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Energy efficiency in pea organic production

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Absract

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Efficient use of energy in agriculture will minimize environmental problems, prevent the degradation of natural resources and improve sustainability. The purpose of this study was to determine the energy use in pea organic production and to compare it with conditions of conventional production through the following parameters: energy value of forage, energy input/output, energy efficiency. The organic system included eight variants with alone and combined application of organic nanoferilizers Lithovit (2000 g ha^{-1}) and Nagro (500 ml ha^{-1}), and bioinsecticides Madex (600 ml ha^{-1}) and Agricolle (1000 ml ha^{-1}).

They are compared with a conventional system (three variants with alone and combined application of synthetic fertilizer Kristalon (5000 g ha^{-1}) and insecticide Proteus (600 ml ha^{-1}) as well as with a control variant. The results showed that pea growing in organic production conditions required energy inputs of 8580.65 MJ ha^{-1}. The obtained energy had increased values (96582.87 MJ ha^{-1} for GE, 55916.47 MJ ha^{-1} for ME and 32972.42 MJ ha^{-1} for NE) and differences from 10.3 to 38.1% compared to the control. In conventional growing, energy consumption and energy outputs were similar to those in organic growing, especially regarding ME and NE. The close values of energy input and output in the organic and conventional production determined and close coefficients of energy efficiency for both productions (11.08 and 11.06). As the most energy efficient variant can be determined the combined application of Lithovit and Madex which increased the energy efficiency by 26.7% (for GE) compared to the control. With high efficiency was distinguished also the alone treatment with organic fertilizer Lithovit (20.8%) and the organic combination of Nagro with Madex (19.7%). Under conventional production, maximum energy efficiency was found in the synthetic combination of Kristalon with Proteus, whose effect was equivalent to that of the organic fertilizer Lithovit.

Keywords: pea; energy; efficiency; organic production
Abbreviations: GE – gross energy; ME – metabolizable energy; NE – net energy

Introduction

Agriculture is becoming an increasingly energy dependent sector due to the considerable inputs of resources (Ghahderijani et al., 2013). It is both a consumer and a producer of energy (Kizilaslan, 2009). Through photosynthesis, plants convert solar energy into biomass, thus ensuring food, forage and fibers (Ozkan et al., 2004; Alam et al., 2005). The increase in energy consumption in agriculture is a result of the growing world population and the limited area of arable land (Rafiee et al., 2010). The continuous increment in food production requires an intensive use of fertilizers, pesticides, machinery and other natural resources (Urban et al., 2007).

On the other hand, intensive use of energy leads to problems endangering human health and the environment (global warming and climate change) (Urban et al., 2007). Overall, the high share of non-renewable energy sources (fertilizers, pesticides, fuels) consumed in crop production results in greater environmental pollution. In order to convert the agriculture into environmentally friendly and to reduce the share of non-renewable energy sources, it is recommended to use more farmyard manure, green manure and organic products (Ghahderijani et al., 2013).

According to Esengun et al. (2007), the efficient use of energy in agriculture will minimize the environmental problems, preserve the natural resources from degradation of and improve sustainability. A challenge in energy policy is to reduce energy inputs and to obtain more energy (Karbassi et al., 2007). The ratio of energy outputs to energy inputs is used to determine the effect of production systems on the environment and also the energy efficiency (Ozkan et al., 2004).

Studies related to the energy efficiency determination have been conducted in crops such as cotton (Singh et al., 2002), sugar cane (Karimi et al., 2008), fodder corn (Pishgar et al., 2011), tomatoes (Hatirli et al., 2006), soybeans (Chamsing et al., 2006), vetch (Georgieva et al., 2016) etc. Peas, beans, chickpeas and all species of the Leguminosae family, are very important, especially in those regions of the world where animal products are insufficient or expensive, or where, for religious or other reasons, animal meat is avoided. Most legumes have a high content of carbohydrates (55% – 60%) and protein (20% to 30%) (Pimentel and Pimentel, 2008), and their biomass is high-quality feed for livestock. Leguminous crops are also defined as key crops for organic farming conditions (European Commission, 2011), due to their favorable effect on the next crops in crop rotation and soil fertility improvement.

The purpose of this study was to determine the energy efficiency of different variants of pea organic production and to compare it with conventional growing conditions.

Material and Methods

Experimental design

The experimental activity was conducted at the Institute of Forage Crops (Pleven) during the period 2015-2017. The randomized block method was used, with three replications and a size of the plot of 10 m^2. Sowing was carried out at the end of March, at a rate of 120 seeds per m^2, with cultivar Pleven 4. Eight variants of organic production were studied under alone and combined application of organic products (leaf fertilizers and insecticides). As leaf fertilizers of organic base were used nano products containing a complex of nutrients. The organic insecticides applied in the experiment were on plant and microbial basis. As comparative characteristics, variants of conventional production using synthetic products (leaf fertilizer and insecticide) were included in the experiment. **Variants:** 1. Control (untreated); *Organic production* (OP) – 2. Lithovit (2000 g ha^{-1}) (CO_2 nano-fertilizer), 3. Nagro (500 ml ha^{-1}) (organic nano-fertilizer containing macro and microelements), 4. Madex (600 ml ha^{-1}) (microbial based bioinsecticide), 5. Agricolle (1000 ml ha^{-1}) (plant based bioinsecticide), 6. Lithovit + Madex (2000 g ha^{-1} + 600 ml ha^{-1}), 7. Lithovit +Agricolle (2000 g ha^{-1} + 1000 ml ha^{-1}), 8. Nagro + Madex (500 ml ha^{-1} + 600 ml ha^{-1}), 9. Nagro + Agricolle (500 ml ha^{-1} + 1000 ml ha^{-1}); *Conventional production* (CP) – 10. Kristalon (5000 g ha^{-1}) (synthetic fertilizer, with macro and trace elements), 11. Proteus (600 ml ha^{-1}) (synthetic insecticide, active substances: thiacloprid 100 g/l and deltamethrin10 g/l), 12. Kristalon + Proteus (5000 g ha^{-1} + 600 ml ha^{-1}).

E*nergy value calculation*

The energy assessment of pea production was based on the determination of the following parameters: energy value, energy input, energy output and energy efficiency. The energy value (determined as gross energy (GE), metabolizable energy (ME) and net energy (NE) in MJ kg^{-1} DM) was calculated on base of chemical composition (crude protein, crude fiber, crude fat, ash) and digestibility coefficient (Todorov et al., 2007).

E*nergy input/output and energy efficiency estimation*

The energy inputs were calculated as follows: for human labour and mechanization – by Yaldiz et al. (1993) and Ozkan et al. (2004) respectively; for diesel fuel – by coefficient of Ozkan et al. (2004); energy equivalents for bioproducts, synthetic fertilizers and insecticides – according to Yaldiz et al. (1993), Bhat et al. (1994) and Tzilivakis et al. (2005) respectively; and energy equivalent for seeds – by coefficient of Zhelyazkova (2007).

The energy output was calculated on base of dry matter yield (DM) obtained and its content of gross energy, metabolizable energy and net energy in kg DM.

The energy efficiency was determined by the coefficient of Pimentel et al. (1983) as a ratio of the energy value of the final product P (MJ ha^{-1}) and the energy spent for its production E (MJ ha^{-1}): $R = P / E$.

Results

The used products did not have a substantial impact on the energy value of pea forage as the averages for GE, ME and NE were 19.59, 11.45 and 6.17 MJ kg^{-1} DM, respectively (Table 1). Regarding GE, maximum was recorded under treatment with the combination of Lithovit and Madex (19.79 MJ kg^{-1} DM), and in terms of ME and NE – after treatment with Agricolle (11.54 **и 6.79** MJ kg^{-1} DM). The data showed slight differences in the energy value of the forage in the different variants, and therefore no conclusions could be drawn related to the use of a particular product or production system.

Table 1. Energy value of pea biomass, MJ kg^{-1}

Varints	GE	ME	NE
Control	19.42	11.45	6.73
Organic production			
Lithovit	19.62	11.42	6.69
Nagro	19.64	11.41	6.69
Madex	19.59	11.42	6.69
Agricolle	19.52	11.54	6.79
Lithovit + Madex	19.79	11.41	6.67
Lithovit + Agricolle	19.56	11.51	6.76
Nagro + Madex	19.69	11.39	6.67
Nagro + Agricolle	19.55	11.37	6.66
Conventional production			
Kristalon	19.44	11.52	6.78
Proteus	19.46	11.44	6.72
Kristalon + Proteus	19.64	11.47	6.73

The yield of GE under conditions of different variants of organic cultivation demonstrated a considerable increase compared to the control, with a variation of 10.3 (Agricolle) to 38.2% (Lithovit + Madex) (Table 2). High values were also established under the combinations Nagro + Madex and Lithovit + Agricolle, which provided a rising in the yield of GE with 29.3 and 30.7%. Under conventional pea cultivation, the used synthetic products provided an increase in the values of the indicator considered by 17.7 (Kristalon) to 30.7% (Kristalon + Proteus). With regard to the yield of ME and NE, similar trends were observed, with maximums in the above-mentioned variants. On average, in organic production, the yields of ME and NE were 56195.84 and 32939.61 MJ ha^{-1} respectively, in relevant values for the conventional production of 55749.53 and 32755.22 MJ ha^{-1}. As a whole, the use of organic products provided an average 23.4% increment in the yield of GE, ME and NE, and the use of conventional ones – by 22.2%.

Pea growing without application of organic and synthetic products required energy inputs of 7981.27 MJ ha^{-1} (Figure 1). The alone application of organic fertilizers and insecticides, which were the subjects of this study, raised the amount of energy inputs by 3.8 to 8.8%. The data showed that higher energy inputs were needed for application of bio-insecticides than for organic fertilizers due to their higher

Table 2. Yield of GE, ME and NE in pea production, MJ ha^{-1}

Variants	GE	ME	NE
Control	77448.30	45670.45	26843.85
Organic production			
Lithovit	96110.46	55939.12	32769.94
Nagro	94811.57	55087.08	32299.09
Madex	88963.56	51866.65	30384.23
Agricolle	85454.48	50511.94	29720.63
Lithovit + Madex	106997.06	61702.03	36069.46
Lithovit + Agricolle	100175.19	58935.62	34613.80
Nagro + Madex	101250.68	58582.00	34305.70
Nagro + Agricolle	97903.62	56942.25	33354.04
Conventional production			
Kristalon	91180.90	54035.91	31802.38
Proteus	92026.96	54089.01	31772.56
Kristalon + Proteus	101231.92	59123.69	34690.71

energy equivalent. Under combined use of organic products (Lithovit + Madex, Lithovit + Agricolle, Nagro + Madex, Nagro + Agricolle), the energy inputs increased on average by 8.5 to 11.0%, which was determined by the greater amount of biomass and the energy needed for its harvesting and transport. The average quantity of energy inputs in organic production for the experimental conditions was 8580.65 MJ ha^{-1}. Comparison with the energy consumption of synthetic products (leaf fertilizer Kristalon and insecticide Proteus, as well as their combination) showed a slightly lower value (on average by 2.0%), mainly due to the smaller quantities of biomass obtained from these variants.

The received biomass of forage pea provided 96582.87 MJ ha^{-1} gross energy in organic production conditions (Table 3). The metabolizable energy and net energy were 55916.47 and 32972.42 MJ ha^{-1}, respectively. Considering the energy

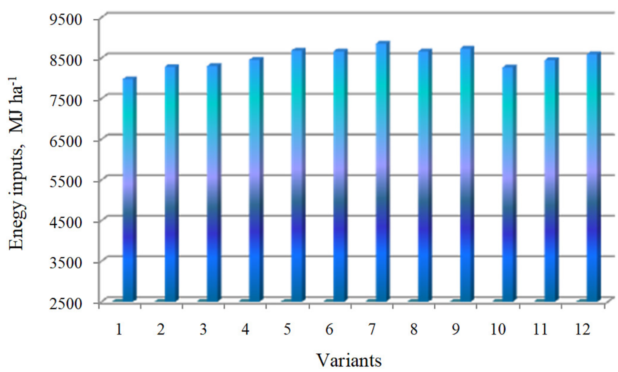

Fig. 1. Enegy inputs in pea production, MJ ha^{-1}

1. Control, 2.Lithovit, 3. Nagro, 4. Madex, 5. Agricolle, 6. Lithovit + Madex, 7. Lithovit + Agricolle, 8. Nagro + Madex, 9. Nagro + Agricolle, 10. Kristalon, 11. Proteus, 12. Kristalon + Proteus

obtained, depending on the type of products, a considerably higher amount was obtained after using the organic nano-fertilizers (95460.43 BE MJ ha^{-1}) compared to the bioinsecticides (87208.76 BE MJ ha^{-1}), with a difference of 9.5% on average. On the other hand, the combined application compared to the alone application of products can be defined as a measure, ensuring a higher energy output, on average by 11.5%. The highest values of GE, ME and NE were found after treatment with the organic combination Lithovit and Madex at an excess of 38.1, 30.3 and 34.4%, respectively, relative to the control.

Table 3. Energy outputs in pea production, MJ ha^{-1}

Variants	GE	ME	NE
Control	77448.19	45672.32	26858.23
Organic production			
Lithovit	96109.27	55915.74	32776.01
Nagro	94811.58	55084.29	32278.09
Madex	88964.87	51851.49	30406.67
Agricolle	85452.65	50510.05	29715.85
Lithovit + Madex	106994.40	50510.05	36091.06
Lithovit+ Agricolle	100177.08	58940.07	34639.37
Nagro + Madex	101249.70	58592.10	34306.50
Nagro + Agricolle	97903.40	56927.99	33365.82
Conventional Production			
Kristalon	91179.61	54041.96	31815.61
Proteus	92028.00	54089.80	31780.01
Kristalon + Proteus	101233.75	59132.60	34695.50

The energy obtained of pea biomass in conventional growing had values close to those in organic growing, especially regarding ME and NE (average 55754.79 MJ ha^{-1} ME and 32763.71 MJ ha^{-1} NE). In this case, the combined application compared to the alone application can also be defined as a measure providing a higher energy output with the biomass (on average by 10.5%), but unlike OP there were no differences determined by the type of product used (synthetic fertilizer or insecticide).

The amount of energy obtained in the pea production was higher than the energy inputs, which determined the energy balance in all variants as positive (Table 4). The coefficient of energy efficiency for organic production conditions was 11.08 (for GE), 6.29 (for ME) and 3.78 (for NE), with values in CP of 11.06, 6.48 and 3.81, respectively. The combined application of Lithovite + Madex was the most effective, resulting in an increase of the coefficient (for GE) by 26.7% compared to the control variant. The highly effective was also the treatment with organic nanofertilizer Lithovit (which was equivalent to the synthetic combination Kristalon + Proteus (20.8%)) and organic combination Nagro + Madex (19.7%). The lowest energy-efficient variant, with a value close to that of the control, was the use of bioinsecticide Agricolle. The low energy efficiency in this variant was determined by both its high energy equivalent and the smaller quantity of plant biomass.

Table 4. Coefficient of energy efficiency (R) in pea production

Variants	R			%		
	GE	ME	NE	GE	ME	NE
Control	9.60	5.62	3.30	100.0	100.0	100.0
Organic production						
Lithovit	11.60	6.75	3.96	120.8	120.1	119.9
Nagro	11.23	6.50	3.80	116.9	115.6	115.3
Madex	10.38	6.04	3.54	108.1	107.35	107.2
Agricolle	9.68	5.73	3.37	100.8	101.9	102.1
Lithovit + Madex	12.17	5.74	4.08	126.7	102.0	123.6
Lithovit + Agricolle	11.10	6.52	3.83	115.5	116.0	116.1
Nagro + Madex	11.48	6.59	3.85	119.6	117.2	116.6
Nagro + Agricolle	11.02	6.42	3.77	114.7	114.2	114.1
Conventional production						
Kristalon	10.86	6.42	3.78	113.1	114.2	114.4
Proteus	10.71	6.28	3.69	111.6	111.8	111.8
Kristalon + Proteus	11.60	6.75	3.96	120.8	120.1	119.9

Discussion

The energy value of forage is of essential meaning for animal husbandry. Energy feeding value is a major criterion for a modern assessment of the quality of the forage biomass (Todorov et al., 2007). The total energy value (gross energy) presents the calorific value of the feed in complete burning. Animals do not use fully the potential energy of the forage because a significant part of it is lost with indigestible fiber components, intermediate metabolism, etc. The amount of metabolizable energy is the physiologically useful energy for animals, and net energy is the productive energy, i.e. for production of meal, meat, etc (Todorov et al., 2001). On average for experimental conditions, ME constituted 58.5% of the total energy content of the biomass (Table 1). In the cultivation of spring pea for grain, Glogova and Nankov (2003) reported that ME represented 68.0% of GE. A slightly higher value (70.9%) was pointed by Gerdzhikova et al. (2012) in winter pea grown for grain. In addition, Gerdzhikova et al. (2012) have found that the agricultural method of production (organic or conventional) does not affect the energy value of winter pea. The authors received values of 19.29 and 19.27 MJ kg-1 DM, respectively in organic and conventional production. Concerning the use of different products, the differences between the variants were also inconsiderable. The data supported the established by Zhelyazkova (2007) almost constant values (17.62 to 17.68 MJ kg^{-1} DM for GE) in the energy value of spring pea biomass after treatment with growth regulators based on auxins and microelements.

According to Klimeková and Lehocká (2007), the pea is a crop with low energy consumption, unlike maize, which is defined as the most energy-dependent crop. By comparing organic and conventional pea production, Arthurson & Jäderlund (2011) found energy inputs of 7.4 and 10.4 GJ ha^{-1}, and energy efficiency of 12.8 and 9.4, respectively. Klimeková and Lehocká (2007) stated, the energy efficiency, calculated on the basis of energy profit, had close values of 0.92 and 0.89 for OP and CP, respectively. In different variants of pea conventional growing (for biomass), Zhelyazkova and Pavlov (2008) indicated an average amount of energy inputs of 20563.3 MJ ha^{-1}, energy outputs (as GE) of 126198.7 MJ ha^{-1} and energy efficiency (as GE) of 6.1. Under present experimental conditions, in conventional production, the energy input was considerably less (8437.4 MJ ha-1) (Figure 1), mainly due to the lack fertilization with nitrogen, phosphorus and potassium and minimal soil treatments, and the energy output and energy efficiency were 94813 MJ ha^{-1} and 11.06, respectively (Table 3 and 4). According to Cormack (2000), comparing and summarizing the results of the various studies is difficult by the fact that there is no "hard and fast" definition of "conventional" production system. Factors such as soil type, climate, farm type and size, etc. can also have an essential impact on the yield and use of energy (Shepherd et al., 2003).

Long-standing researches of Stancheva (2000) showed low energy efficiency in modern intensive agriculture. Agricultural production is approaching the point at which the energy costs and outputs will be equalized. Therefore, the question of energy efficiency in agriculture is of paramount importance. According to some researchers (Hansen et al., 2001; Gomiero et al., 2008), OP had better energy efficiency than CP in absolute terms, but according to others (Mondalaer et al., 2009), based on a production unit, efficiency was the same for both systems. It also appears that different crops use different quantities of energy in conventional and organic growing. Bos et al. (2007) found that sugar beets and beans were more effective under the organic system, while potatoes, onions and lettuce – in the conventional system. Our results showed that the energy efficiency of different variants of OP in pea had an average value of 11.08, which was almost identical to that of CP (11.06) (Table 4). In comparison with the control variant, the efficacy was highest under the combined application of organic nano-fertilizer Lithovit and bioinsecticide Madex (12.17 for BLE), followed by alone use of Lithovit (11.60) and the synthetic combination Kristalon and Proteus (11.60). It is not necessary to put organic and conventional agriculture against each other, but to search for energy-efficient variants and opportunities for both systems. Efficient use of energy is one of the conditions for sustainable agricultural production as it will provide low consumption of non-renewable resources and reduce environmental pollution (Pervanchon et al., 2002). In the future, energy-efficient agriculture can also be achieved by integrating organic and conventional forms of farming. Combining small quantities of mineral fertilizer with useful microorganisms to increase nutrient uptake would help for optimal crop yields without considerable consumption of available environmental resources (Arthurson & Jäderlund, 2011).

Conclusions

Pea growing in organic production conditions and use of organic nanofertilizers and bioinsecticides (Lithovit, Nagro, Madex, Agricolle) alone and in combinations, required energy inputs of 8580.65 MJ ha^{-1}. The obtained energy had increased values (96582.87 MJ ha^{-1} for GE, 55916.47 MJ ha^{-1} for ME and 32972.42 MJ ha^{-1} for NE) and differences from 10.3 to 38.1% compared to the control variant.

In conventional growing of pea and use of synthetic fertilizer and insecticide (Kristalon and Proteus), energy consumption and energy outputs were similar to those in organic growing, especially regarding ME and NE.

The amount of energy outputs in the pea production was higher than the energy inputs, which determined the energy balance in all studied variants as positive. The close values of energy input and output in the organic and conventional production determined and close coefficients of energy efficiency for both productions.

As the most energy efficient variant can be determined the combined application of Lithovit and Madex which increased the energy efficiency by 26.7% (for GE) compared to the control. With high efficiency was distinguished also the alone treatment with organic fertilizer Lithovit (20.8%) and the organic combination of Nagro with Madex (19.7%). Under conventional production, maximum energy efficiency was found in the synthetic combination of Kristalon with Proteus, whose effect was equivalent to that of the organic fertilizer Lithovit.

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