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Adaptive technological methods of forming highly productive fodder agrocenoses on ameliorated lands of kalmykia

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Abstract.

Relevance and practical significance of the research are determined by the fact that the most drought-resistant sorghum crops, along with alfalfa, in the subzone of light chestnut and brown semi-desert Caspian Lowland should serve as the guarantor of creating the fodder base for efficient management of livestock breeding in the Republic of Kalmykia. Despite the existing theoretical and practical bases of the field forage production on ameliorated lands in the region, some scientific provisions and zonal agro-ameliorative methods of growing annual forage crops in the system of intensive irrigated lands require further study and improvement.

The results of long scientific research (1994-2014), and the accumulated production experience assure that the structure of crops should be as much as possible related to the value of the irrigation modulus of the irrigation system with material and technical resources. High profitability of irrigated fodder production is achieved only through integrated combination of two main basic factors that determine the quantity and quality of the yield, namely, irrigation and fertilization. In this respect, significant improvement of irrigated lands' productivity requires developing mechanisms for scientifically substantiated management of water status and mineral nutrition in the grown crops. It has been found that one of the important reserves of increasing productivity of irrigated lands of the Caspian Lowland is efficient combination in crop rotations of main and intermediate forage crops with the aim of obtaining two to three harvests a year on 30 to 40% of the cultivated area. The studies have shown that in the agro-climatic and soil conditions of Caspian Lowland in the technologies of intensive use of arable land, for the guaranteed productivity of 100 t/ha of green mass, the most promising are winter rye, triticale, and postcut corn-sorghum mixtures. With that, rational irrigation modes have been developed, irrigation rates and total water consumption of crops, as well as the degree of influence of estimated dosages of nitrogen-phosphorus fertilizers on the planned yield level, and peculiarities of mineral nutrition of annual forage herbs on light-chestnut and brown semi-desert soil have been determined.

Keywords: forage crops, region, arid zones, Caspian lowland, soil, technology, irrigation, single-crop, mixed crops, irrigation norm, fertilizers, productivity, profitability.

INTRODUCTION

The basis of the Republic of Kalmykia's economy, which is an agricultural region of the Russian Federation, is agriculture and, above all, highly developed animal breeding with specialization in breeding beef cattle and fine-wool sheep breeding. Further successful development of the agrarian sector of economy in the conditions of growing aridization of the climate and positioning of the republic as a leading region of Russia in production of high-quality beef is only possible through the creation of fodder base on the background of irrigation.

The most important reserve of improving the system of field fodder production in the conditions of arid zone is the optimization of the structure of cultivated acreage and resource-saving technologies of cultivating basic fodder crops. Theoretical bases of field fodder production on irrigated lands of the South of Russia were the subject of many works of A. M. Gavrilov, A. F. Ivanov, I. P. Kruzhilin, V. M. Kosolapov, A. V. Alabushev, V. V. Melikhov, V. V. Borodychev, T. N. Dronova, V. I. Philin, M. M. Okonov, B. A. Goldvarg, E. B. Dedova, and many other scientists. However, in the conditions of dry steppe and semi-desert zone of the Republic of Kalmykia, species composition and components of annual forage crops, as well as the technological factors of irrigation that have the greatest effect on the production process and productivity of fodder crops have been insufficiently studied.

The purpose of the research was improving the agro-technological methods of forming highly productive agrocoenoses of fodder crops on the basis of adaptive-landscape farming by the methods of efficient management of water and nutrition regimes of soil in the arid conditions of the Caspian lowland.

MATERIALS AND METHODS

Kalmykia, the agrarian region of Russia, is located in the arid zone characterized by extreme aridity with the aridity index of 0.47 to 0.20, within the dry steppe and semi-desert zones in its natural-territorial complex. Within the dry steppe and semi-desert zones, solonetzic light chestnut and brown soils are most widely spread. The average annual rainfall varies between 200 mm in the east to 360 mm in the west of the Republic. In the structure of agricultural lands, the largest share is taken by grassland – 5,230 thous. ha, arable land - 690 thous. ha, including the area of regular irrigation, which is 19 thous. ha, and inundative irrigation - 29 thous. ha. Field studies for development of new agrotechnical and ameliorative methods of improving the technology of cultivating fodder crops under irrigation were performed on brown semi-desert and light-chestnut soils. Brown soils are characterized by alkaline reaction of the medium and low humus content of 1.1 to 1.3%; the content of mobile phosphorus (R_{25}) is 16 to 18 mg/kg, that of exchange potassium (K_2) - 340 to 360 mg/kg of soil. Light chestnut soils contain 1.25-1.50% of humus, available phosphorus - on the average 20-22 mg/kg, and potassium – 300-320 mg/kg of soil. The highest field moisture-retaining capacity in the one-meter-deep layer is in the range between 21 and 23%, wilting moisture content is between 9 and 10%, the total porosity is 47-48, soil density is 1.41 to 1.43 t/m^3.

Field studies of optimization of irrigation regimes and the system of using fertilizer of forage crops were performed based on systematic approach and modern methods of field experiments. In the research, winter rye, Sudan grass, and maize were studied in mixed crops on light-chestnut and brown soil. In laying and carrying out field experiments, the authors were guided by the methods of experimental work by B. A. Dospekhov (1985, 2014), V. I. Kiryushin (2005), and guidelines of All-Russian Research Institute of hydrotechny and amelioration (VNIIGiM) (2001) and All-Russian Research Institute for Hunting Husbandry and Livestock Breeding (VNIIOZ) (2008). Agrotechnics of cultivating sorghum crops corresponded to zonal landscape-adaptive system of agriculture (2004, 2016). The results of the research and obtained experimental data were subjected to variance and correlation analysis.

Analysis of climatic resources of the dry steppe zone shows that hydrothermal coefficient (HTC) for the warm period (IV-IX) is 0.52...0.58, which indicates dry climate, the annual

precipitation is between 250 and 320 mm. A characteristic feature of the climate is significant evaporation, which exceeds total precipitation in the dry-steppe zone 2.5 to 3.0 times, and in conditions of semi-desert and desert - 3.5 to 4.0 times.

The strategy and tactics of irrigated agriculture in the existing conditions requires certain changes. Fodder production with the presence of perennial and annual crops should take up 70-75% of irrigated areas. Irrigation and watering in the arid regions of the Caspian Lowland has long been used as the main factor for improving productivity of agricultural lands, and for creating a favorable habitat.

RESULTS AND DISCUSSION

Analysis of scientific literature [1-13] and the data of field research show that semi-desert ameliorative zone, where the main area of irrigated lands of Kalmykia is located, should be used for growing the most drought-resistant sorghum grasses, perennial grass mixes, melons; the estimated productivity of irrigated crop rotation should amount to 4.8-5.2 thous. feed units/ha on brown soil, 5.5-6.2 thous. feed units/ha on light chestnut soil, and 7.5 to 9.0 thous. feed units/ha on dark-chestnut and black soils. [14-17]. In the theory of photosynthetic productivity of agricultural crops, important role is played by the coefficient of utilization of the photosynthetic active radiation energy during the vegetation season. According to the theory of optimum crops' programming in the Lower Volga region, including in the Caspian lowland, the real efficiency of fodder crops' photosynthetic active radiation may be taken as 3.0 to 3.5%. However, the obtained yield levels in extensive production practice do not exceed 1.5-2.0%. Therefore, the existing rich resources of radiation should be considered as the reserve of increasing the productivity of field crops that is not fully required by production [18-20]. Out of sorghum crops, Sudan grass is the fodder crop most adaptable to the local climatic and soil conditions, which is the second most important culture after alfalfa, which is cultivated on irrigated lands of the Republic. In case of observing the optimal agricultural and ameliorative methods, its yield reaches 60-70 t/ha of green mass, 12 to 14.0 t/ha of hay and 1.5 to 2.0 t/ha of seeds. Obtaining such high yields of this crop is only possible with maintaining the optimum levels of mineral nutrition and preirrigation soil moisture. The value of Sudan grass is in its high recovery ability; under irrigation it is possible to obtain three full mowings a year. As shown by the results of field research, joint cultivation of Sudan grass and maize is very promising; such a mix has high productivity, ecological plasticity and good nutritional properties. Of the main early spring crops, legume and herbs mixtures are very good, winter rye and triticale are good intermediate winter crops [21]. In the course of long field researches and production testing the authors have developed differentiated technological schemes of cultivating annual fodder crops in various combinations of the main and intermediate crops. Extensive scientific literature exists, which is devoted to the issues of improving photosynthetic productivity of crops. They are most comprehensively described in classic works of A. A. Nichiporovich, A. F. Ivanov, V. I. Philin, et al. The field research of the authors has shown that the main factors determining the values of the photosynthetic characteristics are crops' density and fertilizers in the conditions of a controlled water regime of irrigated soil. The studied annual forage crops become fit for mowing in a relatively short period of time, no more than 2.0-2.5 months. Winter rye is the most common intermediate crop in the Caspian Lowland, which provides, due to its biological features, early regrowth and fast rate of forming the above-ground mass. The primary crop for mowing was corn-sorghum mixture, and their aftergrowth was used as the third crop. Optimization of irrigation modes and the level of mineral nutrition due to the introduction of nitrogen-phosphate fertilizers had the most critical effect on the photosynthetic productivity of crops with photosynthetic active radiation efficiency of about 2.5 to 3.0%. In the irrigated agriculture in the Caspian region, irrigation water is one of the most important natural resources, therefore, its rational usage is of great practical importance.

Analysis of the experimental data obtained in the subzone of light-chestnut soils of dry steppe and brown semi-desert soils of the Eastern part of the Republic has determined the method of water balance, the number of vegetative irrigations, and irrigation norms of annual forage crops, mainly sorghum crops (Table 1). Irrigation norm changes depending on the level of planned productivity and preirrigation threshold of soil moisture. With maintaining the average level of water supply to crops with the irrigation mode of 65-70% and the elevated minimum water capacity of 70-75%, irrigation norm may vary in the arid steppe zone from 3.2 to 4.8 thous. m^3/ha, and in the semi-desert zone - from 4.8 to 6.2 thous. m^3/ha [19, 22, 23].

In the field experiments performed on light-chestnut soils, the total water consumption by intermediate winter rye, which is the primary element in the system for performing three mowings a year in normal weather conditions, is 2,420 to 2,740 m^3/ha, on the average, the irrigation norm is 44.8%, while productive precipitation makes up for 34% of the water consumption, and the used soil moisture reserves are 20-21%. The water consumption by winter rye as an intermediate crop that vegetates the early-string life cycle is considerably lower than in the corn-and-sorghum mixes during summer growing season. The water use by postcut crops of a mixture of maize with Sudan grass, and maize with sorghum was determined at three levels of the irrigation schedule (Table 2).

Table 1. The sorghum crops' irrigation schedule by natural-agricultural zones of the Republic of Kalmykia

Hay yield, t/ha	Irrigation norm, thous. m3/ha	Irrigation norm, m3/ha		The number of vegetative irrigations
		Charging irrigation	Vegetative irrigation	
Central arid steppe zone				
10.0	2.5…3.2	900	500…600	3…4
12.0	3.0…3.7	-	-	4…5
14.0	3.5…4.2	-	-	5…6
16.0	4.2…4.8			6…7
Eastern semi-arid area				
10.0	3.3…4.8	900-1,000	500…800	5…6
12.0	3.8…5.2	-	-	6…7
14.0	4.5…5.7	-	-	7…8
16.0	5.2…6.2	-	-	8…9

Table 2. The structure of total water consumption by the crops in the system of three harvests a year, depending on irrigation schedules

Irrigation schedule % of minimum water capacity	Irrigation norm		Precipitation		Moisture depletion from the soil		Total watercon sumption, m^3/ha
	m^3/ha	%	m^3/ha	%	m^3/ha	%	
Maize+Sudan grass (second harvest)							
75-80	2,600	69.6	835	22.4	299	8.0	3,734
70-75	2,417	66.4	835	23.7	343	9.8	3,595
65-70	2,115	62.7	835	26.2	362	11.1	3,313
Maize+sorghum (second harvest)							
75-80	2,975	75.1	733	18.5	254	6.4	3,963
70-75	2,683	73.5	733	20.1	236	6.5	3,652
65-70	2,467	73.4	733	21.8	165	5.2	3,365

Table 3. Efficiency of the technological schemes of obtaining three harvests of forage crops per year on light chestnut soils

Crop	Irrigation schedule % of minimum water capacity	Calculated dosage of fertilizers, kg of active substance/ha	Green mass productivity		Deviations from schedule, %
			planned, t/ha	actual, t/ha	
Winter rye 1 harvest	65-70	$N_{75}P_{45}$	20	25.8	+29.0
	70-75	$N_{105}P_{65}$	30	32.8	+9.3
	75-80	$N_{135}P_{75}$	40	36.9	-7.7
Maize + Sudan grass 2 harvests	65-70	$N_{105}P_{45}$	30	37.8	+26.0
	70-75	$N_{165}P_{65}$	40	42.9	+5.7
	75-80	$N_{170}P_{90}$	50	46.8	-6.4
Maize + sorghum 2 harvests	65-70	$N_{105}P_{45}$	30	33.8	+12.7
	70-75	$N_{135}P_{65}$	40	38.3	-4.4
	75-80	$N_{170}P_{90}$	50	44.4	-11.2
Sudan grass aftergrowth 3 harvests	65-70	N_{50}	20	24.7	+23.5
	70-75	N_{70}	30	31.2	+4.0
	75-80	N_{90}	40	34.5	-11.7
Sorghum aftergrowth 3 harvests	65-70	N_{50}	20	22.5	+12.5
	70-75	N_{70}	30	26.7	-11.0
	75-80	N_{90}	40	32.4	-19.0

Table 4. The effect of irrigation schedules on the yield of green mass of mixed agrocoenoses of sorghum (comp. for 2010-2012, t/ha)

Irrigation schedule (factor A)	Herbs' mixture composition (factor B)	Cuttings and yields of green mass, t/ha			Total over the vegetation period, t/ha
		I	II	III	
preirrigation soil humidity 60... 65%	sweet sorghum (reference)	29.2+2.02	17.4+1.64	14.5+1.53	61.1+2.89
	sweet sorghum+soya	37.0+6.67	26.9+2.66	17.3+0.61	84.0+4.52
	sweet sorghum +rape	36.9+3.70	27.1+2.82	17.3+1.27	81.3+2.18
	sweet sorghum +amaranth	40.6+5.01	24.8+2.08	18.2+0.58	83.6+4.32
	sweet sorghum+soya+rape	45.8+7.68	33.0+3.52	24.2+3.53	103.0+12.10
	sweet sorghum+amaranth+rape	43.1+6.18	22.9+2.50	19.0+1.64	85.0+3.98
preirrigation soil humidity 70... 75%	sweet sorghum (reference)	35.8+4.69	19.8+1.86	16.6+2.15	72.2+5.37
	sweet sorghum+soya	41.0+7.67	31.8+3.94	21.0+1.20	95.2+9.27
	sweet sorghum +rape	44.6+4.91	34.9+2.51	24.0+1.89	103.5+6.54
	sweet sorghum +amaranth	47.7+4.51	26.2+2.08	19.0+1.04	91.6+1.85
	sweet sorghum+soya+rape	53.6+1.28	37.5+4.75	26.9+2.74	118.0+6.77
	sweet sorghum+amaranth+rape	44.5+4.82	34.5+4.04	27.1+0.45	106.1+1.36
LSD_{05} of factor A		3.36	3.27	2.92	8.13
LSD_{05} of factor B		5.83	5.67	5.05	14.09
LSD_{05} of factors AB		8.24	8.02	7.15	19.92

Table 5. The relationship between productivity (Y) of annual forage crops with the irrigation schedules (x_1) and the dosages of mineral fertilizers (x_2) in the conditions of arid steppe zone of Kazakhstan

Crops	Parameters of the planned yield rate, t/ha	Irrigation schedule % of the minimum water capacity	Dosage of fertilizers	Pairwise correlation coefficient (g)	Linear regression equation
Winter rye	30.0-50.0	70-75	N_{75-135} P_{45-75}	0.949	$Y=19.6+5.91x_2$
Maize + Sudan grass mix	30.0-50.0	75-80	$N_{100-170}P_{45-90}$	0.959	$Y=0.19x_1+7.58x2-25.2$
Sudan grass		70-75	N_{50-70}	0.938	$Y=17.1+7.99x_2$

With the most loaded irrigation schedule with preirrigation soil moisture of 75-80% of the minimum water capacity, the total water consumption of postcut mixture of maize and Sudan grass is 3,734 m^3/ha, and that of the mixture of maize and sorghum - 3,963 m^3/ha. The share of irrigation water in the conditions of a hot summer is 69.5 to 75.1%; the share of productive precipitation is only 18.5 to 22.4%. Aftergrowth of Sudan grass and sorghum in the conditions of gradual temperature decrease in late summer-early autumn requires 2,547 to 2,639 m^3/ha of water with a share of irrigation water of 65.9 to 66.6%. The obtained results confirm the fact that with improving the water regime of soil during the irrigation, the introduced fertilizers are more efficient. In case of intensive irrigation schedule of 75-80% of the minimum water capacity in all fertilized variants, a considerable increase in yield was obtained for all crops. Formation of the primary postcut sorghum mixtures at the level of 30 t/ha of green mass may be achieved on zonal subtypes of soil under the lower acceptable threshold of soil humility that corresponds to 65-70% of the minimum water capacity. For obtaining the yield of 40 t/ha, it is necessary to use fertilizers at higher dosage of $N_{135}P_{65}$ in combination with the irrigation schedule of 70-75% of the minimum water capacity. Higher productivity of the studied crops at the level of 50 t/ha of green mass may be achieved only with intensive irrigation schedule of 75-80% of the minimum water capacity with the introduction of high dosages of fertilizers $N_{170}P_{90}$ (Table 3).

Intermediate seeding of winter rye ensures obtaining up to 40 t/ha of green mass with deviation from the program (-7.7%) with the irrigation schedule of 75-80% of the minimum water capacity and the introduction of nitrogen-phosphorus fertilizers in the dosage of $N_{135}P_{75}$. For the third mowing, Sudan grass grows better than sorghum, and ensures obtaining 38.3 t/ha, and the aim of obtaining 40 t/ha of green mass in both crops has not been achieved, the deviations being (-11.2,-19.0).

On brown semi-desert soils of the Caspian Lowland field experiments were also performed with sorghum in various combinations with soya, rape and amaranth. Out of the studied variants, the highest productivity was formed in the three-component mixture "sorghum+soya+rape" (Table 4), which over three mowings on the average amounted to 118 t/ha [6].

It has been found that maintaining the preirrigation soil humility at the level of 70-75% of the minimum water capacity ensures the highest productivity in the studied three-component crops, which is significantly higher than that of pure crops of sweet sorghum, and two-component mixtures. For the formation of highly productive mixed agrocoenoses of sweet sorghum on brown semi-desert soils, it is recommended to cultivate three-component mixture with the irrigation schedule not below 70...75% of the minimum water capacity. Statistical and mathematical processing of the experimental data allowed obtaining veracious correlation between the yield rate and the main regulated soil factors. The coefficients of their pairwise correlation were quite high, and amounted to 0.94-0.96 (Table 5). The obtained equations for the crops of annual forage crops in single-crop and mixed agrocoenoses are based on the optimal irrigation schedules of 70-75 and 75-80% of the minimum water capacity, and the estimated dosages of nitrogen-phosphorus fertilizers intended for planned yields.

CONCLUSIONS

One of the most promising and significant potentials for increasing production of highly efficient fodders on irrigated lands in the Caspian Lowland is compacting the crop rotation crops with intermediate crops with the aim of obtaining two or three harvests per year from 30 to 40% of the cultivated area. It has been found that in the system of intensive use of arable land, it is advisable to grow winter rye, triticale, early-spring legume-grass mixtures, single crop postcut maize, or maize mixtures with sorghum. The most drought-resistant sorghum crops should be regarded as basic ones in the system of field fodder production. With the optimal combination of two most important soil factors (water schedule and the level of mineral nutrition), the potential photosynthetic productivity of crops increases 1.77-1.93 times. The results of many years of research have shown that in the dry steppe and semi-desert conditions of Northern Caspian Plain, the highest yields of forage crops are formed in case of preirrigation soil humidity of 75-80% of the minimum water capacity. For reaching the medium level of crops' productivity at 50% of the RPY (really possible yield), it is acceptable to use the irrigation schedule according to the scheme of 70-75% of the minimum water capacity, while obtaining the highest yield requires using the irrigation schedule of 75-80% of the minimum water capacity. It has been found that in the structure of total water consumption, the share of irrigation water in postcut crops amounts to 65-70%, and in winter intermediate crops - to 45-50%. Within the optimal soil humidity (75-100% of the minimum water capacity), productivity of annual fodder crops on irrigated lands of Kalmykia largely depends on the level of crops' mineral nutrition.

As a result of the research, it has been found that on light chestnut and brown soils, the decisive role in the formation of highly productive agricultural agrocoenoses of annual forage crops is played by nitrogen nutrition, the phosphorus-containing fertilizers are efficient in annual crops on the background of nitrogen fertilizers, and potassic fertilizers alone do not have mathematically veracious effect on the yield. In introducing environmentally acceptable dosages of mineral fertilizers with the optimum water schedule of soil, it is possible to obtain 100-130 t/ha of green mass with the restoration of the natural fertility on zonal subtypes of soils in intensive forage production in Kalmykia.

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