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Ecological Capacity and Bioenergy Potential of Agrocenoses as a Way of Sustainable Agriculture

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ABSTRACT

Background: Calculation of bioenergy potential and ecological capacity are promising methods for assessing the state of an agro-landscape, allowing us to promptly respond to changes in its sustainability. The article presents the results of soil research and calculation of bioenergy potential of the farm territory in the zone of dry steppe on chestnut soils.

Methods: Assessment of anthropogenic load on agricultural landscape is based on ecological standards and point system of relative fertility. The determination of the ecological capacity by BEPT of an agrocenosis occupied by winter wheat and sunflower was carried out according to the method of V.M. Volodin, R.F. Eremina, N.F. Mikhailova. Determination of erosion and geomorphological characteristics of the research object was carried out using geoinformation technologies. The basis for creation of digital elevation model (DEM) is the data of radar survey of the Earth surface (SRTM4).

Result: Soils of the research object have low and average humus content. Nitrogen level in the soil varies from very low to good; nitrogen availability in the fields is average. Provision with mobile phosphorus is average. Soil potassium content is mostly high. As a result of calculations, it was found that in the conditions of the dry steppe zone, the bioenergy potential of the agrolandscape area occupied by winter wheat is 2735.72 GJ/ha, sunflower-2647.4 GJ/ha. At the same time, the ecological capacity of the field occupied by winter wheat is 2764.6 GJ/ha and sunflower-2676.8 GJ/h.

Key words: Bioenergy potential, Energy capacity, Sunflower, Sustainable agriculture, Winter wheat.

INTRODUCTION

Reduction of the area of agricultural lands occurs due to the loss of their fertility and their allocation for various purposes of national economy (Belyakov *et al*., 2022). In this regard, the rational use of soils becomes a priority task facing society and the basis for sustainable agricultural development. Soils of different agroecological groups need a differentiated approach to treatment, in this regard, the organization of adaptive-landscape farming should take into account new energy approaches related to the ecological capacity of the territory of agrolandscapes (Volodin *et al.,* 2000; Masyutenko *et al*., 2015). It is important to take into account the ecological capacity of the agrolandscape area, as it maintains a certain level of biodiversity and ensures the vitality of various microorganisms and plants. This concept includes the resistance of the ecosystem to change, the ability to self-renewal and maintenance of biological balance.

To assess territorial units of different quality, economic or energy calculations are used (Bultot *et al*., 1988; Hachaichi and Talandier, 2023, Dinh and Shima, 2024; Iswarya *et al.,* 2024; Venkat *et al.,* 2024). Bioenergetic assessment of the territory is necessary for the development of sustainable development strategies, natural resource management and decision-making on the introduction of new resource-saving technologies. Ecological capacity is an energy indicator that allows for a comprehensive assessment of soil and plant resources of an agrolandscape.

The methodology for calculating the energy capacity of an agrolandscape is a tool that allows us to estimate the amount of energy contained in the agrolandscape. Based on the methodology and the resource state of the agrolandscape, it is possible to establish the regulations of the applied agrotechnologies.

In order to assess the bioenergy potential of the study area (BEPT), it is necessary to determine a number of parameters. First of all, the amount of organic matter per unit area and the energy contained in this organic matter are determined. These parameters relate to different vegetation types such as forest, herbaceous and field cenoses. In addition, the area occupied by each vegetation type must be considered, as well as the amount of energy contained in a unit of soil organic matter. It is also important to consider the type of soils and the degree to which they

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are washed away, as well as the area and ratio within each particular site (Volodin *et al.,* 2000).

The ecological capacity of an agrolandscape is understood as the ability of the agrolandscape to accept and transform a certain amount of energy and matter in the process of its sustainable functioning in a given regime (Volodin and Eremina, 2001). Energy is accumulated during the growing season in the form of organic matter, including soil organic matter and perennial plant parts, as well as energy from mineral nutrition elements, expressed in GJ (Kogut, 2012). The permissible anthropogenic load is the degree of load on the components of the agricultural landscape at which the system retains the ability to function almost indefinitely without sudden changes in structure, *i.e.* maintains environmental and productive sustainability (Ryszkowski and Kêdziora, 1987).

The purpose of the study is to determine the bioenergy potential and ecological capacity for cenoses of winter wheat and sunflower in the dry steppe zone of chestnut soils Volgograd and Rostov regions.

MATERIALS AND METHODS

The work was carried out within the framework of the state task of the research work of the FSC of Agroecology RAS No 122020100312-0. ''Theory and principles of the formation of adaptive agroforest reclamation complexes in the dry steppe zone of the south of the Russian Federation in the context of climate change''.

The research was conducted at the test site ''Pronin'' (Serafimovichi district of Volgograd region and Sovetsky district of Rostov region) during the period 2021-2023. (Fig 1). The area of the landfill is 37220 ha. The soils of the survey area are dark chestnut soils. Soil sampling was carried out at the test site with subsequent determination of physical chemical properties of soils in laboratory conditions according to the approved methods (Methods of studying soils in agroforestry research, 1978).

The territory of the test site is located in the southwestern dry-steppe region of the arid region. The climate of the territory where the farm is, it is continental.

An analysis of the soil and climatic conditions of the area showed that they are generally favorable for growing crops, but due to the intensification of farming, erosion processes have intensified, which has resulted in a decrease in soil fertility, increased consequences of droughts and dry winds and a decrease in yield.

That was based on a mosaic of satellite images (Karra *et al.,* 2021) from the maps.google.com service in the Global Mapper software environment, a map diagram of the fields of the research test site was created for field standardization of satellite images and selection of soil samples for laboratory analysis (Fig 2).

The basis for creation of digital elevation model (DEM) is the data of radar survey of the Earth surface (SRTM4). The elevation of the relief is 90-200 meters (Fig 3).

The survey was carried out on 40 hectares and was a mixed sample made up of 20 individual samples. The total area of the study area was 9989 ha (Methodological Guidelines for Conducting Comprehensive Monitoring of Soil Fertility of Agricultural Lands, 2003).

When we were analyzing soil samples, the following methods were used:

- Determination of the granulometric composition of soils was carried out according to the Kachinsky MUM - 1985 method.
- Determination of humus content in soil samples was carried out using the Tyurin method (TsINAO, GOST 26213 - 91).
- Determination of total nitrogen was based on the Kjeldahl method, GOST 26107-84. Soils. Methods for determining total nitrogen.
- Determination of mobile forms of phosphorus and potassium according to Machigin as modified by TsINAO (GOST 26205-84).

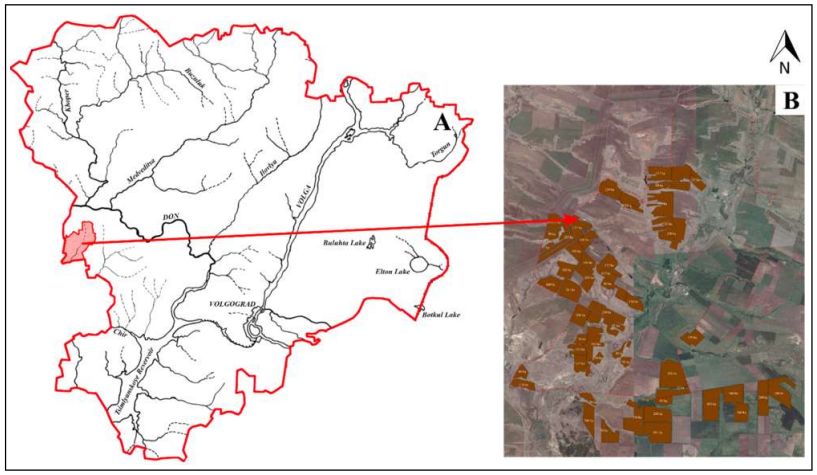


Fig 1: Schematic map of the research object location: (A) Volgograd region;(Â) of the Pronin test site.

The determination of the ecological capacity by BEPT of an agrocenosis occupied by winter wheat and sunflower was carried out according to the methodology by Volodin *et al.,* 2000.

According to Volodin *et al.* (2000) the bioenergy potential of the agricultural landscape territory is composed of the energy reserve of the total biomass (above and underground), the annual increase in phytomass energy, the energy potential of the soil and has the form (Formula 1):

$$BPT = (E_{RTPH} + E_{GPH}) + (E_{RSOM} + \Delta E_{SOM})$$

ERTPH- Energy reserves of the total (aboveground and underground) phytomass.

E_{GPH}- Annual increase in phytomass energy.

E_{RSOM}- Energy reserves of soil organic matter.

ΔE_{SOM}- Increase or decrease in energy of soil organic matter.

For detailed calculations we used formulas with methodology given by Volodin *et al.* (2000). Statistical processing of the results was carried out in MS Excel.

Results and Discussion

The Pronin test site is dominated by dark chestnut soils of medium depth, clayey and heavy loamy granulometric composition, carbonate, slightly and moderately eroded.

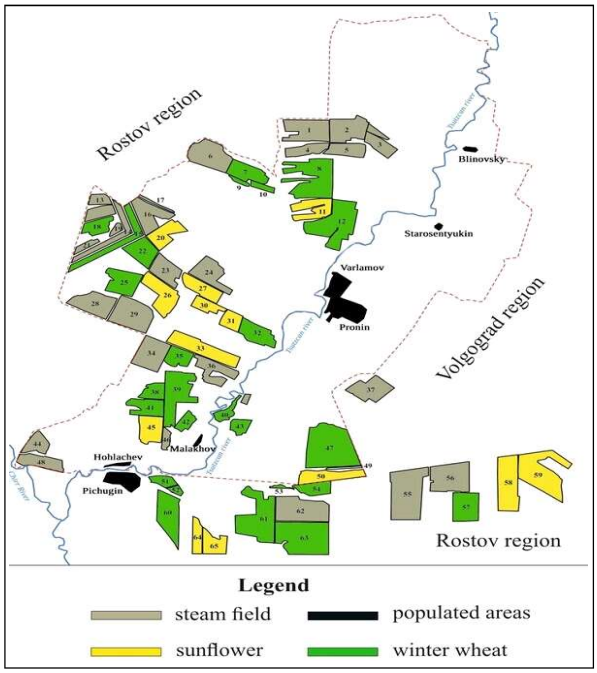


Fig 2: Field map of the test site.

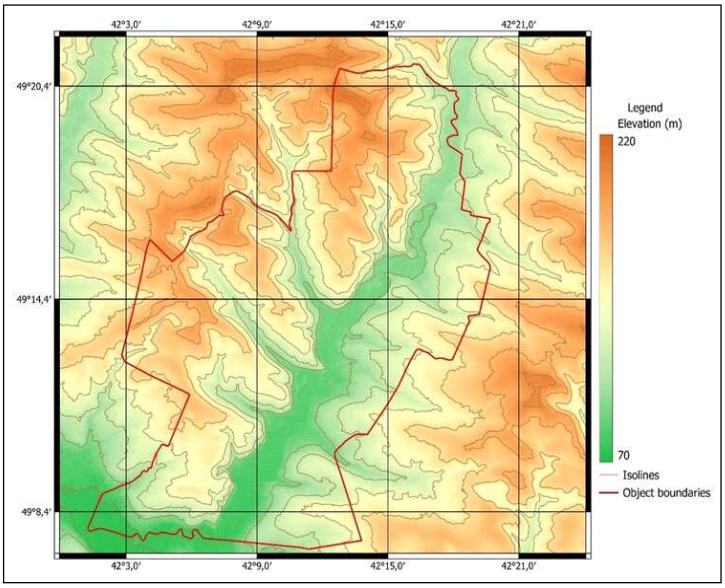


Fig 3: Digital elevation model of the test site.

It was based on the results of laboratory tests, the main agrochemical indicators of the test site soils were determined: particle size distribution, humus content, NPK. Below, Fig 4 shows the groupings of soils according to these indicators at the Pronin test site.

The analysis of the obtained results of granulometric composition of soils shows that clayey soils prevail on 47.6% of the territory of the studied areas. The humus content in the soils of the study area varies over a wide range from 0.85% to 5.31%, that is, from weakly humus to highly humus. The minimum value of humus content (0.85%) was observed in field No. 46 with the area of 32 ha - this is a sandy loam granulometric composition. The maximum value of humus content (5.31%) was observed on field No. 19 with area of 17 ha in the area of the State forest belt this is a soil with light loamy granulometric composition. The variation in the amount of nitrate and ammonium forms of nitrogen ranges from 4.7 to 28.6 mg/kg. The minimum values with very low nitrogen supply correspond to fields No. 5 (115 ha) and No. 11 (156 ha). In total, the share of fields with average and good sup-ply is 78.5% (7844 ha), compared to the share of fields with very low and low supply of 21.5%. Phosphorus plays an important role in the transformation of carbohydrates and as a consequence affects the formation of future crop yields (Yuferev, *et al.,* 2010). Its deficiency in the soil negatively affects the growth and development of plants. Analysis of data on phosphorus content revealed a range of values from 6.8 to 44.2 mg/kg. In general, it can be stated that the fields have an average supply of mobile phosphorus. The studied soil samples have a high potassium content, which amounts to 74.8% of the entire area of the study territory. With an average supply of potassium, the fields are 20.9%, with a high supply - 4.3%.

Table 1 shows the area of fields were occupied by winter wheat and sunflower; the remaining fields were fallow at the time of field research. The total area of fields with winter wheat is 4000 hectares. The average wheat yield was 4 t/ha. The removal of nutrients with such a yield of winter wheat was: for N - 76 kg/ha, for P_2O_5 - 32 kg/ha (separately for P - 14 kg/ha), K_2O - 19.2 kg/ha (separately for K - 15 .9 kg/ha), S - 6.8 kg/ha. The calculation of the removal of nutrients was made using a calculator located on the website of the International Plant Nutrition Institute (IPNI) at www.ipni.net/app/calculator/home.

The total area of sunflower fields is 2127 hectares. The average sunflower yield was 1.82 t/ha. The removal of nutrients with such a sunflower yield was: for N - 49.1 kg/ha, for P_2O_5- 17.7 kg/ha (separately for P- 7.7 kg/ha), K_2O - 16.4 kg/ha (separately for K- 13.6 kg/ha), S - 4.6 kg/ha.

Our studies used a methodology for assessing the ecological balance of agricultural lan dscapes in the dry steppe zone of chestnut soils using a scoring system based on ten indicators (Belyakov *et al.,* 2022). The relative fertility group of the study areas is presented in Table 1.

Analysis of the structure of groups of relative soil fertility shows that the area of the field occupied by winter wheat is 42% of low soil fertility, 23% of very low fertility, 20% of high fertility and 15% of average fertility. The field area occupied by sunflower has 46% average soil fertility, 23% low and very low and 8% high fertility.

Analysis of statistical data processing shows that the soils of the study areas are more uniform in the content of humus and K_2O than in their content of total nitrogen and P_2O_5 (Table 2).

Soil and plant resources determine the ecological capacity of the agricultural landscape territory and the structure of its bioenergy potential (BEPT), which involves analyzing the balance of matter and energy in a certain agricultural landscape unit - a watershed. BEPT of an agricultural landscape is characterized by the amount of energy of phytomass and soil organic matter. To assess the BESP of an agricultural landscape, you need to have the following information (Volodin *et al.,* 2000) (Table 3):

1) The amount of organic mass (aboveground and underground, including crop residues in field and herbaceous cenoses and ground litter in forest cenoses) per unit area, c/ha.

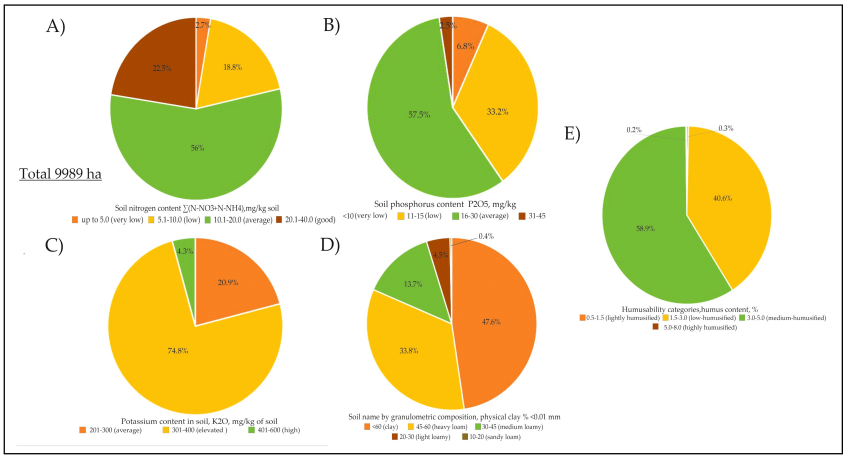


Fig 4: Grouping of soils by: A) nitrogen content (ammonia and nitrate forms); B) by the content of available phosphorus; C) by the content of mobile potassium; D) particle size distribution; E) by humus content.

2) Energy content of organic mass of all types of cenoses, MJ/kg.
3) Reserves of organic matter (humus) in the humified soil profile, t/ha.
4) Energy reserves in soil organic matter, GJ/ha.
5) Content of mobile forms of nutrients in the arable soil layer, mg per 100 g of soil.
6) Energy reserves of mineral nutrients capable of transformation during the functioning of agroecosystems, GJ/ha.
7) Area under each type of vegetation, taking into account the type of soil and the degree of its erosion, hectares.

Based on the above, the bioenergy potential of the cultivated crops was:

BEPT wimter wheat= 252.12+2463.56+20.1= 2735.72 GJ/ha

BEPT sunflower= 154.7+ 2514.2-21.5=2647.4 GJ/ha

The resulting bioenergy potential of the agricultural landscape territory occupied by the agrocenosis of winter wheat and sunflower is reduced to their area, from which we obtain:

Table 1: Indicators of relative fertility of the test site.

Number of fiels	Square, ha	Humus, %	N total, %	P_2O_5, mg/kg	K_2O, mg/kg	Relative group offertility
			Winter wheat			
7	137	2.34	0.048	12.1	294	Very low
8	350	1.91	0.121	16.3	285	Low
9	20	4.75	0.156	16.5	301	High
10	30	2.14	0.046	8.6	310	Very low
12	250	1.67	0.211	32.5	208	Average
15	175	3.47	0.157	19.0	380	Average
18	90	3.23	0.158	15.1	326	Low
22	180	3.5	0.099	13.9	314	Low
25	180	3.86	0.189	18.0	354	High
32	130	1.97	0.074	6.8	274	Very low
35	101	3.73	0.153	18.7	296	Average
38	76	3.28	0.059	13.5	304	Low
39	266	3.22	0.094	16.0	327	Low
40	80	2.00	0.109	10.1	285	very low
41	123	2.72	0.047	12.2	308	Low
42	56	2.68	0.078	11.3	317	Low
43	50	1.99	0.051	9.4	281	Very low
47	426	2.89	0.195	16.2	401	High
51	56	3.54	0.103	15.5	342	Low
52	20	2.61	0.059	12.9	330	Very low
53	13	3.08	0.113	13.8	337	Low
54	90	2.98	0.242	14.8	374	Average
57	160	3.59	0.095	13.7	329	Low
60	200	2.71	0.200	27.0	238	High
61	350	2.71	0.213	30.0	354	High
63	391	3.23	0.092	16.1	306	Low
			Sunflower			
11	156	1.92	0.041	9.1	309	very low
20	126	4.47	0.201	16.5	334	High
26	200	3.43	0.099	20.0	346	Average
27	117	4.26	0.127	14.2	347	Average
30	80	1.56	0.064	10.7	326	Very low
31	80	1.56	0.064	10.7	324	Very low
33	220	3.18	0.099	20.0	315	Average
45	147	2.23	0.056	9.5	318	Low
50	158	3.28	0.056	18.7	346	Low
58	280	3.19	0.164	24.5	377	Average
59	380	3.8	0.121	14.6	392	Average
64	78	3.07	0.056	14.6	284	Low
65	105	2.83	0.090	17.3	200	Average

BEPTats wimter wheat= 2735.72*4000=109.43*10^5 GJ

BEPTats sunflower= 2647.4*2127=56.3*10^5 GJ

Calculation of the ecological capacity of the agrolandscape occupied by winter wheat and sunflower (Nasim *et al.,* 2016; Vilvert *et al.,* 2023) includes the energy of mineral nutrition elements (mobile forms), which consists of the energy stock (EMN) and its increase (±ΔEMN) per unit area. The average phosphorus content (P2O5) in fields with winter wheat is 15 mg/kg, potassium (K2O)-314.42 mg/kg. The average phosphorus content (P2O5) in sunflower fields is 15.4 mg/kg, potassium (K_2O)-324.5 mg/kg (Table 1).

Table 4 shows data on the balance of nutrients, the calculation of which was carried out according to methods adopted in agrochemistry (Mineev, 2004).

According to the methodology, the components for calculating the ecological capacity of the agricultural landscape are determined (Table 5).

As a result of the calculations, the ecological capacity of the agricultural landscape territory occupied by winter wheat and sunflower is equal, respectively:

EP wimter wheat= BPT+(EMN+ΔEMN)=2735.72+(29.30-0.42)=2764.6GJ/ha

EP sunflower= BPT+(EMN+ΔEMN)= 2647.4+(30.01-0.65)=2676.8 GJ/ha

The obtained result of ecological capacity must be reduced to the total area occupied by winter wheat and sunflower, as a result we obtain:

EP agrocensis winter wheat= 2764.6*4000=110.58*10^5 GJ

EP sunflower agrocensis= 2676.8*2127=56.94*10^5 GJ

The activities of international organizations are aimed at sustainable development (Lehmann and Stahr, 2010; Dzhengiz and Niesten, 2020) and minimizing the negative impact on the environment. Thus, the UN recognizes one of the goals of sustainable development as the preservation of terrestrial ecosystems. The agricultural production sector is the most dependent on the state of the environment (Giupponi and Carpani, 2011; Huang *et al.,* 2024).

An analysis of literary sources on the problem under study showed that the study of the ecological capacity of the agricultural landscape began in the late 80s. XX century scientists from the All-Russian Research Institute of Agriculture and Soil Protection from Erosion (Volodin *et al.,* 2000; Udalov and Kalinichenko, 2005; Stamatiadis *et al.,* 2018).

As a result of calculations, it was revealed that in the structure of the total energy of the agricultural landscape of winter wheat and sunflower, the largest share falls on soil energy, then on phytomass energy and energy reserves of soil nutrients. The total energy of the soil under winter wheat

Table 2: Statistical indicators of humus content. Ntotal. P_2O_5. K_2O in the Pronin peasant farm.

Cenosis	n	min	Q1	med	Q3	max	M	s	V. %	x±m
					Humus					
Winter wheat	26	1.67	2.40	2.93	3.42	4.75	2.91	0.73	25	0.14
Sunflower	13	1.56	2.23	3.18	3.43	4.47	2.98	0.94	31	0.26
					Ntotal					
Winter wheat	26	0.05	0.07	0.10	0.16	0.24	0.12	0.06	49	0.01
Sunflower	13	0.04	0.06	0.09	0.12	0.2	0.09	0.04	49	0.01
					P_2O_5					
Winter wheat	26	6.8	12.38	14.95	16.45	32.5	15.77	6.04	38	1.18
Sunflower	13	9.1	10.7	14.6	18.7	24.5	15.45	4.67	30	1.29
					K_2O					
Winter wheat	26	208	294.5	312	335.25	401	314.42	41.63	13	8.16
Sunflower	13	200	315	326	346	392	324	46.85	14	12.9

Table 3: Components for calculating the bioenergy potential of agrocenoses.

	Winter wheat	Sunflower
Mass of by-products (straw) (t/ha)	5.79	3.81
Weight of surface crop residues (SPH) (t/ha)	1.29	1.04
Root mass (SRR) (t/ha)	3.82	2.48
Energy of above-ground phytomass (GJ/ha)	190.35	114.6
Energy of underground phytomass (GJ/ha)	61.77	40.1
Total energy of phytomass (E_{RTPH}) (GJ/ha) (E_{RTPH})	252.12	154.7
Average humus content. %	2.92	2.98
Humus reserve in soil (S_{SOM}) (t/ha)	106.9	109.1
Soil energy potential (E_{RSOM}) (GJ/ha)	2463.5	2514.2
Increase or decrease in energy of organic matter (±+E_{SOM}) (GJ/ha)	20.1	- 21.5

Table 4: Balance of nutrients for calculating growth (loss).

NPK	Income of NPK (kg/ha)				Outlay of NPK (kg/ha)			Balance. kg/ha
	With fertilize	With precipitation	With seeds	Total	With harvest	Loss from surface	Total	
Winter wheat								
N	87	5	2.6	94.6	76	20.5	96.5	-1.9
P	12	0.2	0.5	12.7	32	3.2	35.2	-22.5
K	20	7.5	1.2	28.7	19.2	6.5	25.7	3
Sunflower								
N	40	5	3.36	48.36	49.1	13.23	62.33	-13.97
P	50	0.2	1.92	52.12	17.7	1.77	19.47	32.65
K	30	7.5	2.88	40.38	16.4	5.58	21.98	18.4

Table 5: Components for calculating the bioenergy potential of agrocenoses.

	Winter wheat	Sunflower
Amount of phosphorus (mobile nutrient forms) (kg/ha)	57.83	56.37
Amount of potassium (mobile nutrient forms) (kg/ha)	1150.7	1187.7
Amount of easily hydrolyzed nitrogen (5% of total) (kg/ha)	219	224
Energy reserves of nutrients (EMN) (GJ/ha)	29.3	30.01
Increase or decrease in energy of mobile forms of nutrients (± ΔE_{MN}) (GJ/ha)	- 0.42	- 0.65

was 2463.5 GJ/ha, sunflower 2514.2 GJ/ha, the total energy of the phytomass of winter wheat was 252.12 GJ/ha, sunflower 154.7 GJ/ha. The energy of mineral nutrition elements for winter wheat is 29.3 GJ/ha, for sunflower 30.1 GJ/ha. Similar calculations presented by the All-Russian Research Institute of Agriculture and Soil Protection from Erosion of the Russian Academy of Agricultural Sciences in the Kursk region of the agricultural landscape on a watershed with typical unwashed chernozem, the weighted average BEPT is 9210.00 GJ/ha, the ecological capacity is 9396.10 GJ/ha.

The use of calculations of bioenergy potential will help optimize the structure of the agricultural landscape. Determine the most suitable crops for cultivation in the current soil and climatic conditions.

CONCLUSION

On the test site ''Pronin'', located within the boundaries of Serafimovichi district of Volgograd region and Sovetsky district of Rostov region dark chestnut soils of medium thickness, clayey and heavy loamy granulometric composition, carbonate, slightly and moderately washed out, are used. In general, the soils of the farm have low and medium humus content. In total, the share of fields with average and good nitrogen supply is 78.5%, compared to the share of fields with very low and low supply of 21.5%. The fields have an average supply of mobile phosphorus and a high potassium content. According to agroclimatic zoning, the territory of the farm belongs to the arid region and the southwestern dry-steppe region.

The bioenergy potential of the agricultural landscape territory occupied by winter wheat and sunflower was calculated and the ecological capacity was determined. The BEPT of a field occupied by winter wheat is equal to 2735.72 GJ/ha and the BEPT of a field occupied by sunflower is 2647.4 GJ/ha. At the same time, the ecological capacity of a field occupied by winter wheat is 2764.6 GJ/ha and sunflower is 2676.8 GJ/ha. The data obtained will be used for further calculation of the total ecological capacity of the agricultural landscape of the test site, necessary to assess the compliance of the anthropogenic load with the ecological capacity of the agricultural landscape and ensure its sustainability.

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Conflict of interest

All authors declare that they have no conflict of interest.

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