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Efficiency of Japanese Millet (*Echinochloa Frumentacea*) Fodder Crop Cultivation in the Arid Steppe

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Abstract: Japanese millet is a relatively new, valuable fodder crop. 100 kg of Japanese millet hay contains 54.0-60.5 kg of feed units or 6.9 kg of digestible protein. Besides, Japanese millet makes it possible to obtain environmentally friendly food, since the plant is not affected by diseases and pests, therefore, the use of pesticides is not required when cultivating it. However, in the northern regions of Kazakhstan, Japanese millet is an unconventional culture and is practically not used. Therefore, it is necessary to study the efficiency of the cultivation of Japanese millet in the soil and climatic conditions of the steppe zone of Northern Kazakhstan. The study aimed to compare the efficiency of the cultivation of a non-traditional fodder crop (Japanese millet) with traditional fodder crops in the steppe zone of Northern Kazakhstan to provide farm animals with a diverse and feed-valuable diet. The study was carried out in 2017-2019 at the station of the Kazakh Agrotechnical University named after S. Seifullin, located on dark chestnut soils of the Akmola region of Northern Kazakhstan. It was observed that in comparison with the traditional fodder crop (Sudan grass) Japanese millet exceeded it both in terms of profitability (it was higher by 13.7% when cultivated for feed and by 45.8% when cultivated for grain) and in terms of energy efficiency (it increased by 1.9 times when cultivated for feed and 0.7 times when cultivated for grain). During the cultivation of Japanese millet for feed, an additional net income was received from 1 ha (392 USD), and with grain, this amount equaled 622 USD. Thus, Japanese millet is a promising fodder crop for cultivation in the conditions of Northern Kazakhstan.

Keywords: Efficiency, Japanese Millet, Hay, Grain, Profitability

Introduction

Japanese millet (*Echinochloa frumentacea* Link.) is a little-studied culture that was introduced into cultivation primarily as a grain crop since its grain is suitable for cooking porridge and flour products (Renganathan *et al*., 2020). However, in terms of technological and taste qualities, the grain of Japanese millet is inferior to other cereals and grains, so it is more of interest as a forage plant with high potential productivity (Renganathan *et al*., 2020). Under favorable conditions for vegetation, it can produce 2-3 cuttings during a warm period, while providing high yields of green mass and hay. It is gladly eaten by all types of farm animals (Mukhanov *et al*., 2020).

Japanese millet is characterized by high biological plasticity and adaptability and rationally uses the agro-climatic conditions of the cultivation zone. The crop also deserves serious attention since it provides high yields in extremely arid conditions, which has become relevant in recent years due to frequent droughts, especially on soils with light granulometric composition (Kopylovich and Shestak, 2016; Yessimbek *et al*., 2022; Yesmagulova *et al*., 2023).

In comparison with the annual cereal fodder crop (Sudan grass) widely distributed in the crops of agricultural formations in the steppe zone of Northern Kazakhstan (Nasiyev *et al*., 2021), the green mass of Japanese millet is characterized by high leafiness and nutritional value (Morozov *et al*., 2015; Nogayev *et al*., 2022). Silage

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obtained from the green mass of Japanese millet is chemically equivalent to corn (Istranin, 2013). Straw and green mass of Japanese millet in combination with high-protein fodder crops give a high-quality juicy feed balanced in terms of sugar/protein ratio with a high supply of feed units and digestible protein, which contributes to an increase in the productivity of farm animals (Jayakodi *et al*., 2019). Japanese millet also gives a high yield of seeds, which are a valuable concentrated feed for birds, as well as suitable for use in crushed or ground form for feeding farm animals.

Japanese millet is not affected by diseases and pests, therefore, treatment with chemicals is excluded, which determines the environmental friendliness of the cultivation of this crop (Rzabay *et al*., 2022).

For the northern regions of Kazakhstan, Japanese millet is a relatively new crop, which is one of the reasons that it is practically not used by agricultural producers. Due to the lack of specific information on the efficiency of the cultivation of Japanese millet in the soil and climatic conditions of the steppe zone of Northern Kazakhstan, there is a need to study the feasibility of its cultivation for feed and seeds.

The purpose of the study is to compare the efficiency of the cultivation of non-traditional fodder crops (Japanese millet) with traditional fodder crops in the steppe zone of Northern Kazakhstan to provide agricultural animals.
Objectives of the study:

- A comparative assessment of the yield of Sudan grass and Japanese millet
- A study of the chemical composition and nutritional value of the green and dry mass of Sudan grass and Japanese millet
- Calculation of economic indicators for the production of hay and grain of Sudan grass and Japanese millet

Materials and Methods

Location of the Study

The study was carried out in 2017-2019 at the station of the Kazakh Agrotechnical University named after S. Seifullin, located on dark chestnut soils of the Akmola region of Northern Kazakhstan.

The Object of the Study

The widely popular zoned variety of Sudan grass, Tugai (standard: St) (Baskkir Agricultural Research Institute (BNIISKh)) and the introduced variety of Japanese millet, Krasava (Federal Budget Research Institution Federal Research Center of Cereal, Legume and Grain Cultures (FGBNU FNC ZBK)), were selected as objects of the study.

The experiments were established in four-fold repetition. The area of one experimental plot was 120 m^2 and the plot area was 100 m^2. The placement of variants in the experiments was systematic with a sequential arrangement of repetitions.

Environment

The soils of the experimental site are typical for the steppe zone of Northern Kazakhstan with a pH of salt extract = 6.9, with rather low potential fertility (the humus content in the soil is low: 2.7%), nitrate nitrogen (5.5 mg/kg) and mobile phosphorus (13.8 mg/kg) and a high content of exchangeable potassium (562.7 mg/kg) in the arable soil layer (20 cm) (Serekpaev *et al*., 2020).

The weather conditions of 2016 and 2018 were characterized as moderately arid (Hydrothermal Index (HTI) 0.82 and 0.89) with moderate temperature regimes and had the most favorable effect on the growth and development and formation of the yield of hay Japanese millet. In turn, 2017 was characterized by an acute shortage of precipitation and a high value of the sum of active temperatures and was characterized as very dry (HTI = 0.32) (Serekpaev *et al*., 2020).

The energy assessment of the cultivation of annual fodder crops was carried out according to the method of bioenergetic assessment of the technology of crop cultivation. For this purpose, energy efficiency coefficients were used, which show how many times the energy contained in the crop is greater than the energy invested in the main working capital of production and live labor. According to the technological map, where all types of agricultural work carried out in these experiments were indicated, the total production cost energy using energy equivalents was found. The calculation of the total energy for Fuels and Lubricants (FaL) and labor resources, as well as the total energy for seeds, was carried out.

Study Procedure

Japanese millet and Sudan grass were cultivated after the preceding crop of oats. The main tillage (subsoiling) was carried out to a depth of 22-25 cm (zonal treatment) with a PG-3-5 plow. In winter, snow retention was carried out twice with the help of a snow ridge SVU-2,6. In spring, with the onset of physical ripeness of the soil, the soil surface was leveled with jagged heavy harrows (BZTS-1.0) to a depth of 4-5 cm. Before sowing the Japanese millet for the destruction of weeds by the method of depletion, pre-sowing tillage was carried out to a depth of 8-10 cm with a blade plow KPSH-11, followed before and after sowing by rolling the soil with star-wheeled rollers 3KSH-6A.

Loading of seeds into a vehicle, transportation to the field, and filling of seeders, respectively, were carried out using loaders PKU-0.8 and 2PTS-4 + AZS-25.

Sowing of seeds was carried out in the third decade of May, with a seeding rate of 2.0 million pieces of germinating seeds per 1 ha, to a depth of 3 cm with a row spacing of 30 cm (closing the seed ducts in a row) using a pneumatic universal seeder, S-6MP-1 Bystrica (Radiozavod JSC, Russia).

Hay cutting was carried out in the phases of complete panicle development with a cut height of 7-9 cm with the storage of the mass for mowing (for field drying) using a two-bore semi-mounted mower KDF-4.0. At a moisture content of the mown mass of crops of 40-50%, raking into rolls was carried out using hydraulically trailed rakes GPG-6.5. Hay dried in rolls to a humidity of 22-25% with the help of a cylindrical baler PRF-145A was collected in rolls with a width of 1.5 m, a height (diameter) of up to 1.4 m, and a weight of up to 500 kg.

Transportation of rolls to storage sites and laying of rolls in long-term storage sites (stacks) was carried out using loaders 2PTS-4 + AZS-25 and PKU-0.8, respectively.

Harvesting of Japanese millet seeds was carried out by direct combining with crushing and scattering of straw, with seed moisture below 20% by the combined harvester SH6090. The Sudan grass, due to uneven maturation, was mown into uniform rolls, with a grain moisture content of 25-30% using a roller-trailed harvester ZhVP-9.1. The selection and threshing of rolls with grinding and spreading of straw were carried out at a grain humidity of 20% with SH6090 with a KZS-9.1.20 harvester. The harvested grains were cleaned using a self-moving heap cleaner OVS-25 (Voronezh Agrotechnika LLC, Russia).

The nutritional value of the obtained feed and the chemical composition of its green and dry mass was determined in the laboratories of the Research and Innovation Center for Animal Husbandry and Veterinary Medicine LLP using the DS 2500 (Foss) equipment and in the Oryol State Agrarian University, Innovative Research Testing Center for Collective Use (Orel, Russia), using a Fosskgeitec-2300 protein analyzer, a Soxtek fat analyzer, a Fibertek M6 fiber analyzer, a Seect-hot muffle furnace, and a Conterm sterilization cabinet.

Dry matter in the green mass of annual fodder crops was determined using a two-stage method. The essence of the method lies in the sequential determination of the air-dry substance content in the test sample by drying the sample at a temperature of (60±2)°C. The dried sample is brought to an air-dry state for 1 h on a laboratory bench and weighed. Then the content of hygroscopic moisture in the air-dry sample is determined by drying it at a temperature of (105±2)°C. The mass fraction of dry matter in the test sample is determined by calculation based on the mass fraction of air-dry matter and hygroscopic moisture.

The content of dry matter in the hay of annual fodder crops was determined by drying the sample at a temperature of (130±2)°C for 40 min. Opened bottles with lids were dried in an oven at a temperature of (130±2)°C for 30 min, cooled in a desiccator, and weighed with an accuracy of ±0.001 g. Then, a weighed portion of the test sample weighing 3-15 g was placed in the weighing bottles. Opened weighing bottles with the sample and lids were placed in an oven heated to 130°C and dried for 40 min. Then the bottles were taken out of the oven with muffle tongs, covered with lids, cooled in a desiccator to room temperature, and weighed.

To estimate the energy accumulated in the economically valuable part of the crop, the formula was used:

$$V = Af * \lambda_1 f * Lf \tag{1}$$

where,

- V = The energy content in the economically valuable part of the crop, MJ/ha
- Af = An economically valuable part of the crop yield, kg/ha
- $\lambda_1 f$ = The coefficient of conversion of a unit of the received product into dry matter
- Lf = The total energy content in 1 kg of dry matter, MJ

The energy efficiency coefficient of crop cultivation was determined as follows:

$$Energy\,efficiency\,coefficient = \frac{Energy\,content\,of\,the\,crop}{Total\,energy\,consumption\,for\,production} \tag{2}$$

Statistical Analysis

Statistical processing of the results was carried out using the method of determining the significance of the differences between the samples according to the Least Significant Difference (LSD) using Excel and Snedecor software.

Results

The yield of Annual Cereal Fodder Crops

The productivity of annual fodder crops for an average of 3 years ranged from 15.2-29.4 t/ha of green mass, from 4.0-7.5 t/ha of dry matter, and from 2.0-2.4 t/ha of seeds. The increase in the yield of the green mass of Japanese millet in comparison with the standard (Sudan grass) was 93.4%, dry mass 87.5%, and seeds 20.0% (Table 1).

During the years of the study, the Japanese millet was higher in all indicators of the chemical composition of the green mass than the Sudan grass. The content of crude protein in the green mass of Japanese millet was 2.9%, crude fiber 7.9%, crude fat 0.6%, crude ash 2.2%, Nitrogen-Free Extractive Substances (NFES) 11.3%, and carotene 5.3%, which is higher than the control variant by 3.6, 0.4, 0.5, 0.1, 0.6, 2.1 and 1.1%, respectively.

Table 1: Yield of annual cereal fodder crops (for 2017-2019), t/ha

Crop	Yield: Green mass 2017	2018	2019	Average	Dry mass 2017	2018	2019	Average	Seeds 2017	2018	2019	Average
Sudan grass (control)	15.3	14.5	15.9	15.2	4.00	3.80	4.20	4.00	2.00	2.00	2.10	2.00
Japanese millet	28.7	28.5	31.0	29.4	7.40	7.30	7.90	7.50	2.30	2.20	2.60	2.40
Increase	13.4	14.0	15.1	14.2	3.40	3.50	3.70	3.50	0.30	0.20	0.50	0.40
LSD_{05}	1.85	2.26	2.78	2.30	0.97	0.51	0.69	0.72	0.47	0.61	0.55	0.54

Table 2: Chemical composition of the green and dry mass of annual fodder crops, % (for 2017-2019)

Crop	Product type	Indicators: Dry matter	Crude protein	Crude fiber	Crude fat	Crude ash	NFES	Soluble carbohydrates	Carotene
Sudan grass (control)	Green mass	21.2	2.5	7.4	0.5	1.6	9.2	-	4.2
	Dry mass	78.8	11.9	34.9	2.3	7.8	44.2	1.7	19.8
Japanese millet	Green mass	24.8	2.9	7.9	0.6	2.2	11.3	-	5.3
	Dry mass	75.2	11.6	32.0	2.1	8.6	44.9	2.7	20.9
Increase	Green mass	+3.6	+0.4	+0.5	+0.1	+0.6	+2.1	-	+1.1
	Dry mass	-3.6	-0.3	-2.9	-0.2	+0.6	+0.7	+1.0	+1.1

Table 3: Nutritional value of the green and dry mass of annual fodder crops (for 2017-2019)

Crop	Indicators: Green mass Feed unit	Digestible protein, g	Metabolizable energy, MJ	Dry mass Feed unit	Digestible protein, g	Metabolizable energy, MJ
Sudan grass (control)	0.22	18.44	2.40	0.74	69.9	7.9
Japanese millet	0.22	18.42	2.32	0.66	72.7	7.0
Increase	-	-0.02	-0.08	-0.08	+2.8	-0.9

Table 4: Economic efficiency of cultivation of annual fodder crops

Crop	Product type	Types of costs, USD: FaL	Depreciation	Current repair	Payment labor	Seed materials	Total costs
Sudan grass (control)	Hay	18.33	4.33	4.32	6.76	19.04	52.78
	Seeds	16.16	6.40	6.38	7.27	19.04	55.25
Japanese millet	Hay	18.33	4.33	4.32	6.76	3.14	36.88
	Seeds	15.79	5.45	5.42	6.25	3.14	36.05
Increase	Hay	-	-	-	-	-15.90	-15.90
	Seeds	-0.37	-0.96	-0.96	-1.02	-15.90	-19.21

Chemical Composition of Annual Fodder Crops

The chemical composition of the dry mass of Japanese millet hay was slightly inferior to Sudan grass and according to some indicators, the content of crude ash (by 0.6%), NFES (by 0.7%), soluble carbohydrates (by 1.0%) and carotene (by 1.1%) even exceeded the indicators of the standard variant (Table 2).

Nutritional Value of Annual Fodder Crops

The green mass and hay of the new fodder crop of Japanese millet are not inferior in nutritional value to the traditional Sudan grass, which is widespread in this zone. Compared with the Sudan grass, Japanese millet hay was characterized by a high content of digestible protein and had 2.8 g more of it than Sudan grass (Table 3). The economic efficiency of the cultivation of Japanese millet for feed and seeds showed that the total production costs for hay cultivation were 30.1% lower than the control variant and for grain cultivation 34.8% lower.

Economic Efficiency of Cultivation of Annual Fodder Crops

The difference in total costs depended on the cost of seeds of fodder crops and the consumption of seed material per area unit. In addition, the separate method of harvesting Sudan grass for grain led to an increase in total production costs (Table 4).

Table 5: Economic indicators for the production of hay and grain of annual fodder crops (for 2017-2019)

Crop	Product type	Economic indicators Cost of 1 ton of products, USD/t	Net income, USD	Profitability, %	Energy indicators Energy output from1 ha, MJ	Energy costs, MJ	Energy efficiency coefficient
Sudan grass (control)	Hay	13.20	377.48	7.2	13,112.0	6,696.7	2.0
	Seeds	27.63	2,956.6	53.5	31,544.8	8,154.0	3.9
Japanese millet	Hay	4.92	769.86	20.9	24,585.0	6,281.6	3.9
	Seeds	15.02	3,578.17	99.3	37,853.8	8,141.2	4.6
The increase compared	Hay	-8.28	392.38	+13.7	+11,473.0	-415.1	+1.9
to the control variant	Seeds	-12.61	621.57	+45.8	+6,309.0	-12.8	-2.0

Calculations of the costs for obtaining a unit of production (hay, grain) showed that the lowest cost was observed in the non-traditional Japanese millet crop and amounted to $4.92/ton for cultivation for feed, $ 15.02/ton for seeds, which was lower from the control variant by $8.28 and $12.61/t, respectively.

In comparison with the traditional culture (Sudan grass), when cultivating the new fodder crop (Japanese millet) for feed, an additional net income was received from 1 ha equaling $392.38, and for grain $621.57. Indicators of profitability of cultivation of Japanese millet compared to Sudan grass were higher when cultivated for hay by 13.7% and for grain by 45.8% (Table 5).

In addition, the cultivation of Japanese millet for hay and grain turned out to be energetically more efficient than Sudan grass, since the energy efficiency coefficient of Japanese millet exceeded the energy efficiency coefficient of Sudan grass when cultivated for hay by 1.9 times and when cultivated for grain by 0.7 times.

Discussion

The yield potential of Japanese millet is very high. For example, created in the Federal Scientific Center of Leguminous and cereal crops of Russia in the conditions of the Orel region of Russia, a new variety of Japanese millet has green mass indicators of more than 80 t/ha (Gurinovich *et al*., 2021).

In conditions of the arid steppe, according to the results of these studies, the productivity of Japanese millet is much lower, the green mass yield equaling 29.4 t/ha, the dry mass yield, and the 7.5, grain yield 4.0 t/ha, respectively. Nevertheless, relative to other, widespread, popular annual crops, Japanese millet is very productive. Thus, according to our data, this crop is twice as productive as the Sudan grass, the green mass of which in the experiment was 15.2 t/ha and the dry mass was 4.0 t/ha.

In almost all regions of cultivation, Japanese millet shows high indicators compared to other crops. Thus, according to the results of studies conducted in the Minsk region of the Republic of Belarus, the yield of Japanese millet exceeded even the yield of popular millet, when the yield of green mass from Japanese millet amounted to 36.0 t/ha, dry matter yield to 6.08 t/ha, while millet showed the values of 34.0 t/g and 5.1 t/ha, respectively (Zinovenko *et al*., 2007). Similar indicators were obtained for Japanese millet in comparison with other millet fodder crops. Thus, on average, over three years of research conducted in the south-eastern part of the Republic of Belarus, the yield of green mass of Japanese millet exceeded millet by 14.0 t/ha, Turkestan millet by 19.4 t/ha and foxtail millet even by 25.5 t/ha (Kopylovich and Shestak, 2016).

Similar results were obtained when studying the productivity of annual grasses in the Saratov region of Russia. The highest yield of green mass on average for three years of study was in the pure form of Japanese millet and amounted to 18.84 t/ha, while in Turkestan millet and foxtail millet, it was 16.13 and 15.60 t/ha, respectively (Rodina *et al*., 2021).

The very high productivity of Japanese millet has also been confirmed compared to sugar sorghum. According to the research carried out in the conditions of the north-eastern part of Belarus, the yield of Japanese millet was more than twice the yield of sorghum: The green mass yield of Japanese millet was 63.9 t/ha, dry matter yield was 14.12 t/ha, sorghum yield 25.9 t/ha and 5.44 t/ha, respectively. Even in comparison with the sorghum and Sudan grass hybrid, which proved itself well under these conditions, the Japanese millet was the first in productivity, exceeding it by 20% (Lukashevich *et al*., 2018).

In the study of the productivity and feed value of annual grasses in the conditions of the Krasnoyarsk Territory of Russia, a 182% increase in the green mass of Japanese millet in comparison with oats was noted. Moreover, this crop turned out to be better than oats in terms of nutritional value, i.e., the yield of feed units and digestible protein (Avetisyan *et al*., 2020). In the Amur region, Japanese millet grain is also very valuable in terms of feed, composition, and nutritional value and is not inferior to oats and barley and contains up to 19.0% protein and 4.4% sugar in absolutely dry matter.

In terms of the chemical composition of the green mass, according to the results of our study, it was better than the Sudan grass, but only slightly. The chemical composition of the dry mass of Japanese millet hay, in general, was slightly inferior to the Sudan grass or was at the same level. In terms of nutritional value, the Japanese millet also was equal to the Sudan grass. Moreover, the hay of the recommended crop was distinguished by a higher content of digestible protein (2.8 g). Thus, in 100 kg of Japanese millet hay, there were 54.0-60.5 kg of feed units and 6.9 kg of digestible protein, and in Sudan grass hay they were 56.8 and 6.7 kg, respectively.

It is important to take into account that the indicators of chemical composition, as well as the productivity of crops, are influenced by agrotechnical measures, such as the seeding rate, sowing dates, and irrigation. As a result of long-term experiments, it has been demonstrated that to obtain the highest feed value, a high yield of the green and dry mass of Japanese millet in the conditions of the steppe zone of Northern Kazakhstan, the optimal sowing dates are the second and third decades of May and the second decade of May for obtaining a seed harvest. The optimal seeding rate of Japanese millet is 2.0 million germinating seeds per hectare (Zotikov *et al*., 2018).

In the steppe zone of Northern Kazakhstan, when cultivating new non-traditional annual fodder crops for fodder and seeds, we recommend sowing Japanese millet seeds in the third 10-day period of May with a row spacing of 30 cm and a seeding rate of 2.0 million germinating seeds/ha. Under irrigation conditions, it is recommended to carry out two irrigations per season with a rate of 800-900 m^3/ha in the tillering and booting phases.

One of the methods to reduce the fodder deficit is to expand the species composition of fodder annual crops, which are characterized by good fodder qualities, high and stable yields, lower energy consumption for cultivation, and lower demands for agro-climatic conditions. These crops include a non-traditional and rare annual grain fodder crop-Japanese millet. Despite several advantages, paisa is not widely distributed in the structure of sown areas of the steppe zone of Northern Kazakhstan. One of the reasons that do not allow to successfully expand the crops of these crops is the low knowledge of cultivation technology in the soil and climatic conditions of the steppe zone of Northern Kazakhstan.

Conclusion

The yield of the green mass of Japanese millet was 52% higher than the yield of the Sudan grass and the dry mass yield was 53% higher.

According to the indicators of the chemical composition of the green mass, the Japanese millet, although slightly, exceeded the Sudan grass by 0.1-3.6%. In terms of nutritional value, the recommended crop was at the level of the control one, while the hay of Japanese millet differed by 3.9% higher content of digestible protein.

The production costs for the cultivation of Japanese millet for hay were 30.1% lower than the control variant and for the cultivation of grain 34.8% lower. The very low cost of cultivation of Japanese millet in comparison with Sudan grass ensured high profitability of cultivation. The cultivation of Japanese millet for hay is more profitable by 13.7% and for seeds by 45.8% in comparison with the cultivation of traditional Sudan grass.

The presented material shows that the non-traditional fodder crop (Japanese millet), when cultivated for feed and seeds, can be successfully cultivated in the conditions of the steppe zone of Northern Kazakhstan, since in comparison with traditional fodder crops it is not inferior and, in some indicators, exceeds them.

For the first time in the steppe zone of Northern Kazakhstan, a new fodder crop of Japanese millet was evaluated as a source for introduction, agrotechnological methods of cultivation were studied and a comparative assessment of the productivity of green mass and seeds was carried out in comparison with the traditional culture of Sudanese grass.

The studied technological methods of cultivation of annual crops based on identifying the features of plant development and crop formation allowed us to develop recommendations for farms in the region concerning the technology of cultivating Japanese millet for feed and seeds.

The obtained data allow us to predict the possibility of further introduction of annual fodder crops, including to other regions, while the introduced species can become the source material. The influence of a complex of agrotechnical methods of cultivation (sowing dates, seeding rates) and agrometeorological conditions in different periods of growth and development of Japanese millet plants on the duration of interphase and vegetation periods, the formation of elements of the yield structure and its value in the steppe zone of Northern Kazakhstan was studied.

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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 no ethical issues are involved.

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