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ENERGY EFFICIENCY OF THE MINERAL FERTILIZER APPLICATION IN CEREAL PRODUCTION

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ABSTRACT

Cereal grains have represented the principal component of the human diet for thousands of years. Modern cereal production cannot be imagined without the use of mineral fertilizers, particularly in terms of better utilization of biological potential of the yield of growing plants. The aim of this study was to evaluate the energetic efficiency of wheat and barley production, with special reference to the share of the use of mineral fertilizers in total energy consumption. Input data and yield of wheat and barley fields were collected in the experimental trials in Serbia. Results showed that total energy inputs of wheat and barley fields were 22178.04 and15921.16 MJ·ha^{-1}, respectively. Total energy outputs for wheat and barley fields were 80037.83 and 104496.08 MJ·ha^{-1}, respectively. The results obtained indicate that mineral fertilizers claim a share of the total energy consumption in cereal production ranging from 49.19% in barley to 52.01% in wheat. Specific energy input, energy output–input ratio (energy use efficiency), energy productivity and net energy gain were 5.13 MJ·kg^{-1}, 3.61,0.19 kg·MJ^{-1} and57859.79MJ·ha^{-1}in wheat system and 2.75 MJ·kg^{-1}, 6.56, 0.36 kg·MJ^{-1} and 88574.92 MJ·ha^{-1} in barley system, respectively. According to the results, it seems that barley production is more efficient from different aspects of energy consumption compared to wheat in the studied region. In general, production in barley fields was more sustainable than wheat production because, in view of ecological indices such as amount of energy use and renewable energy consumption, it was more environment-friendly production.

Keywords: *Cereal production, mineral fertilizers, energy consumption, energy efficiency.*

INTRODUCTION

Cereal grains have represented the principal component of the human diet for thousands of years. Their processing comprises an important part of the food production chain, but it is a complex procedure (Zahid *et al*., 2010; Sahabi*et al*., 2012). Efficient use of energy helps to achieve increased production and productivity and contributes to the economy, profitability and competitiveness of agricultural sustainability of rural communities. Modern agricultural production of cereals cannot be imagined without the use of fertilizers, particularly in terms of better utilization of biological potential of the yield of growing plants (Sãulescu*et al*., 2005; Zengin *et al*., 2009; Dawson and Hilton, 2011; Klikocka *et al*., 2019). Otherwise, the yields would be significantly reduced, regardless of the application of all other agricultural practices such as tillage and crop protection. In current agricultural practice, nutritive value of fertilizers was evaluated on the basis of their impact on crop yield increase and the possibility of improving yield quality (Ryan, 2008). However, with the advancement of all sectors, including agriculture, more and more analyses are dedicated to the energy consumption in the production and application of fertilizers. Also, attention is given exceptionally and other processes in dealing with fertilizers such as transport, storage and handling of it and that also affects on the final energy balance (Ziaei, 2015). Share of agriculture in total energy consumption in some countries is very high, up to 5%. From these values of total energy consumption, the value which is built in fertilizers goes up to 50%. This is one of the key reasons why fertilization needs additional attention and rationalization, with the aim of not only economically effective, but also environmentally friendly production (Ozkan *et al*., 2004; Alluvione *et al*., 2011; Dimitrijević *et al*., 2020).

The aim of this study was to estimate the energy input and output in wheat and barley production and to analyse the distribution of different energy input utilized in the production.With these data it was possible to evaluate the influence of the energy input through the fertilizer on overall production energy efficiency.

MATERIALS AND METHODS

Energy consumption is defined through the energy input in wheat and barley production from the moment of soil tillage and preparation for sowing until wheat and barley grain leave the field (Roberts, 2008). This means that energy inputs for storage and post-harvest processes are not included in the energy balance calculation. The data were collected during the three-year field trials (2013/15) on the estate of PKB Corporation (Agricultural Corporation Belgrade) "7 July" Farm in Jakovo (Belgrade region, 44º43′06.42″ N; 20º15′37.68″ E, Serbia). It is situated on the left bank of the Sava river into a narrow band. Of the soil types are represented Humic Gleysols and aluvijum Dystric Fluvisols soil. Under the arable land belonging to the farm is 4011 ha that is used for crop production and animal husbandry. As for the seeding structure, the estate is oriented to wheat (535 ha), maize (1472 ha), maize hybrids (109 ha), silage maize (374 ha), barley (200 ha), soybean (553 ha), sunflower hybrids (10 ha), alfalfa (290 ha), sugar beet (400 ha) and meadows (68 ha). In this particular case presented energy investments and the yields of individual plots sown with wheat and barley, three seasons in a row.

The method used for energy efficiency analysis (Ortiz–Cañavate and Hernanz, 1999; Abrishambaf *et al*., 2019;Ghorbany *et al*., 2011) is based on the definition of directand indirect energy inputs, calculation of the energy output for given plant production. Based on these data in wheat and barley production specific energy input, energy output–input ratio, energy productivity and net energy gain were estimated as follows:

EI = EIP/Y,
ER = EOP/EIP,
EP = Y/EIP,
NEG = EOP - EIP

where: EI is the specific energy input ($MJ \cdot kg^{-1}$), EIP is the energy input in the production ($MJ \cdot ha^{-1}$), Y is yield ($kg \cdot ha^{-1}$), EOP is the energy output of the production ($MJ \cdot ha^{-1}$), EP is energy productivity ($kg \cdot MJ^{-1}$) and NEG is net energy gain ($MJ \cdot ha^{-1}$).

The energy inputs were calculated by multiplying the material input by the referent energy equivalent (Ozkan *et al*., 2004). The quantities of the material input were obtained directly from the farm managers. The input energy indices in agriculture are divided into 4 group of energy: direct energy, indirect energy, renewable energy and non-renewable energy (Wang, 2009).

The direct energy requirements are needed for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production, storage and the transport of agricultural inputs and outputs. Indirect energy needs are in the form of sequestered energy in fertilizers, herbicides, fungicides and insecticides (FAO, 2000). So energy indices divided into following groups (Mobtaker *et al*., 2010; Abdi *et al*., 2012): direct energy - human power, diesel fuel, water and electricity; indirect energy - chemicals, fertilizers, seeds and machinery; renewable energy - human power, seeds, manure fertilizers and irrigation waterand; non-renewable energy - diesel fuel, electricity, chemical fertilizers, herbicides, insecticides, fungicides and machinery.

The energy outputs are determined based on the yield of cultivated plants upon completion of the production cycle and the corresponding energy equivalents.

RESULTS AND DISCUSSION

Energy inputs and energy outputs in wheat production are shown in Table 1. The values represent the average values of data collected within the three-year period. As it can be seen, average energy consumption was 22178.04$MJ \cdot ha^{-1}$.

Table 1. Energy consumption in wheat production

Energy	Quantity per unit area (ha)	Total energy equivalent (MJunit⁻¹)	Percentage of total energy input (%)
Input			
Human labor (h)	7.25	15.70	0.07
Tractor (h)	7.25	664.01	2.76
Combine (h)	0.48	42.36	0.19
Transport (h)	1.70	50.66	0.23
Other Machinery (h)	6.08	381.42	1.56
Diesel fuel (l)	87.38	4176.61	21.07
Nitrogen (kg)	174.59	11599.54	49.23
Phosphate (P_2O_5) (kg)	38.10	474.01	2.78
Insecticides (kg or l)	0.19	18.89	0.10
Fungicides (kg or l)	0.66	142.56	0.65
Herbicides (kg or l)	0.64	153.11	0.78
Water for irrigation (m^3)	0.07	0.07	0.01
Seeds (kg)	303.34	4459.10	20.57
Total energy input (MJ)		22178.04	100.00
Outputs			
Seed yield (kg)	4321.97	63532.91	79.82
Straw yield (kg)	1320.39	16504.92	20.18
Total energy output (MJ)		80037.83	100.00
Energy use efficiency		3.61	

*Source: Author's elaboration based on the questionnaire survey results

Based on the data given in Table 1 we see that the largest amount of energy was consumed over fertilizers.The percentage was 52.01%. The chemical composition of a plot was such that nitrogen was most needed. The fuel energy ranked second with a share of 21.07%. Seeding material within energy input had its share of 20.57% in total energy consumption. Water displayed is the water consumed trough the plant protection and therefore percentage is small. There is no irrigation. Based on the energy analysis we have the following results:

$$EI= 5.13\ MJ\cdot kg^{-1};\ ER= 3.61;\ EP= 0.19\ kg\cdot MJ^{-1};\ NEG = 57859.79 MJ\cdot ha^{-1}$$

Energy inputs and energy outputs in barley production are shown in Table 2. The values represent the average values of data collected within the three-year period. As it can be seen, average energy consumption was 15921.16 $MJ\cdot ha^{-1}$.

Table 2. Energy consumption in barley production

Energy	Quantity per unit area (ha)	Total energy equivalent (MJunit⁻¹)	Percentage of total energy input (%)
Input			
Human labor (h)	6.66	13.06	0.08
Tractor (h)	5.91	541.84	3.38
Combine (h)	0.85	74.49	0.46
Transport (h)	3.03	90.20	0.56
Other Machinery (h)	3.76	235.75	1.47
Diesel fuel (l)	82.40	3938.88	26.23
Nitrogen (kg)	108.75	7225.57	45.00
Phosphate (P_2O_5) (kg)	36.66	456.01	2.80
Potassium (K_2O)	19.56	218.13	1.39
Insecticides (kg or l)	0.22	22.60	0.14
Fungicides (kg or l)	0.64	137.52	0.84
Herbicides (kg or l)	0.62	148.02	0.96
Water (m^3)	0.18	0.18	0.01
Seeds (kg)	191.74	2818.91	16.68
Total energy input (MJ)		15921.16	100.00
Outputs			
Seed yield (kg)	5781.04	84981.29	86.37
Straw yield (kg)	1561.18	19514.79	13.63
Total energy output (MJ)		104496.08	100.00
Energy use efficiency		6.56	

*Source: Author's elaboration based on the questionnaire survey results

According to the results presented in Table 2, the share of fertilizers in the energy balance is lower than in wheat production. Percentage was 49.1%. The fuel energy ranked second with a share of 26.23%. Seeding material within energy input had its share of 16.68% in total energy consumption. Water displayed is the water consumed trough the plant protection and therefore percentage is small. There is no irrigation. The analysis of energy consumption gave the following results:

$$EI= 2.75\ MJ\cdot kg^{-1};\ ER= 6.56;\ EP= 0.36\ kg\cdot MJ^{-1};\ NEG = 88574.92\ MJ\cdot ha^{-1}$$

The amount of energy efficiency of barley fields was obtained higher than wheat fields respectively 6.56 and 3.61. This means that per each unit of energy consumption in the fields of wheat and barley, 6.56 and 3.61 yield units is, respectively, achieved. The amount of energy productivity for two different crops has been reported as 0.19 for wheat and 0.36 for barley. Energy productivity is an almost better parameter in comparison to energy efficiency to compare two different crops on the two different plots from the point of the production of a plant. Because difference in energy efficiency can be due to difference in energy input and yield, it will make it a bit difficult to judge. But energy productivity index calculates the ratio of production yield per kg into consumer energy and better shows the difference between the two crops from same plant family. The amount of specific energy and net energy in wheat production obtained was5.13 $MJ \cdot kg^{-1}$and 57859.79$MJ \cdot ha^{-1}$, respectively; in barley 2.75 $MJ \cdot kg^{-1}$and 88574.92 $MJ \cdot ha^{-1}$, respectively.

CONCLUSIONS

Task of agricultural production is not just to produce the food. Above all, it must be a cost-effective, profitable and must meet certain environmental standards. It is necessary to constantly increase soil fertility, particularly through application of fertilizers and then watering, as well trough the creation of new varieties and hybrids of plants. We should take into account not only energy efficiency of agricultural production, but also environmental protection.

On the basis of the above research results, it can be concluded that the reduction of use of mineral fertilizers effects on the yield decline. In this case, barley production is more efficient from different aspects of energy consumption compared to wheat in the studied region. In general, production in barley fields was more sustainable than wheat production because, in view of ecological indices such as amount of energy use and renewable energy consumption, it was more environment-friendly production. The fact is that without the use of fertilizers we have not sustainable production. Of course, this practice should not be abolished, but it should be adjusted to the optimal value of application. Losses are not extremely high, production will be energy cost-effective and environmental impact will be significant in a positive way. Energy should be transfered to investments at irrigation, better machinery management technique, integrating the legume crops into the rotation and some other good agricultural practices. All of this may be the options to increase the energy use efficiency of cereal production and way to reduce the environmental pollution.

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