Determination of Plant Biomass based on Energy Indicators of The Arid Region

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Abstract. The aim of the research is to find out the energetic efficiency of the applied adaptive landscape agricultural system under the conditions of the arid zone in Kazakhstan. During the field studies at the experimental site in Zhambyl region of the Republic of Kazakhstan the calculation of corn biomass was carried out. The existing technology for determining the biomass values requires a lot of manual labor and time. Therefore, relied on the analysis of long-term data obtained by domestic and foreign scientists, it was concluded that biomass accumulation is closely related to plant height. The results of biomass calculations of corn grown for grain demonstrate that biomass varies within the range of 542-634 c/ha, which corresponds to the index of PAR utilization in the diapason of 32-37%. So, in the field experiment under the conditions of arid zone the dry biomass can amount to 96.6-110.4 c/ha. The proposed methodology allows improving the agricultural system and intensifying agriculture, taking into consideration the rational use of energy resources, which leads to the changes in crop placement structure depending on the solar radiation coefficient (K_R).

1 Introduction

Determining the efficiency of crop cultivation technology in traditional monetary terms is currently difficult due to the constant change in prices for equipment, seeds, fertilizers, etc. The technology efficiency can be more accurately assessed by energy costs. Seeds, machinery, labor, services, fertilizers and other technology components have a certain amount of energy spent on their production or that they themselves spend during the production process.

The total energy spent on forage production characterizes the efficiency of both the technology for growing forage plants and the ones for producing various forage from them (hay, haylage, silage, grain forage) [1-3].

Animal farming consumes 18-22% of liquid fuel and 19-20% of electrical energy of all energy resources used for production purposes in agriculture. The energy intensity of livestock production in Russia exceeds the United States and other leading Western countries by 2.0-3.5 times. A main reason for the high energy intensity of the industry is the lack of

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forage supply, their ill balance in protein and microelements. With such forages animal genetic potential, according to the VIJ (Federal Research Center for Animal Husbandry), does not exceed 60% [3-5].

The energy assessment of forage crop cultivation is carried out by analyzing the technological maps, which indicate a set of machines, considering their productivity and energy equivalents of 1-hour operating time. The calculation of total energy costs is carried out taking into account irrigation, fertilization, plant protection, seeding rates, fuel and lubricants, electricity and labor resources.

In order to ensure the competitiveness of agricultural products, we need to systematically reduce labor, material and energy costs in its production. Labor costs to produce 1 ton of grain in Russia are 9 man-hours, in the USA – 2.6, beets, respectively – 7.5 and 1.1, potatoes – 26.5 and 2.2, milk – 85 and 4, beef – 580 and 22, pork – 330 and 8 man-hours.

With the outstripping growth of tariffs and prices for fuel and electricity compared to the prices of agricultural products, the share of energy costs in its net cost increased dramatically from 3-8 to 10-20%, and for some types – up to 30-50% or more. On average, in the gross agricultural output, direct energy costs in value terms amount to 12-13% [5-8].

With traditional methods of carrying out agro-technical measures, the largest share of energy is spent on moving ballast cargo (agricultural devices, machines, hitches) across the field, which contributes to unproductive spend of engine energy up to 55% for plowing and up to 60% for sowing. The use of combined machines reduces fuel consumption by 20-30%, the metal consumption of the machine complex – by 20-25%. Significant fuel savings are achieved by ordering and optimizing transport operations.

Improving the structure of sown areas for agricultural crops, mastering crop rotations, complying with technological discipline, eliminating losses in the resulting products, using high-yielding varieties with a high content of useful components is the cheapest and most affordable way to increase energy yield in the production. For example, an increase in the dry matter content in the green mass of legumes by 1% at the yield of 30 t/ha increases the crop energy yield by 6600 MJ [8-11].

2 Methods

The main task for rational nature management in the modern utilitarian approach to natural resource potential is to maximize the benefits from the use of natural resources while minimizing environmental damage. With all the scientific and practical "perfection", the methods of the utilitarian approach lag behind the real processes taking place in nature and society.

In agro-landscapes, in contrast to natural ones, the balance of oppositely directed processes is disturbed, they lose the ability to self-regulate, self-organize and self-purify, and its stability decreases. Therefore, the management functions in the economic activity are assigned to a person. For the agro-landscape to perform resource-producing, environmental and other functions, it is necessary to constantly maintain its resource (production and environmental) potential.

3 Results and Discussion

The purpose of the research is to establish an energy assessment on the efficiency of the adaptive agricultural landscape system in the conditions of the irrigated zone in Kazakhstan. To study the intended goal, we considered the solar radiation coefficient, identified on the basis of the correlation between the humidity coefficient (C_H) and the radiation index of the terrain absolute elevation (R_H), resulted in the correlated dependence:

$$C_H=K_R R_H+0.098. \quad (1)$$

Hence, after the transformation, we get that in order to stabilize the ecological, reclamation and energy situation, it is necessary to develop rational technological maps for crop cultivation, based on the accounting for energy costs and technical and energy resources (TER). For practical implementation, we recommend to evaluate through the solar radiation coefficient (K_R), which most accurately reflects the actual situation with the energy resources in a particular area [8,9].

$$K_R=\frac{C_H}{R_H}, \quad (2)$$

where: R_H is the radiation index of the terrain absolute height, kJ/cm^2/m; C_H – humidity coefficient.

Table 1. Calculation of the solar radiation coefficient (C_R) for the Zhambyl region in Kazakhstan.

Meteorological station	C_H	R_H	K_R
Ulanbel	0.10	0.68	0.14
Moyinkum	0.13	0.49	0.26
Uyuk	0.12	0.48	0.25
Baikadam	0.11	0.52	0.21
Tolebi	0.17	0.39	0.43
Umbet	0.14	0.35	0.40
Otar	0.22	0.21	1.04
Korday	0.30	0.27	1.11

The data in Table 1 demonstrates that the radiation index of the absolute terrain mark (R_H) in the Zhambyl region is in the range of 0.21-0.68, and the indicators of the solar radiation coefficient (K_R) ranged from 0.14 to 1.11.

According to Table 1, the irrigated area of the studied territory can be divided into four zones: 1. From 0.1 to 0.14; 2. From 0.21 to 0.26; 3. From 0.40 to 0.43 and 4. From 1.04 to 1.11. Hence, the most favorable areas for crop cultivation are, considerably, the vicinity of the meteorological station Otar and Kordai.

The proposed methodology allows improving the farming system and intensifying agriculture, aimed at accelerating the production growth of grain, industrial, forage and vegetable crops. Based on the information above, we face the need to revise the structure of crop placement depending on the solar radiation coefficient (K_R). The explanation is that in long term due to the irrational use of energy resources anthropogenic desertification has intensified, which has drastically affected the gross yield and the sustainability of agricultural production. It follows that the indicator of the solar radiation coefficient gives all the reason to believe that in order to stabilize the environmental, reclamation and energy situation, it is necessary to optimize the technological maps of crop cultivation, based on the accounting for energy costs along with technical and energy resources (TER).

As a result of the research, it was found that Q_{PAR} (photosynthetic active radiation) can be established according to the dependence proposed by N.N. Khozhanov and presented in (Table 2):

$$Q_{PAR} = K_R h_P, \quad (3)$$

where Q_{PAR} is the PAR during the crop growing season, kcal/ha; K_R – solar radiation coefficient; h_p is plant heights, m.

Table 2. Q_{PAR} calculation for the studied objects, billion kJ/ha.

№	K_R	Plant height, m				
		0.5	1.0	1.5	2.0	2.5
Zhambyl region						
1	0.14	0.035	0.070	0.105	0.14	0.175
2	0.26	0.065	0.130	0.195	0.26	0.325
3	0.25	0.062	0.124	0.187	0.25	0.312
4	0.21	0.052	1.104	0.157	0.21	0.262
5	0.43	0.107	0.214	0.322	0.43	0.537
6	0.40	0.100	0.200	0.300	0.40	0.500
7	1.04	0.260	0.520	0.780	1.04	1.300
8	1.11	0.277	0.555	0.832	1.11	1.387

Further, by the arriving PAR in any period of crop development, it is possible to determine the biomass of both dry and green mass of the studied crop, depending on the height of plant development according to the generally accepted formula proposed by M.K. Kayumov, (1989) (Table 3).

$$Y_{biol} = \frac{Q_{PAR} C_{PAR}}{100q}, \tag{4}$$

where Q_{PAR} is the arriving PAR during the crop growing season, kcal/ha; C_{PAR} – the coefficient of PAR use (assimilation) by seeding, %; q – calorific value per unit of organic matter yield, kcal/kg.

Table 3. Estimated yield of corn green mass, c/ha.

Administrative area	PAR use coefficient, (C_{PAR}),%				
	0.6	1.0	2.0	3.0	5.0
Zhambyl region	21.8	43.6	87.5	131.2	218.7
	40.6	81.2	162.4	243.7	234.1
	39.0	78.0	156.0	234.0	390.0
	32.7	64.0	130.8	196.5	327.5
	67.1	134.2	268.4	402.7	671.2
	62.5	125.0	250.0	375.0	625.0
	62.5	325.0	650.0	975.0	1625.0
	73.3	346.6	693.2	1040.2	1733.7

The existing technology to determine biomass requires a lot of manual labor and time for recalculation. Therefore, based on the analysis of long-term materials of Russian and foreign scientists, we came to the conclusion that the biomass accumulation is in close contact with the plant height, which, according to the theoretical calculations by N.N. Khozhanov, is correlated with the following relation:

$$Q_{PAR} = K_R h_P, \text{ mJ/cm}^2 \tag{5}$$

where K_R is the coefficient of solar radiation, h_p is the plant height, cm.

At the same time, the solar radiation coefficient (K_R) was also determined by the formula of N.N. Khozhanov

$$K_R = \frac{RE_t}{PH}, \text{ mJ/cm}^2\text{/m} \tag{6}$$

where R is the radiation balance, Et is the total evaporation, P is the annual precipitation and H is the height.

The study area is linked to the Taraz meteorological station, from here, according to the average long-term meteorological indicators, we establish the solar radiation coefficient for the territory.

$$R = \frac{LP(1000-H)}{250}, \text{ mJ/cm}^2 \quad (7)$$

In our cases, the indicator of the solar radiation coefficient (K_R) with the annual precipitation P = 353 mm and terrain height H = 642 m was R = 303.3 mJ / cm^2

$$K_R = \frac{303.3 \cdot 1048}{353 \cdot 642} = 1.4 \text{ mJ/cm}^2\text{/m}$$

Hence, according to formula (1), with the plant height of 2.30 m, we determine

$$Q_{PAR} = 1.4 \cdot 2.3 = 3.22 \text{ mJ/ha.}$$

Further, with different indexes of PAR use, we calculate dry and green biomass according to the following formula, which are given in Table 4.

$$Y_{biol} = Q_{PAR} I_{PAR}, \quad (8)$$

where $I_{par} = C_{par}/100q$,
where C_{par} is the coefficient of PAR used by a plant,%; q – calorific value of a unit yield of organic matter, kcal/kg.

Table 4. Calculation of corn biomass per grain, c/ha (according to N.N. Khozhanov).

Biomass	PAR use index, %								
	5	10	20	30	40	50	60	70	80
Dry	16.1	32.2	64.4	96.6	128.8	161.0	193.2	225.4	257.6
Green	80.5	161.0	322.0	483.0	644.0	805.0	966.0	1127	1288

Experimental calculation data of the corn biomass grown for grain indicate that it varies within 483-644 c/ha, which, according to Table 4, is close to the PAR use index of 30-40%. Hence, for the studied area, dry biomass can be in the range of 96.6-128.8 c/ha. At the same time, according to the research results, 3 working days and 2 employees were needed to set the biomass manually, which, in terms of energy costs, is about 1247.4 MJ / per person. It follows that the proposed method for determining biomass can reduce energy costs by 97.6% [12-15].

4 Conclusion

The proposed technology makes it possible to improve the farming system and intensify agriculture, taking into account the rational use of energy resources. In order to do this, it is necessary to revise the structure of crop placement, depending on the solar radiation coefficient (K_R).

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