannot be imagined without the use of fertilizers, particularly in terms of the better utilization of plant biological yields (*Domuþa et al., 2004; Sãulescu et al., 2005; Zengin et al., 2009; Dawson and Hilton, 2011; Cociu, 2012; Šeremešić et al., 2019*). Without fertilizing, crop yields would be significantly reduced despite other cultural practices such as tillage, crop protection, irrigation, etc. The energy consumption of fertilizers claims a major share of the total energy consumption in crop production, approximating to 50 % (*Canakci et al., 2005*).

In agricultural practice, the nutritive value of fertilizers is assessed according to their impact on the increase in crop yields and the improvement of yield quality (*Lupu and Lupu, 2000; Malnou et al., 2008*). However, the energy flow in the production and application of fertilizers has been receiving increased attention, particularly the transport, storage and handling of fertilizers.

The objective of this study was to estimate the total amount of input-output energy in maize, sunflower, wheat, sugar beet and soybean production with an emphasis on the energy consumption and efficiency of fertilizer application.

MATERIAL AND METHOD

The energy consumption in crop production is defined as the energy used for the production of crops until they leave the field (*Safa et al, 2011*). The energy inputs estimated in this research are those allocated to farm production systems prior to storage and post-harvest activities. The experimental data were collected during the course of three-year field trials (2009 – 20012) conducted on the property of PKB Corporation "7 July" in Jakovo (Vojvodina, Serbia).

The method used for the energy efficiency analysis in the present study (*Ortiz-Canavate and Hernanz, 1999*) is based on the energy input analysis (namely direct and indirect energy inputs), the energy used for the production of a specific crop and the energy efficiency of such production. On the basis of sugar beet and wheat production outputs and the associated energy inputs, the specific energy input, the energy output-input ratio and the energy productivity were estimated as follows:

$$\text{Energy input/kg of pro. (EI)} = \frac{\text{energy input for prod.[MJ/ha]}}{\text{output [kg/ha]}} \quad (1)$$

$$\text{Energy out/in ration (ER)} = \frac{\text{energy value of prod.[MJ/ha]}}{\text{energy input for the prod.[MJ/ha]}} \quad (2)$$

$$\text{Energy productivity (EP)} = \frac{\text{prod.[kg/ha]}}{\text{energy input for the prod.[MJ/ha]}} \quad (3)$$

The regression and correlation analysis was used to determine the energy input/yield relation, the energy input for the fertilizer/yield relation and the energy input/output relation.

RESULTS AND DISCUSSION

The energy inputs for maize, sunflower, wheat, sugar beet and soybean production are presented in Table 1. The largest amount of energy was used in the sugar beet production considered (27.84 GJ/ha), whereas the lowest energy consumption per unit area was calculated in the soybean production considered (11.37 GJ/ha) (Fig. 1). *Gulistan et al. (2007)* reported that the energy needed for sugar beet production in Turkey amounted to 39.69 GJ/ha, with fertilizers accounting for 49.33 %. *Asgharipour et al. (2012)* found that the energy consumption in sugar beet production in Iran amounted to 42.23 GJ/ha, with fertilizers accounting for 29 %. *Ramedani et al. (2011)* established that a total of 18.03 GJ/ha are required for the soybean production in Iran, with diesel fuel, fertilizers and irrigation accounting for 66.67 %, 14.32 % and 6.18 % of the total energy consumption, respectively. *Abbas and Majid (2012)* reported similar results for Iran, i.e. an energy consumption of 29.90 GJ/ha with diesel fuel and fertilizers accounting for 67.47% and 9.5 %, respectively.

The energy consumption in the maize production considered was 19.38 GJ/ha. *Memon et al. (2012)* reported an energy input of 12.69 GJ/ha for the maize production in Pakistan, most of which was the energy allocated to fertilizers (10.65 GJ/ha). They also reported a high energy output of 83.11 GJ/ha, which contributed to the better overall energy efficiency. *Abdi et al. (2012)* recorded an energy consumption of 26.92 GJ/ha, whereas *Lorzadeh et al. (2011)* reported an energy input of 29.31 GJ/ha with fertilizers accounting for 48.25 %.

The energy consumption in the sunflower production considered was 15.21 GJ/ha. *Mousavi et al. (2012)* reported an energy input of 9.6 GJ/ha for the sunflower production in Iran, with a fertilizer share of 21.7 %. *Davoodi and Haushhyar (2009)* also reported an energy consumption of 22.95 GJ/ha for the production conditions of Iran, with fertilizers accounting for

Table 1. Energy input and output in maize, sunflower, wheat, sugar beet and soybean production

Input	Energy input in crop production (MJ ha $^{-1}$)				
	Maize	Sunflower	Wheat	Sugar beet	Soybean
Diesel fuel (l)	3,998.14	3,899.68	4,176.59	7,564.83	4,144.9
Kerosene (l)		189.62		200.13	
Labor (h)	11.44	27.87	15.70	19.28	11.52
Tractor (h)	492.36	1028.7	664.01	833.83	491.44
Combine (h)	41.48	36.22	42.36	63.39	42.36
Transport (h)	35.17	52.35	50.66	112.64	32.98
Machinery (h)	312.25	620.94	381.42	380.59	297.62
Manure (t)	2,890.56				
Nitrogen (kg)	9,744.54	5,746.59	11,599.50	11,899.20	4406.1
Phosphorus (kg)	347.49	301.0	480.67	778.74	311.79
Potassium (kg)	48.5	215.6	18.89	997.26	85.19
Insecticides (kg)		301.58	153.11	689.85	101.54
Fungicides (kg)			142.56	212.77	
Herbicides (kg)	1,236.81	2,620.38	154.31	3,330.41	1,105.91
Water (m^3)	0.68	98.06	0.07	1.74	1.16
Seeds (kg)	219.08	67.47	4,459.10	835.17	338.8
Total energy input (MJ ha^{-1})	19,378.5	15,206.06	22,339.00	27,848.92	11,371.28
Output (MJ ha^{-1})	53,207.04	33,963.42	63,499.60	809,044.0	79,948.99

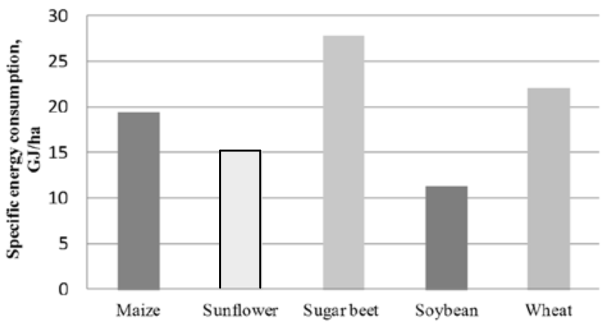

Fig. 1 Specific energy consumption in crop production

26.64 %. The results similar to those recorded in Serbia were reported in Turkey, i.e. an energy consumption of 18.93 GJ/ha with a fertilizer share of 51.28 % (*Uzunoz et al).*

The results obtained indicate that the energy needed for wheat production in Serbia is 22.34 GJ/ha. Acording to *Ramah and Baalij (2011)*, an energy input of 7.48 GJ/ha is required for the wheat production in Morocco, with a fertilizer share of 40.50 %. *Shanin et al. (2008)* stated that, under the production conditions of Iran, an energy input of 38.36 GJ/ha in needed for wheat production, with fertilizers accounting for 38.45 %. *Kardoni et al. (2013)* reported an energy input 35.61 GJ/ha and a fertilizer share of 47.30 % for the wheat production in Iran.

These energy inputs were higher compared to the results obtained in the present study due to irrigation.

As expected, the highest energy output was calculated for sugar beet production (809.04 GJ/ha), whereas the lowest energy output was calculated for sunflower production (33.96 GJ/ha).

On the basis of the correlation between energy inputs and crop yields (Tab. 2), positive regression coefficients were found in soybean and sugar beet production. Therefore, crop yield increases can be expected provided energy inputs are increased by 1 GJ/ha (in cases of soybean and sugar beet such increments would amount to 2.238 t/ha and 2.953 t/ha, respectively). However, an increase in energy consumption leads to lower yields in all other crops considered. A high correlation was found in all the crops considered, with the exception of maize and sunflower.

Table 2. Linear regression equation for the energy inputs and yields in crops production

Crop	Regression equation
Wheat	$\hat{y}_i = 8.450 - 0.182x_i$
Maize	$\hat{y}_i = 32.105 - 1.139x_i$
Soybean	$\hat{y}_i = -22.650 + 2.238x_i$
Sunflower	$\hat{y}_i = 1.844 - 0.031x_i$
Sugar beet	$\hat{y}_i = -34.028 + 2.953x_i$

According to the energy input structure shown in Table 1, indirect energy inputs (namely energy inputs for fertilizers, labor, machinery, water, chemicals and seed) accounted for most of the energy used in crop production. As expected, fertilizers claimed the largest share of the total energy consumption, ranging from 41 % in sunflower production up to 55.19 % in maize production (Fig. 2), followed by fuel and seeding material in wheat production.

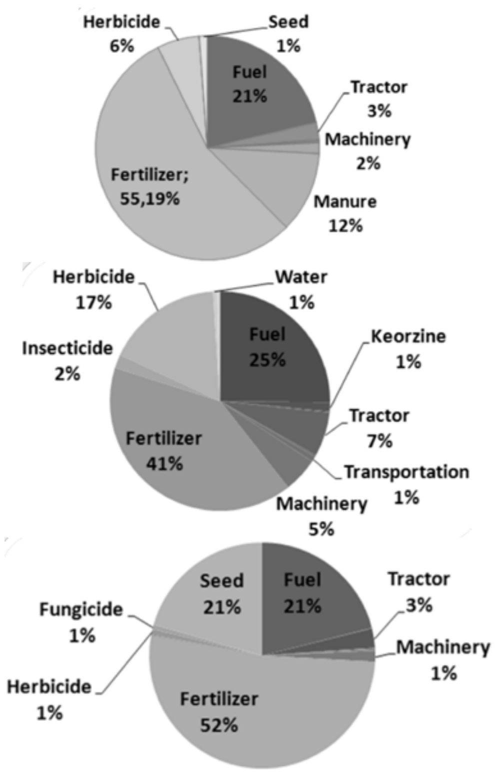

Fig. 2 Energy input share of the total energy consumption in maize, sunflower and wheat production

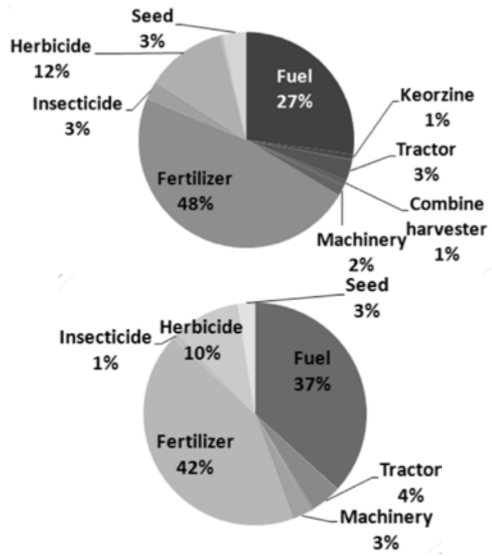

Fig. 3 Energy input share of the total energy consumption in sugar beet and soybean production

A strong functional correlation was found between the energy inputs for fertilizers and yields in all the crops considered, with the exception of soybeans. Linear regression equations (Tab. 3) indicate a positive correlation between the energy inputs for fertilizers and yields in maize, soybean and sugar beet production. As seen in Table 3, an increase of 1 GJ/ha in fertilizer energy inputs results in the following maize, soybean and sugar beet yield increments: 3.815 t/ha in maize production, 0.26 t/ha in soybean production and 3.88 t/ha in sugar beet production. In the case of sunflower production, the results obtained show that, at some point, yields were decreasing with the more intensive use of fertilizers. Therefore, the optimal plant nutrition must be set and followed because increased fertilizer application will not lead to the yield increment in sunflower production.

Table 3 Linear regression equations

	Fertilizer vs. yield energy	Energy input vs. energy output
Maize	$\hat{y}_i = -28.560 + 3.815x_i$	$\hat{y}_i = 322.184 - 10.581x_i$
Sunflower	$\hat{y}_i = 10.838 - 1.503x_i$	$\hat{y}_i = 46.298 - 0.795x_i$
Wheat	$\hat{y}_i = 6.489 - 0.165x_i$	$\hat{y}_i = 161.382 - 3.588x_i$
Sugar beet	$\hat{y}_i = -5.009 + 3.883x_i$	$\hat{y}_i = -571.781 + 49.616x_i$
Soybean	$\hat{y}_i = 1.119 + 0.260x_i$	$\hat{y}_i = -564.298 + 57.711x_i$

The results obtained also indicate that there is a functional correlation between the energy inputs and outputs in crop production. Linear regression equations (Tab. 3) show that there is a positive correlation between the energy inputs and outputs only in sugar beet and soybean production, indicating that only in these cases higher energy inputs lead to higher energy outputs. In all other crops considered, special care must be taken in balancing energy inputs. The specific energy input shows how much energy is spent for the yield produced. The results obtained indicate that the highest specific energy input relative to yield was recorded in sunflower production (11.58 MJ/kg), whereas the lowest specific energy input relative to yield was observed in sugar beet production (0.93 MJ/kg) (Fig. 4). The energy ratio was determined on the basis of energy inputs and outputs (*Ortiz-Canavate and Hernanz 1999*). If the energy ratio value is more than one, the system is generating energy.

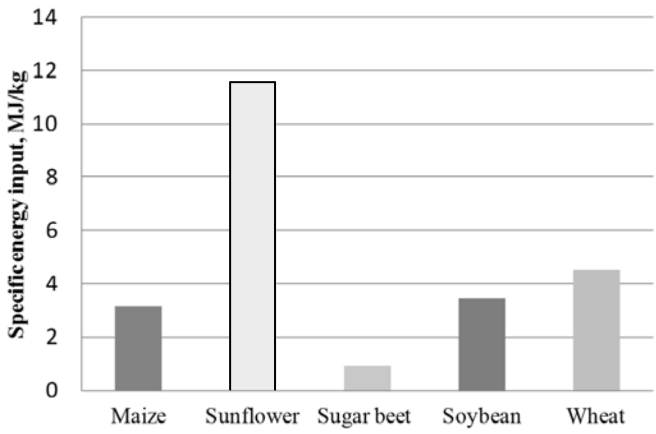

Fig. 4 Specific energy input in crop production

However, if the energy ratio is less than one, the system is losing energy (*Confroti and Gianpietro 1997*). The results obtained show that the production of all the crops considered is generating energy (Fig. 5).

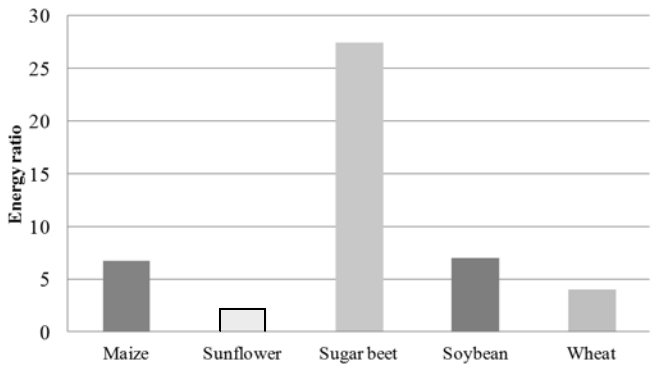

Fig. 5 Energy ratio in crop production

The lowest energy ratio was recorded in the sunflower production considered (2.25), whereas the highest energy ratio was observed in the sugar beet production considered (26.45).

Energy productivity (EP) is the measure of the amount of products obtained per unit of input energy. EP is specific for each agricultural product, location, and time (*Ortiz-Canavate and Hernanz 1999*). It can serve as an evaluator of how efficiently energy is utilized in different production systems that yield a particular product. The results obtained in this study show that sugar beet production is highly energy productive with an EP of 1.58 kg/MJ (Fig. 6). However, sunflower production was found to be the least energy productive of all the crops considered (0.09 kg/MJ).

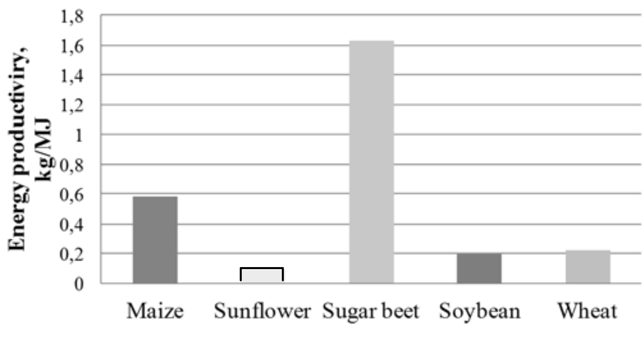

Fig. 6 Energy productivity in crop production

To improve the EP in crop production, it is possible either to reduce the energy sequestered in the inputs or to increase the yield of products. The quantity, quality and application uniformity of fertilizers can be utilized to improve the energy productivity in crop production as fertilizers participate in the total energy input with more than 40 % (*Gavrilović et al., 2018*). Table 4 shows how much energy is used for the handling and application of fertilizers, including fertilizer transport (trailer loading, transport and spreader loading), fertilizer application (fertilizer, tractor and spreader) and human labor.

Table 4. Energy input in fertilizer handling and application

Crop	Transpo. MJ/ha	Application, MJ/ha	Human labor, MJ/ha	Total, MJ/ha
Wheat	14.54	12,154.33	1.99	12,170.86
Maize	8.84	10,175.67	1.20	10,185.71
Sugar beet	12.45	13,732.66	1.70	13,746.81
Soybean	3.23	4,832.00	0.55	4,835.78
Sunflower	7.84	6,324.67	1.15	6,333.66

As expected, fertilizer application was found to be the most energy-consuming. Therefore, special attention should be devoted to fertilizer application to assure more energy productive and efficient crop production. As seen in Table 4, sugar beets are the most energy-consuming corps relative to fertilizer application, followed by wheat and maize.

CONCLUSION

Ecological, economic and energy efficiency are the principal requirements of sustainable agriculture. The energy consumption in agriculture has increased in recent years due to increased food demands and limited supplies of arable land. Fertilizers claim the largest share of the total energy consumption in crop production (exceeding 50 %). Higher energy inputs are introduced to generate higher yields. The objective of this paper was to examine the energy consumption in the production of predominant crops in Serbia.

The largest amount of energy was used in the sugar beet production considered (27.84 GJ/ha), whereas the lowest energy consumption per unit area was calculated in the soybean production considered (11.37 GJ/ha). As expected, the highest energy output was calculated for sugar beet production (809.04 GJ/ha), whereas the lowest energy output was calculated for sunflower production (33.96 GJ/ha). Fertilizers claimed the largest share of the total energy consumption in the crop production considered, ranging from 41 % in sunflower production up to 55.19 % in maize production. Moreover, a positive correlation was found between the fertilizers applied and the yields produced in maize, soybean and sugar beet production. The quantity, quality and application uniformity of fertilizers can be utilized to improve the energy productivity in crop production as fertilizers participate in the total energy input with more than 40 %.

Fertilizer application was found to be the most energy-consuming. Therefore, special attention should be devoted to fertilizer application in order to assure more energy productive and efficient crop production.

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