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INCREASED EFFICIENCY IN THE CULTIVATION OF GRAIN SORGHUM (SORGHUMBICOLOR (L.) MOENCH) ON LIGHT CHESTNUT SOIL IN THE REPUBLIC OF KALMYKIA

ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ВОЗДЕЛЫВАНИЯ ЗЕРНОВОГО СОРГО (SORGHUMBICOLOR (L.) MOENCH) НА СВЕТЛО-КАШТАНОВЫХ ПОЧВАХ В РЕСПУБЛИКЕ КАЛМЫКИЯ

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Abstract. For the first time the influence of the methods of basic soil cultivation on the formation of the grain production process and the yield of different varieties of grain sorghum (Sorghumbicolor (L.)Moench) has been established for the soil-climatic conditions of the semi-desert zone of the Republic of Kalmykia. Sorghum is a multipurpose crop that can be grown on low fertility soils with less water requirement. That makes it a promising crop in the context of climate change. An assessment of the efficiency of rational use of productive moisture reserves by grain sorghum varieties of different groups of ripeness with the use of different methods of basic tillage was made. It has been established that the best yield of 2.47-2.53 t/ha of early ripening grain was obtained by applying flatbed plowing but fall plowing was more effective for mid- ripening varieties providing yields of 2.59-3.20 t/ha with. The economic efficiency of agrotechnological methods of cultivation of different grain sorghum varieties on light chestnut soils was evaluated.

Аннотация. Впервые для почвенно-климатических условий полупустынной зоны Республики Калмыкия установлено влияние способов основной обработки почвы на формирование процесса производства зерна и урожайность различных сортов сорго зернового (Sorghumbicolor (L.)Moench). Сорго является культурой многоцелевого назначения, которую можно выращивать на почвах с низким плодородием и меньшей потребностью в воде. Это делает ее перспективной культурой в условиях изменения климата. Проведена оценка эффективности рационального использования запасов продуктивной влаги сортами сорго зернового разных групп спелости при использовании различных способов основной обработки почвы. Установлено, что наилучшая урожайность 2,47-2,53 т/га зерна раннего срока созревания получена при применении плоскорезной вспашки, а для среднеспелых сортов более эффективна зяблевая вспашка, обеспечивающая урожайность 2,59-3,20 т/га при Дана оценка экономической эффективности агротехнологических

приемов возделывания различных сортов зернового сорго на светло-каштановых почвах.

Key words: Grain sorghum (Sorghumbicolor (L.)Moench.), productivity, tillage, variety, light chestnut soil.

Ключевые слова: сорго зерновое (Sorghumbicolor (L.)Moench.), урожайность, обработка почвы, сорт, светло-каштановая почва.

Introduction.

For more rational use of arable land, especially in arid zones, with harsh soil and climate conditions, it is necessary to select agricultural crops that give the greatest productivity. In such conditions, the priority is to improve the structure of the areas occupied by crops, rational use of them, correct selection and expansion of the range of highly productive drought - resistant crops that can give high and stable grain yields [1, 2]. Grain sorghum (Sorghum bicolor (L.) Moench) – an ideal plant for growing in arid regions, for example, in the southern regions of our country. In addition to being unpretentious to environmental conditions, the plant is characterized by high yield, has a lot of useful properties and is successfully used for various purposes. The plant belongs to the category of low-growing (1-1. 5 m), open or slightly closed by film grains are collected in panicles with a sufficiently high density. The stem is strong, semi-succulent, the leaves have white or greenish central veins, and the above-ground grassy part is covered with a natural waxy coating that prevents rapid evaporation of moisture. The ability of grain sorghum to withstand drought is due to the structure of the developed and powerful root system, which is capable of quick absorbing of a large volume of water. The main advantage of grain sorghum is the absolute unpretentiousness to the conditions of cultivation. Unlike traditional grain crops in our area, sorghum grows well even on heavy soils such as clay, alkaline and sub-sand soils [3]. An important point is outstanding nutritional qualities of sorghum: 100 grams of grains contain up to 15% of protein rich in lysine, about 70% of useful carbohydrates and no more than 4% of fat, 70-75% of starch, 17 essential amino acids, vitamins (E1, B1, B2, B3, carotene), minerals (P_2O_5, K_2O, MgO), tannins (tanning substances) [4, 5].

Regular consumption of sorghum in food, stimulates metabolism in the human body, contributes to activation of brain functions, increases muscle tone and regulates appetite, stimulates the synthesis of amino acids, proteins, steroid hormones, fatty acids, vitamins A and D, cholesterol, normalizes hematopoietic processes and blood sugar, improves the condition of the mucous membranes and skin. Raw grains contains polyphenol compounds that positively influence the immune system, have protective effects, minimize the influence of tobacco smoke and alcohol, and are a powerful antioxidant. Grain sorghum is a multi-purpose crop (a good concentrated feed for all types of livestock, poultry, fish), for technical and food purposes) [1-4]. Sorghum is now known for highly diversified utilization, so-called “6F’s”: food (grain and sugar), feed (grain and forage biomass), fuel (production of ethanol), fiber (production of cellulose, paper), fermented products (beer, methane) and fertilizer (organic manure from byproducts) [5].

It belongs to the bread of the second group. It is used for producing cereals and flour, combined feed and a raw material in starch production and for producing alcohol [5-7]. In terms of nutritive value, 100 kg of grain is equivalent to 118-130 fodder units [8]. The content of exchange energy is 10.8-12.5 MJ per kg of grain, 31.24 GJ/ha per 1 ha of crops, while barley, for example, has only 26.56 GJ / ha [9]. In terms of chemical composition and energy content, grain sorghum is similar to corn [10, 11]. The area of cultivation of Sorghum bicolor (L.) Moench covers vast areas of the Earth: from the tropics, desert and semi-desert zones to temperate, humid zones (Russia, USA, Nigeria, Sudan, Mexico, Ethiopia, India, etc.). It is grown in 85 countries around the world, and the crop acreage covers about 50 million hectares [12, 13]. Upon that, according to the FAO, there is an increase in the gross harvest of sorghum grain, if in 2010 - 55.6 it was million tons, in 2016-63.9 it was million tons [15]. It occupies the fifth place in the world (~ 60 million hectares) after wheat, rice, corn and barley. It is most common in Africa (40 million ha), India (up to 15 million ha), and the United States (6-8 million ha). In arid areas, sorghum yields are often higher than spring barley and corn [14]. It is regarded as only sorghum can reduce strong fluctuations in grain and feed production under extreme weather conditions. Thus, the barley harvest was at the level of 0.5-1.0 t/ha in extreme 2009 in the Lower Volga region, while sorghum output yield was 2.3-2.5 t/ha [12]. The largest success in agricultural technology and seed production of grain sorghum was achieved in the United States, where 14.4% of the world's total crop acreage is concentrated, and the gross output is 40%. Recently, there has been a trend in the world to reduce the area allocated for sorghum, but the yield per hectare is growing. The average yield was 1.37 tons per hectare and the highest yield obtained in Jordan was 12.7 t/ha [14]. In our country, sorghum crops occupy only 0.1-0.3% in the total structure of sown areas. According to Rosstat [16], the acreage of planted crop in the Russian Federation ranged from 20.0 to 228.7 thousand hectares over the past decade. An analysis of statistical data showed that the gross grain sorghum harvest in the last five years in the Russian Federation was 1035–3120 thousand hundredweights (hwt). Grain sorghum in the Russian Federation is cultivated in almost all districts, with the exception of the North-Western and Far-Eastern Federal districts. For most years, the gross harvest in the Republic does not exceed 2.0 thousand hwt per ha of grain. The average yield of sorghum grain for 2007 – 2017 in the Republic of Kalmykia was 5.0 cwt/ha. The maximum yield was observed in 2011 and 2017. On average, according to this indicator, the Republic occupies one of the last places in the Federal district. When growing sorghum for industrial purposes or for grain, yields depend on competent agricultural planning and technologically correct preparation of seed material and soil. Sorghum seeds should be dried and ventilated throughout the entire storage period, at the same time protecting them from pests, due to chemical treatment as the most effective way to prevent seeds. To preserve the quality of the genetic material, sorghum grain for sowing should be selected with some care at the harvest stage and immediately before sowing period, removing off-grade specimens as much as possible. As soon as the soil reaches optimal physical condition, it must be harrowed in with a single or tandem method, depending on the composition and gravity of the soil. When processing heavy soils, it is also recommended to use chisel tillage of the surface to a depth of 12 cm. The recommended depth of pre-sowing cultivation with a small number of weeds is 5-6 cm and 12-15 cm if the weed age is significant [17]. In that case double treatment is the most effective.

Despite the unpretentiousness and resistance of sorghum to droughts, it is desirable to prepare the soil with the maximum preservation of the moisture content. Application of mineral fertilizers contributes to a higher stable yield of any crop, and sorghum is no exception. One ton of grain and the corresponding amount of grass mass requires up to 25 kg of nitrogen, 10 kg of phosphorus and about 30 kg of potassium. The addition of fertilizers to the soil must be done either in the fall or during spring cultivation- directly during sowing and during the first feeding [18]. The insufficient knowledge of agro-technological techniques which may increase sorghum production in the dry conditions of Kalmykia, requires the development of improved technology for its cultivation. The aim of this work was to study the effects of basic soil cultivation and selection of sorghum varieties adapted to conditions of insufficient moisture, which allows to get the grain yield of 2.5–3.2 t/ha.

Materials and methods.

Field experiments on improving sorghum technologies were carried out in 2016-2018 years in a field of the Vernigorov private farm in the Sarpinsky district of the Republic of Kalmykia on an area of 60 hectares. The centre of the test field was N 46° 24′ 44″ E 44° 07′ 01″. Dynamics of air temperatures and precipitation in research years on the field site is presented in the Figures 1and 2.

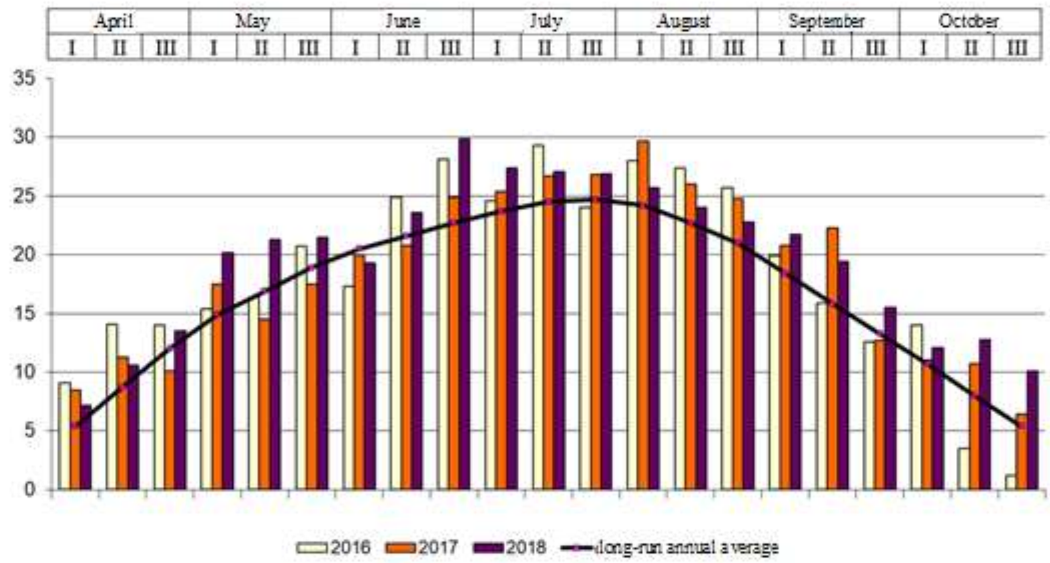


Figure 1. Dynamics of air temperatures (^oC) at meteorological station S. Derbets in 2016-2918 years.

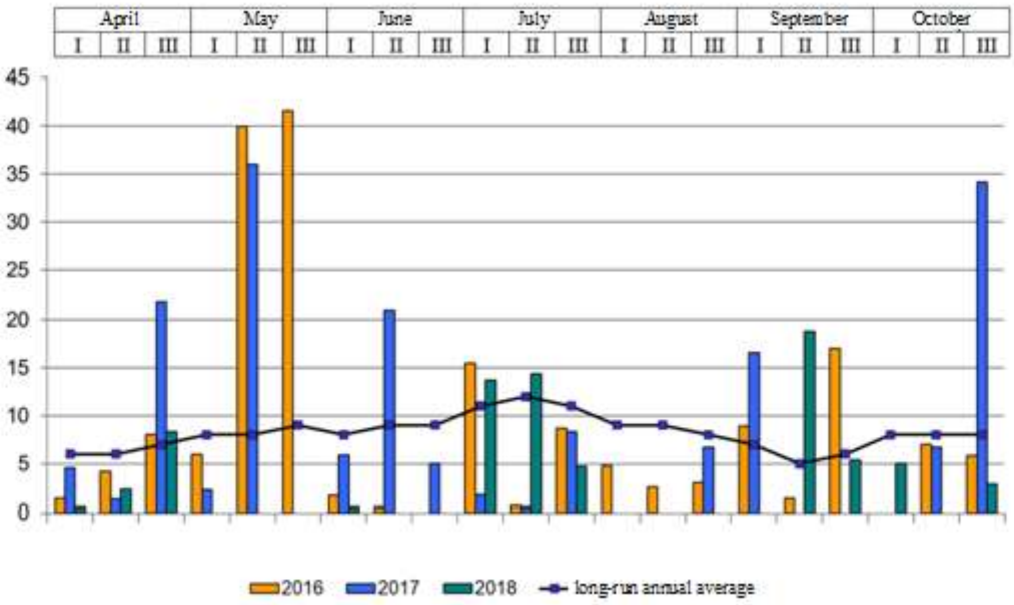


Figure 2. Dynamics of precipitation (mm) at meteorological stations S. Derbets in 2016–2018 years.

Zonal light chestnut soils were dominant on the territory of the test area. The soil-forming rocks of these soils were the middle Khvalyn deposits of loamy granulometric composition. Zonal light chestnut soils lie on the elevation of the gently undulating plain.

Structure of the soil profile of zonal light chestnut soil was as follows:

A_{tillable} 0-18 cm – fresh, light chestnut, medium loamy, lumpy-powdery, loose, there are plant roots, the transition is clear.

B_1 18-35 cm ochre – brown, medium loam, lumpy-nutty, compacted, there are plant roots; the transition to the horizon B_2 is noticeable.

B_2 35-47 cm – wet, brown, medium loam, nutty, dense, the transition to the next horizon is noticeable.словами

B_{Ca} 47-77 cm – pale brown, medium loam, nutty, dense, with accumulation of carbonates in the form of white soft spots.

$B_{\text{intermittent horizon}}$ 77-170 cm – yellow-brown, medium loam, structureless, dense, with carbonates veins.

The soil of the experimental site according to [18] was light chestnut saline medium loam. The soil was classified according to the international classification [19] as Protosodic Protosalic Cambisol (Loamic, Aric, Protocalcic, Ochric).

According to the classification of N. A. Kachinsky, the main granulometric composition of light chestnut soil was represented by medium loams [20] (Table. 1). At the same time, the upper horizon ($A_{tillable}$ 0-18 cm) of the soil belonged to medium coarse-powdery loam with the main fractions of 0.05-0.01 mm (42.23%). The largest amount of fraction of soil particles with a size of less than 0.01 mm was observed in the illuvial horizon ($B_1$18-35 cm) of the soil (43.63%), which permitted to classify them as powdery loams.

The soil density varied from 1.18 to 1.60 g/cm^3, and increased with depth. The total porosity of the soil with depth decreased from 51.6% to 49.3%. In the upper soil horizon in the 0-20 cm layer, the density value was 1.21 g cm^3, while the porosity had an optimal value (more than 50%) (Table 2). The inverse correlation between total porosity and soil density was determined.

Table 1. Granulometric composition of light-chestnut soil.

Soil layer	Content of fractions, %							Grain-size structure
	1-0.25 mm	0.25-0.05 mm	0.05-0.01 mm	0.01-0.005 mm	0.005-0.001 mm	<0.001 mm	<0.01 mm	
$A_{tillable}$ 0-18	0.15	25.87	42.23	6.97	10.00	14.78	31.75	medium loamy
B_1 18-35	0.09	15.12	28.42	4.87	15.06	23.70	43.63	heavy loamy
B_2 35-47	0.10	28.95	31.44	9.12	17.25	13.14	39.51	medium loamy
B_{Ca} 47-77	0.09	15.53	40.11	4.96	11.17	28.14	44.27	heavy loamy
BC 77-170	0.15	31.45	33.70	3.54	6.74	24.42	34.70	medium loamy

Where A - humus layer; B - transitional horizon; B_{Ca} - carbonated horizon; BC - intermittent horizon

Table 2. Water-physical properties of the light-chestnut soil of the test plots.

Depth of soil layer, m	Soil density, t/m^3	Maximum hygroscopic moisture, %	MMHC/ SWV, %	AMIP, mm	PMR, mm
0-0,1	1.18	6.15	23.19	9.72	17.6
0.1-0.2	1.23	6.57	26.49	10.83	21.7
0.2-0.3	1.29	7.05	25.73	12.19	21.0
0.3-0.4	1.33	7.29	25.78	12.99	21.2
0.4-0.5	1.35	7.88	26.32	14.25	21.3
0.5-0.6	1.37	8.15	23.77	14.96	17.6
0.6-0.7	1.42	10.06	21.42	19.14	11.3
0.7-0.8	1.47	9.12	21.65	17.96	13.8
0.8-0.9	1.60	9.79	21.36	20.99	13.2
0.9-1.0	1.60	9.85	23.12	21.12	15.8
0-0.2	1.21	6.36	24.85	20.55	39.3
0-1.0	1.38	8.19	23.89	154.16	174.5

Where: MMHC - minimum moisture holding capacity.

SVW – soil volume weight.

AMIP – amount of moisture inaccessible to plants.

PMR – productive moisture reserve

It was shown that the value of maximum hygroscopicity (a type of moisture capacity) in the arable layer of soil 0-0. 20 m was 6.36% and in the meter layer it was 8.19%. Knowledge of the maximum hygroscopicity of the soil allows us to calculate the wilting point of plants or the wilting moisture (WM). The lowest moisture content of the soil of the experimental site varied from 21.36 to 26.49%. This indicator was

24.85% and 23.89% of soil volume weight in the upper and in the meter soil layer, respectively.

The amount of moisture inaccessible to plants or “dead water storage” in the soil in the meter layer was 154.16 mm. and the productive moisture reserves was 174.5 mm at the maximum field soil moisture. According the results of agrochemical analysis the humus content in tillable layer of light chestnut soil was low and ranged from 1.18 to 1.87% (Table 3). Due to the low humus content, the soil is poorly structured and highly dispersed (silt soil). that leads to poor resistance to water and wind erosion.

Table 3. Agrochemical indicators of light chestnut soil of the experimental field.

Depth of soil layer. m	Humus. %	Exchange capacity. mg-equival.	Na of cation-exchange capacity. %	Easily-accessible forms. mg/kg of soil		
				N- alkali hydrolyzable	P_2O_5	K_2O
2016 year						
0.2-0.4	1.11	14.1	8.4	40.7	10.6	485
2017 year						
0-0.2	1.87	12.7	7.9	47.5	14.5	491
0-0.2	1.28	13.8	8.1	61.5	21.4	516
0.2-0.4	1.20	14.2	9.2	38.9	8.9	452
2018 year						
0-0.2	1.58	11.7	8.5	52.4	18.7	505
0.2-0.4	1.07	13.6	8.8	41.7	11.1	422

The content of the main macronutrients in the soil was as follows: alkaline hydrolyzable nitrogen varied from 47.5 to 52.4 mg/kg of soil and was characterized by low availability; mobile phosphorus ranged from 14.5 to 21.4 mg/kg of soil with low availability; exchange potassium was characterized by high content of 491-516 mg/kg of soil, that is typical for this type of soil. The absorption capacity of the soil was low:

absorbed sodium was 7.9-8.5% in the arable layer and 9.2% in the subsurface layer. The content of water-soluble salts was 0.15-0.19 % in the 0-0. 20 m layer of soil and it was 0.22- 0.29% in the meter layer.

Methods

The following studies were carried out in the field experience in 2016 – 2018:

-The determination of the phenological stages of grain sorghum growth was studied according to common methods [20].

-The field germination rate, plant stand at the "seedlings" phase and their capacity for survival for the period of grain harvesting was assessed on $1m^2$ sites in four- fold repetitions.

-Biometric indicators of agrocenoses of various varieties of grain sorghum namely the height of plants in phenological stages were examined in each variant for 30 plants in the repeat of the field experiment.

-Monitoring and recording of the dynamics of leaf surface formation of grain sorghum agrocenosis , as well as photosynthetic capacity and net crop productivity were determined as in [10, 19, 20].

-Measurement of the raw mass of crops in various phenological stages of growth and development of grain sorghum was carried out by manual mowing of plants in four-fold repetitions. The weight of the dry mass of plants was determined by drying at a temperature of 60^oC.

-Observations of soil moisture were carried out by the thermostatic-weight method. Soil samples were taken with the use of a sampler in a meter layer of soil through every 0.1 m. Soil was collected before sowing and harvesting of sorghum.

-Determination of productive moisture reserves in the soil, indicators of the structure of total water consumption by agrocenoses of grain sorghum were calculated according to [21].

-Agrochemical indicators of soil were determined within 0-0. 20 m and 0-0.40 m deep soil layers by classical analytical methods [21]: humus content was determined by the Tyurin method, total nitrogen – by Cornfield method, nitrate nitrogen – by colorimetric method, ammonium nitrogen – by acid extraction method (GOST 26951-86) and mobile phosphorus and potassium – by Machigin method (GOST 26205-91).

-Determination of water-physical properties of the soil were determined as follows: granulometric composition – by the Kachinsky method [20], density of the solid phase – by the pycnometric method, density of soil consistency – by the cutting ring method, the lowest moisture capacity (LMC) – by the method of flooded areas (2x2 m).

-Harvesting was carried out by the Don-1500 combine harvester; also sheaves were selected from every1 m^2 according to the variants of the experiment followed by weighing.

-Determination of the chemical composition and quality of plant samples was performed using standard methods [21, 22]: total nitrogen was determined by the Kjeldahl method, crude protein – by calculating the coefficient of 6.25, crude fat – by the Soxlet method (GOST 1349.15–85), crude fiber – by the Henneberg and Stoman method (GOST 13496.2–84), sugar – by the Bertrand method, ash – by dry ustion, phosphorus – by the colorimetric method with a molybdenum reagent, calcium – by the trilonometric method.

-Mathematical data processing was carried by methods of correlation-regression. and variance analysis [20]. using the STATISTIKA 10.0 program of the MicrosoftExcelXP spreadsheet processor.

-Field experiments on agroecological testing of Sorghum bicolor (L.) Moench were conducted with 5 varieties of different degree of ripeness: early-ripening varieties – Orlovskoe (st) and Sostav as well as mid-ripening varieties – Zernogradsky 53. Zersta 99 and Ayushka.

Cleaning of the soil from vegetative organs, weed seeds, pests and diseases was conducted as a type of soil pretreatment as well as the preservation and accumulation of moisture in the soil [21, 23].

Method of flatbed soil plowing. disk tillage and fall plowing were used for soil treatment. It should be noted that the chosen methods of soil treatment have some advantages because early fall plowing leads to the formation of the best structure of the arable layer due to the most fully using of the autumn precipitation and spring meltwater [20]. Flatbed plowing provides greater stability and protection from water and wind erosion and increases productivity, especially in very dry years. The preservation of up to 70-80% of stubble on the surface of the field in an undisturbed state in autumn is not only a reliable means of protecting the soil from wind erosion, but also contributes to a large accumulation of snow in the fields [20]. A pithy layer forms at the top of the soil when we use disk-tillage. This porous layer prevents the evaporation of moisture from underlying layers. and promotes rapid absorption of precipitation [20, 23].

Results

A review of the literature showed the insufficient state of knowledge on the influence of agro-technological practices on the cultivation of grain sorghum in boharic conditions. The study of the optimal conditions of light chestnut soil treatment in arid arias of the Republic Kalmykia, as well as testing of different ripeness groups of sorghum giving grain yield of 3-4 t/ha were conducted under experimental and laboratory conditions.

Field studies showed that the largest top mass yield of 41.33 t/ha was formed by the plants of mid- ripening variety Aushka when fall plowing was used as the basic soil treatment in 2016. The early-ripening variety Orelovskoe showed the smallest top mass yield of 18.47 t/ ha with the use of disk tillage. The variation in sorghum top mass in 2018 ranged from 20.78 t/ha (Zernogradskiy 53 variety, disk tillage) to 38.11 t/ha (Aushka variety, fall plowing).

In laboratory study it was shown that the nutritive value of grain sorghum as an average value for three years was as follows: (Table 4).

Table 4. Influence of tillage methods on the grain chemical composition of various sorghum varieties. % (on dry matter).

Factor A: variety	Factor B: method of basic tillage	Protein	Fat	Fibre	NNE	Ash
early- ripening varieties						
Orlovskoe	fall plowing	10.15	3.37	4.45	78.20	3.83
	flatbed plowing	10.16	3.43	4.22	78.21	3.98
	disk-tillage	9.88	3.26	4.67	78.85	3.34

Sostav	fall plowing	10.17	3.47	4.23	79.73	2.39
	flatbed plowing	10.30	3.66	4.30	78.81	2.93
	disk tillage	9.93	3.49	4.36	79.46	2.77
mid-ripening varieties						
Zernogradskiy 53	fall plowing	11.21	3.70	4.10	78.49	2.50
	flatbed plowing	11.23	3.76	4.09	78.44	2.48
	disk tillage	10.82	3.57	3.90	79.48	2.23
Zersta 99	fall plowing	11.47	3.40	4.20	78.49	2.44
	flatbed plowing	11.39	3.46	4.26	78.46	2.43
	disk tillage	11.05	3.29	4.72	78.68	2.26
Ayashka	fall plowing	11.05	3.37	3.89	79.13	2.56
	flatbed plowing	11.16	3.66	4.11	78.56	2.50
	disk tillage	10.93	3.49	4.72	78.48	2.38

It was shown that the content of protein. fat and NNE (nonnitrogenous extractives) was at a high level. The methods of the main soil treatments have not a special effect on the chemical composition of the grain. There are only two differences concerning fat and fiber content for studied varieties. The high fat content among early ripening variety had the Sort variety (3.49-3.66%) and among the group of mid-ripening variety it was Zernogradskiy-53 (3.57-3.70%).

The fiber content among early-ripening varieties was higher in the Orlovskoe variety (4.22-4.67%) and among mid-ripening varieties in the Zersta 99 variety (4.20-4.72%). The protein content was slightly higher in the group of mid- ripening variety – 10.82-11 .4 7%. This indicator was 9.88-10.30% in the early-ripening varieties. A small decrease in the content of protein and fat with the use of disk tillage can be explained by the current level of moisture availability. but the types of tillage did not significantly affect the decrease of these indicators.

As is well known good sprouts and the formation of optimum degree of plant density before harvesting are the determining factors for high yield. In our studies these characteristics directly depended on the studied agricultural practices and meteorological conditions in the years of research (Table 5).

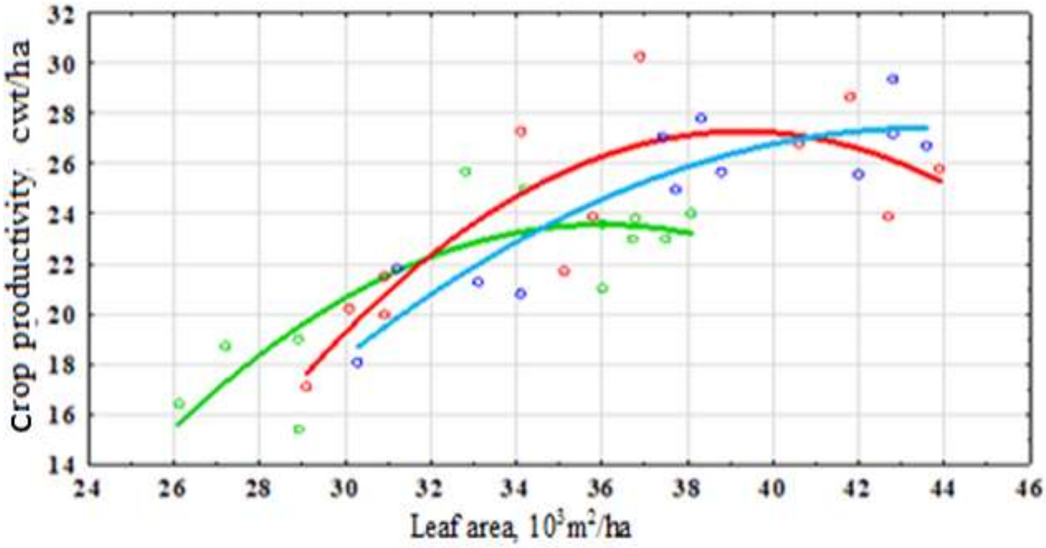
Table 5. Plant population and completeness of sprouting for different varieties of grain sorghum, depending on the type of basic soil treatment.

Varieties (Factor A)	Type of the main soil treatment (Factor B)	Number of plants. units/m^2		Field emergence. %	Seedling survival	
		sprouts	harvest		number of sprout.%	number of sown plants. %
early-ripening varieties						
Orlovskoe (st)	fall plowing	17.0	12.9	85.2	75.6	64.4
	flatbed plowing	17.2	13.9	86.2	80.4	69.3
	disk tillage	16.6	12.2	83.1	73.2	60.8
Sostav	ploughing	17.2	13.4	86.0	77.7	66.8
	flatbed plowing	17.5	14.4	87.4	82.3	71.9
	disk tillage	16.7	12.4	83.5	74.3	62.0
mid-ripening varieties						
Zernogradskiy 53	fall plowing	16.9	13.8	84.6	81.8	69.2
	flatbed plowing	16.6	13.3	83.2	79.8	66.4
	disk tillage	16.1	11.7	80.7	72.8	58.7
Zersta 99	fall plowing	17.1	14.3	85.6	83.4	71.4
	flatbed plowing	16.9	13.6	84.3	80.5	67.9
	disk tillage	16.5	12.3	82.6	74.7	61.7
Ayushka	fall plowing	17.0	14.1	85.2	82.6	70.4
	flatbed plowing	16.7	13.4	83.6	80.2	67.0
	disk tillage	16.4	12.1	81.9	73.9	60.5

The field germination of seeds during 2016-2018 years was relatively high: average value was 83.1-87.4% for early-ripening varieties and 80.7-85.6% for mid-ripening varieties. The sparseness of the seeding in growing season led to the decrease of total number of plants at the time of harvesting. However seedling survival was rather high due to drought tolerance of plants, namely the average value was 60.0-71.9% in the group of early-ripening varieties and it was 58.7-71.4% in the group of mid- ripening varieties. That makes it possible to obtain a harvest close to the planned one.

The dependences of productivity of early-ripening varieties on the leaf surface area (S) are presented in Fig. 3.

A



B

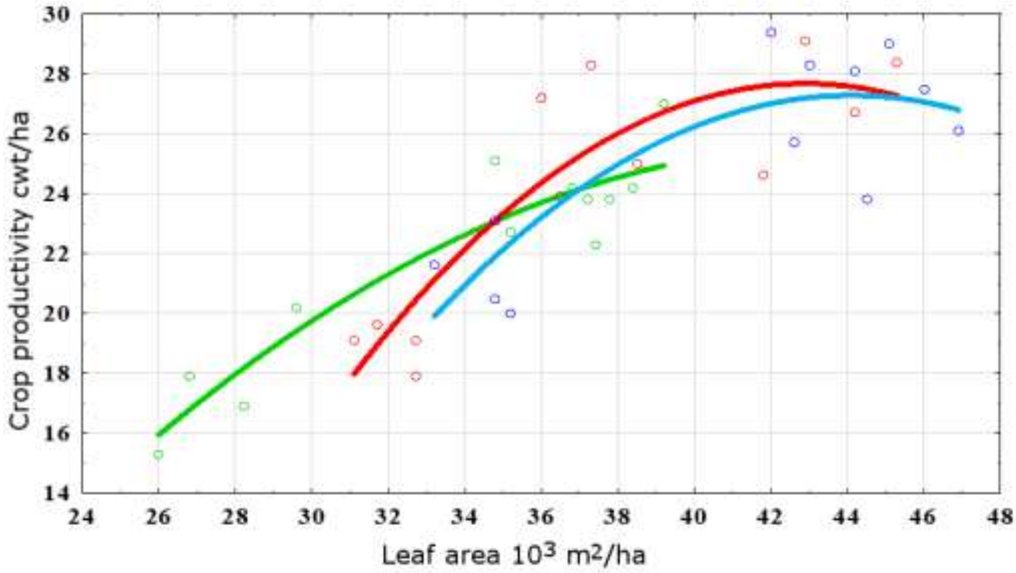


Figure 3. Crop productivity (CP) dependences of early-ripening sorghum varieties on leaf surface area (S) for various methods of soil treatments. where: red line – fall plowing, blue line – flatbed plowing, green line – disk tillage; A – Orlovskoe variety, B – Sostav variety.

For comparison of dependences of CP=f (S) for mid-ripening sorghum variety *Zernogradskiy 53 (st)* we give following equations:

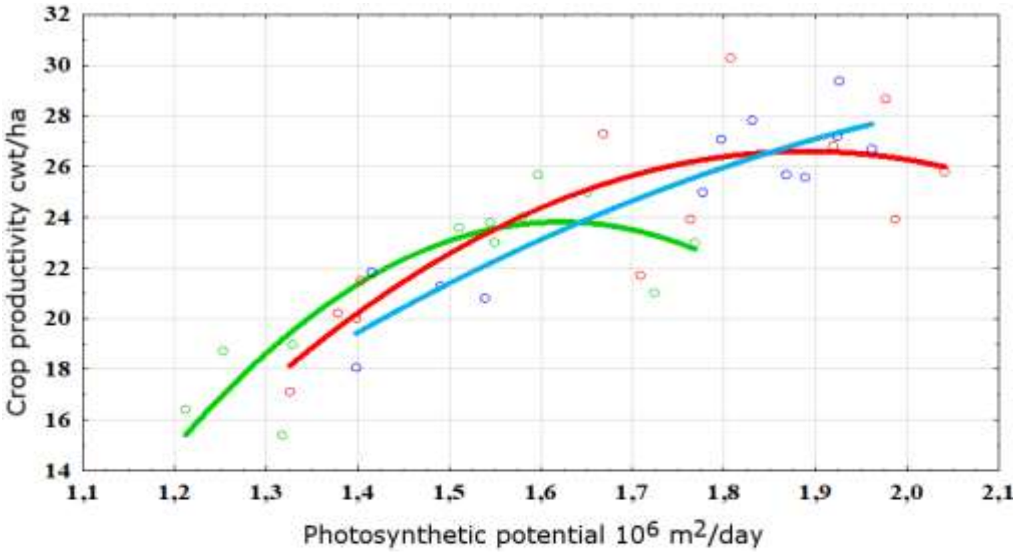
fall plowing $У= -28.9555+2.8137*S-0.034*S^2$

flatbed plowing У= -27.4403+2.5967*S-0.0336*S^2

disk tillage У= 15.3184-0.1046*S+0.0046*S^2

The dependences of crop productivity of sorghum on the leaf photosynthetic potential (PhP) are presented in Fig. 4.

A

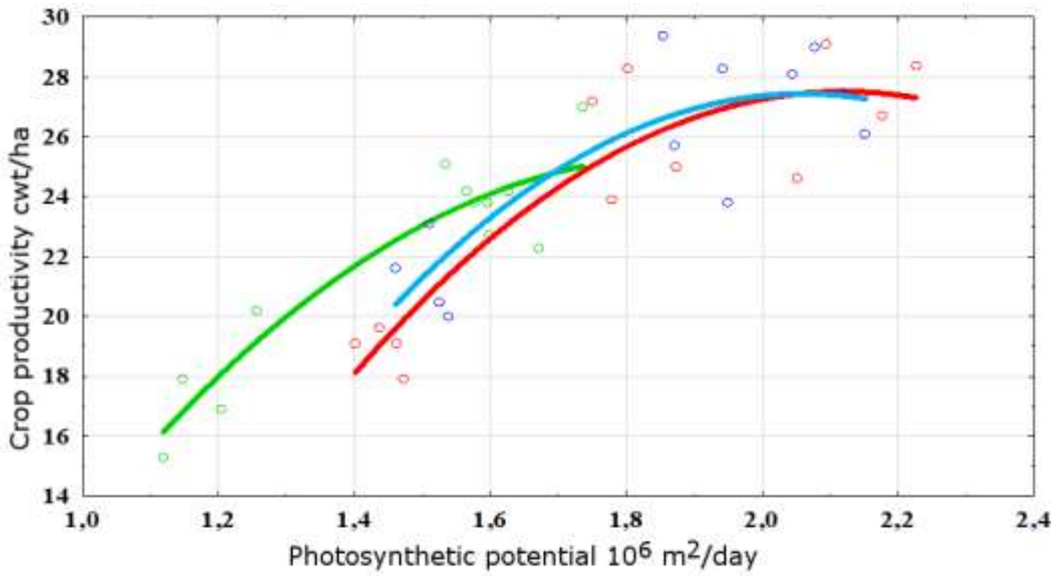


fall plowing У = -68.6059+100.8032*PhP-26.6824*PhP^2

flatbed plowing У = -29.1162+48.9952*PhP-10.2167*PhP^2

disc tillage У= -107.9569+162.5204*PhP-50.1119*PhP^2

B



fall plowing У = -54.3867+77.287*PhP-18.2328*^{2}

flatbed plowing У = -55.9107+80.9503*PhP-19.6543*PhP^{2}

disc tillage У= - 30.6783+59.5322*PhP-15.8121*PhP^{2}

Figure 4. Crop productivity dependence of early-ripening sorghum varieties on leaf photosynthetic potential (PhP) for various methods of soil treatment, where: red line – fall plowing, blue line – flatbed plowing, green line – disk tillage; A – Orlovskoe variety, B – Sostav variety.

As an example of the dependences of CP=f (PhP) for mid-ripening sorghum variety (Zernogradskiy 53(st)) we give the following equations:

fall plowing У= -17.6595+45.9467*PhP-11.2818*PhP^{2}

flatbed plowing У= 0.3056+21.5848*PhP-5.2473*PhP^{2}

disc tillage У= -13.1286+32.3051*PhP-8.2839*PhP^{2}

Economic assessment of advanced agrotechnical methods of cultivation of grain sorghum showed that the greatest yield indexes 2.70 and 2.87 were obtained for mid-ripening varieties Zernogradskiy 53 and Zersta 99, respectively with the use of fall plowing. At that net income was 17.77-19.95 thousand rubles/ha. The yield indexes for early-ripening varieties of grain sorghum Orlovskoe and Sostav were 2.70 and 2.87 respectively.

It was shown that the best method for soil treatment for early ripening variety was flatbed plowing. The crop yield of variety Sostav was 2.13-2.77 t/ha. which was higher than the standard Orlovskoe variety by 2.5-4.0%.

The grain yield of various varieties of grain sorghum was directly depended on values of the assimilation surface area of agrocenoses and characterized by a high degree of correlation convergence with the correlation coefficient - r = 0.83-0.94.

Based on the experimental data, models of dependences of sorghum grain yield for various methods of tillage on the indicators of photosynthetic activity of crops were developed. They were described by regression equations having a parabolic shape. For example it was shown that the maximum yield with the use of the flatbed plowing in the case of early-ripening variety Sostav was 30.0 c/ha while the use of fall plowing and disk tillage gave 28.7 c/ha and 27.2 c/ha, respectively.

The yield of various varieties of grain sorghum is estimated by such characteristic value as the mass of 1000 seeds which reflects the size of the grain and the filled grains. Since sorghum seeds are small enough that the more there is the degree of grain filling, the better the harvest will be. This indicator is highly dependent on seed varieties, soil and climate conditions and basic soil treatments. In our experiments the mass of 1000 seeds ranged from 22.8 to 25.0 g in 2016 to 21.7-23.8 g in 2018. There were no significant differences between these indicators in studied experiments.

The total water consumption of grain sorghum as an average over the years of research was 1628-1770 m^3 / ha. The largest amount of total water consumption was obtained in 2016 - 2065-2253 m^3/ha for all variants of the experiment, which was more than in 2017 and 2018, 360-448 m^3/ha and 928-1022 m^3/ ha, respectively. The structure of total water consumption was as follows: 55.3-55.0% of precipitation and 45.0-46.7% of soil moisture in 2016. 53.1-55.0% of soil moisture in 2017 and 69.9-72.9% of soil moisture in 2018.

Evaluation of water-use efficiency for early-ripening varieties of grain sorghum showed that the use of flatbed plowing gave the least coefficient of water consumption (variety Sostav - 652 m^3/t and the variety Orlovskoe - 667 m^3/t), while the highest grain yields were obtained compared to fall plowing and disk tillage.

The results of field research showed that the yield of various varieties of grain sorghum depended on the meteorological conditions of the growing season and soil treatment methods. The highest yield for all variants of the experiment was obtained in 2016 – 1.75-3.23 t/ha, the lowest one in 2018-1.42-2.67 t / ha.

An improved technology for growing grain sorghum based on the grain sorghum selection and basic tillage methods adapted to rational use of productive moisture reserves and the formation of a yield of 2.5-3.2 t/ha of grain has been developed [21, 24].

The innovative method of the sorghum cultivation used in north-eastern Ethiopia is similar with our approach for improving grain sorghum productivity [25]. Further cooperative researches on the influence of methods of basic soil treatment on the productivity of grain sorghum, taking into account their agro-physical properties, should be conducted.

Conclusion

Agro-climatic and soil conditions of the semi-desert zone allow realizing the biological potential of grain sorghum (Sorghum bicolor (L.) Moench) on the soil with limited water resources.

High water-use efficiency was provided for early-ripening varieties of grain sorghum when flatbed plowing was used and for mid- ripening varieties in the variant fall plowing, with water consumption coefficients 652-667 m^3/t and 559-659 m^3/t. respectively.

An analysis of correlation relationships showed that the yield of grain of early-ripening varieties was directly related to the indicators of the assimilation surface area of agrocenoses and characterized by a high degree of correlation (- r = 0.83-0.94).

We have determined that the filling of grain occurred evenly in all variants of the experiment and all the processes of seed formation were completed by the harvest period. Significant differences in the mass of 1000 seeds were observed only for varieties in accordance with their genetic characteristics and conditions of natural moisture availability during the growing.

Economic assessment of agrotechnical methods of cultivation of grain sorghum on light-brown soils of the semi-desert zone of the Republic of Kalmykia showed that the greatest profitability index were obtained for mid- ripening varieties Zernogradskiy 53and Zerta 99 with the use of fall plowing.

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