

Enhancement of resource-saving technology of corn growing on the basis of energy resources assessment

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Abstract. The article deals with the issues of rational use of the farming system under the conditions of anthropogenic impact. In this regard, a new scientific direction is considered to improve the modern technology of growing crops that contribute to the rational use of the indicator of energy resources by 2-3 times. This approach necessitates a revision of the structure of crop placement depending on the solar radiation coefficient (K_R). In the long term, due to the irrational use of energy resources, the degradation of soil potential has intensified, which has dramatically affected the gross yield and the sustainability of agricultural production. Therefore, there is a need to move to a new level of assessment of the basic principles and methods of the farming system. Suggested comparative analysis of two technologies for the cultivation of corn for grain in the Zhambyl region is proposed: the existing and resource-saving. The article was carried out as part of the implementation of applied scientific research in the field of the agro-industrial complex under the scientific and technical program (IRNBR10764920) "Technologies and technical means of irrigation when introducing new irrigated lands, reconstructing and modernizing existing irrigation systems" for 2021-2023.

1 Introduction

The history of the development of civilization is inextricably linked with the development and improvement of technologies that require large expenditures of fuel, energy and raw materials. The more developed a society, the more it produces a complex energy-intensive and science-intensive product. In modern conditions, the development of agricultural production is hindered by the processes of degradation of the soil cover, the remaining low level of material and technical support for farms, as well as changes in natural resources. Under these conditions, scientific substantiation of changes in the structure of sown areas and diversification of agricultural crops is of great importance.

The degradation of natural resources occurred as a result of the transition period to market relations, ill-conceived and wasteful management of water and land potential for the development and placement of the agro-industrial sector. Therefore, there is an urgent need

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to develop and implement a set of measures aimed at the balanced use of a combination of natural and industrial resources.

Plants use nutrients and soil moisture as a "building material" from which biomass is formed as a result of the process of photosynthesis. Thus, the energy of solar radiation is embodied in plants in the form of the exchange energy of nutrients. Any human impact on the soil and plants should be aimed at intensifying these processes.

2 Conditions and methods of research

Many scientists [1-14] testify that climatic zones are formed under the influence of thermal energy resources and atmospheric precipitation, and some evaporation functions were used as energy resources in determining the moisture supply of geographical zones. Undoubtedly, the functions of air humidity and temperature deficit, evaporation to some extent reflect the energy resources of the climate, however, the radiation balance of the day surface (R) used [4,5] to determine the indicator of the effect of radiation on evaporation (P), and the radiation "dryness index » (\check{R}) [10] fully characterize the essence of the open V.V. Dokuchaev of the law of natural zonality.

The principles of conjugated and systemic approaches, as well as methods accepted in agrochemistry, soil science and hydrochemistry, were used in the research. The research results were processed using statistical methods. Accounting for the total costs for the production of agricultural products was carried out according to the method of G.A. Bulatkin [14].

3 Results of the study and their discussion

The energy resources of landscapes, as a process of heat exchange at a specific geographical point in space over a known period of time, is characterized by a balance of energy input and output [1-14]. Therefore, the radiation balance of the day surface (R) used by A.A. Grigoriev to determine the indicator of the effect of radiation on evaporation ($P_1=P/LE$), and the radiation "dryness index" ($\check{R}=R/LO_c$) fully characterizes the essence of the open V.V. Dokuchaev of the law of natural zonality. However, the hydrothermal indicator (\check{R}) does not take into account the indicator of the absolute height of the terrain (H). Therefore, we have made attempts to fill this gap and clarify the actual energy indicators of the productivity of the natural system of Kazakhstan, taking into account the geography of the area. The correlation dependencies established by us indicate that the relationship between the terrain mark (H) and the dryness index (\check{R}) for certain regions of Kazakhstan has specific features. So, for the Turkestan region, it is described by an equation of the form: $\check{R}=4.0-H/250$; for the North Kazakhstan region $\check{R}=1.6-H/794$; for the West Kazakhstan region $\check{R}=2.2-H/113.6$.

Further, taking into account that the dryness index ($\check{R}=R/LO_c$) and equating it with the calculated one, it is possible to establish a relationship between the actual indicator of the radiation balance (R) depending on the absolute elevation of the terrain:

- for the Turkestan region $R= LO_c(1000-H)/250$;
- for the North Kazakhstan region $R= LO_c(1270-H)/794$;
- for the West Kazakhstan region $R= LO_c(250-H)/113.6$.

The farming system of irrigated regions still uses post-Soviet crop cultivation technologies. So, for example, irrigation is carried out along furrows, the doses of mineral fertilizers are based on the recommendations of the 90s of the last century, and the technical equipment is low. These and other negative circumstances of the irrigated zone, such as the degradation of soil potential, lead to the search for new

directions that allow rational use of water and land and energy resources of a particular area.

An analysis of the solar energy input per unit area allowed us to identify the indicator of the radiation index of the absolute height of the area as the ratio of the radiation balance to the absolute mark of the area and describe it as $R_H = R/H$ [11,12].

According to our calculations, in the Republic of Kazakhstan, the indicators (R_H) - fluctuate within $2.0 < R_H < 0.3$; from which it follows that the farming system can be divided into three zones:

- neutral (R_H) > 2.0 and more;
- optimal (R_H) = $0.3 - 2.0$;
- dicey (R_H) < 0.3

The data show that for many years the issues of zoning agricultural crops, despite sufficient heat supply, have not been successful, since cultivated crops have significant differences in relation to R_n . This circumstance allowed us to establish the following conceptual methodology for substantiating the classification of the farming system, based on the indicators of the radiation index of the absolute height of the area (Table 1).

Table 1. Classification of the arable farming system

The absolute height of the area(H), m	The radiation index of the absolute height of the area (R_H)	Arable farming system
0- 100	> 2.0 and more	neutral
100 - 450	$0.3 - 2.0$	optimal
451 - 1200	< 0.3	dicey

In addition, we have identified a relationship between the index of moisture coefficient (k_m) and the radiation index of the absolute elevation of the terrain (R_H), which is correlated in the following way: $k_m = 0.281 \cdot R_H + 0.098$; from here substituting together $k_m = O_c/E_o H R_H = R/H$ after transformation we get that:

$$R = K_R \cdot O_c \cdot H / E_o; \text{ or } K_R = R \cdot E_o / O_c \cdot H = R_H \cdot \check{R};$$

Hence, as can be seen from the data in Table 2, the radiation index of the absolute elevation of the terrain (R_H) in the objects of study under consideration is characterized in the range from 0.41 to 1.0. Hence, Pavlodar region can be considered the most favorable, where the indicator was 1.0. In other areas, it ranged from 0.41 to 0.65, i.e. in these areas, issues of the efficient use of energy resources should be worked out.

Table 2. Calculation of the solar radiation coefficient (K_R)

O_c, mm	H,m	E_o, mm	$R, kJ/cm^2$	R_H	\check{R}	K_R
Akmola region						
427	398	790	125.4	0.31	1.85	0.57
438	383	828	128.6	0.33	1.89	0.62
372	219	951	139.1	0.63	2.55	1.61
386	303	884	133.4	0.44	2.29	1.00
411	304	904	135.1	0.44	2.19	0.96
396	320	865	131.8	0.41	2.18	0.89
411	347	895	134.3	0.38	2.17	0.82
384	439	882	133.2	0.30	2.29	0.68

390	294	988	142.2	0.48	2.53	1.21
Average				0.41	2.21	0.79
Pavlodar region						
399	144	704	133.2	0.92	1.76	1.61
381	182	718	132.6	0.72	1.88	1.35
359	93	732	134.0	1.44	2.03	2.92
441	107	713	132.1	1.23	1.61	1.98
347	126	731	133.9	1.06	2.11	2.23
330	112	750	135.9	1.21	2.27	2.74
319	148	760	137.0	0.92	2.38	2.18
352	144	795	140.6	0.97	2.25	2.18
411	162	758	136.7	0.84	1.84	1.54
334	197	803	141.4	0.71	2.40	1.70
Average				1.0	2.05	2.04
Jambyl region						
224	266	1116	181.5	0.68	4.98	3.38
294	350	1052	174.4	0.49	3.57	1.75
283	373	1116	181.5	0.48	3.94	1.89
237	337	1083	177.9	0.52	4.56	2.37
336	455	1096	179.3	0.39	3.26	1.27
333	512	1103	180.1	0.35	3.31	1.15
316	742	935	161.5	0.21	2.95	0.62
355	643	1068	176.2	0.27	3.00	0.81
Average				0.42	3.69	1.65
Turkestan region						
186	316	1147	184.8	0.58	6.16	3.57
238	206	1305	202.3	0.98	5.48	5.37
951	789	1163	186.6	0.23	1.22	0.28
275	237	1325	204.6	0.86	4.81	4.13
582	543	1219	192.9	0.35	2.09	0.73
243	215	1245	195.7	0.91	5.12	4.65
651	1224	1071	176.5	0.14	1.64	0.22
264	238	1391	203.9	0.85	5.26	4.47
176	192	1158	186.1	0.97	6.57	6.37
Average				0.65	4.26	3.31

On the other hand, the indicator of the radiation dryness index (\bar{R}) in the irrigated areas of Kazakhstan represents a slight increase from the center of the country to the south and ranges from 2.05 to 4.26. At the same time, in relation to Pavlodar region, other studied regions were slightly higher, so Akmola region by 0.16; Zhambyl region by 1.64; Turkestan region by 2.21, which makes it clear about the sufficiency of thermal resources in these regions.

In relation to the solar radiation coefficient (K_R), the indicators ranged from 0.79 to 3.31, however, in the Akmola region, the decrease in the solar radiation coefficient is 0.21, while in other studied areas it ranged from 0.65 to 2.31. At the same time, the highest indicator is noted in the Turkestan region (2.31). This allows us to conclude that, in relation to other regions, such as Zhambyl and Pavlodar in the Turkestan region, in order to obtain a sufficiently high yield of cultivated crops, large expenditures of irrigation water and technical resources are required.

It follows that the indicator of the solar radiation coefficient gives full grounds for the fact that in order to stabilize the ecological, reclamation and energy situation, it is necessary to develop improved technological maps for the cultivation of crops based on accounting for energy costs and fuel and energy resources (FER).

Thus, for the irrigated zone of Kazakhstan, the optimal value of the radiation balance can be considered 136 kJ/cm², which corresponds to the average indicator of the Pavlodar region, and in the Zhambyl and Turkestan regions this indicator exceeds by 40.5-52.1 kJ/cm². This gives us reason that in these areas there are opportunities to get two crops a year by improving the technology for the revival of forest reclamation work aimed at optimizing the energy resources of the foothill zone of Kazakhstan.

Therefore, taking into account the current state of irrigated lands and the environmental and energy circumstances occurring in the arid zone, we propose the introduction of a landscape-restoration system of agriculture, which is based on the following approaches:

- organization of water-saving technologies for the cultivation of crops based on the assessment of energy resources;
- restoration of degraded lands through the use of bioameliorants from local raw materials;
- high-quality improvement of drainage and waste water through the use of modern resource-saving technologies;
- development of theoretical foundations for water consumption of agricultural crops based on energy resources;
- development of the scientific foundations of the farming system, aimed at the qualitative improvement of the water-physical parameters of the soil;
- implementation horticulture and viticulture in all farms on an area of at least 15-20% of the total area;
- implementation resource-saving cultivation technologies aimed at maximizing the use of bioameliorants, biostimulators of plant growth and development made on the basis of local raw materials (phosphogypsum, glauconite clay, bentonite, etc.);
- implementation less costly technologies for irrigating crops aimed at reducing soil salinity, improving and increasing soil fertility (sharbat method, discrete method, irrigation through a furrow, etc.).

In this article, we provide a comparative analysis of two technologies for the cultivation of corn for grain in the Zhambyl region - the existing and resource-saving. The studied technologies of cultivation of corn for grain have fundamental differences. The existing technology aims to obtain the highest possible yields by using an unlimited amount of water resources, fertilizers and plant protection products. As a result, it led to the deterioration of the reclamation and ecological condition of irrigated lands.

Resource-saving technology, in comparison with the existing one, implies a reduction in the use of water resources, fertilizers, plant protection products and their use, taking into account the needs of agricultural crops. The use of bio stimulators and bio ameliorants, prepared on the basis of local raw materials, provides an increase in soil fertility and desalinization of the soil in the rhizosphere zone, which contributes to the normal growth and development of the cultivated crop.

In our studies, the total energy costs per 1 ha of corn crops for grain are the sum of the total energy costs for machinery and equipment, working capital and labor resources (Table 3).

Table 3. The structure of total energy costs by items of expenditure for the cultivation of corn for grain

Total energy costs	Name of technologies			
	existing		resource-saving	
	absolute value, MJ/ha	distribution structure of energy costs, %	absolute value, MJ/ha	distribution structure of energy costs, %
1. Aggregate energy	5660.5	11.7	5527.7	17.7

for machinery and equipment, incl.				
Basictillage	446	0.92	446	1.43
Pre-sowing tillage	120.5	0.25	95.7	0.30
Seed preparation and sowing	302	0.62	302	0.96
Preparation and application of the main fertilizer	150	0.31	200	0.64
Crop care	395	0.82	395	1.26
Watering	724	1.5	566	1.8
Desiccation and spraying of crops	122	0.25	122	0.39
Harvest	1524	3.1	1524	4.8
Post-harvest processing	1877	3.9	1877	6.0
2. Total energy for working capital, incl.	41699.7	86.7	25049.5	80.3
Fertilizers	17360	36.1	4952	15.8
Pesticide	1574	3.27	412	1.32
Fuel	21441	44.5	18534	59.4
Electricity	425	0.88	391	1.25
Seeds	164	0.34	164	0.52
3. Total energy for labor resources	735.7	1.5	596.5	1.9
Total (Q _n)	48095.9	100	31173.7	100

The total energy costs per 1 ha of corn crops for grain when it is cultivated according to the existing technology amounted to 48095.9 MJ/ha, according to the resource-saving technology - 31173.7 MJ/ha.

Thus, the resource-saving technology is also energy-saving, allowing saving 16922.2 MJ/ha or 35.2% of energy compared to the existing one.

As follows from the data in Table 1, energy savings occurred mainly due to a reduction in energy costs for working capital, including fuel, fertilizers and pesticides.

In technologies, there are high fuel costs (44.5 and 59.4%), which requires the need to select vehicles, save fuel, etc.

In addition, it is of great interest to determine the energy content in the economically valuable part of the crop per 1 ha [13, 14].

The energy content in the economically valuable part of the crop is calculated by the formula:

$$E_c = Y \cdot K_{it} \cdot E;$$

The content of energy stored in corn for grain, taking into account by-products, is determined by the formula:

$$E_o = E_c \cdot K_o;$$

where: E_c – energy content in the economically valuable part of the crop without by-products, MJ/ha;

E_o – energy content in the main and by-products, MJ/ha;

Y – economically valuable part of the crop (without by-products), kg;

K_c – coefficient of conversion of a unit of production into dry matter;

E – total energy content in 1 kg of dry matter, MJ/ha;

K_o – overall product yield ratio, defined as the ratio of main and by-products to the main one.

Using the above formulas, we determine the energy content in the main product with the existing technology at a yield of 3.65 t/ha.

$$E_c = Y \cdot K_c \cdot E = 3650 \cdot 0.25 \cdot 16.39 = 149558.75 \text{ MJ/ha.}$$

Given that the currently used system of machines during harvesting allows you to collect an insignificant part of economically valuable by-products, which is about 75% of the main products. Thus, the indicator of the overall output coefficient (K_o) will be $1 + 0.75 = 1.75$. Then the total amount of energy in the main product and the collected side product will be:

$$E_o = E_c \cdot K_o = 149558.75 \cdot 1.75 = 2617277.12 \text{ MJ/ha}$$

With resource-saving technology with a yield of 3.47 t/ha, the energy content in the main product was:

$$E_c = Y \cdot K_c \cdot E = 1000 \cdot 3470 \cdot 0.25 \cdot 16.39 = 142183.25 \text{ MJ/ha}$$

The total amount of energy in the main products and collected by-products with resource-saving technology was:

$$E_o = E_c \cdot K_o = 142183.25 \cdot 1.75 = 248820.68 \text{ MJ/ha}$$

The indicators of energy coefficients (μ_1 and μ_2) in the cultivation of corn for grain according to the studied options, which are given below, indicate that energy-intensive technologies are still widely used in the arid zone. In our cases, the researched resource-saving technology made it possible to increase the energy coefficient by 1.4 and 2.5.

With existing technology: $\mu_1 = E_c/Q_n = 149558.75/48095.9 = 3.1$;

$$\mu_2 = 261727.71/48095.9 = 5.4$$

With resource-saving technology: $\mu_1 = 142183.25/31173.7 = 4.5$;

$$\mu_2 = 248820.68/31173.7 = 7.9$$

In the studied technologies, the accumulated energy of corn biomass significantly exceeds the costs of the total energy spent on corn cultivation ($E_o > Q_n$).

Considering that the reduction of energy costs for the production of a unit of production is currently the main task, we tried to analyze the accumulated energy in the aboveground phytomass of agricultural crops of grain-grass crop rotation in the Zhambyl region (tables 4,5,6).

Table 4. Productivity, conversion factors for dry matter, energy content of the main and by-products of agricultural crops

Agriculture	Mainproducts			By-products		
	Yield, U_o , t/ha	Conversion factor, C_o	Energycontent, Q_o	Yield, U_o , t/ha	Conversion factor, C_o	Energycontent, Q_o
Corn for silage	30,0	0,25	16,39	-	-	-
Sugar beet	40,0	0,25	18,26	40,0	0,18	16,36
Winter wheat	3,5	0,86	19,13	5,3	0,84	17,15
Barley	4,0	0,86	19,13	4,8	0,84	17,15
Alfalfa	35,0	0,83	18,91	-	-	-

Table 5. Seeding rate, doses of mineral fertilizers and herbicides, direct and indirect costs of anthropogenic energy

Agriculture	Seeding rate, kg/ha	Doses of mineral fertilizers, kg/ha, a.m.			Doses of pesticides, (Dp) kg/ha	Direct and Indirect costs, (B) MJ/ha
		Nitrogen (N)	Phosphoric (P)	Potassium(K)		
Corn for silage	30	80	80	80	2,0	6799
Sugar beet	5	100	50	50	5,0	17158
Winter wheat	250	90	45	45	2,0	3663
Barley	220	60	60	-	2,0	4016

Alfalfa	8	60	60	-	2,0	5972
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Table 6. Energy assessment of the effectiveness of crop cultivation technology

Agricultur e	E_{of}	E_{pf}	E_{fp}	E_u	E_{ya}	E_c	A_n	E_{an}	R_n
Corn for silage	122925	-	122925	8752	211,2	550,5	9513,7	12869, 7	9,5
Sugar beet	182600	117792	300542	1736 0	1574, 5	92,0	19026, 5	22982, 5	13, 4
Winter wheat	57581,3	76351, 8	133933	1562 4	211,2	4732, 5	20617, 7	23973, 7	5,5 8
Barley	65807,2	69148, 8	134956	1041 6	211,2	4208, 6	14835, 8	18191, 8	7,4
Alfalfa	549335, 5	-	549335, 5	1041 6	211,2	157,6	10784, 8	14140, 8	38, 8

Note: E_{of} - energy in the main product; E_{pf} - energy in by-products; E_{fp} is the energy of the total aboveground phytomass; E_u - energy content of mineral fertilizers; E_{ya} - is the energy contained in pesticides; E_c - energy contained in the seeds; A_n is the sum of the energy of materialized costs; E_{an} - anthropogenic energy spent on the cultivation of agricultural crops; R_n is the energy efficiency of agricultural technology.

From the data in Table 6 it follows that in the conditions of the Zhambyl region, the most energy efficient is the cultivation of alfalfa (38.8) and sugar beet (13.4). The rest of the studied crops are also considered energy efficient, however, in order to achieve higher rates, it is necessary to improve the technologies for growing agricultural crops in the direction of reducing the use of fuel and energy resources, the use of mineral fertilizers and minimizing the work of agricultural machinery.

Thus, the energy efficiency of grain corn cultivation in the conditions of the Zhambyl region is about (3.1), and the resource-saving technologies used, due to a more advanced irrigation system and the introduction of a bioremediant, made it possible to save energy resources by 35.2%.

Therefore, further improvement of resource-saving technology should be aimed at reducing the total energy for working capital.

4 Conclusion

The proposed technology, based on the fundamental laws of nature, makes it possible to enhancement the farming system and intensify agriculture, aimed at accelerating the process of increasing the production of grain, industrial, fodder and vegetable crops. This provision necessitates a revision of the structure of crop placement depending on the solar radiation coefficient (K_R). In the long term, due to the irrational use of energy resources, the degradation of soil potential has intensified, which has dramatically affected the gross yield and the sustainability of agricultural production. Therefore, there is a need to move to a new level of assessment of the basic principles and methods of the farming system.

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