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Evaluation of Solar Radiation and Atmospheric Air during Hay Harvesting in Kazakhstan

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Abstract: The study presents a probabilistic and statistical assessment of the actinometric characteristics of solar radiation and temperature and humidity parameters of atmospheric air during the hay harvesting period in Kazakhstan. The following characteristics are considered actinometric: The duration of the sunshine period, the total solar radiation flow, and the average intensity of the total solar radiation per unit area of the horizontal surface with clear skies and average cloud cover. From the parameters of atmospheric air, its temperature, humidity, and moisture absorption capacity are calculated. The authors present their average values, standard deviations, confidence intervals for the average value, coefficients of variation, and probability densities of the distribution of these parameters.

Keywords: Atmospheric Air Parameters, Probabilistic and Statistical Estimation, Solar Radiation

Introduction

Modern agriculture is developing along the path of intensification, increasing the efficiency of all industries, intensifying production, and improving product quality. The most important task of agricultural production in the Republic of Kazakhstan (RK) is to ensure a significant increase in livestock production. The decisive prerequisite for the intensification of animal husbandry is the widespread introduction of progressive, scientifically-based feed production technologies (Balehegn *et al*., 2020; Bekezhanov *et al*., 2022).

In the creation of an adequate feed base, an important place is given to coarse feed, especially hay. The increased attention to the issue of hay harvesting both in the RK and abroad is explained by the high biological value of hay, its irreplaceability in the diet, and a large share in the feed balance of many farm animals (Mertens, 2011).

According to the BNSASPRRK (2021), there were about 7,500 thousand heads of cattle, 19,200 thousand sheep and goats, 2,900 thousand horses, and about 220 thousand camels in the RK. The volume of hay harvesting for their feeding amounted to about 24 million tons.

It is important not only to fulfill the stated plan for hay harvesting but also to significantly improve its quality. High-quality hay largely satisfies the animals' need for proteins, carbohydrates, vitamins, and a whole complex of nutrients, thereby ensuring a high level of their productivity in winter (Mukhanov *et al*., 2018; Nasiyev *et al*., 2019).

The aim of the study was a probabilistic and statistical assessment of the actinometric characteristics of solar radiation and temperature and humidity parameters of atmospheric air during hay harvesting in Kazakhstan to calculate the optimal parameters of ventilation equipment and technical means for receiving and converting energy. The study consists of five sections, namely the introduction, materials and methods, results, discussion, and conclusion.

Materials and Methods

The study objects were such actinometric characteristics of solar radiation as the duration of the sunshine period, the flow of total solar radiation, and the average intensity of total solar radiation per unit area of a horizontal surface with clear skies and average cloud cover, as well as the average daily values of temperature, relative humidity, and moisture absorption capacity of atmospheric air during hay harvesting in the West Kazakhstan region. The methods for evaluating the study objects consisted in summarizing the results of observations of the National Hydrometeorological Service of Kazakhstan for the Atyrau observation station using a probabilistic and statistical approach.

The duration of sunshine depends on the length of the day and the cloudiness regime (Zhu *et al*., 2020).

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Cloudiness is one of the most important climatic factors. It determines, in addition to the duration of sunshine, the intensity of solar radiation entering the lower layers of the atmosphere and the surface of the earth. Cloudiness was estimated by the degree of sky coverage by clouds, which is determined by visual observations on a 10-point scale. The main characteristic of the cloudiness was the frequency of clear (0...2 points), semi-clear (3...7 points), and overcast (8...10 points) sky conditions.

The daily course of the intensity and density of the radiation flux was determined primarily by the change in the height of the sun above the horizon. The efficiency of the drying process by active ventilation depended mainly on the relative humidity temperature and the moisture absorption capacity of the atmospheric air. With active ventilation of hay, it is important to understand the nature of the change during the day in temperature, relative humidity, and the moisture-absorbing capacity of air determined on their basis.

At the latitude of the Atyrau observation station, considering the transfer of the coordinate of the time reference to the phase difference between the value under study and the time of day, temperature, relative humidity, and moisture-absorbing capacity of atmospheric air changed during the day, respectively, according to the laws:

$$t = 22.33 + 5.1\cos \cos\left[15\left(\tau_i - 9\right) - 8.3\right] + 0.49\cos \cos\left[30\left(\tau_i - 9\right) - 32.2\right] + \left[45\left(\tau_i - 9\right) - 79.1\right] \quad (1)$$

$$\varphi = 51 + 16\cos \cos\left[15\left(\tau_i - 9\right) + 78.3\right]\cos \cos\left[30\left(\tau_i - 9\right) + 78.3\right] + 0.44\cos \cos\left[45\left(\tau_i - 9\right) + 10.2\right] \quad (2)$$

$$\Delta d + 3.1 + 1.7\cos \cos\left[15\left(\tau_i - 8\right) - 7.9\right] + 0.19\cos \cos\left[30\left(\tau_i - 8\right) + 39.6\right]\left[45\left(\tau_i - 8\right) + 8.0\right] \quad (3)$$

The change in the flux density of the total solar radiation incident on a horizontal surface with average cloudiness was determined by the dependence:

$$H = 1.41\cos \cos\left[15\left(\tau_i - 8\right) - 83.1\right] + 0.07\cos \cos\left[45\left(\tau_i - 8\right) - 49.5\right] \quad (4)$$

In this expression, for fluctuations in the solar radiation flux density fluctuating during the day with a half-period ual to approximately 12 h, the coefficient a_0 and harmonic components of an even order were absent.

The main characteristic for assessing the degree of stability of climatic data during the hay harvesting period is the mean square deviation, as generally accepted in the statistical literature. The main characteristic for assessing the variability of average values is the coefficient of variation, which makes it possible to compare the mean square deviation of the parameter and its average value for a certain period.

The standard deviation σ and the coefficient of variation k_v were calculated using the formula (Jessen, 1985):

$$S\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \underline{x}\right)^2}{n-1}} \quad (5)$$

$$k_v = \frac{\sigma}{\underline{x}} \quad (6)$$

where, x_i and $\underline{x}$ are the current and average values of the observed parameters and n is the number of observations from which the average value is calculated.

The accuracy of the average data Δ_x was found using the formula:

$$\Delta_x = \frac{t \cdot \sigma_x}{\sqrt{n}} \quad (7)$$

where, t is Student's t-test.

We considered the series of climate observations data for the period from 2000 to 2020 as a random sample from an infinite general population with a normal distribution of the studied parameters.

Statistical processing of actinometric and meteorological data also included their probabilistic assessment with a daily change by compiling variational series and constructing differential curves of probable distribution based on them. To do this, the entire range of changes in the analyzed parameter was divided into intervals and the number of hours falling into one or another interval was determined. The value of intervals i was determined based on the ratio (Ivanova *et al*., 1981):

$$i = \frac{x_{\max} - x_{\min}}{n} \quad (8)$$

where, $x_{\max}$-$x_{\min}$ are the maximum and minimum values of the observed parameter and n is the number of hours of observations.

The frequency of the parameter p_i (probability) in each of its intervals was determined using the formula:

$$p_i = \frac{\tau_i}{\sum_{i=1}^{n}\tau_i}100\% \quad (9)$$

where, τ_i is the duration of a certain interval (hours).

Based on the calculated frequency values, differential curves of the probability distribution of the studied actinometric and meteorological parameters were constructed.

Results

Figure 1 shows the daily course of the intensity of solar radiation on a horizontal surface with a clear sky and average cloudiness during the haymaking period.

With a cloudless sky or in the presence of clouds that do not cover the disk of the sun throughout the day, the daily variation of the solar radiation intensity had a maximum at noon and was practically symmetrical concerning it (curve 1). The presence of maximum solar radiation at true noon, when the position of the sun at the zenith coincides in azimuth with the southern direction, is because the length of the path of the solar ray in the atmosphere at this time is minimal. Therefore, the attenuation of the radiation intensity is also the smallest. However, in the process of observation under real conditions, the sky was rarely completely cloudless. Thus, the observed daily course of the solar radiation intensity decreased to a certain extent (curve 2).

In summer, the arrival of direct radiation before true noon is greater than in the afternoon due to the often-observed development of convective cloudiness in the afternoon hours. The intensity of total radiation, which is a power characteristic of solar radiation, varied during a clear day on a horizontal surface from 0.2 to 0.9 kW/m^2 and during a day with average cloudiness from 0.24 to 0.79 kW/m^2 (Fig. 1).

Figure 2 shows the average daily values of temperature, relative humidity, and moisture-absorbing capacity of atmospheric air in summer.

The values of temperature and moisture-absorbing capacity of air averaged over the summer period reached their daily maximums ual to 27.2°C and 5.3 g/m^3, respectively, by approximately 2 pm (Fig. 2).

According to the data averaged over the summer period, the average daily values of temperature, moisture absorption capacity, and relative humidity of the air were respectively ual to 25.2°C, 44.6%, and 3.8 g/m^3.

Table 1 shows the daily average statistical assessment of the main meteorological characteristics of the West Kazakhstan region during the hay harvesting period.

Tables 2-5 and Fig. 3 also show a probabilistic assessment of the intensity of solar radiation and temperature and humidity parameters of atmospheric air for the West Kazakhstan region during the hay harvesting period. The ranges of changes in the intensity of solar radiation, temperature, relative humidity, and moisture absorption capacity of atmospheric air are divided, respectively, into intervals of 0.15 kW/m^2 (Table 2), 1°C (Table 3), 4% (Table 4) and 0.5 g/m^3 (Table 5).

Table 1: Daily average assessment of the main meteorological data of the West Kazakhstan region of the RK during the hay harvesting period

	Statistical characteristics in the hourly interval between 8 am and 8 pm			
Type of data	Mean value	Square deviation	Confidence interval for the mean value	Coefficient of variation, %
1	2.000	3.000	4.000	5.0
Duration of sunshine per month, hours	334.000	88.000	±38.000	2.6
The flow of total solar radiation per month, MJ/m^2:				
Clear skies	872.900	62.800	±30.500	7.2
Average cloud cover	767.800	47.900	±23.000	6.2
The average daily intensity of the total solar radiation, kW/m^2:				
Clear skies	0.510	0.030	±0.015	5.6
Average cloud cover	0.499	0.051	±0.024	10.1
Atmospheric air (average daily values):				
Temperature, °C	25.200	3.200	±1.500	12.0
Relative humidity, %	44.600	1.400	± 0.700	3.1
Moisture absorption capacity, g/m^3	3.800	0.430	±0.210	14.0

Table 2: Probability density of the daily distribution of the intensity of total solar radiation on a horizontal surface with different sky conditions, %

Condition of the sky	The average value of the solar radiation intensity interval, kW/m^2					
	0.15	0.30	0.45	0.6	0.75	0.9
Clear skies, (probability) %	4.20	9.20	12.10	14.7	25.00	33.8
Average cloud cover, (probability) %	3.80	10.00	15.00	18.3	23.30	29.6

Table 3: Probability of atmospheric air temperature distribution, %

Period of change from 8 am to 8 pm	Average value of the atmospheric air temperature change interval, °C				
	23.0	24.0	25.0	26.0	27.0
Probability, %	15.0	15.8	17.3	28.3	23.3

Table 4: Probability of distribution of relative humidity of atmospheric air, %

Period of change From 8 am to 8 pm	Average value of the change interval in the relative humidity of atmospheric air, %				
	33.0	38.0	43.0	48.0	53.0
Probability, %	8.8	32.0	19.8	20.0	19.4

Table 5: Probability of distribution of moisture-absorbing capacity of air, g/m^3

Period of change 8 am to 8 pm	Average value of the change interval in the moisture absorption capacity of the atmospheric air, g/m^3				
	3.5	4.0	4.5	5.0	5.5
Probability, %	4.2	16.7	18.3	25.0	19.2

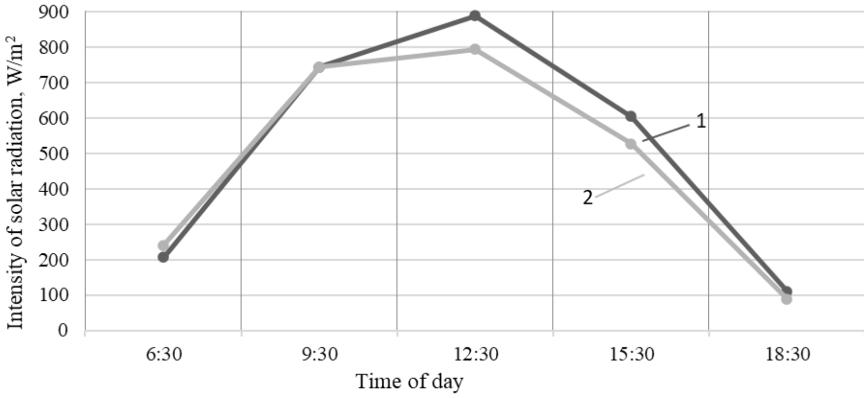

Fig. 1: Daily course of the intensity of total solar radiation on a horizontal surface with different cloudiness: (1) Clear sky; (2) Average cloudiness (points show the average statistical data of the National Hydrometeorological Service of Kazakhstan for the Atyrau observation station)

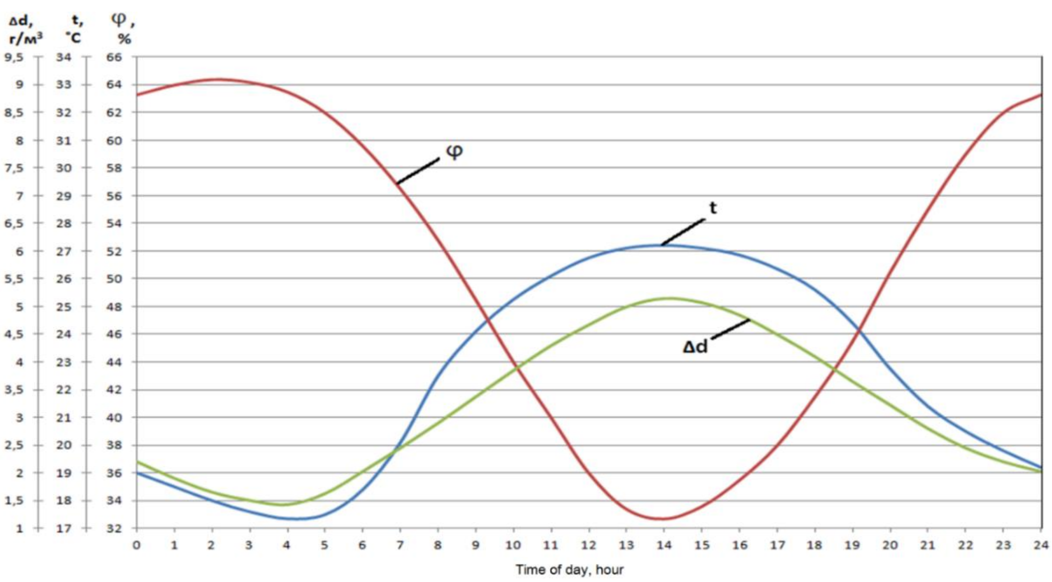

Fig. 2: Daily variation of temperature (t), relative humidity (φ), and moisture absorption capacity (Δd) of atmospheric air averaged over the summer period (points show the average statistical data of the National Hydrometeorological Service of Kazakhstan for the Atyrau observation station)

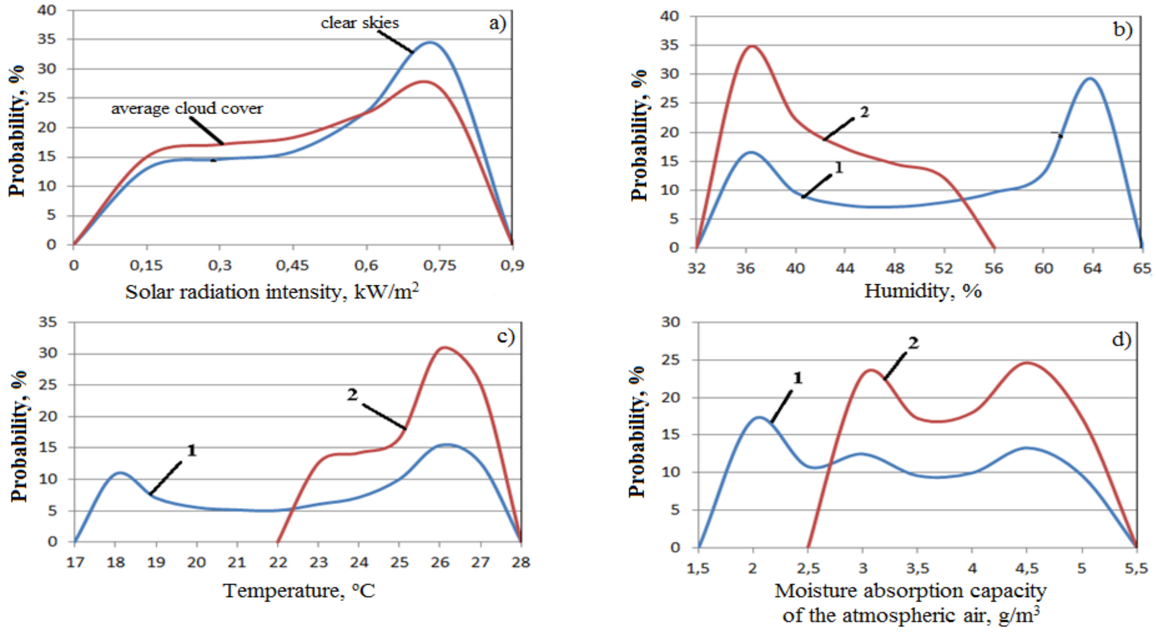

Fig. 3: Differential probability curves of the distribution of solar radiation intensity, with different sky conditions (a); temperature (b); relative humidity (c), and moisture absorption capacity of atmospheric air (d): 1: From midnight to 11 pm, 2: From 8 am to 8 pm

Discussion

In conditions of unstable weather, typical for many regions of Kazakhstan (Russell *et al*., 2018), one of the main ways to improve the quality of hay is harvesting hay from grass dried in the field with drying to the normal amount of moisture by active ventilation with atmospheric air. However, the use of unheated atmospheric air does not provide sufficient drying performance due to the low intensity of heat and mass transfer processes and requires a large air consumption (Kulshikova, 2019).

The noted disadvantages are eliminated by using heated air in active ventilation systems, which reduces the drying time of raw materials to the normal amount of moisture and is the most important factor in reducing nutrient losses and therefore obtaining high-quality hay (Zaica *et al*., 2019; Umarov *et al*., 2020).

The process of drying hay with heated air requires significant energy costs: An average of 40-60 kg of petroleum products or 350-450 kWh of electricity is consumed per ton of dried hay. One of the ways to save energy resources when drying hay by active ventilation with heated air is to involve renewable energy sources in this process, in particular solar energy (Farkas, 2013; Prakash and Kumar, 2013).

According to our data, the values of temperature and moisture-absorbing capacity of air averaged over the summer period reached their daily maximums ual to 27.2°C and 5.3 g/m^3, respectively, by approximately 2 pm. The relative humidity of the air during this period was minimal and amounted to 32.7%. At night, the situation became the opposite: The air temperature decreased to a minimum and its relative humidity reached a maximum, at which the air not only lost its ability to absorb moisture but when ventilated with it, could additionally moisten the material. Therefore, it is more rational to dry hay in the daytime.

Conclusion

In the example of the West Kazakhstan region, we performed a probabilistic and statistical assessment of actinometric and temperature-humidity characteristics of atmospheric air during the hay harvesting period.

We also considered such actinometric characteristics of solar radiation as the duration of the sunshine period, which averaged 334 h over the summer month with a coefficient of variation of 2.6%; the flow of solar radiation to the horizontal surface, which averaged 872.9 MJ/m^2 with clear skies and 767.8 MJ/m^2 with average cloud cover with coefficients of variation of 7.2 and 6.2%, respectively, as well as the average daily intensity of total solar radiation, which was 0.51 kW/m^2 with a coefficient of variation of 5.6% with clear skies and 0.49 kW/m^2 with a coefficient of variation of 10.1% with average cloud cover.

The maximum values of the probability of the daily distribution of the intensity of total solar radiation corresponded to its specific power ual to 0.75 kW/m^2 and amounted to 33.8% with clear skies and 26.7% with average cloud cover.

The most likely daytime values of temperature, humidity, and moisture absorption capacity of the air during the hay harvesting period were 26°C, 36%, and 4.5 g/m^3, respectively.

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Author's Contributions

All authors equally contributed to this study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved.

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