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Energy justification of parameters of hydroamelioration systems at the development of wetland landscapes of Western Siberia

V V Novohatin[1] and N G Osipova[2]

[1]Industrial University of Tyumen, 38 Volodarskogo st., Tyumen, 625000, Russia.
[1]Orcid ID: 0000-0002-4157-4022
[2]University of Tyumen, 6 Volodarskogo st., Tyumen, 625003, Russia.

Abstract

The modern technology of design, construction and operation of hydroamelioration systems, intended ultimately to obtain stable and high yields of agricultural crops, must be energy-saving, that ensures minimum expenditures of aggregate energy for obtaining a unit of production. In the conditions of an unstable economic situation, when the cost of growing perennial grasses on drained peat soils within even one region, Western Siberia, differs significantly, it is rather difficult to determine the economic efficiency of the hydroamelioration systems and their parameters with sufficient reliability. Today one way to give an objective assessment is a calculation of bioenergy efficiency, based on the implementation of bioenergy coefficients independent of the influence of economic factors. It is important because after analyzing the bioenergy calculations, it becomes possible to optimize separate and the most energy-intensive technological stages of the creation of hydroamelioration systems. Bioenergy estimation is carried out according to the indicators characterizing the object, technology, technological process and final product. These indicators includes the aggregate energy expenditure in the process of construction of amelioration systems, its' production, technological energy intensity, energy returned (useful energy content), the bioenergy efficiency coefficient of the technological process, which is assessed by the bioenergy yield of the final product [1]. From the point of view of bioenergy such a technology is advantageous, which provides the maximum output of energy in production per unit of aggregated energy input [1]. The ratio of energy, contained in the product, to the aggregate energy input is determined by the bioenergy efficiency coefficient. For this, it is necessary to optimize the interaction of natural and artificial energy flows [2]. The use of bioenergy coefficients, which do not depends on environmental factors and economic aspects, gives a possibility to objectively assess the effectiveness of drainage technologies of amelioration.

Key words: hydrotechnical systems, energy assessment, bioenergy efficiency, energy equivalents, peat soils, drainage, parameters of drainage systems, productivity of wetland landscapes.

INTRODUCTION

The energy assessment of the efficiency of amelioration development practices of wetland landscapes completes their economic assessment. It should be noted, that in the unstable economic conditions the most objective assessment is the energy assessment. Its importance arises from a disproportion between energy consumption and energy production, that the ratio of energy (anthropogenic) input and accumulated solar energy in the yield of agricultural crops obtained [3]. The use of bioenergy indicators makes it possible to measure, in comparable units, the costs of aggregate labor, resources, to identify the expenditure of irreplaceable energy and to find ways to optimize it.

The aim of the research is to carry out a comparative bioenergy assessment of the parameters of the hydroamelioration systems during the development of the long-term frozen wetland landscapes of Western Siberia.

METHODS AND MATERIALS

For nine years we conducted the studies of the efficiency of structures of hydroamelioration systems used for draining peat-bog soils in the subtaiga subzone from the viewpoint of the system and energy approach for assessing their parameters. The study covered the drainage systems used in peat soils on medium peat and on fine texture peat in a long-term field experiment with a pressurized groundwater type of water supply.

RESULTS AND DISCUSSION

Theoretical calculations and the justification of the optimal parameters of amelioration systems on the basis of the energy assessment were carried out using the works: G.A. Bultatkin [4], Yu.I. Ermokhin, A.F. Neklyudova [5], methodical recommendations prepared by: N.V. Abramov, G.P. Selyukova [6], A.F. Neklyudov, and others [7].

An objective of increasing the efficiency of amelioration systems, agricultural machinery, oil products, fertilizers and other means requires an accurate record of energy for the reproduction of production from a unit of area for individual technological operations. The use of the system and energy approach for this purpose makes it possible to reliably assess the parameters of amelioration systems and outline the ways to increase the productivity in amelioration agriculture.

Initial information in the analysis of expenditure of aggregate energy per 1 hectare of the drained area was the results of calculations carried out according to a generally accepted methodology using energy equivalents. Due to the fact that in the analyzed literature sources there are no energy equivalents for some types of amelioration machines and equipment, we determined their values by the formula:

$$J_Z = M_Z \cdot JO_Z \quad (1)$$

where: M_Z - mass of one machine, equipment, kg; JO_Z - energy equivalent for this type of technical equipment, MJ / kg.ha.

Comparison and analysis of the quantitative characteristics of energy expenditures on the options shows that the total energy savings per 1 hectare, at the development of long-term frozen wetland soils, is achieved through the implementation of energy-saving draining methods that should ensure optimal soil regimes, as well as appropriate technologies for a cultivation of agricultural crops. To obtain full and reliable information on energy expenditures we conducted an analysis of the structure of anthropogenic energy flows with as full as possible calculation of direct and indirect energy costs. At the same time, the aggregate anthropogenic energy inputs consisted of operational and materialized energies. To operational expenditures we attributed the energy expenditures for construction and agricultural equipment and machinery, exploitation of amelioration systems, fuel, living labor and electricity. Energy contained in building materials, a drainage tube, fertilizers and seeds was considered as materialized.

Analysis of energy expenditures for amelioration development of wetlands shows that the share of this expenditure item of energy accounts for no more than 8-12% of all aggregate energy costs. They depend on the parameters of the drainage-collector systems and vary in the range from 1475.28 to 2237.44 MJ / ha respectively with extensive and intensive drainage of the peat deposit (Table 1).

Performed calculations of energy consumption values for technological operations have made it possible to establish that in the structure of general anthropogenic energy expenditures at the growth of perennial grasses for hay, the main share (56.7%) falls on operational energy. At the same time, energy expenditures for fuel, machinery and equipment prevail here.

Table 1: Bioenergy efficiency of cultivation of perennial grasses for hay on the drained peat soil of long-term field experiment "Usalka", 2007-2015

Indicators	Unit of measure	Depth of drain, m	Distance between drains, m				
			10	20	30	40	Open network, 250 m
Aggregate energy expenditure	MJ / ha	1.2	25683.77	23500.68	20039.17	18985.44	
		1.5	-	26608.34	24167.92	22359.47	15579.86
		1.8	23575.00	23767.05	25122.41	26266.24	
Yield of hay	centner/ha	1.2	69.8	61.2	46.1	41.6	
		1.5	-	75.2	64.7	56.8	29.3
		1.8	60.3	62.4	69.0	74.4	
Energy intensity for 1 centner of hay	MJ	1.2	1780	1780	1780	1780	
		1.5	-	1780	1780	1780	1780
		1.8	1780	1780	1780	1780	
Output of gross energy in the crop	MJ / ha	1.2	124244	124244	108936	82058	
		1.5	-	133856	115166	101104	74048
		1.8	107334	111072	122820	132432	
Gross energy gain	MJ / ha	1.2	98560.23	85435.32	62018.83	55062.56	
		1.5	-	107247.66	90998.08	78744.53	36574.14
		1.8	83759.00	87304.95	97697.59	106165.76	
Energy factor		1.2	4.84	4.64	4.09	3.90	
		1.5	-	5.03	4.77	4.52	3.35
		1.8	4.55	4.67	4.89	5.04	

It should be noted, that a significant part of the operational energy expenditure (69.8%) falls on the loading, transportation and laying of rolls of hay.

Considering the materialized energy expended for each hectare of the ameliorated area, it can be noted, that the energy expenditures for building materials, fertilizers and seeds reach 43.9% of the aggregate energy. The greatest amount of materialized energy (27.4%) is mineral fertilizers.

The results of the determination of energy expenditures on the options given in Table 1 show that the total energy expenditures for hydrotechnical construction and agricultural use of drained soils depend on the parameters of amelioration systems and the yield of agricultural crops.

The maximum aggregate energy expenditures of 25,683.77-26608.34 MJ / ha are noted on options, providing soil regimes close to optimal for perennial grasses. On slightly drained peat deposits, as a result of a decrease in the yield of grasses, anthropogenic expenditures are reduced. Thus, when draining hydromorphic soils with drainage systems with a drains laying depth of 1.2 m and when draining with open channels, the aggregate energy expenditures on average during the study period varied from 15579.89 to 23500.68 MJ / ha. With an increase in the depth of the drains laying to 1.5 m, their quantitative values increased to 22359.47-26608.34 MJ / ha.

The total energy expenditures are influenced by the distance between the drains. As noted above, changes in the inter-spaced distances cause variation in yields of agricultural crops. The combination of these given factors explains the dynamics of aggregate energy for draining options. For example, if on the options of deep drainage with a reduction in the distances between drains from 40 to 10 m, the total energy expenditures in grass cultivation decreased by 2691.24 MJ / ha, then on the options of slight drainage inverse correlation is observed. A fourfold decrease in the distances between the drains led to an increase in the energy consumed by 6698.33 MJ / ha.

Analyzing the parameters of the output of gross energy in the crop, it can be noted that they reached the greatest value on amelioration systems with depths of laying 1.5 and 1.8 m with drainage distances of 20 and 40 m respectively, where optimal conditions for the growth and development of perennial grasses are provided. The amount of accumulated in produce solar energy was 133856 and 132432 MJ / ha. On the remaining drainage options, the amount of gross energy accumulated in the crop was 7.2-39% less. When draining peat soils with an open regulating network, in all years, the lowest yields of agricultural crops were obtained, and as a result, the yield of gross biological energy in the crop was most minimal and did not exceed 74048 MJ / ha.

Having determined as the resultant the component between the anthropogenic energy expended for each hectare of drained peat soils and the obtained amount of gross energy in the crop from a given area, we determined the value of the energy increment. Comparing the results of the performed calculations, it should be noted that amelioration and agricultural development of hydromorphic soils from the energy point of view is an effective measure in the forest steppe and subtaiga subzones of Western Siberia. The maximum increment in gross energy was recorded in areas drained by drainage systems of 1.5 and 1.8 m deep with the distances between the drains of 20 and 40 m respectively. The amount of the resultant energy in these options was 107247.66 and 106165.76 MJ / ha. Analysis of the long-term, quantitative values of the reviewed energy component makes it possible to note that, in any, in relation of meteorological conditions, vegetation periods the drainage system options provided a positive energy balance.

The complex metrics of bioenergy assessment, characterizing the effectiveness of hydrotechnical ameliorations and agricultural development of wetland soils, are the energy coefficients reflecting the ratio of the gross energy accumulated by the produce obtained from 1 hectare of the area to the aggregate energy expenditures, used to obtain this produce from a given area. A comparative assessment of the reviewed energies shows that anthropogenic energy is less susceptible to dynamics than solar energy reserves concentrated in the obtained product [6]. The amount of the latter is influenced by bioclimatic conditions of vegetative periods, which vary considerably over the years. As a consequence, the energy coefficients also vary by year.

The results of the calculations, given in Table. 1, show that the ratio of the considered energies also varies for the draining options. The highest values of bioenergy coefficients of 5.03-5.04, are characteristic for drainage systems with a laying depth of 1.5 and 1.8 m and with inter-drainage distances of 20 and 40 m, respectively, providing the optimal soil regimes for perennial grasses. When draining wetland landscapes with a collector-drainage network with depth of 1.2 m and open channels, the lowest yields of grasses were obtained and, as a result, the coefficients varied in the range of 3.35-4.84. It should be noted, that in all options of intensive draining the energy coefficients, in all years, were higher than in options with extensive regulation of the water-air regime of soils.

Thus, according to the energy assessment, the most effective amelioration systems are deep drainage systems with parameters: depth of laying of 1.5-1.8 m and distances of 20-40 m. The completed energy assessment confirmed the results of the technical and economic analysis of the effectiveness of the hydrotechnical measures studied.

CONCLUSION

Summarizing the above, it should be noted that:

1. Draining of wetland systems gives a reliable effect only when the whole complex of technological measures for their cultivation is applied. Regional peculiarities and

ecological safety of wetland soils arise the need to use their potential fertility in meadow crop and forage crop rotations, where the dominant role belongs to perennial grasses. Intensification of production of perennial grasses on the basis of drainage amelioration of long-term frozen wetland soils is associated with an increase in direct and indirect costs of energy. At the same time, the energy value of the produced production is growing at a slower rate compared with the expenditure, which leads to a reduction in the return of expenditures in the production (by energy units).

2. An energy assessment of the parameters of the hydroamelioration systems used in the drainage of hydromorphic soils has established the advantage of deep drainage systems in comparison with shallow drainage laying. The maximum yield of gross energy in the crop was 132432-133856 MJ / ha on options with the depth of drainage of 1.5 and 1.8 m and distances of 20 and 40 m respectively. In the same options the maximum increment of gross energy (106165.76-107247.66 MJ / ha) and values of the energy coefficients (5.03-5.04) were noted. When draining the wetland soils with shallow drainage systems and open channels, the increment in gross energy did not exceed 36574.14-85435.32 MJ / ha, and the energy efficiency coefficients were 3.35-4.64.

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