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FINANCIAL AND ECONOMIC MANAGEMENT OF THE EFFICIENCY OF ENERGY CROP PRODUCTION IN THE SYSTEM OF SMART TECHNOLOGICAL DEVELOPMENT OF LABOR RESOURCES

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Abstract
The article presents the author's concept of integrated financial and economic management of energy crop production using the example of growing fireweed in the forest-steppe zone of Ukraine. The study is based on comprehensive monitoring of the agro-technological cycle, the dynamics of biomass indicators, economic feasibility and energy efficiency in the context of innovation challenges. For the first time, the feasibility of combining adaptive agricultural technologies with elements of smart analysis of labor and material resource productivity has been substantiated, which allows not only to increase yield, but also to optimize costs at all stages of the production process. The results demonstrate that the most effective is the spring sowing strategy, which provides the highest level of profitability and the greatest energy profit. The proposed network model allows structuring technological operations in the form of a logistical sequence taking into account calendar periods and resource provision, which is key for planning the load on personnel. The author's methodology for assessing energy efficiency shows that the energy efficiency coefficient indicates an average level of technological feasibility of the selected model. Thus, the presented system is a unique multidimensional platform for managing energy agricultural production, which can be integrated into strategies for sustainable development of rural areas through the prism of technological transformation of labor resources.

Keywords: *switchgrass, energy crops, smart technologies, financial and economic management, energy efficiency, biomass, profitability of agricultural production, agricultural logistics, labor resources, yield modeling, resource conservation, agroenergy, cost management, bioeconomy.*

JEL Codes: *Q16, Q42, O13, J24*.

Introduction

In the current conditions of transformation of agricultural production, the relevance of the search for economically viable, energy-efficient and environmentally sound models of growing agricultural crops, focused on sustainable use of resource potential, is increasingly growing. Against the background of global challenges associated with the growth of demand for alternative energy sources, depletion of traditional energy reserves and the aggravation of the problem of energy independence, the production of energy crops is gaining not only economic, but also strategic importance for the agro-industrial complex of Ukraine. Of particular importance in this context is the institutionalization of financial and economic management mechanisms that are able to ensure the effective functioning of all links of the technological chain - from soil preparation to the logistics of biomass processing. At the same time, classical approaches to managing agricultural production reveal their limitations in the conditions of increasing complexity of agricultural systems that are changing under the influence of climatic, social, technological and financial disturbances. This highlights the need to integrate smart technologies that combine digital analytics, precise resource planning, adaptive agrotechnical solutions and reflective labor management. In this regard, the production of energy crops – in particular, such as switchgrass – can become not only an object of agro-industrial exploitation, but also a testing ground for new management approaches capable of generating long-term productivity and energy-saving effects.

The need for a new methodological framework for studying the efficiency of energy-oriented agricultural production requires taking into account a number of interrelated factors: the biological potential of crops, the specifics of agro-climatic zones, the labor intensity of the technological cycle, the dynamics of costs and revenues, as well as energy returns per unit of invested resources. It is especially important to understand the role of labor resources not as a passive element of the production system, but as a subject of dynamic management of knowledge, competence and time synchronization of operations. That is why the article proposes a new configuration of financial and economic management of the efficiency of energy crop cultivation, built on the principles of logistical consistency, economic feasibility, energy balance and technological synergy.

Based on the need to optimize agricultural production in conditions of resource shortage and climatic instability, this study is aimed at developing an adaptive management model based on empirical data from field research, energy economic analysis and principles of smart agromanagement. Thus, the article not only fills the scientific discussion with new conceptual content, but also forms a methodological basis for the practical implementation of flexible and productive management mechanisms in the field of energy crop production as a component of Ukraine's agro-energy security.

Literature review

Analysis of modern scientific achievements shows growing attention to the problems of effective management of energy crop production both in the domestic and international research environment. Publications devoted to agrobioenergetics, biomass logistics, smart labor management, digital financial instruments and modeling of innovative activity create a powerful theoretical and applied basis for the formation of new strategies for sustainable development. It is at the intersection of these scientific fields that this study is based, the goal of which is to build an integrated model of financial and economic management of the efficiency of switchgrass cultivation in a smart technological environment, capable of synchronizing productivity, resource efficiency and personnel mobility.

The scientific work of Bakhmat et al. (2022) emphasizes the importance of quality management in education for sustainable development, which allows integrating the training of qualified labor resources for new agro-energy challenges. Ensuring managerial quality through the higher education system creates an institutional basis for the introduction of smart technologies in the production of energy crops. The key publication by Elbersen et al. (2013) summarizes many years of research on switchgrass in Ukraine. It forms a scientific basis for the biological potential of the crop, its agrotechnical characteristics and recommendations for implementation. It is extremely valuable as an empirical basis for building production and economic models. The publication by Gryshchenko et al. (2023) is devoted to the management of innovative entrepreneurship in the conditions of post-war reconstruction. It has conceptual significance for

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understanding how integrated structures can be effectively transformed into ecosystems of agro-energy production. Heletukha et al. (2011) assess the energy potential of biomass in Ukraine, with an emphasis on energy crops. The scientific article is valuable for the economic justification of scaling up switchgrass production, taking into account the regional characteristics of the agricultural sector. The scientific work by Bosniuk et al. (2021) concerns the social content of the professional activities of psychologists, but supports the concept of developing labor potential, in particular the competencies necessary for work in the innovative agricultural sector.

Kalinichenko et al. (2017) provide economic estimates of the availability of phytomass for biofuel production. I support the feasibility of using switchgrass as an object for modeling financial efficiency in the context of smart management. In this work, Hnatenko et al. (2024) analyzes changes in the Ukrainian renewable energy market. The work creates a strategic context for understanding the macrofinancial environment in which agro-energy enterprises operate. Kubitskyi et al. (2023) focus on the development of HEIs in the face of change, which is of great importance for the formation of the institutional capacity of higher education to train personnel for energy agribusiness. Kalinichenko & Kulyk (2018) directly analyze the economic efficiency of growing switchgrass in the forest-steppe zone, which is one of the most important empirical sources in building models of production profitability. Hnatenko et al. (2020) investigate the innovative infrastructure of an enterprise, which helps to identify key organizational and managerial elements necessary for launching agro-energy innovations. Purdenko et al. (2023) study the financial management of ecological entrepreneurship, which correlates with the requirements for financial and economic management of energy crop production. Kulyk et al. (2017) propose a methodology for conducting agronomic research on switchgrass, which can be adapted for financial and energy planning in agro-bioenergy projects. Semenov et al. (2021) consider the management of energy-saving innovation projects in the food industry, which methodologically coincides with the tasks of optimizing production cycles in bioenergy. Shumilova et al. (2023) focuses on the formation of managers' competencies in conditions of change, which is relevant for managing human capital in a smart environment of agricultural production. Kulyk et al. (2020) will investigate optimized switchgrass cultivation technologies and identify effective agronomic models that can be included in the general financial and economic management system. Mazur et al. (2021) consider improving the controlling system in financial management, which has applied value for cost control and assessing the economic feasibility of agricultural projects. Kumar & Sokhansanj (2007) model the logistics of delivering switchgrass to bioenergy processing plants, which provides an engineering and financial basis for building integrated logistics systems in bioagroenergy. Voznyuk et al. (2022) form a system model of self-managed management teams, which is important for building flexible management structures in the bioenergy sector. Mooney et al. (2009) calculate the profitable price for switchgrass in the US. The data can be adapted for predictive analysis of the Ukrainian biomass market. Mykhailichenko et al. (2021) reveal HR management strategies in a digitalized agricultural sector that supports the concept of smart workforce development in energy crop production. Muir et al. (2001) studies agronomic parameters of switchgrass at different fertilizer doses, which is the basis for modeling the cost of agrotechnological operations. Schmer et al. (2008) estimates clean energy from switchgrass bioethanol. A strategic source for assessing crop energy efficiency in the context of sustainable development.

Prokopenko et al. (2021) investigates state management of clustering, which correlates with the formation of agroenergy clusters within regional development systems. Tkachuk et al. (2016) considers energy saving as a factor of competitiveness of agricultural enterprises. Directly supports the concept of financial efficiency in the article. Prylipko et al. (2021) model the management of innovation activity in the regional dimension, which is key for the implementation of agroenergy programs at the local level. Sokhansanj et al. (2009) describe the large-scale logistics of collecting and transporting switchgrass. The scientific work contains practical solutions for optimizing biomass supply chains. Zhyvko et al. (2024) study the impact of international markets on the management of innovative development, which allows extrapolating financial risks and opportunities in the context of globalized bioenergy.

A systematic analysis of the above works allows us to conclude that there is a powerful interdisciplinary base that forms conceptual, analytical and methodological guidelines for building an effective model of financial and economic management of energy crop production in the context of smart technological development of labor resources. On the one hand, studies of the agronomic, logistical and energy profile of switchgrass provide an empirical basis for assessing the bioeconomic feasibility of its cultivation as an energy crop. On the other hand, publications dedicated to innovation management, the transformation of educational institutions, improving the quality of human resources, and the implementation of digital financial instruments create an intellectual foundation for rethinking the role of labor resources in new agro-energy realities.

Materials and methods

Switchgrass were grown during the 2009–2016 period. Energy plantations were located and summer-autumn soil tillage was carried out in 2009. In the next period, during 2010–2011, the spring-summer farm operations were made. Their aim was row-spacing weed control by using agrotechnical measures and chemicals.

Beginning from the end of 2012, during the autumn-winter period, switchgrass biomass was being mowed to chaff by combine harvester and taken out of the field. Spring fertilization of crops after plant vegetation regeneration and biomass harvesting at the period of crop vegetation completion were carried out annually in 2013–2016.

It has been established that switchgrass provides the highest biomass yield, starting in 2013, increasing to 2016, with the stabilization of yield in the following years.

Calculation of economic and energy efficiency of biomass production involved all costs spent on switchgrass cultivation, which were the largest in 2009–2012, with the subsequent decrease in the next periods. This is due to the decrease in the number of cultivation technological operations (fertilization, harvesting and removal of biomass) and yields increase.

The chart of the experiment combined: factor A is the research year (2012–2016), factor B is the seeding term (variant 1 – early-spring (ST 1), variant 2 – spring (ST 2), variant 3 – late spring (ST 3), variant 4 – summer (ST 4), factor C – seeding rate (SR 1 – 0.95, SR 2 – 1.9, SR 3 – 3.8, SR 4 – 5.7, SR 5 – 7.6 kg/ha).

The method of field and laboratory researches were used (Kulyk et al., 2017) during the experiment in conditions of the forest-steppe of Ukraine. The productivity of switchgrass biomass was determined by mowing along a one-meter wide field and biomass weighing.

Results and discussion

According to the research results, it has been found that switchgrass biomass yield depending on the seeding periods and seeding rates within the limits from 7.1 to 15.5 t/ha varied during 2012–2016. Seeding rates during the spring seeding period greater affected this indicator value comparing to the early, late and summer period (Figure 1).

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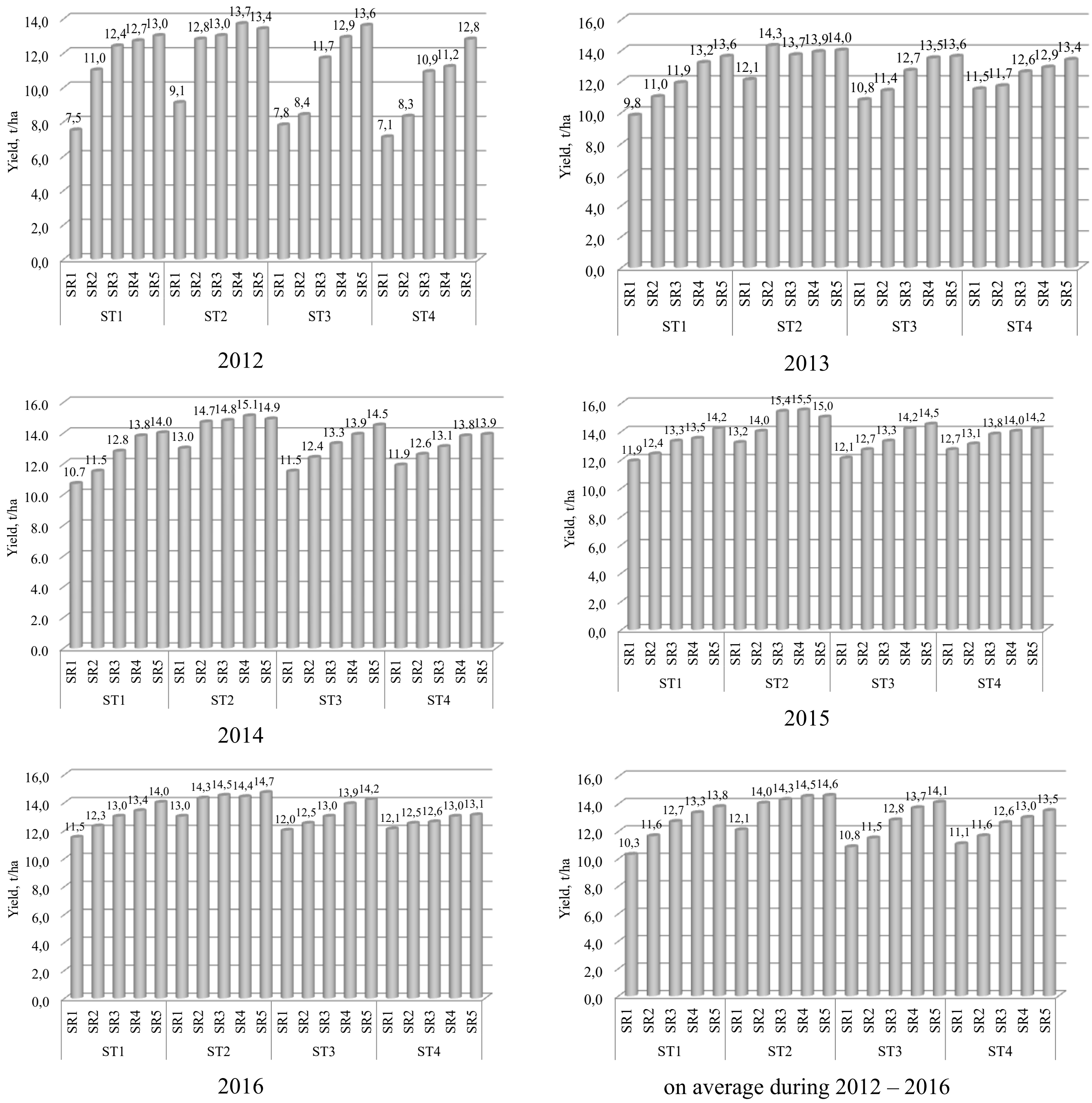

LSD$_{05}$ (factor A) – 0.95; LSD$_{05}$ (factor B) – 0.91; LSD$_{05}$ (factor C) – 1.01.

Figure 1. The yield of switchgrass dry biomass depending on the cultivation technology elements (seeding terms and seeding rates) in conditions of the forest-steppe of Ukraine, t/ha (2012–2016)

During the second period of seeding (spring), switchgrass formed a higher yield of vegetative mass in comparison with others. So, during the spring seeding term, the biomass yield varied from 12.1 t/ha (with the seeding rate of 1.9 kg/ha) to 15.5 t/ha (with the seeding rate of 5.7 kg/ha) with the subsequent decrease of the indicator while applying other seeding rates. At the same time, a tendency to decrease the crop yield during the late spring and summer seeding terms was observed.

Such characteristics as costs of production; full cost; revenue from sales of products; profit from sales of products; the level of products profitability should be used in order to evaluate (express-analysis) economic efficiency of switchgrass cultivation (Table 1).

Table 1. Economic evaluation (express analysis) of switchgrass cultivation (Kalinichenko and Kulyk, 2018)

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

Economic evaluation of the technologies of switchgrass biomass cultivation in Ukraine (Forest-Steppe zone), depending on the cultivation technology elements has been carried out in order to approbate the proposed methodological approaches. It has been determined that switchgrass cultivation during the spring seeding term with the seeding rate of 5.7 kg/ha is the the most efficient,with 14.5 t/ha biomass yield level. The profit from the biomass sale is 5427.8 UAH, a level of profitability is 65%, with the decrease of these indicators, respectively, by 78.38 UAH and 2.2%, at the seeding rate of 7.6 kg/ha. Both earlier and late seeding terms with different seeding rates also have lower economic efficiency compared to the given ones (Table 2).

Table 2. Economic efficiency of switchgrass biomass production in conditions of the forest-steppe of Ukraine, on average during the period of 2012–2016

Factor B (seeding terms)	Factor C (seeding rates)	Yield, t/ha	Indicators of economic efficiency				
			C_p, UAH/ha	C_t, UAH/ha	R_s, UAH/ha	P_b, UAH/ha	P, %
Variant 1	SR 1	10.3	6410.0	7038.2	9785.0	2746.8	39.0
	SR 2	11.6	6540.0	7187.5	11020.0	3832.5	53.3
	SR 3	12.7	6870.0	7450.3	12065.0	4614.7	61.9
	SR 4	13.3	7180.0	7962.6	12635.0	4672.4	587
	SR 5	13.8	7240.0	8065.4	13110.0	5044.6	62.5
Variant 2	SR 1	12.1	6620.0	7328.3	11495.0	4166.7	56.9
	SR 2	14.0	7710.0	8581.2	13300.0	4718.8	55.0
	SR 3	14.3	7510.0	8343,6	13585.0	5241.4	62.8
	SR 4	14.5	7520.0	8347.2	13775.0	5427.8	65.0

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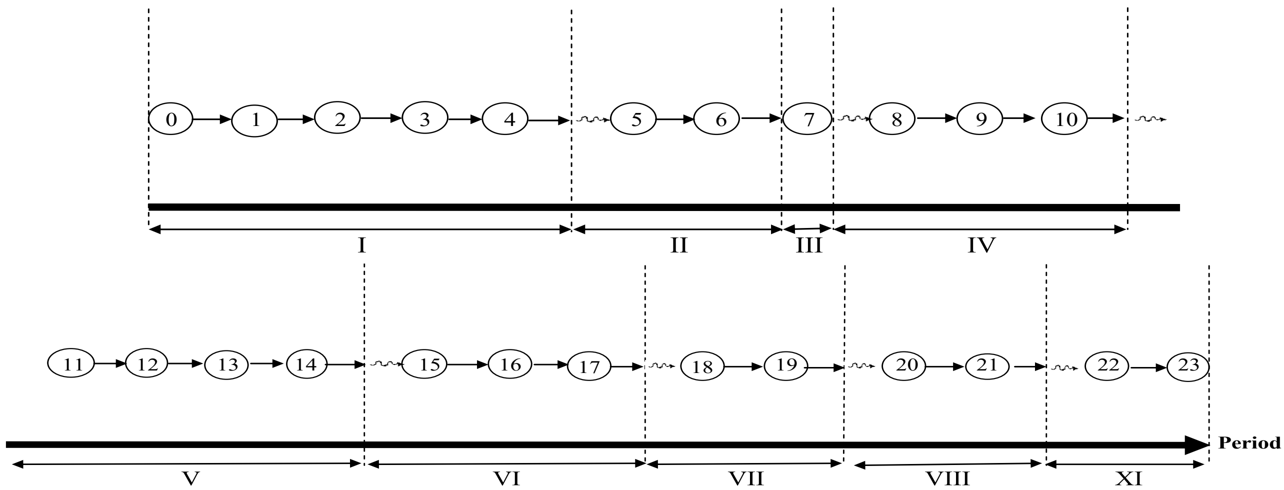
	SR 5	14.6	7690.0	8520.5	13870.0	5349.5	62.8
Variant 3	SR 1	10.8	6400.0	7065.6	10260.0	3194.4	45.2
	SR 2	11.5	6540.0	7226.7	10925.0	3698.3	51.2
	SR 3	12.8	6680.0	7401.4	12160.0	4758.6	64.3
	SR 4	13.7	7220.0	7978.1	13015.0	5036.9	63.1
	SR 5	14.1	7720.0	8515.2	13395.0	4879.8	57.3
Variant 4	SR 1	11.1	6510.0	7128.5	10545.0	3416.5	47.9
	SR 2	11.6	6540.0	7187.5	11020.0	3832.5	53.3
	SR 3	12.6	6940.0	7423.9	11970.0	4546.1	61.2
	SR 4	13.0	7120.0	7881.8	12350.0	4468.2	56.7
	SR 5	13.5	7220.0	8014.2	12825.0	4810.8	60.0

**Note*. Yield (t/ha) according to seeding rates: SR1 – 0.95, SR2 – 1.9, SR3 – 3.8, SR4 – 5.7, SR5 – 7.6 kg/ha.
**Note*. Biomass price of 950 UAH/t was taken into consideration while calculating economic efficiency of switchgrass cultivation.

A network model that reflects the logical technological subsequence and interconnection of operations in the process of switchgrass cultivation has been offered to increase the economic efficiency of switchgrass cultivation (Figure 2). This model allows to plan the optimal number of employees and material resources. Thus, the following factors have been determined: 1) the optimal duration of technological operations; 2) the possible duration of technological operations implementation, formed on the basis of available material and technical resources necessary for the implementation of technological operations; 3) the parameters of necessary technological operations implementation (Kalinichenko and Kulyk, 2018).



Calendar terms: I – the third decade of August – the first decade of September; II – the first decade of September – the first decade of October; III – the first decade of October – the third decade of October; IV – the first decade of April – the second decade of April; V – the third decade of April – the first decade of May; VI – the second decade of May – the third decade of May; VII – the first decade of June – the third decade of June; VIII – the first decade of July – the third decade of July; XI – the first – the second decade of December.
Technological operations: 1 – 2 – soil disking in two tracks (I); 3 – ploughshare hoeing (I); 4 – plowing (I); 5 – 6 – 7 – autumn cultivation (II – III); 8 – spring harrowing (IV); 9 – 10 – spring cultivation in two tracks (IV); 11 – pre-sowing cultivation (V); 12 – rolling before sowing (V); 13 – seeding (V); 14 – rolling of crops (V); 15 – 17 – loosening of row spacing (VI); 18 – 19 – 20 – 21 – row spacing cultivation (VII – VIII); 22 – switchgrass mowing with simultaneous grinding to chaff (XI); 23 – chaff transportation to a place of storage or processing (XI).

Figure 2. The network graph of switchgrass cultivation in conditions of the forest-steppe of Ukraine

The energy efficiency of switchgrass cultivation is based on the use of energy-saving production technology, which is defined as a number of interconnected operations that provide the reduction of energy expenditures per unit of output:

$$EI = \frac{E_c}{Y} \Rightarrow \min,$$

EI – energy intensity of the cultivation technology, MJ/t;

E_c – total energy resources expenditures per 1 hectare of switchgrass crops, MJ/ha;

Y – yield of switchgrass biomass, t/ha.

The application of a unified methodology of the energy efficiency evaluation allows to evaluate the energy intensity of the technological operations and develop the reserves for its reduction causing the least negative impact on the environment (Table 3).

Table. 3. Evaluation of energy efficiency of switchgrass cultivation

Indicators	Calculation methods
Direct energy expenditures on switchgrass biomass cultivation (E_d), MJ/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, MJ/ha; E_{mi} – energy expenditures, reified in seeds, mineral and organic fertilizers, plant protectants, MJ/ha; E_{zi} – expenditures of live labour energy, MJ/ha; E_{ui} – energy expenditures, reified in the main means of production, MJ/ha
Indirect energy expenditures on switchgrass biomass cultivation (E_{in}), MJ/ha	$E_{in} = \sum_{i=1}^{n} (E_{si} + E_{yi} + E_{di}),$ E_{si} – energy expenditures of management and maintenance personnel, MJ/ha; E_{yi} – energy expenditures on management and maintenance personnel allowance, MJ/ha; E_{di} – energy expenditures on industrial and social infrastructure, MJ/ha
Total energy expenditures on switchgrass biomass cultivation (TE_c), MJ/ha	$E_c = E_{np} + E_{нпр},$ E_{di} – direct energy expenditures on switchgrass cultivation, MJ/ha; E_{in} – indirect energy expenditures on switchgrass biomass cultivation, MJ/ha
Aggregate energy accumulated in switchgrass biomass (E_{aa}), MJ/ha	$E_{aa} = \sum_{i=1}^{n} O_i \cdot K_i \cdot e_i \cdot 100,$ O_i – output of switchgrass biomass (yield), t; K_i – coefficient of switchgrass biomass transformation into dry matter; e_i – energy content in 1 kg of dry matter, MJ; n – number of switchgrass varieties
Energy profit of switchgrass biomass cultivation (EP_c), MJ/ha	$EP_c = E_{aa} - E_c,$ E_{aa} – aggregate energy accumulated in switchgrass biomass, MJ/ha; E_c – total energy expenditures on switchgrass biomass cultivation, MJ/ha
Energy profitability of switchgrass biomass (P_e), %	$P_e = \frac{EP_c}{E_c} \cdot 100\%,$ EP_c – energy profit of switchgrass cultivation, MJ/ha; E_c – total energy expenditures on switchgrass cultivation, MJ/ha
Coefficient of energy efficiency of switchgrass biomass cultivation (K_{ee})	$K_{ee} = \frac{E_{aa}}{E_c},$ E_{aa}– aggregate energy accumulated in switchgrass biomass, MJ/ha; E_c – total energy expenditures on switchgrass cultivation, MJ/ha. If $K_{ee} < 1$ – switchgrass 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
Energy capacity of switchgrass biomass cultivation (EC_c), MJ/UAH	$EC_c = \frac{E_c}{G_b},$ E_c – total energy expenditures on switchgrass biomass cultivation, MJ/ha; G_b – gross switchgrass biomass, UAH/ha

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Energy output of switchgrass biomass cultivation (EO_b), UAH/MJ	$$EO_b = \frac{G_b}{E_c},$$ G_b – gross switchgrass biomass, UAH/ha; E_c – total energy expenditures on switchgrass cultivation, MJ/ha

Energy evaluation of the switchgrass cultivation technology elements has been carried out in order to approbate the proposed methodological approaches. It has been defined that the variants of spring seeding terms with all gradations of seeding rates – from 61148.8 to 61549.6 MJ/ha, the energy efficiency coefficient is from 3.2 to 3.8 (average level of energy efficiency) have the highest aggregate energy in biomass.

The largest energy profit can be obtained on the variants of spring seeding terms with seeding rate from 5.7 to 7.8 kg/ha (respectively 170466.4 and 172050.4 MJ/ha). Herewith, the lowest energy intensity is 4.47 and 4.44 MJ/UAH. The tendency to the decrease of energy efficiency is observed at the early and late switchgrass seeding terms.

The variants of the early spring and summer seeding terms with low seeding rate of 0.95 and 1.9 kg/ha have the lowest energy yields – less than 200000 MJ with the energy efficiency coefficient of 3.0 and lower. This testifies to a low level of biomass production efficiency.

The energy efficiency coefficient of switchgrass biomass production on all variants of the experiment during the period of 2012–2016 exceeded 1, and varied within the range from 2.3 to 3.8, with the maximum value of the indicator on all variants of spring, late spring and summer seeding terms with seeding rate from 1.9 to 7.6 kg/ha (from 4.4 to 5.7). So, this testifies to the low and average levels of energy efficiency of switchgrass cultivation applying determined agrarian measures.

The following variants: switchgrass sowing in spring seeding term with seeding rate of 3.8 to 7.6 kg/ha and with the energy efficiency coefficient of more than 3.1 (average level of energy efficiency) were the most effective among the studied variants (Table 4).

Table 4. Energy efficiency of switchgrass biomass production in conditions of the forest-steppe of Ukraine depending on the elements of cultivation technology, on average in the period of 2012–2016

Factors		Yield, t/ha	Indicators of economic efficiency						
seeding terms	seeding rates		E_c, MJ/ha	E_{aa}, MJ/ha	EP_c, MJ/ha	P_e, %	K_{ee}	EC_c, MJ/UAH	EO_b, UAH/MJ
Variant 1	SR 1	10.3	60860.3	164800.0	103939.7	170.8	2.7	6.22	0.16
	SR 2	11.6	61021.9	185600.0	124578.1	204.2	3.0	5.54	0.18
	SR 3	12.7	61245.0	203200.0	141955.0	231.8	3.3	5.08	0.20
	SR 4	13.3	61341.2	212800.0	151458.8	246.9	3.5	4.85	0.21
	SR 5	13.8	61421.4	220800.0	159378.6	259.5	3.6	4.69	0.21
Variant 2	SR 1	12.1	61148.8	193600.0	132451.2	216.6	3.2	5.32	0.19
	SR 2	14.0	61453.4	224000.0	162546.6	264.5	3.6	4.62	0.22
	SR 3	14.3	61501.5	228800.0	167298.5	272.0	3.7	4.53	0.22
	SR 4	14.5	61533.6	232000.0	170466.4	277.0	3.8	4.47	0.22
	SR 5	14.6	61549.6	233600.0	172050.4	279.5	3.8	4.44	0.23
Variant 3	SR 1	10.8	60940.5	172800.0	111859.5	183.6	2.8	5.94	0.17
	SR 2	11.5	61052.7	184000.0	122947.3	201.4	3.0	5,59	0.18

	SR 3	12.8	61261.1	204800.0	143538.9	234.3	3.3	5,04	0.20
	SR 4	13.7	61405.3	219200.0	157794.7	257.0	3.6	4,72	0.21
	SR 5	14.1	61469.4	225600.0	164130.6	267.0	3.7	4,59	0.22
Variant 4	SR 1	11.1	60988.5	177600.0	116611.5	191.2	2.9	5,78	0.17
	SR 2	11.6	61069.0	185600.0	124531.0	203.9	3.0	5,54	0.18
	SR 3	12.6	61229.0	201600.0	140371.0	229.3	3.3	5,12	0.20
	SR 4	13.0	61293.1	208000.0	146706.9	239.4	3.4	4,96	0.20
	SR 5	13.5	61373.3	216000.0	154626.7	251.9	3.5	4,79	0.21

Note. Yield (t/ha) according to seeding rates: SR1 – 0.95, SR2 – 1.9, SR3 – 3.8, SR4 – 5.7, SR5 – 7.6 kg/ha.

Conclusions

The conducted research allowed to comprehensively assess the efficiency of growing switchgrass in the conditions of the forest-steppe of Ukraine through the prism of financial and economic management adapted to the requirements of smart technological development of labor resources. The analysis of agricultural practices conducted for the period 2009–2016 revealed a consistent dynamics of crop yield growth starting from 2013, which indicates the effect of adapting the agroecosystem to the technology of growing switchgrass. The rational combination of crop rotation, agrochemical load, seeding rates and sowing dates allows achieving stable indicators of biomass productivity, with a special emphasis on spring sowing dates with a rate of 5.7 kg/ha, which provided the highest profitability of production (65%) and the best energy efficiency parameters.

The proposed network model of the technological process of cultivation allowed not only to formalize the logical sequence of agrotechnical operations, but also to reflect the temporal coordination of actions, which is a necessary condition for optimal utilization of labor resources. Such structuring of operations allows for a more accurate assessment of the need for material, fuel and energy and human resources, which is critically important in the context of smart planning of agricultural production processes. Energy analysis proved that the energy efficiency coefficient when using optimal technological elements reached values of 3.2–3.8, which indicates an average level of energy saving of the system, suitable for further intensification due to improved logistics and flexible resource planning.

Formalization of economic indicators demonstrated a close relationship between agrotechnical parameters and financial results, which opens up opportunities for creating adaptive management models focused on the hybrid logic of cost optimization and productivity improvement. The most promising in terms of integration into production practices are those technology options that combine economic feasibility, energy balance and high adaptability to changing production conditions.

Thus, the results of the study confirm that financial and economic management of the efficiency of production of energy crops based on switchgrass can be successfully implemented under the condition of an integrated approach that combines smart technological planning, institutional support of labor resources and high-precision energy monitoring. This creates the basis for the transformation of the agricultural sector towards greater sustainability, competitiveness and resource autonomy.

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