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ECONOMIC AND BIOENERGY ASSESSMENT OF CROP CULTIVATION TECHNOLOGIES

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ABSTRACT

To determine the energy efficiency of crop production, bioenergy assessment of technological processes involves a comparative analysis of the energy intensity of technologies in producing agricultural products. The implementation energy consumptions are evaluated and assessed using cost of direct and indirect energy per unit of consumed objects and means of labor. To consider the amount of energy per unit mass of production, total energy costs include the costs of electrical, thermal energy, and fuel consumed in all stages of the process. This work analyzes and evaluation of the economic efficiency of crop cultivation technologies. As a case study of applying the technology to winter wheat, corn for grain, sunflower, and silage corn of a private company, it finds significant improvements in productivity for all crop types with enhanced energy efficiency. The automated economic crop information management system is built to include all relevant cost and energy factors.

Disciplinary: Green and Sustainable Agriculture and Crop Farming, Agriculture and Energy Economics.

1. INTRODUCTION

The problems of crop management and support for managerial decision-making are relevant at the moment. Despite the number of studies on crop management in an agro-industrial enterprise, the use of mathematical models, methods, and means of information support for the analysis and evaluation of the economic efficiency of technological processes in crop production remain poorly understood. The relevance of these problems determined the choice of topic and the setting of goals and objectives of the study.

Maslov et al. (2020) presents the improvement of cultivating field crops by combining operations

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on tillage, sowing, fertilizing, harvesting, and technical based on optimization of machines, energy, multifunctional technology. The research improved technical and economic efficiency, such as labor productivity, energy intensity of processes and the cost of investing in the mechanization of technological processes.

Raising the level of agricultural development in Russia requires finding ways and means to increase the efficiency of agricultural production. The rational use of the existing technical potential, the development of a regional investment strategy are possible economic levers for the stable growth of agricultural production.

Under conditions of market, the main criterion for the economic efficiency of agricultural production is to obtain the maximum possible profit per unit area by increasing production at the lowest cost of living labor based on the rational use of material and labor resources, as well as the profitability of product sales.

Crop management is a complex dynamic process to adopt the selection, evaluation, and optimal use of limited production resources. For example, when cultivating winter wheat, scientists from the Kuban State Agrarian University developed and experimentally tested more than 48 alternative technologies for winter wheat cultivation in experimental plots and production conditions. Variants of these alternative technologies differ from each other in the level of application of fertilizers, plant protection products, the multiplicity of tillage, and other resources. These are essentially energy and resource-saving technologies for cultivating winter wheat in a crop rotation with various predecessors, providing stable crops, saving production resources, and also ensuring the conservation of black soil fertility (Burda et al., 2016).

The enlarged alternative technologies are recommended for four groups of agricultural enterprises depending on their economic potential: economically strong, economically medium, economically weak farms and nature protection zones.

When choosing the technology of crop cultivation, the agronomist has at his disposal a database of more than one hundred different alternative technologies for each of the crops. The decision-maker (DM) has the task, according to certain criteria, to select the technology of cultivating the crop that is most suitable for the given economy, climate zone (Baranovskaya et al., 2016). Table 1 shows a fragment from a set of economic indicators for assessing and selecting technology for the cultivation of winter wheat.

Table 1: Economic indicators of winter wheat cultivation technology in prices for 2019 (Authors' result).

Indicator	Winter wheat cultivation technologies				
	0113	1113	0330	2222	3132
Grain productivity (kg/ha)	50	53	65	70	76
Costs per 1 ha:					
person-hr	9.903	10.12	17.21	15.26	16.89
Fuel, kg	82.49	85.82	98.43	91.01	99.85
The number of costs (rubles)					
total direct	8041.36	8094.86	18512.58	10724.32	14479.26
Fertilizers	1064.20	1064.20	7844.80	4024.40	2064.20
means of protection	994.80	994.80	4598.36	2005.60	5598.30

Next, the process of compiling and calculating technological maps for the cultivation of agricultural crops, followed by their assessment and selection. For these purposes, a set of models and methods for the economic assessment of technologies has been developed. At the first stage of the selection of the technological technique, the method of binary decision matrices is used, which makes it possible to select from the database a set of six to eight technologies that most satisfy the restrictions set by the agronomist.

In recent years, the problem of fuel and energy supply for agricultural production has become especially acute. This necessitates the rational consumption of electricity and fuel. The use of the subsystem of bioenergy assessment of technological processes in crop production, which allows you to choose the most effective energy and resource-saving technologies, can contribute to solving this problem in agriculture (Petrik et al., 2016).

Bioenergy assessment of technological processes involves a comparative analysis of the energy intensity of agricultural technology, determining the energy efficiency of production. At the same time, the energy intensity of the technological process is understood as the energy consumption for its implementation.

Energy efficiency is characterized by an indicator that establishes the ratio between the energy contained in agricultural products and the energy spent on the production of this quantity of products.

The total energy costs per 1 hectare of the sown area, that technological process is calculated taking into account the energy costs expended using: fuel; fertilizers and pesticides; seed; living labor; agricultural machinery, machinery, and implements; electricity; production facilities for storing products, seeds, and other material resources.

Energy costs for these types of resources are calculated based on the datasheet of the production process and energy equivalents.

The accuracy of the results of bioenergy assessment of crop cultivation technologies largely depends on the completeness of the accounting of technological operations, and bioenergy efficiency on the fulfillment of agrotechnical requirements, the composition of units, production, and fuel consumption per unit of work, organizational, soil-climatic and other factors (Tkachenko et al., 2016). A complete list of technological operations and agricultural requirements (depth of tillage, frequency of operations, seed sowing rate and a dose of fertilizer for the content of nutrients and active substance, a dose of herbicides and pesticides by their types, headland distance of transportation of crops, fertilizers, etc.); the composition of the unit and the number of trailed implements, the capacity of the unit for 1 hour of working time or the unit time per 1 ha; the number of staff: tractor drivers, drivers, auxiliary workers and labor costs per 1 ha for each category of these contractors; consumption rate and actual fuel consumption per 1 ha, depending on agricultural requirements, Table 2.

Having this information, they begin to calculate the energy expenditure per 1 ha of agricultural cultivation area. To do this, use energy equivalents and data on the costs of material and labor resources per 1 hour and 1 ha.

Using this information, the energy expended is calculated per 1 hectare of agricultural crop cultivation. To do this, use energy equivalents and data on the costs of material and labor resources per 1 hour and 1 ha. Table 1 shows an example of bioenergy performance indicators for winter wheat cultivation technologies.

Table 2: Bioenergy efficiency of winter wheat cultivation technologies (authors' work).

Indicator	Technology code		
	1122	1132	0232
Grain productivity, kg/ha	58	66	67
Energy output from 1 ha, GJ, total	181.65	206.92	162.04
Total energy consumption per 1 ha, GJ	28.31	29.33	38.15
Energy increment, GJ	153.44	177.59	123.89
The ratio of received and expended energy	6.41	7.05	4.24
Net efficiency ratio	5.41	6.05	3.24
Labor costs, person-hr			
- on 1 ha	12.71	13.73	14.81
- per 1 centner of grain	0.21	0.2	0.22
Liquid fuel consumption (kg)			
- on 1 ha	40.71	46.43	47.34
- per 1 centner of grain	0.7	0.7	0.7
- 1 GJ of energy expended	2.04	2.25	1.75
- 1 kg of liquid fuel	1.42	1.42	1.41
- 1 person-hr	4.56	4.8	4.52

With such a time-consuming process, such as forming a technological map and conducting an economic and bioenergy analysis of technological processes, one of the specialists (the so-called human factor) is likely to make mistakes. That is why it became necessary to automate such labor-intensive processes, and this problem must be solved within the framework of creating an enterprise management information system as a whole (Vasilko et al., 2016).

Based on the analysis of the subject area and the bioenergy technology assessment methodology, a conceptual model of information flows of the crop production management process was developed, based on which an information subsystem of the economic and bioenergy assessment of technological processes of crop production of agricultural enterprises using the methods of economic and mathematical modeling will be designed.

Therefore, the development and implementation of the crop management information system and the automated assessment of technological maps by the bioenergy method will allow agricultural enterprises to promptly, in a short time, make decisions on choosing the most energy and resource-saving technology for cultivating crops, save production costs of one or another type of agricultural product, and increase production profitability products will help the agricultural organization become more competitive in the world like agricultural products.

2. MATERIALS AND METHOD

Bioenergy assessment of technological processes involves a comparative analysis of the energy intensity of technologies, agricultural products, determining the energy efficiency of production. At the same time, the energy intensity of the technological process is understood as the energy consumption for its implementation. The energy intensity of a product is the expended energy to produce a unit mass of agricultural products. The energy equivalent is the cost of direct and indirect energy per unit of consumed objects and means of labor. The energy supply of agricultural products - the amount of energy per unit mass of production. Total energy costs or total energy costs are the costs of electrical, thermal energy, and fuel consumed in the process.

Indirect energy costs are energy costs for objects and means of labor, through which the production process is carried out. Energy intensity of mechanization means is the energy consumption for the manufacture and repair of agricultural machinery, machines, and implements. The energy intensity of labor costs is the energy costs of performers of technological processes of production.

Energy efficiency is characterized by an indicator that establishes the ratio between the energy contained in agricultural products and the energy spent on the production of this quantity of products.

This indicator is calculated by

$$R = \frac{P}{E} \quad (1),$$

where R is the energy efficiency of the technology;

P is the energy contained in the final agricultural product, MJ;

E - energy spent on obtaining products, MJ.

The energy contained in the final agricultural product is determined by

$$P = \alpha \times \gamma \quad (2)$$

where α is the energy equivalent of the main product, MJ/c;

γ - crop productivity, kg/ha.

The total energy costs for the entire production technology are

$$E = \sum_1^n E_i \quad (3)$$

where E_i is total energy costs per 1 ha of agricultural crop area of the i-th technological process, MJ; n is the number of technological operations.

The total energy costs per 1 hectare of the sown area - that technological process is calculated taking into account the energy costs expended using: fuel; fertilizers and pesticides; seed; living labor; agricultural machinery, machinery, and implements; electricity; production facilities for storing products, seeds, and other material resources.

Energy costs for these types of resources are calculated on the basis of the datasheet of the production process and energy equivalents.

$$E_i = (S_i \times K_s) + (Z_i \times K_z) + (T_i \times K_t) + \left(F_i \times K_f\right) \quad (4)$$

where S_i is the amount of planting material per 1 ha (kg/ha);

K_s - energy intensity factor of planting material;

Z_i - the amount of plant protection products, fertilizers per 1 ha (kg/ha) or (l/ha);

K_z - energy intensity coefficient of plant protection products, fertilizers;

T_i - the amount of fuel and lubricants consumed per 1 ha (kg / ha) or (kW/ha);

K_t - the coefficient of energy consumption of fuels and lubricants and electricity;

F_i - the number of man-hours of staff per 1 ha;

K_f - the energy intensity coefficient of farmworkers.

The accuracy of the results of bioenergy assessment of crop cultivation technologies largely depends on the completeness of the accounting of technological operations, and bioenergy efficiency on the fulfillment of agrotechnical requirements, the composition of units, production, and fuel consumption per unit of work, organizational, soil-climatic and other factors. The experimental conditions should be approximately the same so that the results of the assessment are comparable.

A complete list of technological operations and agricultural requirements (depth of tillage, frequency of operations, seed sowing rate and a dose of fertilizer for the content of nutrients and active substance, a dose of herbicides and pesticides by their types, headland distance of transportation of crops, fertilizers, etc.); the composition of the unit and the number of trailed implements, the capacity of the unit for 1 hour of working time or the unit time per 1 ha; the number of staff: tractor drivers, drivers, auxiliary workers and labor costs per 1 ha for each category of these contractors; consumption rate and actual fuel consumption per 1 ha, depending on agricultural requirements. Having this information, they begin to calculate the energy expenditure per 1 ha of agricultural cultivation area. To do this, use energy equivalents and data on the costs of material and labor resources per 1 hour and 1 ha.

3. RESULT AND DISCUSSION

The economic information management system for the cultivation of field crops is informationally and organizationally connected with the agricultural enterprise management system, with other subsystems and functional tasks.

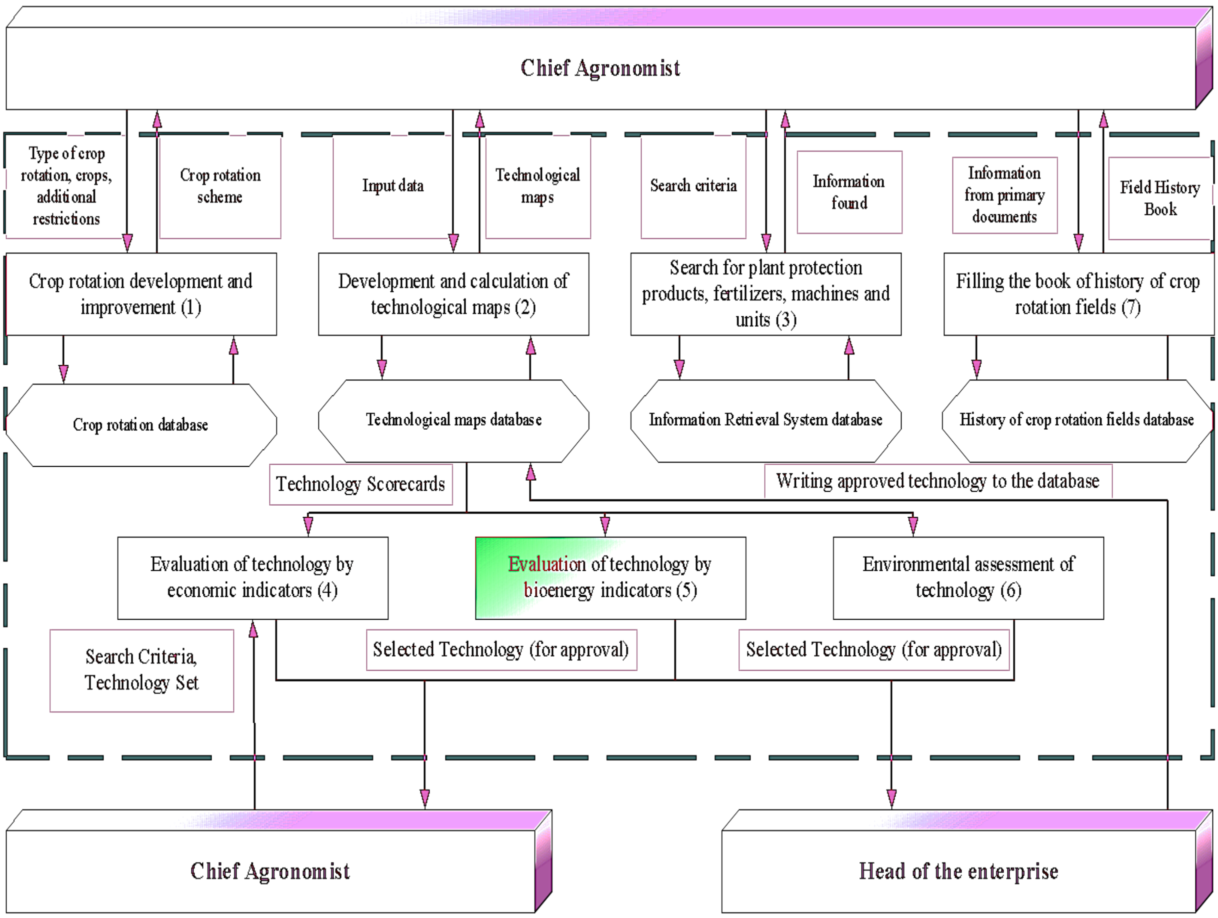

Figure 1: The model of information flows of crop management processes (authors' work).

The developed automated information system is based on eight mathematical models and management optimization methods, which includes the following modules:

1) The subsystem of crop rotation optimization
2) Information retrieval subsystem
3) Module for compiling and calculating technological maps
4) Decision Support Subsystem
5) An electronic map of the history of crop rotation fields

The organization and functional structure of the developed crop management system can be represented in the form of a functional diagram and data flow diagrams.

With such a time-consuming process, such as forming a technological map and conducting an economic and bioenergy analysis of technological processes, one of the specialists (the so-called human factor) is likely to make mistakes. That is why the need arose to automate such labor-intensive processes, and this problem must be solved within the framework of creating an integrated information management system and decision support in crop production.

Based on the analysis of the subject area and the bioenergy technology assessment methodology, a conceptual model of information flows of the crop management process was developed (Figure 1).

Based on this model was developing an information subsystem for the economic and bioenergy assessment of technological processes of crop production of agricultural enterprises using the methods of financial mathematical modeling. Using this system was assessment bioenergy efficiency of winter wheat cultivation technologies for economically weak farms (Table 3).

Table 3: Bioenergy efficiency of winter wheat cultivation technologies for economically weak farms

Indicator	Types of technology for economically weak farms					
	0000	0002	0102	0122	0132	2032
Grain productivity, kg/ha	22	31	44	51	55	54
Energy output from 1 ha, GJ, total	66.39	96.37	137.43	159.54	170.63	169.02
Total energy consumption per 1 ha, GJ	12.78	14.44	27.18	27.88	28.76	17.35
Energy increment, GJ	53.61	81.93	110.25	131.66	141.87	151.67
The ratio of received and expended energy	5.19	6.67	5.05	5.72	5.93	9.74
Net efficiency ratio	4.19	5.67	4.05	4.72	4.93	8.74
Labor costs, person-hr						
- on 1 ha	6.483	8.369	11.05	10.849	13.253	11.593
- per 1 center of grain	0.29	0.26	0.25	0.21	0.24	0.21
Liquid fuel consumption, kg						
- on 1 ha	15.586	26.923	39.762	43.352	47.762	38.122
- per 1 center of grain	0.7	0.86	0.9	0.85	0.86	0.7
The output of the main products based on						
- 1 GJ of energy expended	1.72	2.14	1.61	1.82	1.91	3.11
- 1 kg of liquid fuel	1.41	1.15	1.1	1.17	1.15	1.41
- 1 person-hr	3.39	3.7	3.98	4.7	4.15	4.65

The analysis shows that the most energy-intensive technology is 0132, in which the total energy consumption per 1 ha with a yield of 55 kg/ha is 28.76 GJ. In the structure of energy costs, the largest share has been spending on fertilizers 37.06%, seeds 29.9%, fuel 13.2%. The least energy-intensive technology is 0000, in which the total energy consumption per 1 ha with a yield of 22 kg/ha is only 12.78 GJ.

We propose to pay special attention to technology 2032, which, at a relatively low cost of total energy 17.35 GJ, provides a yield of 54 kg/ha. In its structure of energy costs, the largest share was spending on seeds 49.57%, liquid fuel 17.47%. The economic effect, in this case, is achieved through the use of the required number of new plant protection products.

3.1 TECHNOLOGY APPLICATION TO THE PRIVATE COMPANY "FOOTHILLS OF THE CAUCASUS"

Noteworthy is the experience of introducing zero energy and resource-saving anti-erosion technology in the PC "Foothills of the Caucasus" in the Seversky district of the Krasnodar Territory, where crops have been sown for 11 years using surface tillage. The essence of this technology is the complete or partial cessation of mechanical tillage, which can significantly save fuels and lubricants, spare parts, and, in general, sharply reduce the cost of cultivating field crops.

Since 2017, crop rotation on the farm has been adapting by the agrochemical service to the conditions of minimizing tillage (Table 4).

Table 4: Yield dynamics of the main field crops in the farm "Foothills of the Caucasus" in comparison with the average for the Seversky district of the Krasnodar Territory

Crop types	2017 r		2018r		2019 r	
	Average productivity, kg/ha in the district	Productivity, kg/ha by farm	Average productivity, kg/ha in the district	Productivity, kg/ha by farm	Average productivity, kg/ha in the district	Productivity, kg/ha by farm
Winter wheat	22.3	22.6	23.3	31.6	26.5	39.4
Corn for grain	19.3	26.6	30.7	32.9	32.9	39.1
Sunflower	0.4	-	12.9	17.8	9.0	12.4
Silage Corn	81	147	98.0	126	104.3	210

Despite the rejection of a significant part of the mechanical tillage, the productivity of the main field crops remains stable and tends to increase (Table 4).

These measures made it possible to practically switch to zero technology, that is, to exclude all types of mechanical tillage except sowing.

Currently, with rising prices for energy, fertilizers, spare parts for domestic and imported agricultural machinery, the economic efficiency of the zero-technology used in the economy has sharply increased.

The use of resource-saving technologies in the KPS "Foothills of the Caucasus" allowed:

- reduce diesel consumption by 35-40%;
- 25-50% (depending on the cultivated crop) in comparison with traditional techniques to reduce costs in the production of agricultural products;
- significantly reduce the number of agricultural machinery;
- increase soil fertility - the content of humus increased by 30-40% at a depth of 0-15 cm.

Zero and minimal tillage methods are alternatives to conventional tillage methods. Their importance will inevitably increase in the future, due to the need to improve soil fertility and the ecological situation due to the reduction of the technogenic load on arable land.

For a group of economically medium farms, it is possible to recommend technology 1132, when fulfilling which, the total energy consumption per 1 ha is 29.33 GJ, with a yield of 66 c / ha. The largest share in the structure of energy costs is spent on fertilizers 36.33%, on seeds 29.32%, liquid fuel 18.48%, electricity 12.58% (Table 5).

Table 5: Bioenergy efficiency of winter wheat cultivation technologies for economically medium-sized farms

Indicator	Types of technologies for economically medium-sized farms			
	1122	1132	0232	2132
Grain productivity, kg/ha	58	66	67	73
Energy output from 1 ha, GJ, total	181.65	192.04	206.62	229.03
Total energy consumption per 1 ha, GJ	28.31	29.33	38.15	33.4
Energy increment, GJ	153.44	177.59	123.89	195.63
The ratio of received and expended energy	6.41	7.05	4.24	6.85
Net efficiency ratio	5.41	6.05	3.24	5.85
Labor costs, people - hr				
- on 1 ha	12.7	13.732	14.808	17.416
- per 1 center of grain	0.21	0.2	0.22	0.23
Liquid fuel consumption, kg				
- on 1 ha	40.712	46.432	47.34	67.812
- per 1 center of grain	0.7	0.7	0.7	0.92
The output of the main products based on				
- 1 GJ of energy expended	2.04	2.25	1.75	2.18
- 1 kg of liquid fuel	1.42	1.42	1.41	1.07
- One person – hr	4.56	4.8	4.52	4.19

The most energy-intensive technology is 0232, the total energy consumption per 1 ha is 38.15%. The implementation of this technology provides for complete chemical protection of plants with herbicides (in the structure of energy costs 5.17%), fertilizers for the main treatment N70P90K60 in top dressing in early spring, N70 is added to tillering of winter wheat, N30 added to the tillering.

Using Heavy Disk Harrow (HDH) machinery, the methods of surface and shallow soil cultivation include peeling, cultivation, hilling, harrowing, rolling, trailing, malanie and others. With HDH, the soil cultivation is of 8-10 cm depth. The largest share in the cost structure is spent on fertilizers 49.6%, seeds 22.54%, liquid fuel 9.87%, plant protection products 4.53% (Table 4).

Table 4: Bioenergy efficiency of winter wheat cultivation technologies for economically stable farms

Indicator	Types of technologies for financially stable farms					
	2132	3132	2232	1332	2222	0330
Grain productivity, kg/ha	73	76	83	76	70	65
Energy output from 1 ha, GJ, total	229.03	238.51	260.62	238.5	218.01	202.21
Total energy consumption per 1 ha, GJ	29.76	32.14	41.56	42.13	39.13	57.08
The increment of energy., GJ	199.27	206.37	219.06	196.4	178.88	145.13
The ratio of received and expended energy	7.69	7.42	6.27	5.66	5.57	3.54
Net efficiency ratio	6.69	6.42	5.27	4.66	4.57	2.54
Labor costs, people-hr						
- on 1 ha	14.209	16.894	20.68	19.44	15.256	17.208
- per 1 center of grain	0.19	0.22	0.24	0.25	0.21	0.26
Liquid fuel consumption, kg						
- on 1 ha	47.862	62.556	65.7	67.83	56.475	66.255
- per 1 center of grain	0.65	0.82	0.79	0.89	0.8	1.01
The output of the main products based on						
- 1 GJ of energy expended	2.45	2.36	1.99	1.8	1.78	1.13
- 1 kg of liquid fuel	1.52	1.21	1.26	1.12	1.23	0.98
- One person - h	5.13	4.49	4.01	3.9	4.58	3.77

For this group of farms, based on bioenergy assessment, we can recommend technology 2132, in which the total energy consumption per 1 ha is 29.76 GJ, with a yield of 73 kg/ha. The economic efficiency of this technology has been achieving by providing an increased level of soil fertility, the humus content of 3.2-3.3% in the arable layer. The fertilizer system is presented by N35P45K30 for the primary tillage, in fertilizing in early spring N35 and N30 at heading. Crops had entirely protected from weeds with the help of herbicides. Normally, a HDH machine is run in 2-3 tracks against the background of plowing under the predecessor of winter wheat - sunflower.

It is easy to notice that a decrease in the level of technology intensity accompanied by structural changes in the total energy - the proportion of mineral fertilizers decreases, but the balance of power spent on seeds, fuel, machinery, and equipment increases.

Also, from the calculation data, it is seen that with an increase in the energy intensity of the technology, the energy efficiency coefficient of wheat production decreases. Along with a decrease in bioenergy efficiency, the efficiency of resource use had reduced.

The software product, including the module for analysis, assessment, and selection of effective crop cultivation technology, by bioenergy and environmental indicators, will be useful to agronomists of small agricultural enterprises. It will also become indispensable for specialists in sizeable agrarian production. It is an essential tool for solving tasks on the restoration of soil fertility and the reduction of technogenic load.

Therefore, the development and implementation of the crop management information system and the automated assessment of technological maps by the bioenergy method will allow agricultural enterprises to promptly, in a short time, make decisions on choosing the most energy and resource-saving technology for cultivating crops, save production costs of one or another type of agricultural product, and increase production profitability products will help the agricultural organization become more competitive in the world like agricultural products.

4. CONCLUSION

The studies showed that the lack of objective and timely information at all stages of crop production, and, as a result, the suboptimal choice of crop cultivation technology, leads to the fact that the cost of labor and material resources increase significantly, the company loses profit and sometimes incurs losses. Therefore, the development of mathematical models for the analysis and evaluation of the economic efficiency of crop cultivation technologies, and the introduction of a decision support system based on these models in production management processes, has become very relevant. Also, the methodological possibility and expediency of using information technologies and mathematical models and methods for analyzing and evaluating the economic efficiency of technological processes in crop production were identified.

It should be especially noted that the developed software package is based on models and techniques that take into account the specifics of the Kuban agribusiness. The software product, including the module for analysis, assessment, and selection of effective crop cultivation technology for economic, bioenergy and environmental indicators, will be useful for small agricultural enterprises, and will also become indispensable for large agricultural enterprises.

5. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding authors

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