

Irrigation as means to reduce the risks of agricultural production in the South Ural

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Abstract

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The cultivation of crops in arid zones is subject to risks due to the possibility of atmospheric and soil droughts and, as a consequence, damage due to shortage or loss of crops. In addition to agrotechnical and forest ameliorative methods of accumulating and preserving soil moisture reserves, the selection of drought-resistant varieties of crops, irrigation amelioration plays a crucial role in minimizing damage from the destructive effects of drought. The significant area of the Republic of Bashkortostan, which geographically belongs to the territory of the Southern Urals, is located in the zone of risk farming. In the region, irrigation is used to obtain high and sustainable crop yields on an area of about 40 thousand hectares, which is 0.8% of the arable land. Sprinkling dominates among irrigation methods. Irrigation sprinkling allows you to get 2-3 cuttings of perennial grasses, while there is only one using dry land farming. During irrigation the average yield of irrigation of the awnless brome averaged to 4.4, of the bluegrass alfalfa – 6.7, and the fodder galega 8.15 t/ha of dry matter.

The optimization of the water regime of the soil under the crops of sugar beets by sprinkling irrigation allowed to increase its yield to 60.7 t/ha. The irrigation of potatoes increases its yield by 1.5 times compared with that on dry land. The region is actively introducing a drip irrigation method for vegetable crops and potatoes, which is more efficient than sprinkling. Field experiments showed that the yield increase from drip irrigation was 6.8 t/ha, while with sprinkling irrigation – only 4.7 t/ha. In the steppe zone on floodplain meadows with an area of 2.4 thousand hectares, the flood irrigation of natural grasslands is used, which makes it possible to obtain up to 2.9 t/ha of dry matter. At the same time, the yield on dry land plots does not exceed 0.9 t/ha. As part of the federal target program in the Republic of Bashkortostan, a long-term republican target subprogram “Development of agricultural land reclamation in the Republic of Bashkortostan for the period 2014-2020” is being implemented, which will increase the area of irrigated land to 54 thousand hectares.

Keywords: drought; coefficient of moisture; irrigation of land; sprinkling; irrigation rate; federal; target program

Introduction

The practice of agriculture should be oriented in such a way as not to cause damage to the environment, to preserve the fertility of the soil. As noted by Meena & Jha (2018), the indicators of climate change are such as elevated levels of carbon dioxide, floods, droughts, sharp temperature fluctuations, etc.

According to Abid et al. (2018), assessing the degree of drought of arable land, hayfields and pastures is crucial for agriculture in semi-arid regions of North Africa and the Mediterranean. To estimate the drought index, the potential total evaporation is calculated using the Penman – Monteith equation and a modified FAO-56 approach based on yield coefficient (Kc), combined with remote sensing data.

Ghana faces numerous risks due to severe climate variability and extreme events. This is particularly evident for the northern regions of the country, where dry land farming is the main source of livelihood. The drought risk was spatially mapped in ArcGIS 10.5 using data on indicators such as precipitation, temperature, vegetation, soil, land use, and proximity to water bodies. The results showed that two thirds of the study area is highly likely to be subject to droughts during the growing season of crops. Therefore, small farms in these areas can expect moderate or high losses due to crop loss. The use of spatial mapping to assess climate risks enhances the ability to conduct climate monitoring and develop strategies for adapting agricultural production to changing climatic conditions (Atampugre et al., 2019). The same opinion is shared by Kavitha et al. (2019), who note that timely information on the duration of the onset of drought, its scale, intensity, duration of impact will help reduce damage to the economy and the environment. Drought assessment and monitoring is necessary for the agricultural sector to take appropriate mitigation measures.

Drought stress, particularly in the reproductive phase, significantly reduced wheat yields due to a significant decrease in crop growth rate (CGR), leaf area index (LAI) and deterioration in crop structure indicators (Hussain et al., 2018). Obtaining consistently high yields is impossible without the use of irrigation, especially in arid areas (Nikanorova et al., 2016). The effectiveness of irrigation has long been proven and its use can increase crop yields by several times (Arampatzis et al., 2018; Bakhsh et al., 2018; Mabhaudhi et al., 2018). However, irrigation can lead to a number of negative phenomena: changes in the physical properties of the soil (Sun et al., 2018), salinization (Aragues et al., 2015), alkalinity, alkalization (Aydin et al., 2015), acidification (Storke et al., 2003), under flooding and waterlogging (Gebrehiwot, 2018), dehumification (Ibraeva et al., 2010), irrigation erosion (Komissarov & Gabbasova, 2017; Mustafin et al., 2018), soil pollution (Meng et al., 2016), the impoverishment of the mineralogical composition and the unfavorable change in the number of biota species (Qin & Leskovar, 2018), and the reduction of the environmental sustainability of farmlands (Hafizov & Kamaletdino, 2017).

Currently, irrigation is used in many countries around the world. For example, in the US, irrigated land accounts for 14%, in China – 40.3%, in India – 32.3%. The area of irrigated land in most European countries (Germany, France, the Netherlands, Italy, Bulgaria, Romania, etc.) exceeds 10% of the total area (Olgarenko & Olgarenko, 2012). In the Russian Federation (RF), 4.69 million hectares are allocated for irrigation. At the same time, in fact, 3.89 mil-

lion hectares are used in agricultural production. The largest area of irrigated land is concentrated in the Southern, North Caucasus and Volga Federal Districts, their share of the total irrigated area is 32.2, 21.5 and 19.3%, respectively (Table 1). The structure of irrigated lands in the Russian Federation has fodder orientation, and about 62% of the total sown area is occupied mainly by perennial and annual grasses. Grain crops (28.6%), potatoes and vegetables (7.5%), fruit, berries, grapes, melons (2.0%) are cultivated in the remaining area (Yurchenko, 2018).

Table 1. Availability and use of irrigated land in the Russian Federation as of 01/01/2018, thousand hectares

Federal district	Availability	Use
Central	484.528	425.436
North-Western	16.723	14.365
North-Caucasian	1 010.869	937.347
Southern	1511.491	1052.439
Volga	904.856	850.503
Ural	120.508	100.166
Siberian	498.195	436.755
Far-East	139.518	73.499
Total in the Russian Federation	4686.688	3890.510

On the territory of the Russian Federation, agricultural production is conducted in difficult climatic conditions. The main part of crop production is produced in risky farming areas with insufficient or uneven precipitation regimes, frequent droughts and dry winds, while the other part is in areas of excessive moisture. Agricultural commodity producers often face the problem of partial loss of farm crops due to abnormal weather conditions. The annual shortage of agricultural products in the Russian Federation from the impact of natural and anthropogenic factors amounts to more than 47 million tons (in grain equivalent), including 24.1 million tons – from the effects of drought. The damage to agriculture as a result of emergency situations in 2009 amounted to 13 billion rubles, in 2010 – 41.8 billion rubles, in 2012 – 14.4 billion rubles, in 2013 – 10.2 billion rubles, in 2014 – 3.7 billion rubles, in 2015 – 6.4 billion rubles. Under these conditions, a stable and sustainable level of crop production and minimization of crop losses is largely achieved through the development of irrigated land.

In the Russian Federation, irrigation lands mainly use sprinkling – 90% of the area, and the level of surface irrigation mechanization is less than 5%. The use of other methods of irrigation is due to landscape-geographical factors of the area or the peculiarity of the cultivation of culture. Thus, the technology of rice cultivation requires the use of a superficial method of irrigation by check. This method of irrigation is

used in the Southern and Far Eastern Federal Districts. In the steppe and semi-desert regions of Russia, with no regular sources of irrigation, they use the resources of the spring flood and apply flood irrigation. In the countries of the African continent, about 70% of the area is irrigated by surface methods by checks, contours or furrows, and only 30% is allocated to sprinkling and drip irrigation systems. In most countries of the Asian region, surface irrigation covers 96% of the area, and only 2% is allocated for irrigation and drip irrigation. At the same time, in Europe, 82% of irrigated areas are irrigated with sprinkling and drip systems, and 14% – by the surface method. In the USA, irrigated areas amount to 19.9 million hectares, of which 11.1 million hectares are watered by surface irrigation (Olgarenko et al., 2018).

The purpose of the research is to substantiate the need for irrigation and assess the effectiveness of the use of various irrigation methods in the South Ural region of the Russian Federation, using the example of the Republic of Bashkortostan (RB).

Results and Discussions

The Republic of Bashkortostan is an important agro-industrial region in the Russian Federation (Akhiyarov et al., 2018; Ismagilov et al., 2018), located between the Volga River and the Ural Mountains. The climate in RB is characterized as continental, with moderately warm or hot summers and cold winters. The average annual temperature in the Republic of Bashkortostan is +0.3°C in the mountains and +2.8°C in the plain. In RB an average of 600 mm of precipitation falls, of which about a third is in solid form.

Most of the precipitation falls over the territory of the Ufa Plateau (up to 700 mm), in the Trans-Urals it is about 400 mm. RB is in the zone of unstable natural moisture. According to the Russian hydro-meteorological center, the probability of dry years in the Republic of Bashkortostan is 42% (Khomyakov et al., 2005). The analysis of climatic conditions over the past 60 years shows that only 4 years of them had enough moisture supply. 8 years had relatively enough moisture supply. The remaining 48 years were arid in varying degrees, of which 4 years were arid (Sobol et al., 2015).

In accordance with the regionalization of the territory of the Republic of Bashkortostan, according to the conditions of the natural moisture and heat supply, using the MC (moisture coefficient), 3 natural-agricultural zones were distinguished (Figure 1): steppe ($MC = 0.41 \dots 0.50$), forest-steppe ($MC = 0.51 \dots 0.80$) and forest-meadow (MC over 0.80).

The coefficient of natural moisture MC is a generalized indicator of the lack or excess of moisture of the territory in question, which characterizes its climatic, soil and geomorphological features, is calculated by the formula:

$$MC = (W + P) / E, \text{ mm} \quad (1)$$

where W is the active moisture reserves in the meter layer of soil at the beginning of the calculation period (the date of transition of the average daily air temperature through +5°C), mm;

P – precipitation for the calculation period, mm;

E – evaporation for the calculation period, mm.

The main part of the territory of Bashkortostan is occupied by the forest-steppe (73.6 thousand km² or 51%) and forest-meadow zones (59.8 thousand km² or 42%). The steppe zone is 7% of the territory or 10.1 km² (Safin & Galin, 2000).

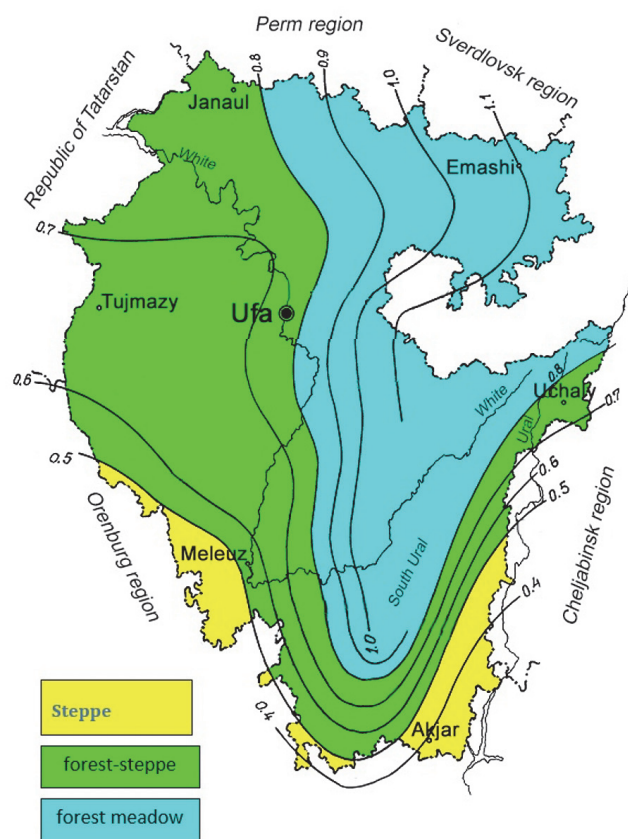


Fig. 1. Moisture coefficient of the territory of Bashkortostan

Of the selected natural areas, the least perspective and least developed area is the forest-meadow zone. The need for irrigation appears in this zone occasionally in dry years and is of an auxiliary nature.

Agricultural production is mainly developed in the forest-steppe and steppe zones. However, heat resources and pho-

tosynthetically active radiation are realized here by no more than 50-70%. To improve the efficiency of the use of natural resources in the field of agricultural production, it is necessary to fill the deficit of soil moisture by irrigation. The quantitative irrigation parameters (irrigation rate, regimes and irrigation technology) have significant territorial variability.

We have calculated the level of demand for irrigation of major agricultural crops in different natural zones of the Republic of Bashkortostan in the years of different wetting conditions according to the methodology of the All-Russia Research Institute "Raduga" (Table 2). A close relationship has been established between the irrigation rates and the change in the degree of natural heat and moisture supply, characterized by a moisture coefficient. Irrigation rates increase from the forest meadow to the steppe zone, in the direction from the north-east to the south-west. The variability of the irrigation rate in different years of humidity has significant values: compared to the average year, the irrigation rate in dry years

Table 2. Irrigation norms of crops during years with different moisture content in the territory of Bashkortostan, m³/ha

Crops	Moisture supply of the year	Nature-agricultural zone		
		Steppe	Forest-steppe	Forest-meadow
Spring wheat	average	1200	800	400
	medium dry	1700	1200	800
	dry	2300	1900	1400
Maize for silage	average	1600	1100	500
	medium dry	2200	1700	900
	dry	3100	2400	1700
Alfalfa for hay	average	2250	1350	550
	medium dry	3100	2200	1000
	dry	4400	3400	2000
Late potatoes	average	1700	1100	500
	medium dry	2300	1700	1200
	dry	3200	2600	2100
Late cabbage	average	1900	1300	600
	medium dry	2500	1900	1200
	dry	3400	2700	1900
Annual grasses (multicut)	average	2200	1300	450
	medium dry	3100	2150	950
	dry	4300	3300	1950
Sugar beet	average	1850	1250	550
	medium dry	2500	1950	1300
	dry	3500	2950	2300

increases in the steppe zone by 1.9 times, in the forest-steppe zone by 2.4 times, in the forest-meadow zone by 3.8 times.

The area of irrigated land in the Republic of Bashkortostan is not large and amounts to 38.8 thousand hectares. For irrigation of land in the RB, the waters of ponds and reservoirs, rivers, lakes, as well as diluted wastewater of livestock farms and sugar factories are used. The irrigation area dedicated to ponds and reservoirs is 56%, to rivers – 29%, to lakes – 13%, diluted wastewater – 2%. In the Republic of Bashkortostan there are more than 300 ponds of land-reclamation purposes, 34 reservoirs of complex designation, with a total useful capacity of more than 3 billion m³, which are the main sources for irrigation and water supply.

Studies have shown that the irrigation waters of Bashkortostan have mostly good and satisfactory irrigation properties (Kovshov et al., 2013). On a larger area of irrigated land (68%), water used for irrigations suitable without restrictions (class 1) or low hazard (class 2). By hydrogeological and ameliorative status, 72% of irrigated lands belong to lands of good ameliorative status and 22% are in the category of satisfactory ameliorative status.

The main irrigation method used in the region is sprinkling (90%). The share of arable land in the structure of all irrigated lands is 9/10 (Ishbulatov et al., 2017). Significant areas of irrigated land are located on black soils in the steppe and southern forest-steppe zones. The main directions of development of irrigated agriculture in the Republic of Bashkortostan are the cultivation of perennial grasses with high protein content to meet the needs of livestock with quality feed, rational use of flood meadows (Kaipov et al., 2018), the introduction of water-saving technologies and methods of irrigation of agricultural crops, the environmentally safe use of livestock and industrial irrigation, expansion of irrigated areas of high-yielding crops – potatoes and sugar beets, using safe regimes of irrigation, contributing to the preservation of soil fertility.

Flood irrigation. In world practice, the flood irrigation or irrigation with flooded waters has shown its effectiveness (Paz-Kagana et al., 2017). But sometimes, in wet years, on the contrary, it can lead to a reduction in yield, for example, of wheat to 40-50% (Zhou, 2010).

Currently, in Bashkortostan, flood irrigation is used in the Khaibulinsky district on an area of 2,400 hectares in the floodplain of the Tanalyk River (right tributary of the Ural River). Long-term studies have shown that flood irrigation in this region has a positive effect on the basic properties of the soil and their salt regime (Komissarov & Komissarov, 2014). It contributed to the improvement of the water regime of soil grounds, the active development of cereals and the improvement of soil fertility of the estuaries, while the

thickness of the humus horizon increased, the soil structure improved, the nutrient elements increased in soil, partial desalinization of the rooting soil layer occurred (Komissarov & Komissarov, 2013). Flood irrigation of natural grasslands allows getting only one full cut. After mowing, the natural herbage of the estuary experienced an acute shortage of moisture until the end of the growing season. With an increase in the duration of flooding of estuaries from 10 to 40 days, the yield increased (from 2.5 to 2.9 t/ha of dry matter), the proportion of cereal grasses (from 40 to 88%) and the productivity of herbage stands (from 1,620 to 1,920 feed units/ha). The yield of perennial grasses in dry land areas did not exceed 0.9 t/ha of dry matter. The construction of large reservoirs on the river Tanalyk and its tributaries led to a decrease in the regularity and duration of spring flooding of floodplain estuaries and, as a consequence, a decrease in the yield of natural hayfields from 2.87 to 1.96 t/ha, as well as a decrease in the share of moisture-loving valuable cereal grasses (wheatgrass, slough grass) in botanical composition from 61 up to 32%.

About 100 thousand hectares of land can be used for flood irrigation in the steppe zone of the RB, including 40 thousand hectares in the Trans-Urals (Zhigulev et al., 2010).

The effectiveness of flood irrigation in various regions of the Russian Federation is shown in the works of B. Tuktarov, N. Mosienko, A. Pleshakova, B. B. Shumakova and other researchers (Komissarov, 2016).

Drip irrigation. This type of irrigation is considered to be effective and environmentally friendly, since irrigation water is metered directly into the root zone, without slope runoff, and surface evaporation becomes minimal (Nouri et al., 2019).

In the south of Russia, drip irrigation is widely used in greenhouses, vegetable growing, horticulture, fruit growing and viticulture. With regard to greenhouse, drip irrigation systems in the Russian Federation are applied on an area of 350 thousand hectares. (Shchedrin et al., 2018).

In Bashkortostan, this method of irrigation in the open ground for the first time (2006) was tested in the state farm "Aleksееvsky" of the Ufa district on the area of 10 hectares. With this method of irrigation, the yield of early Red Scarlet potato varieties was 56.3 t/ha and was higher than in other areas irrigated with sprinkling (Andrianov et al., 2007).

In the RB, the largest number of drip irrigation systems was introduced in the Tuimazy district on an area of 103 hectares on 10 farms. The drop irrigation as a promising energy and water saving method is introduced in other areas of the country. So, in the Chekmagushevsky district in LLC "ARS" drip irrigation was introduced on an area of 13 hectares, in the Ufa region in LLC "Krasny Yar" – 21

hectares, in the Sharan district on the enterprise "Galim" – 120 hectares.

We have studied the effect of drip irrigation and sprinkling on the yield of potatoes in the Southern Urals (Ufa region, RB) on clay-illuvial black soil (Luvic Chernozems (Pachic)). Depending on the meteorological conditions of the growing season, the value of the irrigation rate ranged from 650 to 1350 m³/ha, i.e. 2 irrigations with rates of 300-700 m³/ha. The studies have shown that irrigation increases yields, by an average of 1.5 times compared to dry land. The most effective was drip irrigation, in which the highest yield of potatoes was obtained – 19.3 t/ha. The yield increase from drip irrigation was 6.8 t/ha, while when irrigating with sprinkling it was only 4.7 t/ha. This is due to the fact that during drip irrigation, unlike sprinkling during the growing season, more optimal soil moisture was maintained in the root zone of the soil. The total water consumption of potatoes in the non-irrigated area did not exceed 235 mm, and in the irrigated area it was more and amounted to 306-321 mm due to the use of irrigation water, the share of which reached 33-34% (Komissarov et al., 2012).

Sprinkling. The experimental studies (2000-2013) of the soil water regime and the effect of irrigation on the productivity of various crops, which we conduct on the experimental field of the water balance station of the "Bashkir reclamation water farm" Department showed that in the southern forest-steppe zone of Bashkortostan in the cultivation of perennial grasses, precipitation and soil moisture reserves in conditions of dry land provide only one full mowing. The duration of the water deficit during the growing season averaged to 38 days for the awnless brome, 60 days – for bluegrass alfalfa, and 33 days for the fodder galega. To eliminate the water deficit of the awnless brome, bluegrass alfalfa, fodder galega, it was necessary to moisten the soil with the irrigation rate of 900-3400, 1,350-4,500, 850-3,550 m³/ha, respectively. The amount of the irrigation rate and the number of irrigations (3-7, 3-8, 2-6, respectively) varied depending on the availability of precipitation during the growing season. The sprinkling irrigation was an effective reclamation technique and contributed to obtaining 2-3 mowing. The yield of the awnless bone averaged to 4.4, the bluegrass alfalfa – 6.7, and the fodder galega – 8.15 t/ha of dry matter. The response of perennial grasses for irrigation increased in the following order: awnless bone (increase in yield 26%) – fodder galega (37%) – bluegrass alfalfa (90%). The highest productivity was observed in grass stands 4-5 years of use.

In the irrigated area, where sugar beet was cultivated, in order to maintain soil moisture in a layer of 0-50 cm within optimal limits from the capillary rupture moisture to the lowest moisture capacity, irrigation was performed at a rate

of 200 to 700 m³/ha. The amount of the irrigation rate in the years of research varied from 1,150 to 1,650 m³/ha and depended on the prevailing meteorological conditions. The optimization of the water regime of leached black soil under sugar beet crops by sprinkling irrigation allowed to increase its yield to 60.7 t/ha. The additional root crops harvest amounted to 23 t/ha. The average weight of the sugar beet root crop in the irrigated area was 102 grams more than that in the non-irrigated area (Figure 2).

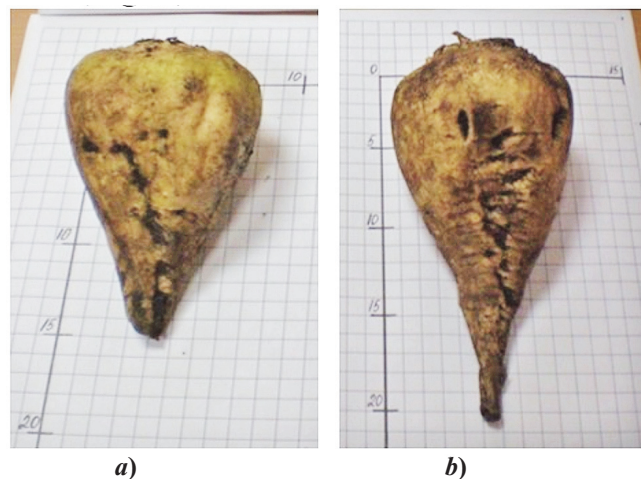


Fig. 2. Sugar beet root crops:

a – without irrigation (average tuber weight ~ 425 g);
b – sprinkling irrigation (~ 527 g)

The total water consumption of sugar beets in the irrigated area averaged over 3 years was 411 mm. The largest share (55%) in water consumption of sugar beet was occupied by precipitation, and the smallest – by soil moisture reserves (10%). The share of irrigation in the total water consumption was 35%.

The sown perennial grasses with sprinkling provide 8.4-14.3 thousand rubles/ha, and natural hayfields with flood irrigation – 5.2 thousand rubles/ha of profit. The high-yield crops cultivated with sprinkling irrigation are sugar beets and potatoes, giving respectively 38.1 and 28.6 thousand rubles/ha of net profit. The use of drip irrigation of potatoes allows, in comparison with sprinkling, to increase profits from 28.6 to 35.8 thousand rubles/ha, profitability from 57 to 60%.

The results of research on the effect of irrigation on the yield of sown perennial grasses and tilled crops that we conducted in the Republic of Bashkortostan are consistent with numerous studies on this subject in other regions of the Russian Federation and abroad.

Currently, within the framework of the Federal Target Program, the long-term republican target subprogram “De-

velopment of agricultural land reclamation for the Republic of Bashkortostan for the period 2014-2020” is being successfully implemented in the republic. The purpose of this subprogramme is to increase soil productivity and the sustainability of agricultural production by means of integrated land reclamation in the face of climate change and natural anomalies, as well as increasing the potential of reclaimed land and the efficiency of using natural resources. As part of the subprogramme, it is planned to commission 25.3 thousand hectares of reclaimed land due to reconstruction, technical re-equipment and construction of new land-reclamation systems, including land-reclamation systems for general and individual use, and to bring the area of irrigated land to 53.9 thousand hectares. The financing of works on the construction of irrigation systems and their technical re-equipment is carried out by agricultural producers and investors, followed by subsidizing up to 70% of the costs from the state budget.

Conclusion

One of the ways to combat drought is irrigation, which can significantly reduce the damage caused to agriculture by abnormal weather conditions and significantly increase the yield of cultivated crops. The use of certain methods of irrigation of agricultural crops depends on the crop and natural climatic zone. In the Republic of Bashkortostan, on natural hayfields, the flood irrigation is used, perennial sown grasses and forage crops are sprinkled over, and during the cultivation of vegetable crops and potatoes, and the areas of drip irrigation are expanded. The irrigation regime for agricultural crops should be aimed at covering the water deficit during different periods of vegetation. The quantitative irrigation parameters have significant territorial variability. In the Republic of Bashkortostan, irrigation rates increase from the forest-meadow to the steppe zone. The highest irrigation rate in the medium dry year (1,300-2,250 m³/ha) is required for the cultivation of alfalfa and annual multi-cutgrasses in the steppe and forest-steppe zones, and the smallest (800-1,200 m³/ha) for spring wheat. In the forest-meadow zone, the irrigation rates for various crops differ little from each other and are 400-600 m³/ha. Sprinkling irrigation allows getting 2-3 cuttings of perennial grasses, while there is only one on dry land. During irrigation the average yield of the awnless brome averaged to 4.4, of bluegrass alfalfa – 6.7, and of the fodder galega – 8.15 t/ha of dry matter. The optimization of the water regime of the soil under the crops of sugar beets by sprinkling irrigation allowed to increase its yield to 60.7 t/ha. The irrigation of potatoes increases its yield by 1.5 times compared with that on dry land. A drip irrigation method is

more effective than sprinkling. The yield increase from drip irrigation was 6.8 t/ha, while with sprinkling irrigation it was only 4.7 t/ha. Flood irrigation of natural grasslands allows getting up to 2.9 t/ha of dry matter, which is 3 times more than in dry land.

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