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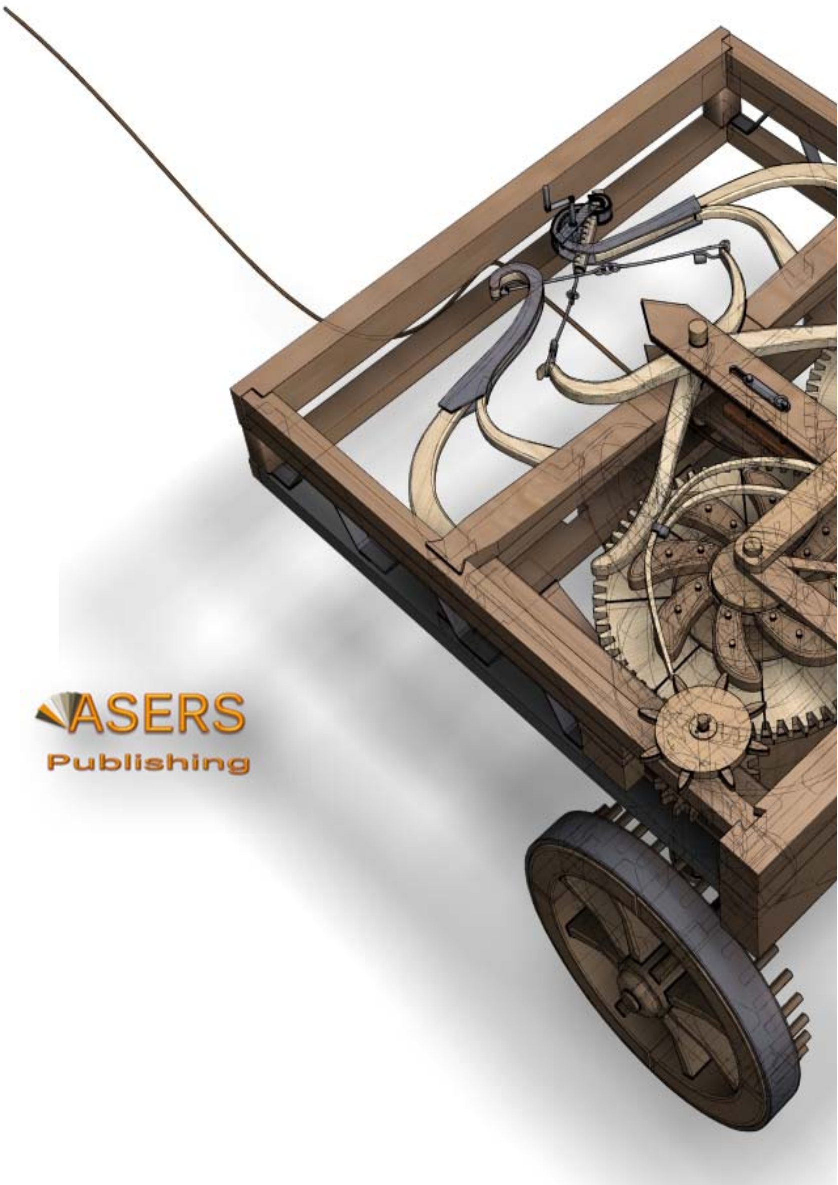

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Journal of Environmental Management and Tourism is an interdisciplinary research journal, aimed to publish articles and original research papers that should contribute to the development of both experimental and theoretical nature in the field of Environmental Management and Tourism Sciences.

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Efficiency of Using Biomass from Energy Crops for Sustainable Bioenergy Development

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Abstract:

The need to study energy crops as an alternative source of energy for providing the population and rural development is justified in the article. In the course of the study, the following methods were used: laboratory – to determine the moisture content in the phytomass, field – to determine the quantitative indicators of plants and biomass productivity, special – to determine the energy and economic efficiency of biomass production. Features of yield formation and yield of dry biomass of energy crops by quantitative indices of plants were determined. The economic and energy efficiency of biomass production, as well as the output of solid biofuel, its energy intensity and energy output have been calculated. A logistic scheme for biomass cultivation including the use and supply of biomass from biomass energy crops (from producer to consumer) has been developed. It has been found that switchgrass and giant miscanthus of the third to fifth year of vegetation form a high yield of dry biomass (up to 15.2 and 18.8 t / ha, respectively) with a maximum level of production profitability - up to 108.6% and 128.1%, provide high indicators of biofuel output (up to 18.2 and 24.0 t / ha) and energy (up to 313.0 and 396.0 GJ / ha) with an average level of energy efficiency coefficient (Kee> 4.5).

Keywords: switchgrass; giant miscanthus; biomass yield; profitability level; energy efficiency ratio.

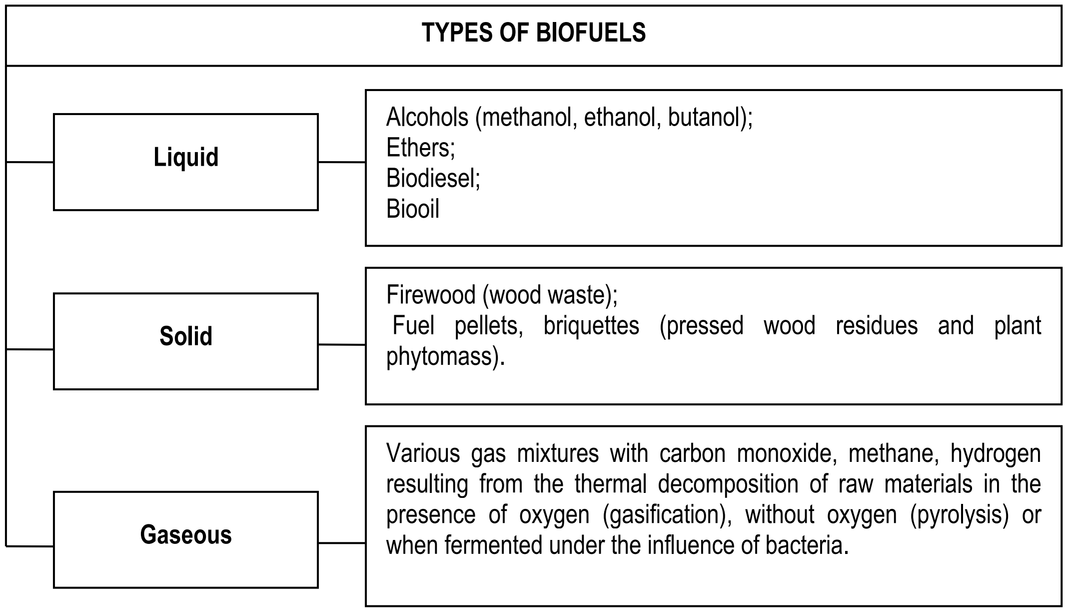
JEL Classification: N54; Q01; Q20.

Introduction

Currently, in Ukraine, and in developing countries, one of the priorities for the effective functioning of the national economy is to reduce energy dependence on external energy sources based on the development of the bioenergy sector. The cultivation and use of special plants for biofuel purposes is an efficient measure of the effective functioning of energy sufficient rural areas. These plants are called energy crops, they are mainly perennial, well adapted to growing conditions, able to form high biomass productivity (Kulyk 2017). Energy crops biomass is characterized by a low content of chemical elements, contains a significant amount of lignin and cellulose, in some plants - sugar and starch, and is an excellent feedstock for the production of energy-intensive biofuels (Roik *et al.* 2015).

Energy crops include herbaceous plants, shrubs, fast-growing trees, or other plant species whose phytomass can be used as a feedstock for biofuel production (Kulyk 2015) (Figure 1).

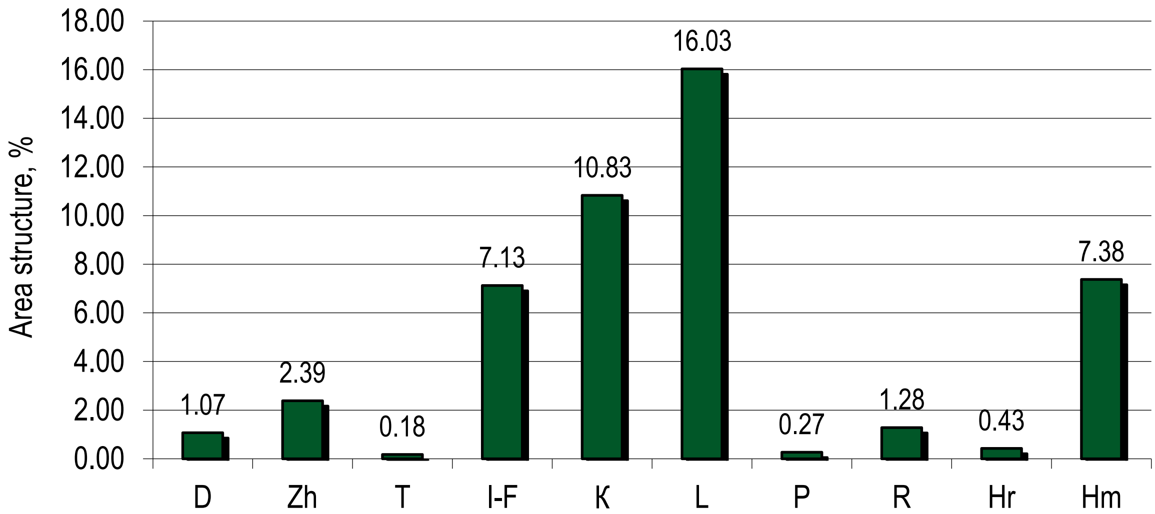
Figure 1. Types of biofuels from energy crops



Source: developed by the authors.

In Ukraine, energy crops are grown on areas of more than 4 thousand hectares, of which the largest areas are planted with willow (more than 2 thousand hectares) and miscanthus (more than 750 hectares). The largest areas under energy crops are concentrated in the Vinnitsa region (53.02%), much less in the Lviv (L), Kiev (K), Ivano-Frankivsk (I-F) and Khmelnitsky regions (Hm), in other areas - less than 100 ha (Figure 2).

Figure 2. The structure of areas under energy crops in Ukraine,%



Note: D – Dnepropetrovsk region, Zh–Zhytomyr region region, T – Transcarpathian region, I-F – Ivano-Frankivsk region, K – Kiev regions, L –Lviv region, P – Poltavaregion, R – Rivne region, Hr –Kharkiv region, Hm – Khmelnytsky region.
Source: composed by the authors according to the data of State Statistics Service of Ukraine, *Geletukha et al* (2014)

According to the complex of adaptive properties, economically useful traits and productivity potential, energy crops distinguish such cultivars as switcgrass (Panicum virgatum L.) and giant miscanthus (M. × giganteus) (Kulyk, 2017) (Figure 3).

Figure 3. Energy crops

Switchgrass

Giant miscantthus

Source: Photo by the authors.

On average, in the conditions of Ukraine, the yield of dry biomass of switchgrass and giant miscanthus can reach from 15 to 30 tons per 1 ha with the energy intensity of raw materials 17-18 MJ / kg (Kurylo *et al.* 2018). In addition to biofuel advantages these energy crops have the following directions of use (Figure 4).

Switchgrass and giant miscanthus are more commonly studied as a feedstock for biofuel production and heat generation. Along with this, they are used in animal husbandry and poultry farming, for pulp and paper production, fiber reinforcement, in the construction industry, and also as raw materials for plastic composites. Energy crops also have the potential for sequestration (accumulation) of carbon in the soil and renewal of organic matter in it, purification of polluted effluents and the environment (phytoremediation properties), plants are also used as a component for creating pastures, etc.

An experiment was conducted to study the characteristics of the growth and development of plants of energy crops, their formation of biomass productivity in the conditions of the central forest-steppe of Ukraine. Material for research – switchgrass and giant miscanthus plants.

Literature review.

Biofuels are being progressively explored as a successful alternative energy source and identified as a key element of the future energy market, which can play a vital role in maintaining energy security (United Nations, 2020).

Biofuels are produced from a wide range of diverse resources. The use of such resources has mainly grown in recent years, contributing to the formation of new sub-complexes of agriculture, they are constantly looking for new technologies and feedstock (OECD-FAO 2019). With more than ten years of commercial-scale production experience, the biofuel industry has developed its own approaches to shaping marketing policies, improving and setting clear goals for sustainable development.

A significant number of researchers have dedicated their work to the sustainable development of bioenergy by biofuels production from biomass. Bioenergy crops are versatile renewable sources with the potential to alternatively contribute on a daily basis towards the coverage of modern society's energy demands (Margaritopoulou *et al.* 2016).

Biomass to be used for bioenergy and biofuels should therefore be produced primarily from excess farm and forest residues or from land not required for food and fiber production. The overall efficiency of biomass production, conversion, and use should be increased where possible in order to further reduce land competition and the related direct and iLUC risks (Fritsche *et al.* 2010).

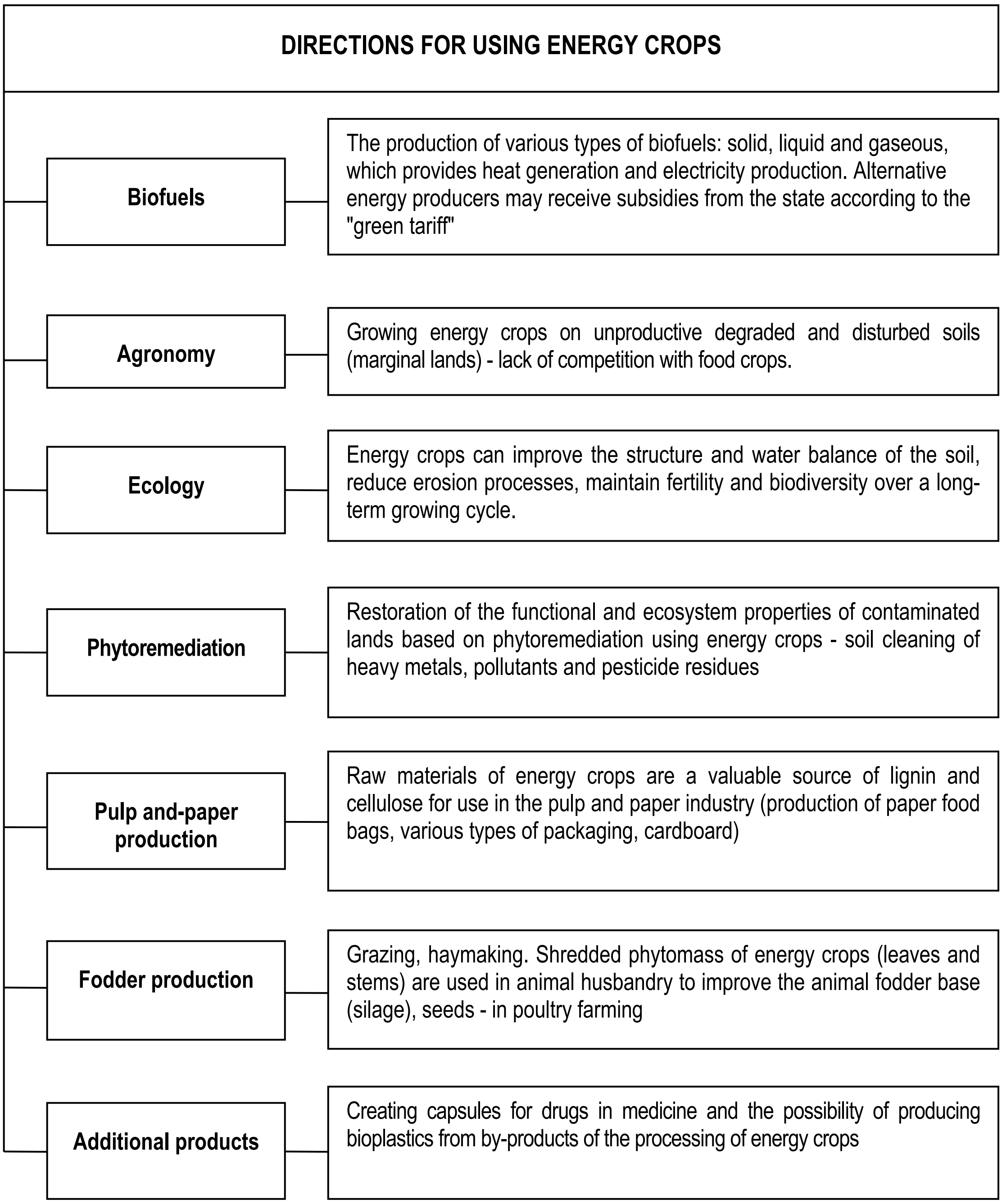
López-bellido *et al.* (2014) focus their study on the potential of bioenergy crops development in European agriculture. Bioenergy is the chemical energy stored in organic material, which can be directly converted into useful energy sources by biological, mechanical or thermochemical processes. The substitution of food crops with energy crops and the demand for agricultural raw materials for liquid biofuel production will affect agriculture over the next decade and possibly beyond.

Despite the presence of both positive and negative effects of biofuels the world production and consumption of biofuels have been increasing significantly. To a large extent, this is due to an active public policy in the field of stimulating the production and consumption of biofuels (Kaletnik *et al*. 2019).

Zulauf *et al.* (2018) note that Ukraine is the only major agricultural producer with declining biofuels production since 2010. Nevertheless, in 2017, Ukraine set a target of 11.5 percent of its primary energy supply from biomass, biofuels and waste by 2035 (Energy Strategy of Ukraine 2017). Moreover, Ukraine seeks integration into the EU, which has set a renewable energy target of 10 percent of transport energy from renewable energy by 2020 (Berezyuk *et al.* 2019).

The corn, sugar beet, palm oil, soybean, rapeseed, and wheat are being used for biofuels and energy production in most of the developed countries that create food versus fuel conflict. Therefore, the agricultural waste, energy crops, crop residues, and animal wastes are considered the most potential bioenergy feedstocks (Anawar and Strezov 2018).

Figure 4. Directions for the use of energy crops



Source: formed by the authors according to (Kulyk *et al.* 2019, Kalinichenko *et al.* 2018, Kalinichenko *et al.* 2017).

Pryshliak and Tokarchuk (2020) emphasize that production of biofuels will have social, economic and environmental effects. With the use of SWOT they have determined factors that will affect the development of biofuel production from agricultural waste.

There is a variety of crops that may be considered as potential biomass production crops. In order to select the best suitable for cultivation crop for a given area, a number of several factors should be taken into account.

During the crop selection process, a common framework should be followed focussing on financial or energy performance (Rodias *et al.* 2019). Taranenko *et al.* (2019) justify that switchgrass (Panicum virgatum L.) is a most adaptable plastic crop, forming extensive ground cover and vegetative biomass, providing a very high productivity over a short period of time that can been processed for biofuels.

There is very little information on the energy and economic substantiation of growing energy crops. The publications (Sanderson *et al.* 1996, Christian *et al*. 2002) only determine the effectiveness of growing switchgrass varieties for biofuel purposes and contain little information on the profitability of production of biomass.

It has been established that in order to provide a strong switchgrass phytocenosis with long-term use, it is necessary to improve the cultivation technology (Gumentyk and Kharytonov 2018). Kulyk *et al.* (2020) investigated the impact of conditions and cultivation techniques on yield of switchgrass. Also, the effects of optimized growing technology and growing conditions on the energy efficiency of switchgrass biomass production have been studied.

1. The Aim and Objectives of the Study

The aim of the research is to determine the level of biomass productivity, economic and energy efficiency of growing energy crops, the yield of biofuel and its energy intensity, the characteristics of the yield formation and economic efficiency of biomass, the output of solid biofuel, its energy intensity and energy output, the development of a logistic scheme for using biofuel from biomass of energy crops.

2. Methodology

The experiment was laid and conducted in accordance with the methodology of experimental work in agronomy (Dospehov *et al.* 1985), using the scientific methods of Kulyk *et al.* (2017) and the recommendations of Kurylo *et al.* 2012 and Kurylo *et al.* 2016. Each research site had an area of 50 m^2, they were placed in randomized repetitions (random method). The number of repetitions for each energy plant was 4.

Due to the fact that energy crops are perennial plants, during the experiment, the principle that all the data obtained from the 3rd year of crops vegetation were average values for the experiments of 2015-2017, 4th year of crops vegetation were average values for the experiments of 2016 -2018, the 5th year of crops vegetation were average values for the experiments of 2017-2019 have been adhered.

To take into account the quantitative indicators of plants (height and number of stems), annually (from the third year of the growing season) before the end of the growing season, sheaves samples from 1 linear meter (l.m.) were taken along the diagonal of the plot in four places.

Yields were determined by mowing each plot, weighing biomass in the field (conditionally wet biomass). After drying the plant samples (5 kg each), the moisture content in the biomass was determined in laboratory conditions, according to the method. After establishing the moisture content in the biomass, the yield was recalculated to dry biomass (according to Kulyk, 2012).

The efficiency of growing energy crops was evaluated by the yield of solid biofuels, according to formula:

$$A\,tb = \frac{U \times d \times (100 + w)}{10000}$$

where A_{tb} – solid biofuel yield, t / ha;

u – yield of the collected biomass, t / ha;

d – dry matter of collected biomass, %;

w – moisture of solid biofuel, %.

The output of energy and solid biofuel was calculated by the formula (2):

$$E_{aa} = BE_{тб} \times A_{tb}$$

where E_{aa} – solid biofuel energy output, GJ / ha;

T – solid biofuel output, t/ha;

Eb – energy intensity of solid biofuels, MJ / kg.

$$ei = \left(\frac{100 - w - z}{10000}\right)Eto$$

The energy intensity of solid biofuels was calculated according to the formula (3):

where ei – energy intensity of solid biofuels, MJ / kg;

w – humidity of solid biofuels, %;

z – ash content of solid biofuels, %;

Eto – energy intensity of absolutely dry ash-free solid biofuels, MJ / kg.

Other calculations of indicators of economic and energy efficiency of growing energy crops were carried out in accordance with the methods of Kalinchenko and Kulyk, 2019. (Table 1-2).

Table 1. Economic evaluation (express-analysis) of energy crops growing

Indicators	Calculation methods
Cost of production of energy crops cultivation (C_p), USD/ha	$C_p = WC + SC + FC + CPP + CFL + DD + RFE + PR + MC_o + IP + GPS$, WC – wage costs (basic, additional), USD/ha; SC – seed costs, USD/ha; FC – fertilizer costs, UAH/ha; CPP – costs on plant protection products, USD/ha; CFL – costs on fuel and lubricants, USD/ha; DD – depreciation deductions, USD/ha; RFE – repair of fixed equipment, USD/ha; PR – payment for the rent of land plots, USD/ha; MC_o – other material costs, USD/ha; IP – insurance payments, USD/ha; GPC – general production costs, USD/ha
Total cost of energy crops cultivation (C_t), USD/ha	$C_t = C_p + C_a$, C_p – production cost of energy crops, USD/ha; C_a – additional costs, USD/ha
Revenue from energy crops biomass sale (R), USD/t	$R = \sum_{i=1}^{n} V_i \cdot P_i$, V_s – volume of energy crops s sale, t; P_s – price of switchgrass sale, USD/t; n – number of energy crops varieties
Profit from switchgrass biomass sale (P_b), USD/ha	$P_b = S_r – C_t$, S_r – revenue from switchgrass biomass sale, USD/ha; C_t – total cost of switchgrass cultivation, USD/ha
Profitability of energy crops biomass production (P), %	$P = \frac{G_p}{C_t} \cdot 100\ \%$, G_p – gross profit from energy crops biomass sale, USD/ha; C_t – total cost of switchgrass cultivation, USD/ha

Source: Kalinchenko and Kulyk 2019, Kulyk *et al.* 2020

While calculating economic efficiency of energy crops growing, biomass price of 36.5 USD/t was taken into account.

Table 2. Energy evaluation (express-analysis) of energy crops growing

Indicators	Calculation methods
Aggregate energy accumulated in energy crops biomass (E_{aa}), GJ/ha	$E_{aa} = \sum_{i=1}^{n} O_i \cdot K_i \cdot e_i \cdot 100$, O_i – output of energy crops biomass (yield), t; K_i – coefficient of energy crops biomass transformation into dry matter; e_i – energy content in 1 kg of dry matter, GJ; n – number of energy crops varieties
Direct energy expenditures on energy crops biomass cultivation (E_d), GJ/ha	$E_d = \sum_{i=1}^{n} (E_{di} + E_{mi} + E_{zi} + E_{ui})$, E_{di} – energy expenditures, reified in fuel and oil materials, electrical energy, GJ/ha; E_{mi} – energy expenditures, reified in seeds, mineral and organic fertilizers, plant protectants, GJ/ha; E_{zi} – expenditures of live labour energy, GJ/ha; E_{ui} – energy expenditures, reified in the main means of production, GJ/ha
Indirect energy expenditures on energy crops biomass cultivation (E_{in}), GJ/ha	$E_{in} = \sum_{i=1}^{n} (E_{si} + E_{yi} + E_{di})$, E_{si} – energy expenditures of management and maintenance personnel, GJ/ha; E_{yi} – energy expenditures on management and maintenance personnel allowance, GJ/ha; E_{di} – energy expenditures on industrial and social infrastructure, GJ/ha
Total energy expenditures on energy crops s biomass cultivation (E_c), GJ/ha	$E_c = E_d + E_{in}$, E_{di} – direct energy expenditures on energy crops cultivation, GJ/ha; E_{in} – indirect energy expenditures on energy crops biomass cultivation, GJ/ha
Energy profit of switchgrass biomass cultivation (EP_c), GJ/ha	$EP_c = E_{aa} - E_c$, E_{aa} – aggregate energy accumulated in switchgrass biomass, GJ/ha; E_c – total energy expenditures on switchgrass biomass cultivation, GJ/ha
Coefficient of energy efficiency of energy crops biomass cultivation (K_{ee})	$K_{ee} = \frac{E_{aa}}{E_c}$, E_{aa}– aggregate energy accumulated in energy crops biomass, GJ/ha; E_c – total energy expenditures on energy crops cultivation, GJ/ha. If $K_{ee} < 1$ – energy crops biomass cultivation is inefficient; 1 – 3,0 low level of efficiency; 3,1 – 5,0 – average level of efficiency; $K_{ee} > 5,0$ – high level of energy efficiency

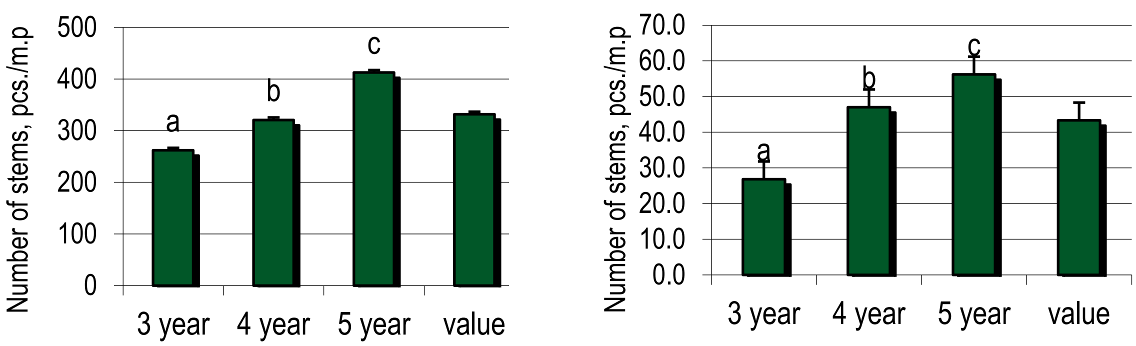
Source: Kalinchenko and Kulyk 2019.

For objective interpretation of the obtained experimental data (analysis of variance), computer programs Statistica and Excel were used.

3. Results of the Research

Based on the results of quantitative indicators of switchgrass and giant miscanthus plants, the following indicators were obtained (Figure 5–6).

Figure 5. The number of stems in the switchgrass (a) and giant miscanthus plant (b), 2015-2019



a b

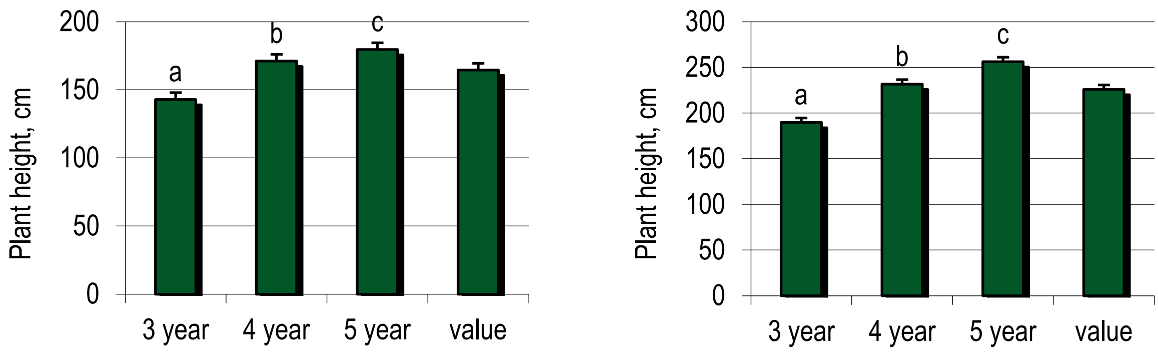
Note: (a) and (b) show significant differences
Source: author's research

By the number of stems in the plant, both within the study years and on average over the years, switchgrass prevailed in comparison with the giant miscanthus. This also determined the general density of the stalk of energy crops, which was determined from one linear meter.

In the giant Miscanthus, the dynamics of the increase in the number of stems was from 26.8 to 56.2 pcs./l.m., on average over the years - 43.3 pcs / l.m. For switchgrass, the number of stems per 1 m varied widely - from 261.8 to 412.5 pcs, on average over the years - 331, 6 pcs.

Giant miscanthus plants stood out in terms of stem height - from 189.7 to 256.1 cm, within average over the years - 225.8 cm. Over the years of experiment switchgrass had the increased dynamic in this indicator - from 142.8 to 176.9 centimeters (cm), the average height was at the level of 163.6 cm (Figure 6).

Figure 6. Height of switchgrass (a) and giant miscanthus (b) plants, 2015-2019



a b

Note: (a) and (b) show significant differences
Source: author's research

In the context of years of research, the dynamics of increasing biomass productivity was noted — from the third to fifth year of vegetation, which is typical for both studied crops (Table 3, Figure 7).

Table 3. Dry biomass yield of energy crops, 2015–2019

Crop	Year			Average over the years
	third	fourth	Fifth	
Switchgrass	14,1	15,0	16,5	15,2
Giant miscanthus	16,2	18,4	21,8	18,8
HIP_{05} (year)	-	-	-	1,32
HIP_{05} (crops)	1,03	1,13	1,34	0,94
HIP_{05} (average)	-	-	-	0,21

Source: author's research

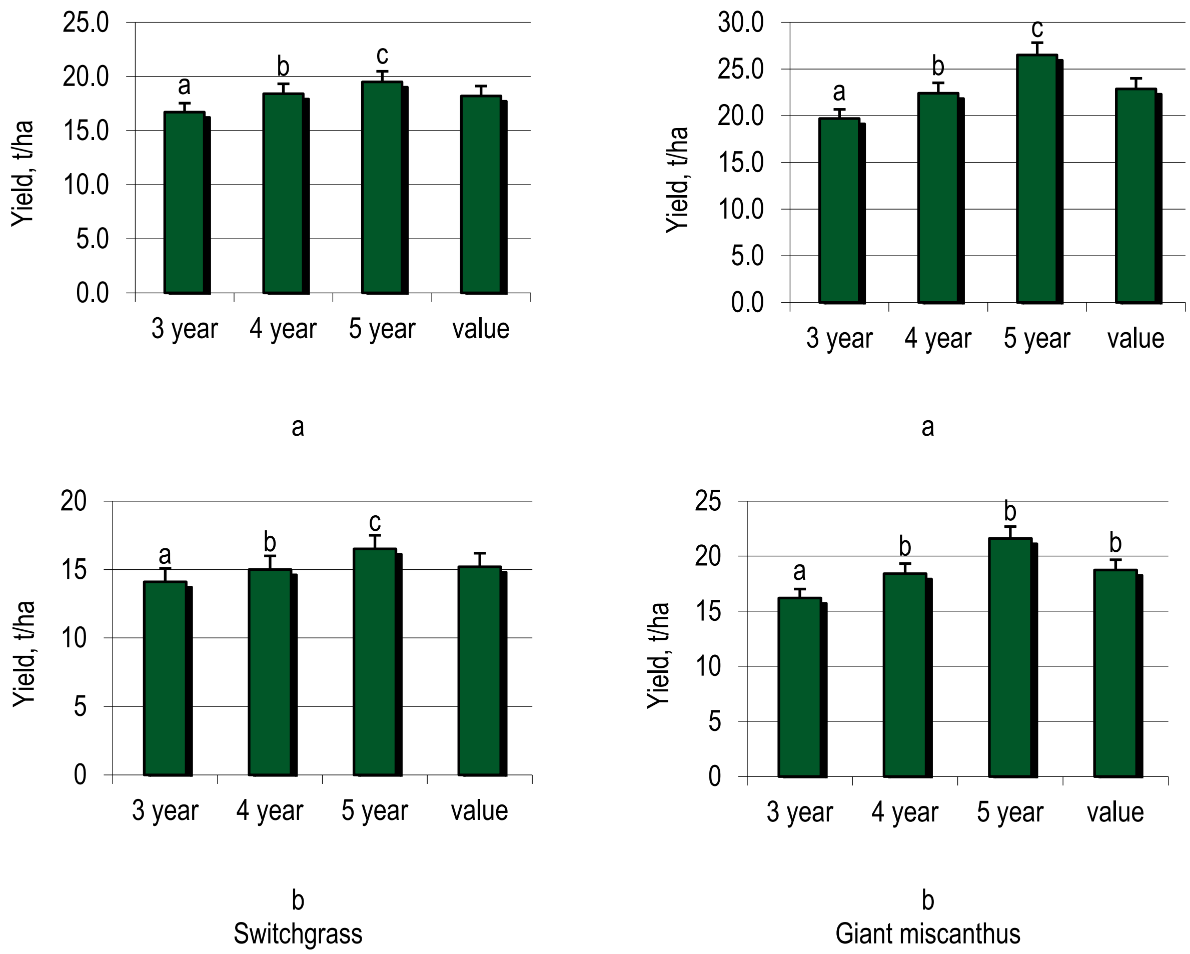
Significant differences between the experimental options are confirmed by the results of variance analysis (table 4).

Table 4. Table of the dispersion

	SS	Degr. of	MS	F	p
Intercept	17321,24	1	17321,24	418538,3	0,00
Var 1	195,67	1	195,67	4728,0	0,00
Var 2	163,30	2	81,65	1972,9	0,00
Var 1 * Var 2	26,49	2	13,25	320,1	0,00
Error	2,23	54	0,04	-	-

Source: calculated by the authors

Figure 7. The yield of conditionally wet (a) and dry biomass (b) of switchgrass and giant miscanthus, average for 2015-2019

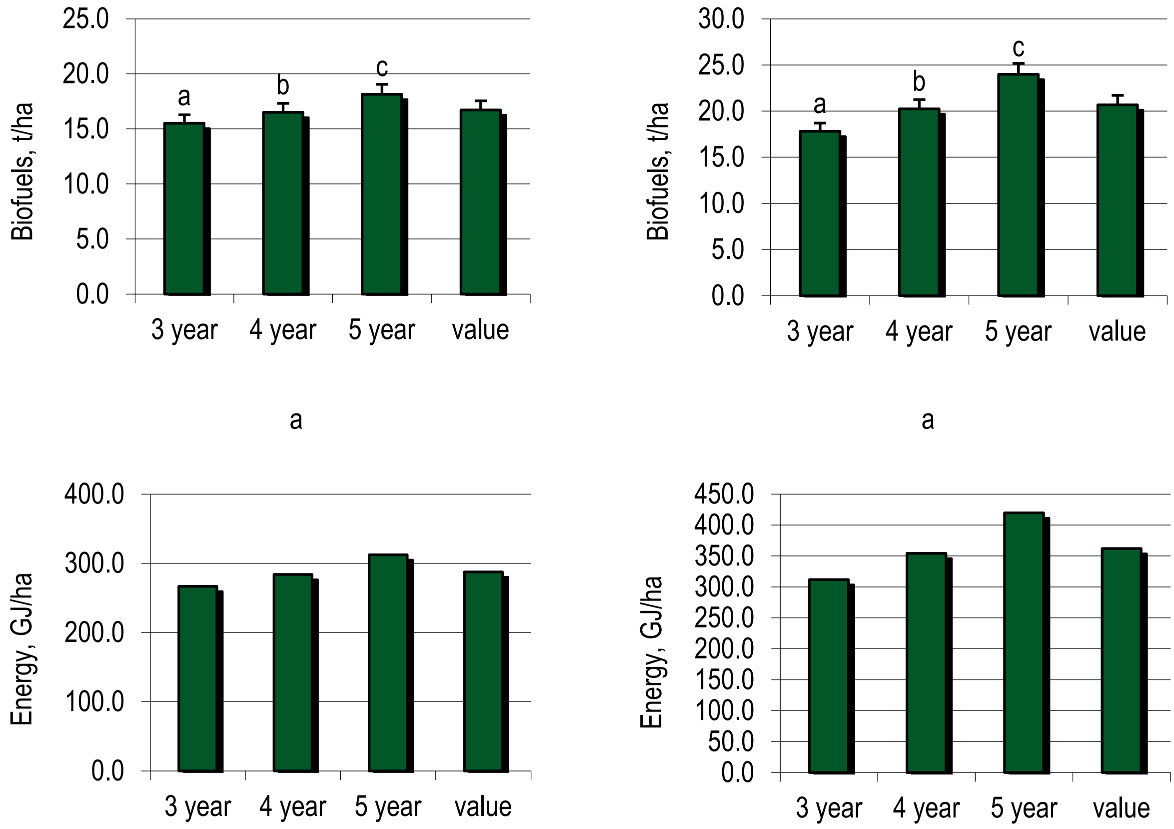


Note: (a) and (b) show significant differences
Source: author's research

Switchgrass plants on average provided a significant increase in conditionally wet biomass – from 16.7 to 19.5 t / ha, and absolutely dry biomass – from 14.1 to 16.5 t / ha. For giant Miscanthus, a similar trend was noted, but with increased indicators: in terms of yield of conditionally wet biomass – from 19.7 to 26.5 t / ha, and absolutely dry biomass – from 16.2 to 21.6 t / ha.

Considering absolutely dry biomass, the volume of solid biofuel and energy output from energy crops were determined (Figure 9).

Figure 9. The output of solid biofuel (a) and energy (b) from the biomass of sitchgrass and giant miscanthus, average for 2015-2019



a a

b b

Switchgrass Giant Miscanthus

Source: author's research

On average, over the years of research, the yield of solid biofuel was the largest from the giant Miscanthus plantings (17.8-24.0 t / ha), the energy yield was from 311.9 to 419.7 GJ / ha, and slightly less from switchgrass crops (15, 5-18.2 t / ha), energy output - from 266.8 to 312.2 GJ / ha.

Rational use of energy is the use of energy by consumers in the most efficient way from an economic point of view, taking into account social, financial constraints, environmental requirements, etc. (Kalinichenko 2017).

For the efficient functioning of energy-independent rural areas, an important aspect is the development of a logistic chain for growing energy crops, supplying bio-feedstock and rational use of biofuels (Figure 10).

Figure 10. Logistic chain of growing energy crops biomass

Crop	First year				Second year				Third year				Forth year			
	spr*	sum	aut	win	spr	sum	aut	win	spr	sum	aut	win	spr	sum	aut	win
Switchgrass	sowing / planting	plant care			plant care							harvesting phytomass	plant care			harvesting phytomass
Miscanthus	sowing / planting	plant care			plant care								harvesting phytomass; plant care			

Designations:

– sowing / planting – plant care

– harvesting phytomass

* Note: spr – spring period; sum-summer period; aut – autumn period; win-winter period.

Source: formed by the authors based on Gorb *et al.* 2018.

According to the logistic chain, the energy crops biomass can be processed starting from the third year of energy crops vegetation.

The economic efficiency of biomass production of energy crops, taking into account their level of productivity, provides the determination of the following economic indicators: production costs, revenue and gross profit from the sold biomass and profitability (table 5).

Table 5. Economic efficiency of switchgrass and miscanthus biomass production, average during 2015–2019

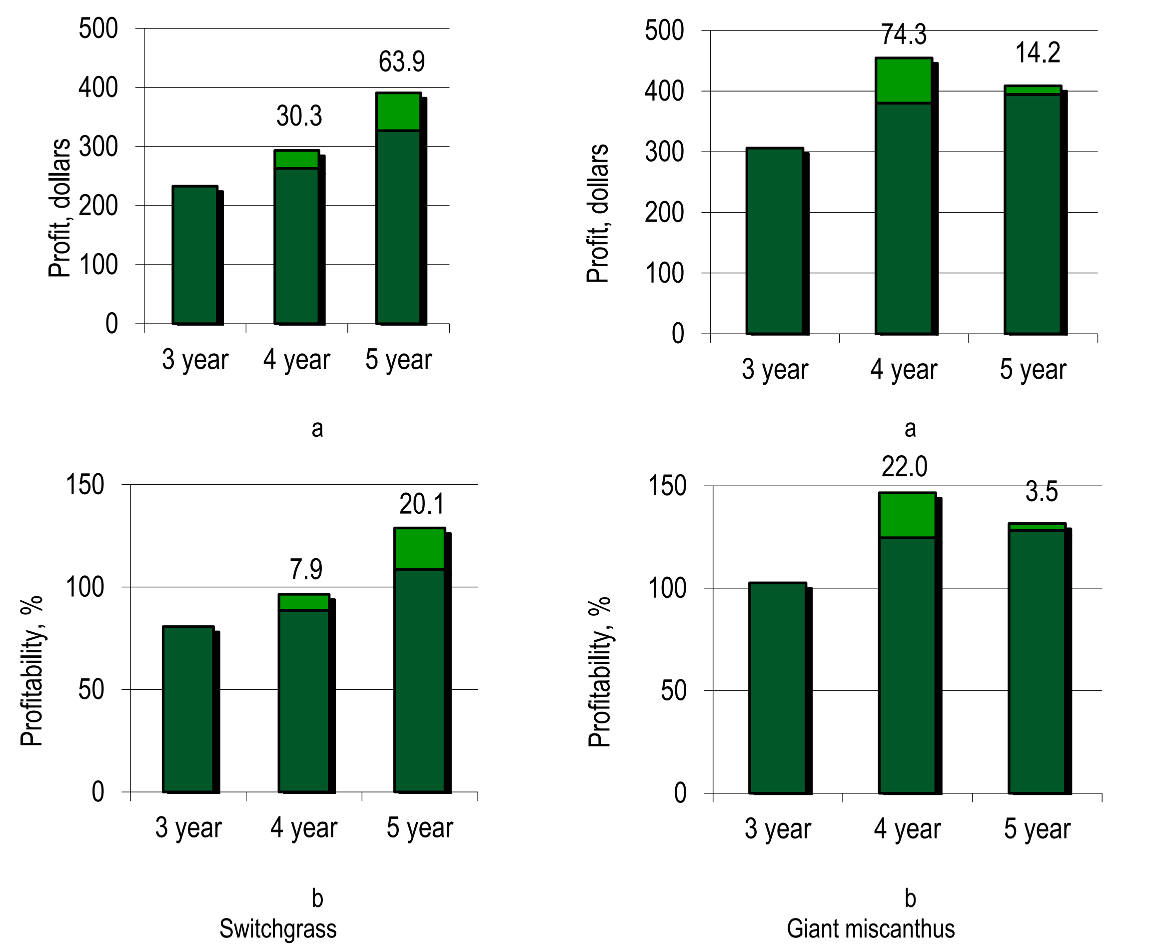
Culture	Vegetation year	Economic efficiency indicators*				
		C_p	C_t	R	P_b	P
Switchgrass	the third	264,7	293,3	525,9	232,6	80,7
	the fourth	268,1	296,9	559,8	262,9	88,6
	the fifth	261,5	300,9	627,7	326,8	108,7
Miscanthus	the third	258,7	298,1	603,9	305,9	102,6
	the fourth	280,8	305,1	685,4	380,2	124,6
	the fifth	281,9	307,9	702,3	394,4	128,1

* *Note*: C_p – cost of production of switchgrass cultivation, USD/ha; C_t – total cost of switchgrass cultivation, USD/ha; R – revenue from switchgrass biomass sale, USD/t; P_b – profit from switchgrass biomass sale, USD/ha; P – profitability of switchgrass biomass production, %.

Source: calculated by the authors.

The cost of growing switchgrass (full cost) for the 3rd, 4th and 5th year of vegetation is 393.3; 296.9 and 300.9 USD / ha. For Miscanthus over the years, this indicator was respectively – 298.1; 305.1 and 307.9 USD / ha. Growing giant Miscanthus compared to switchgrass allows to increase profits over the years by an average of 86.1 USD / ha.

Figure 11. Economic efficiency indicators (a – profit, b – profitability level) of biomass production of switchgrass and giant miscanthus, average for 2015-2019



Source: calculated by the authors

Miscanthus cultivation is more cost-effective than switchgrass cultivation. Therefore, for the 3rd year, the profitability of miscanthus was more than switchgrass by 21.9% , for the 4th year – by 36.0%, and for the 5th year of the growing season – by 19.4%. On the 5th year of the growing season, the profitability level of giant miscanthus was 128.1%, and switchgrass – 108.7% (Figure 11).

The volume of the obtained biomass of switchgrass and giant miscanthus allows to compare the energy efficiency indicators of these crops for the output of solid biofuel and energy, the total cost of energy resources per 1 ha, the energy intensity of the production technology, and the energy efficiency coefficient (Table 6).

Table 6. Energy efficiency of switchgrass and miscanthus biomass production, average during 2015–2019

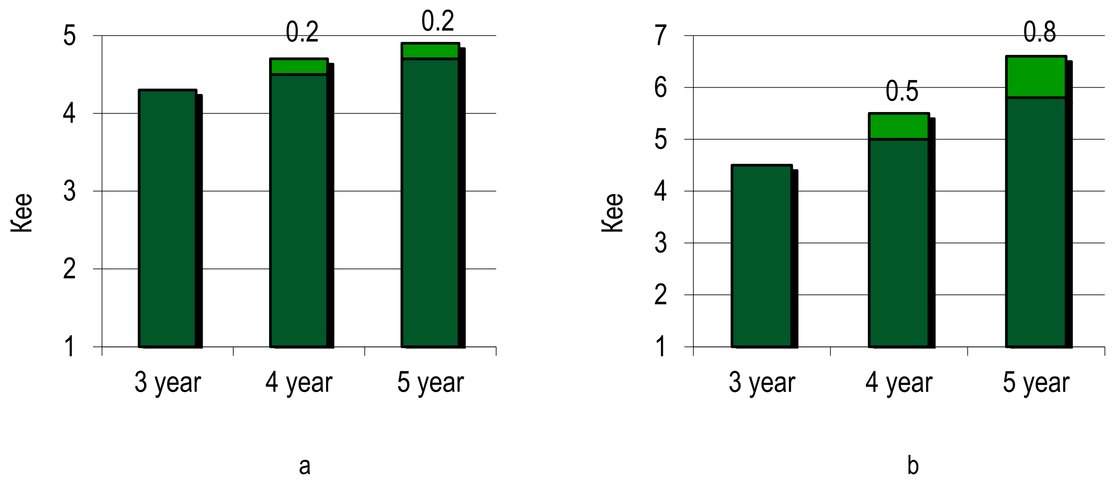
Culture	Vegetation year	Energy efficiency indicators *				
		A_{tb}	E_{aa}	E_c	EP_c	K_{ee}
Switchgrass	the third	15,5	266,6	61,9	4,0	4,3
	the fourth	16,5	283,8	63,7	3,9	4,5
	the fifth	18,2	313	66,3	3,6	4,7
Miscanthus	the third	17,8	293,7	65,5	3,7	4,5
	the fourth	20,2	333,3	66,8	3,3	5,0
	the fifth	24,0	396,0	67,9	2,8	5,8

* *Note*: A_{tb} – output of solid biofuel, t/ha; E_{aa} – aggregate energy accumulated in switchgrass biomass, GJ/ha, E_c – total energy expenditures on switchgrass biomass cultivation, GJ/ha; EP_c – energy profit of switchgrass biomass cultivation, GJ/ha; K_{ee} – coefficient of energy efficiency of switchgrass biomass cultivation.
Source: author's calculations.

Compared to growing switchgrass, the production of giant miscanthus biomass for the 5th year of vegetation provides a higher yield of solid biofuel at 5.8 t / ha, a greater energy output at 83.0 GJ / ha. At the same time, there is a tendency towards an increase in the total usage of energy resources per 1 ha of switchgrass crops by 4.4 GJ / ha (from 61.9 to 66.3 GJ / ha) and a decrease in the energy intensity of biomass production technology by 0.4 GJ / t. When growing giant miscanthus, there is an increase in total energy consumption by 2.4 GJ / ha (from 65.5 to 67.9 GJ / ha) and a decrease in energy intensity by 0.9 GJ / t.

Both the biofuel and energy output and the energy efficiency coefficient of biomass production turned out to be at the average level for both studied energy crops: giant miscanthus K_{ee} = 5.8; switchgrass K_{ee} = 4.7 (Figure 12).

Figure 12. The energy efficiency coefficient of the production of switchgrass biomass (a) and giant miscanthus (b), 2015-2019



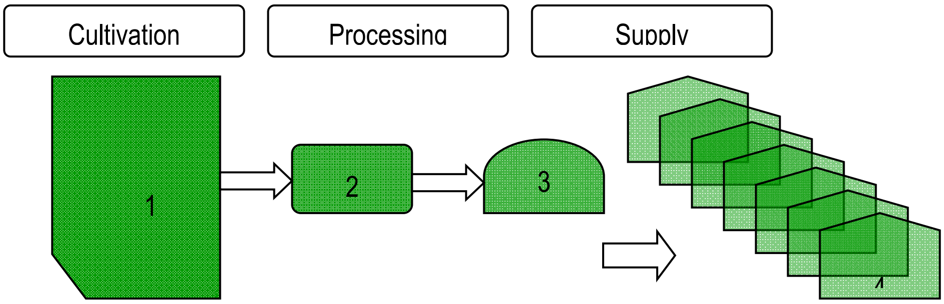
Source: calculated by the authors.

For the rational use of biofuels from energy crops biomass (produced on marginal lands) and for providing alternative energy to consumers in rural areas, the following scheme is proposed (Figure 13).

The creation of infrastructure, which involves attracting the resource of agricultural enterprises for growing energy crops and collecting biomass, as well as processing enterprises with the participation of energy service companies, will enable the stable supply of transformed energy to consumers.

As for confrontation of results with the results obtained by other authors, Dubis *et al.* (2019) found that in the first year of the experiment, the energy costs associated with the production of M. × giganteus and M. × sacchariflorus were determined to be 70.5 and 71.5 GJ ha-1. In other years of cultivation, the total amount of energy associated with the production of both energy crops reached 13.6-15.7 (M. × giganteus) and 16.9-17.5 GJ ha - 1 y - 1 (M. sacchariflorus).

Figure 13. Logistic scheme for the use of biofuels from biomass energy crops



Note: 1 - energy crops (growing biomass) 2 - processing complex of biomass into biofuel; 3 - a boiler for power generation of biofuel; 4 - energy consumers.
Source: developed by the authors

Starting from the second year of cultivation, mineral fertilizers were the main energy source in the production of M. × giganteus (78-86%) and M. sacchariflorus (80-82%). In 2-11 years, the energy growth of M × giganteus reached 50 (year 2) and 264-350 GJ ha – 1 y – 1 (years 3-11), and its energy efficiency coefficient was determined to be 4.7 (2 years) and 18.6 -23.3 (years 3-11). The energy growth coefficient and the energy efficiency coefficient of biomass M. sacchariflorus in the corresponding periods were determined in accordance with 87-234 GJ ha - 1 y - 1 and 6.1-14.3, respectively.

Other results were obtained by the authors Farrell *et al.* 2006. They argue that the energy requirement for switchgrass energy plantations are 7.5 GJ/ha, and according to Wang (2001), the energy requirement are about 12 GJ/ha. The similar results were confirmed by Sokhansanj *et al*. (2009) according to which energy requirements were 7.2 GJ/ha.

Conclusion

1. It has been established that miscanthus contains higher percentage of dry biomass (on average over the years of research – by 3.6 t / ha) than switchgrass. According to the logistics chain, it has been determined that the biomass of energy crops can be used annually for processing into biofuels starting from the third year of vegetation on energy plantations.

2. The yield of solid biofuel and energy output was higher from the giant miscanthus plantations (biomass yield – 17.8-24.0 t / ha, energy yield – from 311.9 to 419.7 GJ / ha). The yield of solid biofuel from switchgrass crops amounted to 15.5-18.2 t / ha, the energy output ranged from 266.8 to 312.2 GJ / ha. The energy efficiency of biomass production for both studied energy crops turned was on average level (K_{ee}> 4.5).

3. Both in terms of years and on average over the years of cultivation, miscanthus was more profitable and cost-effective compared to switchgrass.

4. The use of a logistic scheme for the use of biofuels from biomass of energy crops will provide the population with alternative energy and will contribute to the sustainable development of the bioenergy sector in rural areas.

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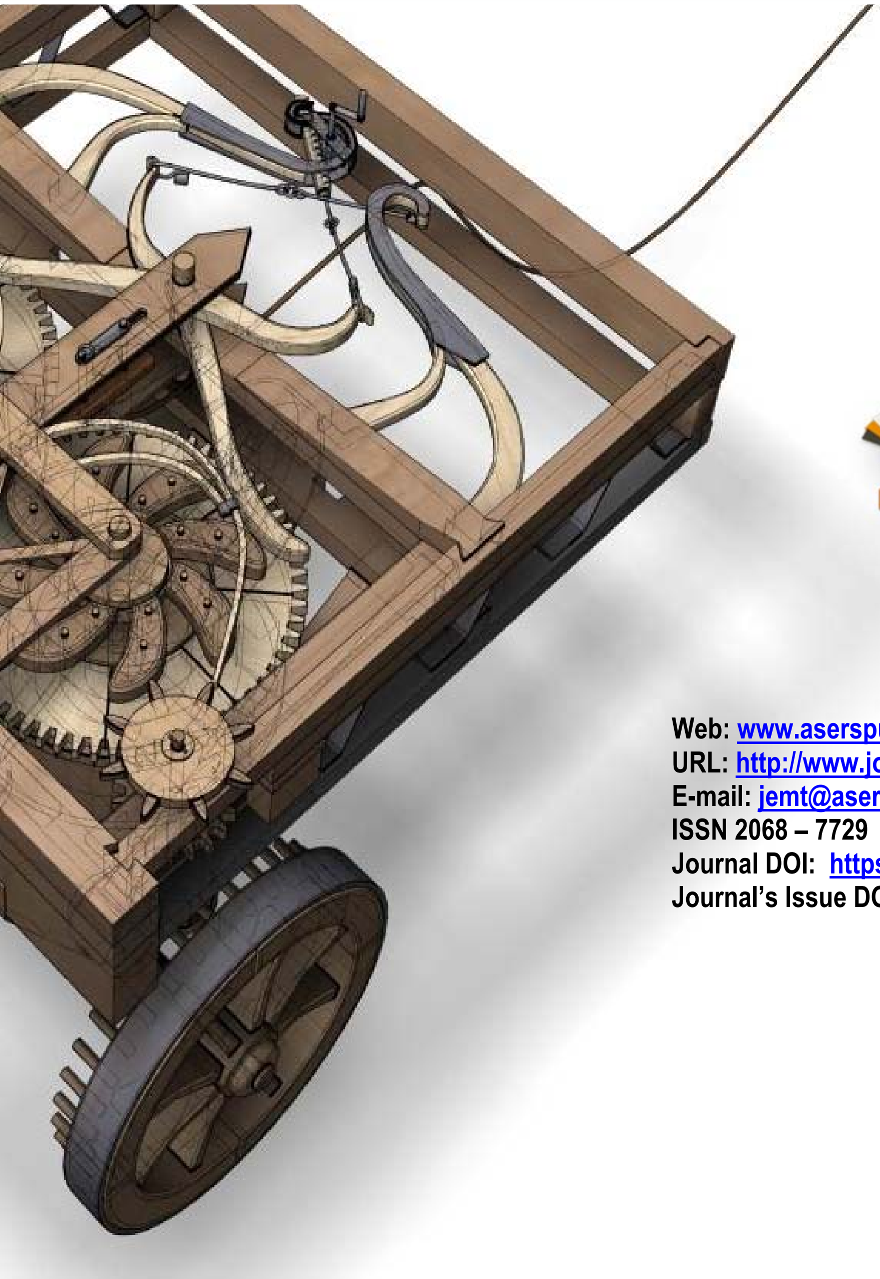

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