The Improvement of the Technology of Winter Wheat Grain Production for the Purpose of Energy Saving

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The technological directions of energy saving in winter wheat grain production, an advanced technological set of machinery, and the structure of the components of total energy expenditure are substantiated. The purpose of the paper is to substantiate the reduction of the energy intensity of winter wheat grain production due to design and technology factors and combining operations when implementing manufacturing processes. The comparative assessment of machines and sets of machines on the energy criterion is made in a differentiated way, with regard to the individual components of total energy expenditure in the compared wheat cultivation technologies. The proposed technology ensures the improvement of the energy efficiency of grain production by 42 per cent.

Key words: Energy expenditure, energy efficiency, technology, machine-tractor units, combined harvester, the complexity of works, crop rotation.

The reduction of the cost of power supply of agricultural processes and improving the competitiveness of agricultural products have always been the focus of attention of science and industry. The problem of energy saving in the agroindustrial complex (AIC) has become especially urgent in recent years, taking into account the constant rise in the prices for fuel and lubricants, fertilizers, pesticides, and the lack of stability in the foreign exchange market.

By energy saving in the agroindustrial complex we shall mean savings in raw materials, fuel and lubricants, manpower, and funds, for the purpose of ensuring the competitiveness of agricultural products. Therefore, the task of

reducing the labor, material and energy costs, related to the manufacturing of these products, remains relevant. The problem of energy saving is in the focus of attention both in Russia [1, 7, 16, etc.] and abroad [2, 3, etc.].

The labor and material costs of the production of agricultural products in Russia are very high. For example, the labor input, required for the production of 1 ton of grain, amounts to 9 man hours, while in the United States – 2.6, for the production of beets, respectively, 7.5 and 1.1, for potatoes – 26.5 and 2.2, for milk – 85 and 4, for beef – 580 and 22, for pork – 330 and 8 man hours[16]. The energy intensity of agricultural products in Russia is 2-4 times higher than in the United States and other countries of the world. For the production of 1 ton of grain 178 kg of fuel equivalent is consumed, while in the United States – only 45 kg. Total energy expenditure per 1 ha of farmland is respectively 280 and 121 kg of fuel equivalent[8]. Agricultural energy

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expenditure annually increases by 1.1% [16].

Taking the foregoing into consideration, the purpose of the paper is to substantiate the reduction of the energy intensity of winter wheat grain production due to design and technology factors and combining operations when implementing manufacturing processes.

The substantiation is provided for four parts of the wheat production technology: tillage and sowing; crop tending; harvesting and processing of grain; carrying out basic works of post-harvest complex.

Methodology

The analysis of the operations of the basic technology of winter wheat grain production and the synthesis of the proposed new technology solutions are implemented on the basis of our own research, the results of testing the technologies and equipment in the Krasnodar region, as well as the analysis of domestic and foreign literature [2, 3, 10, etc.]. The calculation of the efficiency of technological operations in terms of the energy efficiency is carried out using the methodology of the All-Russia Research Institute for Mechanization of Agriculture (WIM)[12]. Total energy expenditure was determined for each operation of the flow process chart of winter wheat cultivation according to the basic technology (Table 1) and the proposed advanced technology (Table 2).

Table 1 presents the main operations of winter wheat cultivation according to the basic technology, as well as the set of post-harvest works (processing of grain, tillage and post-harvest sowing of mustard as green manure). All the normative indicators for the calculation are taken according to the methodology of the All-Russia Research Institute for Mechanization of Agriculture [12] and the State Research Institute for the Repair and Maintenance of Tractors and Machines (GOSNITI) [19]. The basic technology (Table 1) applies the widely used agricultural machinery, which is not always able to fully introduce modern energy-saving technologies and needs to be replaced, which was implemented in the proposed advanced winter wheat cultivation technology (Table 2).

The flow process charts show the list and sequence of all technological operations (column 2), agrotechnical requirements for their implementation (column 3), the configuration of the unit: the model of the tractor (column 4) and agricultural machine (column 5), the performance rate of the unit (column 6), the amount of attending personnel (column 7), the components of energy expenditure: direct (energy of the consumed fuel, column 8), materialized (energy expenditure for the production of fertilizers, pesticides, etc., column 9), human labor energy expenditure (column 10), energy expenditure for the production of tractors and machines (column 11) and total energy expenditure (column 12).

The calculation of energy expenditure takes into account materialized energy expenditure for the production of fertilizers, pesticides, etc. (column 9, Table 1). The latter have a very high level of energy expenditure compared to other technological operations, exceeding by several times even plowing as the most energy-intensive operation. In this regard, it is very important to reduce the total energy expenditure of the most energy-intensive operations[8].

The materialized energy expenditure in crop production takes into account the energy expenditure for the use of fertilizers, chemicals, water, grain, etc. The energy, which is materialized in them, is included into the energy expenditure for the processing, treating, harvesting and storage of crops[12]. For example, according to Table 1, the energy expenditure for the production of manure (column 9) amounted to 4200 MJ/ha, for the sowing of wheat – 630 MJ/ha, for the application of fertilizers using an aircraft AN-2 – 1260 MJ/ha. When using the basic technology, the total energy expenditure for tillage, wheat sowing, crop tending, harvesting and processing of crops amounts to 12371.79 MJ/ha. Of these, direct energy expenditure (fuel consumed) amounts to 3499.34 MJ/ha, energy expenditure for utilities and machines – 2498.96 MJ/ha, or 20.29%, materialized energy expenditure – 6354 MJ/ha, or 51.4%, and human labor energy expenditure – 19.59 MJ/ha, or 0.15%.

The post-harvest set of works in the winter wheat cultivation technology includes the post-harvest tillage and sowing green manure to be used as fertilizer. This technique is already widely used in practice, and its effectiveness is studied in [4]. In the Kuban region, mustard is most commonly used as green manure.

The post-harvest set of works according to the

basic technology (stubble disking and mustard sowing) requires, according to our calculations, 903.57 MJ/ha. Thus, the structure of total energy expenditure for the production of winter wheat grain according to the basic technology, including the post-harvest set of works (stubble disking and post-harvest sowing of mustard as green manure) is the following (Table 1): direct energy expenditure – 4127.34 MJ/ha, or 31.09%; energy expenditure for utilities and machines – 2773.1 MJ/ha, or 20.9%; materialized energy expenditure – 6354 MJ/ha, or 47.9%; human labor energy expenditure – 20.9 MJ/ha, or 0.16%, in total – 13275.4 MJ/ha.

RESULTS

The basic technology of winter wheat cultivation (Table 1) includes 19 technological operations for the production of grain and non-grain part of the crop – chaff, which is used for forage. The set of basic machinery includes outdated equipment, which is still in use, but is no longer able to ensure the increase of labor efficiency, the reduction of all kinds of expenditures (energy, labor, and cash expenditures), high quality of field works and their timely implementation. The technology insufficiently uses combination of operations, energy saving in the process of fertilizing, spraying, multifunctional units. Harvesting and post-harvest processing of crops are organized inefficiently, and this problem has not been addressed up to the present moment. The use of heavy combined harvesters results in large crop losses and shattering of grain; together with cargo vehicles, combined harvesters contribute to the overconsolidation of soil, which reduces future yields. In this regard, the transition to a new energy-saving technology, which would eliminate the above-mentioned disadvantages and improve the competitiveness of grain, is an extremely relevant task.

In the proposed advanced technology (Table 2) many technological operations are significantly improved. The total amount of technological operations is reduced to 17. The proposed set of new-generation machinery includes new tractors, tillage machines, sowers, mineral and organic fertilizer applicators, low-volume sprayers, high-performance trailed combined harvesters, on the basis of which

multifunctional units were assembled, according to our patents for inventions [6]. In the process of grain crop harvesting, along with trailed combined harvesters, grain auger wagons are to be used to transport grain from combined harvesters to the thrashing floor (if the distance is up to 3 km) or to large capacity trailers (if the distance is more than 3 km), like Fliegl trailers. These techniques alone will reduce the overconsolidation and dispersion of soil, losses of grain and all kinds of expenditures. The technology of unwinnowed grain harvesting is used: grain and chaff are collected into the grain tank of a combined harvester, and straw is cut and spread across the field or is left standing in case of harvesting grain by stripping (using a special adapter of a combined harvester). The unwinnowed heap of chaff and grain, which is transported to the threshing floor, is divided into pure grain and chaff – non-grain part of the crop, very valuable for livestock farming, which is stored at feeding platforms or under shelter.

To divide the unwinnowed heap into grain and chaff, the high-performance aspiration and screening separator ÌN230 (Canada) can be used, which has a throughput rate of 100 t/h. The technology of unwinnowed grain harvesting has been developed in our country for many years by the All-Russia Research Institute for Mechanization of Agriculture (VIM), the All-Union Institute for Agricultural Machine Building (VISHOM), etc., but this technology has not become a frequent practice because of the bulkiness of the stationary processing unit. Currently the availability of the series-produced and tested MN230 separator easily solves the problem of unwinnowed grain harvesting[2,3].

The proposed technology of wheat cultivation also effectively solves the problems of the transportation of seeds and fertilizers and loading grain seeders using Reboke-16 loaders, the transportation and application of manure using PUS-15 trailers, seeding using Rapid seeders (Sweden), spraying crops using high-performance self-propelled sprayers Tuman-2D [18], which can also be reequipped to apply mineral fertilizers (Table 2). Additional advantages of Tuman-2D sprayers are high performance (up to 1000 ha per day) and low ground pressure of tires (no more than 100 g per 1 cm2), which also reduces the consolidation of soil [18]. High performance and functional

Table 1. The flow process chart of winter wheat cultivation (basic technology)

No.	Technological operations	Agrotechnical requirements	The configuration of the unit — tractor	The configuration of the unit — agricultural machine	The performance rate of the unit, ha/h	Attending personnel, persons	Direct energy expenditure, MJ/ha	Energy Expenditure for the Production of fertilizers, etc., MJ/ha	Human labor energy expenditure, MJ/ha	Energy Expenditure for tractors and machinery, MJ/ha	Total energy expenditure, MJ/ha
1	2	3	4	5	6	7	8	9	10	11	12
a)	Tillage and sowing										
1	Stubble plowing	6-10 cm	DT-75	LDG-10	6.12	1	140.0		0.20	44.0	184.2
2	Loading manure	30 t/ha	MTZ-80	PF-0.5	0.97	1+1	218.0		4.5	58.0	280.5
3	Manure transportation	7 km	DT-75	2 PTS-6	0.15	1	897.0		8.7	1020.0	1925.7
4	Manure application	30 t/ha	DT-75	RPN-4	3.8	1	341.0	4200	0.33	142.7	4684.03
5	Plowing with harrowing	22-24 cm	T-150	PLN-5-35	1.63	1	503.9		0.79	96.3	601.0
6	Loading seeds and fertilizers	3 cwt./ha	MTZ-80	PF-0.5	56.0	1+1	21.0		1.5	0.9	23.4
7	Transportation of seeds and fertilizers	5 km	DT-75	2 PTS-6	11.0	1	21.0		0.1	8.0	29.1
8	Cultivation with harrowing	6 cm	DT-75	KPG-4	3.13	1	119.0		0.38	70.6	190.0
9	Sowing of winter wheat	3 cwt./ha	T-150	C3-3.6 (3 PCs.)	3.63	1+1	120.0	630	0.25	76.0	826.25
b)	Crop tending										
10	Loading mineral fertilizers	1 cwt./ha	MTZ-80	PF-0.5	33	1+1	21.3		0.03	1.6	23.0
11	Transportation	5 km	DT-75	2 PTS-6	170	1+1	256		1.0	1.0	257.84
12	Application of mineral fertilizers	1 cwt./ha	Aircraft AN-2		150.0	1+2	47.0	1260	0.02	0.24	1307.3
13	Water delivery(200 l/ha)	5 km	MTZ-80	RZHT-4	29.5	1	9.74		0.04	3.22	13.0
14	Crop spraying	200 l/ha	MTZ-80	OPSH-15	9.0	1	40.6	264.0	0.14	11.1	
c)	Harvesting and post-harvest processing of crops										
15	Straight cutting	70 cwt./ha	SK-5 Niva		1.2	1	512.4		1.03	625.0	1138.43
16	Grain transportation	6 km	ZIL-130A		1.5	1	214.0		0.86	312.5	527.4
17	Post-harvest processing of grain	70 cwt./ha	3AV-40		5.7	1+2	17.3		0.68	27.0	45.0
	Total						3499.34	6354	19.59	2498.96	12371.79
d)	Post-harvest set of field works										
18	Stubble disking	8-10 cm	T-150	BDT-7	2.2	1	508.1		0.59	198.16	706.85
19	Sowing mustard	20 kg/ha	T-150	SZT-3.6 (3 PCs.)	3.63	1+1	120.0		0.72	76.0	196.72
	Total:						4127.34	6354.0	20.9	2773.12	13275.36
	%						31.09	47.86	0.16	20.89	100

Table 2. The flow process chart of winter wheat cultivation (advanced technology)

No.	Technological operations	Agrotechnical requirements	The configuration of the unit — tractor	The configuration of the unit — agricultural machine	The performance rate of the unit, ha/h	Attending personnel, persons	Direct energy expenditure, MJ/ha	Energy Expenditure for the Production of fertilizers, etc., MJ/ha	Human labor energy expenditure, MJ/ha	Energy Expenditure for tractors and machinery, MJ/ha	Total energy expenditure, MJ/ha
1	2	3	4	5	6	7	8	9	10	11	12
a)	Tillage and sowing										
1	Stubble plowing	6-10 cm	K-3180	LDG-15	7.7	1	94.0		0.17	59.7	153.8
2	Loading manure	30 t/ha	MTZ-922	PE-0.8B	5.6	1	18.6		0.18	22.6	41.4
3	Manure transpor-tation and applica-tion	7 km 30 t/ha	K-5280	PUS-15	5.0	1	884.0	4200	0.26	92.5	5176.7
4	Plowing with har-rowing	22-24 cm	K-3180	RN-100 (5)	2.1	1	768.6		0.62	102.8	872.0
5	Loading seeds and fertilizers	0.3 t/ha	MTZ-922	PE-0.8B	240	1+1	12.4		0.01	55.1	67.5
6	Transpor-tation of seeds and fertilizers	5 km	K-3180	Re-boke-16	143	1	27.0		0.01	4.34	31.4
7	Cultiva-tion with harrow-ing	6 cm	K-3180	KBM-10.8	8.1	1	196.4		0.16	31.7	228.3
8	Sowing of winter wheat	0.3 t/ha	K-3180	Rapid RD-600	6.3	1	158.0	630	0.21	82.6	870.8
	Total:						2159	4830	1.62	451.4	7441.9
b)	Crop tending										
9	Loading min-eral fertilizers	0.1 t/ha	MTZ-922	PE-0.8B	250	1	10.7		0.01	0.51	11.2
10	Transportation of mineral fertilizers	5 km	K-3180	Reboke-16	153	1	26.9		0.01	4.03	30.9
11	Application of mineral ferti-lizers	0.1 t/ha	Tuman-1		41.7	1	7.1	1260	0.03	1.94	1269.10
12	Water delivery (20.0 l/ha)	5 km	K-3180	APV-10	600.0	1	0.7		0.002	0.34	1.04
13	Crop spraying	20.0 l/ha	Tuman-2D		41.7	1	1.03	198	0.03	1.94	201.0
	Total:						46.43	1458	0.082	8.76	1513.2
c)	Harvesting and post-harvest processing of crops										
14	Straight cutting with sim-ultaneous sow-ing of mustard	7 t/ha	Tractor 182.7 kW	Multifunctional unit	3.3	1	384.3		0.39	360.2	744.89
15	Transportation of the heap of chaff and grain to motor vehicles	3 km	Tractor 173.3 kW	NPB-20	19.2	1	80.7		0.07	160.2	210.97
16	Transportation of the heap of chaff and grain to the threshing floor	6 km	MN-230	Fliegl	16.0	1	125.5		0.08	195.7	321.3
17	Threshing the heap at the stationary pro-cessing unit and putting chaff into stor-age	7 t/ha	MN-230		20.0	1+2	54.0		0.15	21.7	75.9
	Total:						644.5		0.69	707.8	1353.0
	Total:						2850.43	6288.0	2.39	1167.9	10308.2
	%						27.65	61.0	0.02	11.33	100

Table 3. The components of total energy expenditure for basic and advanced technologies

No.	Technologies	Direct energy expenditure		The components of total energy expenditure						Total energy expenditure	
				Human labor energy expenditure equipment		Energy expenditure for the production of mechanical tilizers, etc.		Expenditure of the energy for the production of fer			
		MJ/ha	%	MJ/ha	%	MJ/ha	%	MJ/ha	%	MJ/ha	%
1	Basic	4127.34	31.09	20.9	0.16	2773.12	20.89	6354	47.86	13275.36	100
2	Advanced	2850.43	27.65	2.39	0.02	1167.9	11.33	6288	61.0	10308.2	100

efficiency are ensured by the Norwegian swivel plows RN-100 (5) [15] and the MSC-10 cultivator MSC-10.5 [20] (Yaroslavl, Russia).

All the machines, proposed in the advanced technology, successfully passed official and performance tests. They make it possible to successfully achieve the goal of the work – that is, to reduce total energy expenditure for the production of winter wheat grain. In our view, this is the preferred criterion of the comparative assessment of the basic and advanced sets of machines. Other criteria, such as minimum operating costs, maximum productivity, minimum labor requirements for the manufacturing of products, minimum fuel consumption, etc., although useful, do not address the issue systemically and do not take into account market conditions. Energy expenditure and its reduction in the agricultural sector and, in particular, in crop production, is a necessary method of the comprehensive study of the energy intensity of products and makes it possible to systemically assess the efficiency of manufacturing. Table 3 shows the total energy expenditure for the basic and advanced winter wheat cultivation technologies, and the components of energy expenditure in megajoule per 1 ha of planting acreage and also in percentage terms.

DISCUSSION

The comparison of technological sets of machinery for winter wheat cultivation should be made in a differentiated way with the calculation of the following coefficients of energy expenditure:
- direct energy expenditure

$$K_{ED} = \frac{E_{DN}}{E_{DB}} = \frac{2850.45}{4127.34} = 0.69;$$

- human labor energy expenditure

$$K_{EL} = \frac{E_{LN}}{E_{LB}} = \frac{2.39}{20.9} = 0.12;$$

- energy expenditure for the production of mechanical equipment

$$K_{EM} = \frac{E_{MN}}{E_{MB}} = \frac{1167.9}{2773.12} = 0.42;$$

- total energy expenditure

$$K_E = \frac{2850.45 + 2.39 + 1167.9}{4127.34 + 20.9 + 2773.12} = \frac{4020.74}{6921.36} = 0.58 ;$$

where K_{ED} is the coefficient of direct energy expenditure; E_{DN} and E_{DB} are, respectively, direct energy expenditure for new and basic technologies, MJ/ha;

K_{EL} is the coefficient of human labor energy expenditure; E_{LN} and E_{LB} are, respectively, human labor energy expenditure for new and basic technologies, MJ/ha;

K_{EM} is the coefficient of energy expenditure for the production of mechanical equipment; E_{MN} and E_{MB} are, respectively, energy expenditure for the production of mechanical equipment for new and basic technologies, MJ/ha;

K_E is the coefficient of energy expenditure.

Thus, the advanced technological set of machines makes it possible to improve the efficiency of winter wheat cultivation technology by 31% in terms of direct energy expenditure, by 88% in terms of human labor energy expenditure, by 58% in terms of the energy expenditure for the production of mechanical equipment, and to improve the overall efficiency by 42%.

A well-known methodology of the All-Russia Research Institute for Mechanization of Agriculture[12], according to which our calculations were made, does not make it possible to make accurate assessment of the overall effectiveness of the advanced technology on the coefficient of total energy expenditure K_E. We propose to call this coefficient "the level of energy saving of the advanced technology" L_E and define it according to the formula[5]:

$$L_E = (1 - K_E) \cdot 100 = (1 - 0.58) \cdot 100 = 42 \%,$$

where L_E is the level of energy saving of the advanced technology, %.

Thus, L_E makes it possible to immediately answer the question, by how much percent the total energy expenditure for grain production is reduced in case of introducing the advanced technology. In our example it is reduced by 42%.

To improve the performance and quality of operation, reduce labor and cash expenditures, and improve working conditions, manufacturing processes are constantly improved during designing by fundamental changes of the process itself, improving the design and the reliability of the machines, using integrated and multi-purpose units, reducing the number of passes of heavy machinery, etc.

For example, the technology of cultivation of grain crops provides for many operations, related to the movement of tractors and machines across the field and adversely affecting the soil, wherein all the operations (plowing, fertilizing, pre-sowing cultivation, harrowing, leveling and packing of the surface, sowing) are, as a rule, carried out separately (Table 1). As a result, a lot of labor and energy is consumed, and, more importantly, the repeated impact of tractor units on the soil results in the deteriorating of the soil structure and reduced fertility.

Therefore, for the purpose of the minimization of tillage it is important to create and use combined units, carrying out several operations simultaneously (in one pass), and also to apply soil herbicides, boardless plowing, etc. The units were created, that perform simultaneously five technological operations: application of mineral fertilizers, loosening of the plow layer, leveling and packing of the soil, sowing of grain. There are also units, combining operations only in the process of preplanting tillage – cultivation, leveling and packing of the soil[20], harvesting[9], or grain harvesting and tillage[14, 21].

The industrialization of agriculture resulted in the growing consumption of energy and chemicals, on the one hand, and on the other hand – in greater soil erosion and contamination of the agricultural products. The costs of energy and nature protection in agriculture are constantly increasing, therefore, the improvement of the crop cultivation technology for the purpose of the reduction of these costs needs further scientific research.

In the developed countries, farming is developing in the direction of searching new techniques of organic agriculture and the expansion of human knowledge about transformations and transfer of nutrients and water in artificial associations. This will contribute to: 1) minimal tillage; 2) improved energy efficiency; 3) the reduction of water losses and soil erosion caused

by irrigation; 4) the reduction of the consumption of fertilizers and improving their efficiency; 5) the use of crop residues and stubble for mulching of soil; 6) increasing the number of crops in the rotation; 7) the reduction of the use of pesticides (especially broad-spectrum pesticides); 8) introducing permanent crops, primarily legumes, into crop rotation; 9) breeding plant varieties, designed for the maximum utilization of the resources of certain areas; 10) the improvement of soil fertility and the reduction of the chemical contamination of soil (Belyuchenko, 1996).

In other words, environmental protection technologies will bring agricultural landscapes closer to natural systems and separate them from industrial cities and enclaves, therefore, agricultural systems will be more harmonically integrated in the structure of the overall landscape of local and regional ecosystems. All this will contribute to the reduction of the energy expenditure for agricultural production (Belyuchenko, 1996).

In this paper, we have already noted that simple saturation of soil with mineral fertilizers, as well as the use of chemicals for crop protection, on the one hand, don't pay off, and on the other hand, are harmful for the environment. Therefore, a balanced biologized farming system is needed, which should become the basis of maintaining fertility and high productivity of soil. The introduction of biologized farming systems on a landscape basis makes it possible to maintain the fertility of intensely used chernozems in crop rotations within three years after the plowing of the sod layer, composed of perennial legumes, due to the presence of nitrogen, accumulated by alfalfa in soil, to restore soil structure and the optimal water-air regime of active root habitable layer[11]. The proportion of perennial legumes in plain agricultural landscape shall be 17.4%, and in the lowland – 28-33%[11]. All of the above will contribute to energy saving in crop production.

An important reserve of energy saving is also a scientifically founded system of machinery for the mechanization of crop production. A set of technical facilities in the system should first of all be considered from the point of view of direct energy saving (the reduction of fuel consumption). For example, the domestically produced plow PSK-4-8 considerably reduces fuel consumption in the process of plowing, as compared to the

counterparts, including the foreign ones. According to the research [24], the above-mentioned plow PSK-4-8 ensures saving of 10-15% of diesel fuel, or direct energy expenditure, in the process of plowing. The same relates to the grain seeder Rapid (Sweden) and the sprayer Tuman-2D[18], additionally equipped with an innovative device for the application of mineral fertilizers.

Therefore, the search for alternative less energy-intensive and soil-protecting technologies, in combination with moldboard plowing, nonmoldboard cultivation, zero tillage, and direct seeding, undoubtedly, contribute to the reduction of total energy expenditure. The optimization of the above-mentioned biologized farming system in terms of energy expenditure, and, of course, with regard to the productivity of the land, is also very important.

For example, in the above-mentioned paper[11], the structure of the methods of soil cultivation in percent of the crop rotation area of the Krasnodar region is provided for the system of primary soil cultivation. For example, moldboard plowing should account for 54% in the crop rotation of the steppe plain agricultural landscape, boardless plowing with chiseling – 19%, surface cultivation – 18% and zero tillage – 9%. To maintain soil fertility in this system, it is necessary to apply shredded straw of spiked cereals (2.5 t/ha) + manure (9 t/ha)[11].

Let us build a mathematical model of the above-mentioned system of primary soil cultivation in the steppe plain agricultural landscape, using the minimum total energy expenditure for all cultivation processes as an optimization criterion.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{z=1}^{z} E_{ijz} \cdot \delta_{ijz} \cdot F \to min,$$

where E_{ijz} is the total energy expenditure for the soil cultivation by the i-th unit, using the j-th method of cultivation, for the to z-th operation;

δ_{ijz} is the share of the soil area (in %), cultivated by the i-th unit, using the j-th method of cultivation, for the z-th operation (according to the recommendations of [11, p. 128]);

F is the total area of arable land in the steppe plain agricultural landscape, ha.

On the basis of the minimum value of the

optimization criterion (minimum total energy expenditure for all z-th technological operations), the composition of the i-th unit (tractor and machine) and the j-th method of cultivation for each z-th operation are substantiated.

CONCLUSIONS

Given the high level of energy saving (L_E) in the proposed technology, which amounts to 42%, it is possible to suggest ways of further reducing the total energy expenditure for grain production. According to Table 3, in terms of the components of the total energy expenditure, the energy expenditure for the production of fertilizers, pesticides, etc. accounts for the largest share of the total energy expenditure for the production of grain. For example, in the basic technology, this proportion is 47.86% of the total energy expenditure per 1 ha of wheat planting acreage, while in the advanced technology – 61%, though the level of energy expenditure for this component in the advanced technology (6288 MJ/ha) is slightly lower than that of the basic technology (6354 MJ/ha).

The level of human labor energy expenditure reduces almost 9 times: for the basic technology it amounts to 20.9 MJ/ha, while for the advanced technology – 2.39 MJ/ha. The energy expenditure for the production of mechanical equipment is reduced almost 2 times in the advanced technology: 1167.9 MJ/ha in the advanced technology and 2773.12 MJ/ha in the basic technology.

The reduction of the energy expenditure for the production of fertilizers, pesticides, etc. can be achieved in the near future by using the latest biotechnologies (humification agents and Rizobakt)[13]. The improvement of the quality of grain[17] is also very important, and it depends on the technology of cultivation (the best varieties, the best predecessors of wheat, harvesting in a short period of time (no longer than 5 days), the newest equipment, etc.[9]). Thus, the extensive use of the latest achievements of agricultural technology for plant protection[23], soil cultivation[11], operation of equipment[16] create reliable prerequisites for further reduction of the energy intensity of crop production. The directions of our further research include the study of the consistent patterns of qualitative indicators and the preservation of harvested grain depending on the design features of modern and advanced threshing units.

The level of energy saving for the proposed winter wheat cultivation technology amounted to 42%, as compared to the basic technology, and the specific total energy expenditure per one ton of grain amounted to, respectively, 1896.5 MJ/t and 1472.6 MJ/t.

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