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ASSESSMENT OF THE IMPACT OF IRRIGATION TECHNOLOGIES ON THE RECLAMATION STATUS OF LANDS UNDER THE CONDITIONS OF KHOREZM REGION

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Abstract
The article presents the results of a scientific study conducted in the Khorezm region on the volume and mineralization of collector–drainage waters. The study evaluates the impact of implementing drip irrigation technology to reduce the formation of collector–drainage waters and examines the use of biological preparations to improve the reclamation status of irrigated lands. The findings provide insights into optimizing water use, improving soil conditions, and enhancing crop productivity under water-limited conditions.

Keywords: Water scarcity, irrigated area, total water volume, water resources, irrigation networks, collector–drainage networks, water–salt balance, water use efficiency (WUE), land reclamation status, irrigation technology, drip irrigation, soil texture, irrigation rate, seasonal irrigation rate, crop yield.

Introduction
The main water resources in the Aral Sea basin are the Amu Darya and Syr Darya rivers. In addition, the region also has smaller rivers, streams, and groundwater resources. The long-term average annual runoff in the basin is 116.2 billion m³, of which 67.4% is generated in the Amu Darya and 32.6% in the Syr Darya sub-basin. The average water allocation for different sectors in Uzbekistan is 52 billion m³, of which 20% (approximately 11 billion m³) is formed within the territory of the country. Currently, the total irrigated area in Uzbekistan is 4.3 million hectares, and 90% of the water allocated to the country is used for agricultural production.

In the Khorezm region, increasing water scarcity has made the efficient and rational use of water resources one of the most critical challenges in crop production. Efficient water use, reduction of water losses in irrigation networks, improvement of the reclamation status of irrigated lands, and reduction of the load and formation of water in collector–

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drainage networks are particularly important. Developing the scientific foundations of water-saving technologies is essential to address these issues.

The introduction of water-saving irrigation technologies in agriculture can improve the reclamation status of soils, increase the water use efficiency (WUE) of irrigation networks, and mitigate the negative impacts of climate change on agriculture and water management. Accordingly, the Government of Uzbekistan has adopted a series of strategic resolutions and decrees, including:

- Presidential Decree No. PF-6024 of 10 July 2020, "On Approving the Concept for the Development of Water Management in the Republic of Uzbekistan for 2020–2030";
- Resolution No. PQ-5005 of 24 February 2021, "On Approving the Strategy for Water Resources Management and Development of the Irrigation Sector in the Republic of Uzbekistan for 2021–2023";
- Presidential Decree No. PF-60 of 28 January 2022, "On the Development Strategy of the New Uzbekistan for 2022–2026";
- Resolution No. PQ-144 of 1 March 2022, "On Measures to Further Improve the Implementation of Water-Saving Technologies in Agriculture"

These policy documents emphasize the adoption of water-saving technologies as a key priority to ensure sustainable water use, enhance agricultural productivity, and improve the reclamation status of irrigated lands in the country.

Literature Review

The study of water–salt regimes of irrigated lands, as well as the flow directions of soil and geological layers in the aeration and groundwater zones, has been the focus of numerous international and national researchers. Notable contributions have been made by I.S. Kanwar, W.P. Kelley, I.D. Oster, I. Szabolcs, L.V. Wilcox, A.N. Kostyakov, S.F. Averyanov, V.A. Kovda, V.V. Egorov, V.R. Volobuev, D.M. Katz, N.I. Parfenova, N.M. Reshetkina, V.A. Baron, A.A. Rachinsky, Kh.I. Yakubov, F.M. Rakhimbaev, M.A. Pankov, R.K. Ikramov, A.U. Usmanov, T.U. Bekmuratov, V.G. Nasonov, M.A. Yakubov, B.K. Saraev, I.Kh. Khabibullaeva, E.Zh. Makhmudov, S.I. Khudaykulov, I.E. Makhmudov, Kh.M. Yakubov, Sh.A. Usmanov, and other scholars.

In the Khorezm region, several studies have examined the irrigation regimes of cotton under the local natural, soil–reclamation, and hydrogeological conditions. N.F. Bespalov and N.I. Malabayev recommended that, depending on hydrological zones, the seasonal irrigation rate for cotton should range from 3000 to 7200 m³/ha.

Research conducted by I. Masharipov, J. Yuldoshev, R. Karimov, and B. Mukhamadiev at the Khorezm branch of UzPITI demonstrated that the promising Khorezm-150 cotton variety, when grown under uniform agrotechnical measures, yielded an average of 36.4 c/ha. Trials of different sowing dates showed that planting in the first decade of April resulted in 35.2 c/ha, while planting at later dates, when the top 10 cm of soil exceeded 13–14°C, produced 33.1 c/ha.

According to N.V. Kurambayev, in the traditionally irrigated pasture soils of Khorezm, which are medium sandy, saline, and with shallow groundwater (1.1–1.5 m), four

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irrigations under a 1–3–0 schedule are recommended, with an irrigation rate of 850–1000 m^3/ha and a seasonal irrigation volume of 3700–4000 m^3/ha.

M.Kh. Khamidov recommended maintaining soil moisture at 70–80–60% of field capacity in the semi-saline soils of Khorezm during cotton irrigation. Similarly, research by S.Kh. Isaev and B. Suvonov in Shovot district showed that, under a 0–3–0 irrigation scheme and maintaining pre-irrigation soil moisture at 70–80–60% of field capacity, the seasonal irrigation rate was 2122 m^3/ha, resulting in a cotton yield of 42.8 c/ha and a water consumption of 49.8 m^3 per 1 c of cotton.

G.M. Satipov and I. Ismoilova reported that, for the Khorezm-150 variety grown on alluvial–pasture soils under a 0–3–1 irrigation schedule with pre-irrigation soil moisture maintained at 60–75–70%, high yields of 40–41 c/ha were obtained.

Despite these advances, studies in the Khorezm region on improving the reclamation status of irrigated lands remain limited. In particular, there is a lack of comprehensive research addressing the combined effects of water resources, water–salt balance, technical condition of irrigation networks, and the reduction of collector–drainage water formation through irrigation technologies and the use of biological preparations for leaching saline soils.

Research Objectives

To investigate the impact of water-saving irrigation technologies on reducing the formation of collector–drainage waters in soils of different mechanical compositions under saline conditions in the Khorezm region.

To assess the natural, agricultural, and soil–reclamation conditions that determine the reclamation status of irrigated lands in the Khorezm region, as well as to identify factors contributing to its deterioration.

To collect and process data on available water resources, the current state of irrigation and drainage networks, and their technical parameters.

To analyze the formation of collector–drainage waters and their discharge volumes through main collector channels.

To study the irrigation and leaching processes and evaluate their influence on the formation of collector–drainage waters.

To determine the formation of collector–drainage waters under both traditional furrow irrigation and drip irrigation technologies for cotton on pilot plots that are highly representative of the soil–hydrogeological conditions of irrigated lands served by inter-republican river collectors.

Analysis and Results

In the Khorezm region, irrigated lands consist of 60% slightly saline, 29% moderately saline, and 11% highly saline areas. Between 38% and 71% of the total water allocated for irrigation in the region is discharged through collector–drainage networks. Of this discharged water, 33.2–42.7% flows into the inter-republican “Daryolik” collector, and 49.1–56.2% into the “Ozerniy” collector.

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The results of research on the scientific basis for implementing water-saving technologies to reduce the formation of collector–drainage waters are presented. The studies analyzed soil–climatic conditions and the reclamation status of lands to develop scientifically grounded irrigation regimes for cotton using water-saving drip irrigation. These regimes were applied to study the formation and discharge volumes of collector–drainage waters in the Khorezm region.

Field experiments were conducted at the "Diyorbek Jumaniyozov" farm in Khonka district. On sandy loam soils, cotton was planted in rows with 60 cm spacing. Pre-irrigation soil moisture was maintained at 70–80–60% of field capacity. During the growing season, irrigation was applied 12 times according to a 3–6–3 scheme, with irrigation rates of 180–220 m³/ha per application, resulting in a total seasonal irrigation volume of 2400 m³/ha.

Materials and Methods

2.1 Study Area.

Khorezm region is located in the northwestern part of the Republic of Uzbekistan and covers a total area of 608.2 thousand hectares, of which 267.7 thousand hectares (44%) are classified as irrigated lands.

The region is bordered to the north and northeast by the Amu Darya River and the Republic of Karakalpakstan, and to the south and southwest by Turkmenistan.

The total length of irrigation networks in the region is 16,836.3 km, including 347.0 km of main canals, 2294.5 km of inter-farm canals, and 14,194.8 km of intra-farm irrigation networks. These networks include 12,053 hydraulic structures and 1,181 hydroposts, which provide water for agricultural crops across the region.

The Amu Darya River serves as the primary source of irrigation water in the region, delivering water to irrigated lands via canals such as Toshsaqa, Qilichniyozbai, Pitnak, Oktyabr, and Urganch.

In 2023, the regional water allocation limit was 4854.85 million m³; however, only 3937.67 million m³ was withdrawn, 19% below the limit. In 2022, the water allocation limit was 5115.35 million m³, with 3013.48 million m³ actually withdrawn (Table 1).

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Table 2.1.1

№	District Name	Years	Total Water Allocated to District Boundaries (million m³)		Source of Irrigation Water	Water Withdrawn During the Growing Season (million m³)	
			Limit	Actual		Limit	Actual
1	Bogot	2022	411,33	241,28	241,30	295,97	191,53
		2023	412,41	316,97	316,97	303,71	217,74
2	Gurlan	2022	387,44	334,00	334,00	430,64	263,52
		2023	594,82	486,93	486,93	447,49	349,69
3	Qushkupir	2022	380,60	348,14	348,14	373,73	248,18
		2023	577,28	454,53	454,53	384,63	284,77
4	Urganch	2022	327,48	286,54	286,54	229,98	219,86
		2023	491,91	401,63	401,63	358,15	280,72
5	Khazarasp	2022	309,64	267,13	267,13	218,95	208,42
		2023	467,26	385,55	385,55	350,93	276,71
6	Khonka	2022	304,35	259,86	259,86	213,11	199,31
		2023	424,20	346,72	346,72	303,80	241,82
7	Khiva	2022	244,39	214,57	214,57	169,54	163,42
		2023	363,06	276,48	276,48	263,41	187,55
8	Shovot	2022	334,96	309,91	309,91	346,79	228,12
		2023	506,54	402,87	402,87	359,08	278,20
9	Yangiariq	2022	216,54	197,02	197,02	232,36	151,64
		2023	330,37	265,60	265,60	235,89	180,03
10	Yangibozor	2022	288,69	262,01	262,01	312,50	203,55
		2023	431,36	352,40	352,40	313,72	247,88

Irrigation networks in the region consist of 1,812.7 km (72%) earthen channels, 5,322.1 km (28.2%) concrete-lined channels, and 2.7 km (0.2%) tray-based irrigation systems.

2.2. Total Land Fund and Its Utilization

According to the State Cadastre of Land Resources of Khorezm region, the total area of irrigated land is 267,618 hectares. Of this, 2,002 hectares correspond to Urganch, Khiva, and Pitnak cities. In 2021, a total of 266 observation wells were equipped with "Diver" devices for online monitoring, including 66 wells in Urganch city and 200 wells in the districts. Full reclamation monitoring is carried out over the remaining 265,616 hectares.

Geomorphologically, Khorezm region consists of alluvial deposits such as clay, clayey sand, sandy loam, and sand, with slopes ranging from 0.00015 to 0.0005. Due to its

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location in the lower reaches of the Amu Darya, historically irrigated lands have developed anthropogenic (agro-irrigation) layers with a thickness of 2–3 m.

Based on soil texture, the region's alluvial soils are composed primarily of heavy loamy and clay soils (17.3%), medium loamy soils (40.3%), light loamy soils (29.1%), and sandy to sandy-loam soils (13.3%).

From a hydrogeological perspective, the region is characterized by a very gentle slope, which significantly complicates the flow of groundwater. Groundwater (capillary) is located relatively close to the surface, with an average annual depth in irrigated areas ranging from 1.0 to 2.5 m. During the growing season, the average depth of groundwater is 1.4–1.5 m (Figure 1). Consequently, slightly saline soils and shallow groundwater have a significant impact on the soil's moisture and salt regimes.

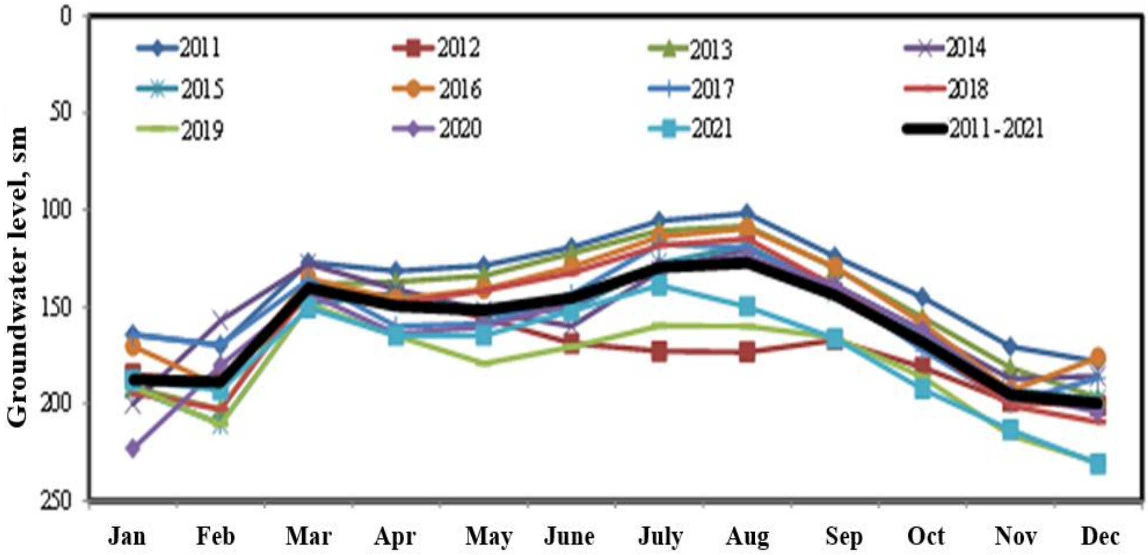

Figure 1. Average Monthly Changes in Groundwater Table in Khorezm Region (based on 2011–2021 data).

Results

Soil Analysis. In 2023, irrigated areas in Khorezm region were characterized by varying levels of soil salinity: 11.4% of the land was highly saline, 29.9% moderately saline, and 58.5% slightly saline.

Existing Irrigation and Collector-Drainage System

The internal irrigation network in Khorezm primarily consists of open soil-bed canals and ditches, with irrigation mainly performed via surface furrow (egat) systems. The region has 2,416.3 km of inter-farm canals and 14,084.8 km of intra-farm canals (Figure 2). Among these, 264.5 km of inter-farm canals and 168.7 km of intra-farm canals are reinforced with concrete, representing 11% and 1.2% of their total lengths, respectively.

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As a result, the average efficiency of intra-farm canals in the region is 0.71–0.72, while inter-farm and district-level canals have efficiencies of 0.81–0.82, and main canals reach 0.92–0.93. The overall irrigation network efficiency is estimated at 0.55–0.56.

Due to the region's micro-relief, 176.3 thousand ha (69% of irrigated land) are supplied with irrigation via pumps. In total, 1,892 pumping units operate within the irrigation network, including 420 pumps (covering 57.8 thousand ha) financed by state funds.

Measurements conducted by ISMITI researchers revealed significant water losses within the internal irrigation network. Specifically, 3–6% of water was lost due to uneven distribution within farms, 6–7% due to uncleaned canals, 0.5–1.0% from evaporation, and the largest share, 15–20%, due to infiltration. Additional technical factors contributed to 2–5% of water loss.

In the Khorezm region, groundwater (sizot) and drainage (tashlama) waters from the existing collector-drainage networks are primarily discharged via major and minor drainage networks into the "Daryolik" and "Ozerniy" collectors, thereby leaving the region.

In 2023, the area equipped with drainage networks covered 263.4 thousand ha, of which 255.2 thousand ha were served by open drains, while 8.2 thousand ha were served by closed drains.

As of January 1, 2021, the comparative length of internal farm collector-drainage networks was 25.4 m/ha in irrigated areas and 25.6 m/ha in areas served by drains. According to 2023 data, the total length of drainage networks reached 10,473.5 km, including:

- 327.9 km of main (inter-regional) collectors
- 527.6 km of district-level collectors
- 2,862.7 km of inter-farm collectors
- 6,755.2 km of internal farm collectors and clusters (including 504.1 km of closed drains)

For detailed monitoring of collector-drainage outflows, two representative pilot sites were selected:

1. Bagot District – "Dilshod Diyor" Farm: The farm is located between the Divankul and Arpakul drainage networks. Drainage waters from the area are discharged into the Ozerniy collector.

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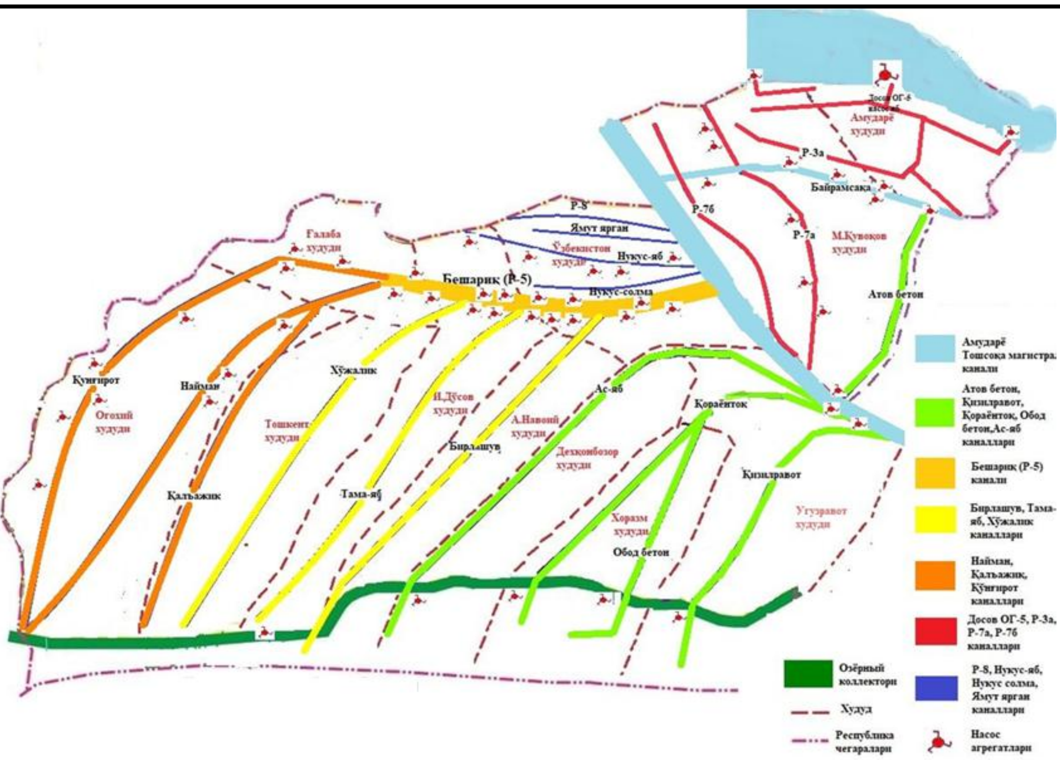

Figure 2. Irrigation and Drainage Networks in Bagot District

In Gurlan District, the “Muhandis” farm is located near the Divankul collector. Drainage waters from the farm are discharged into this collector, which subsequently merges with the Daryolik collector.

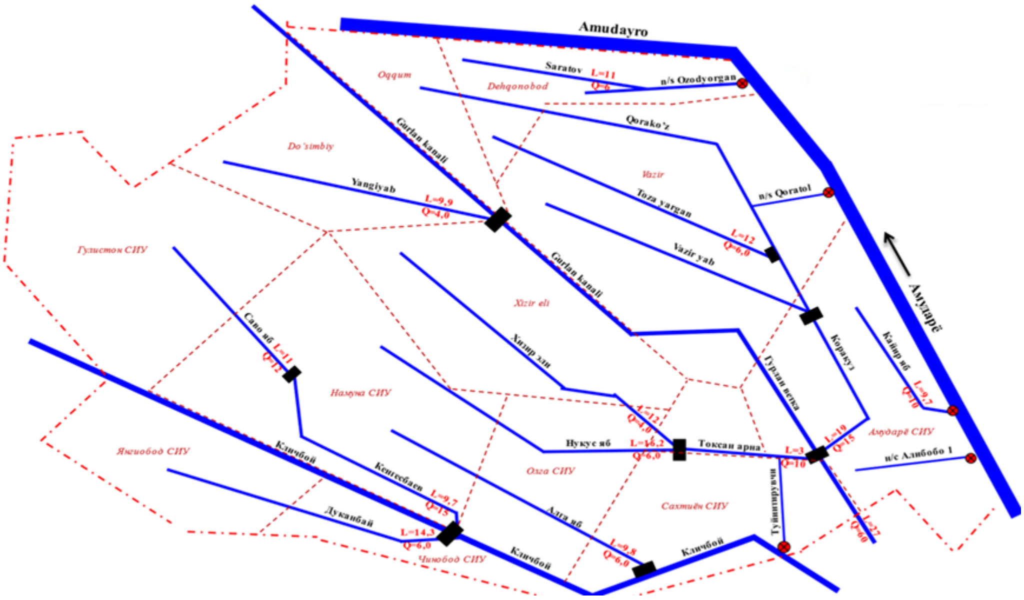

Figure 3. Irrigation Networks in Gurlan District

(Volume and Mineralization of Water Discharged from Collector-Drainage Networks in Khorezm Region)

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The volume and mineralization of drainage water discharged from irrigated areas in the region were monitored every ten days using installed hydroposts along the collector-drainage networks, with laboratory analysis conducted for salinity.

In 2023, the total volume of drainage water discharged from the irrigated areas of the region reached 1,275.61 million m³, with 3,278.32 thousand tons of salts exported via collector waters. Specifically:

- Volume of drainage water per hectare: 4.80 thousand m³/ha
- Salt content per hectare: 11.1 t/ha
- Drainage water as a percentage of total irrigation water: 37% (compared to 39.5% in 2020)
- Salt input with irrigation water: 2,752.27 thousand tons
- Water reused from collector networks: 342.874 million m³
- Direct reuse from runoff and collector water: total salt input to irrigated areas 2,817.11 thousand tons
- Total salt discharged through collector-drainage networks: 3,278.32 thousand tons

Summary

The volume of collector-drainage water leaving the region via main interregional collectors was 1,275.61 million m³, with 626.77 million m³ through the Ozerniy main collector and 544.46 million m³ via the Daryolik main collector.

For pilot sites, water-salt balance analysis revealed:

- Gurlan District: Total irrigation water applied: 334.33 million m³; drainage water leaving the district: 144.92 million m³; salt input per liter of irrigation water: 0.81 g/L; total salt discharged via drainage: 349.26 tons
- Bagot District: Total irrigation water applied: 259.86 million m³; drainage water leaving the district: 111.58 million m³; salt input per liter of irrigation water: 0.80 g/L; total salt discharged: 270.02 tons

On average, 42–44% of applied water in both districts was lost through collector-drainage networks. Each liter of irrigation water carried ~0.8 g of salts into the system, while 2.3–2.4 g/L of salts were discharged. High salt concentrations in drainage water are explained by vegetative irrigation and leaching processes, whereby dissolved salts are carried into collector-drainage networks.

Field and laboratory studies, as well as phenological observations, were carried out following UzPITI (2007) “Field Experimentation Methods” and ISMITI standards for determining irrigation equipment performance. The studies evaluated water-saving technologies for cotton irrigation in saline-prone alluvial soils with light, medium, and heavy textures in the pilot districts of Gurlan, Khonka, and Yangibozor. Irrigation experiments were conducted using the systems described in Tables 2 and 3.

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Table-2 Experimental scheme for determining optimal irrigation technique elements in the irrigation regime of drip irrigation technology (Light-Textured Soils)

Variants	Irrigation Method	Distance Between Irrigation Pipes, m	Dripper Water Flow Rate, l/h	Distance Between Drippers, sm	Pre-Irrigation Soil Moisture Relative to Field Capacity, %
1 (control)	Furrow	Production control			
2	Drip	to each furrow, 0.6 m	1,8	25	70-80-60
3		every other furrow, 1.2 m	1,8		
4		to each furrow, 0.6 m	2,0		
5		every other furrow, 1.2 m	2,0		

Table-3

Variants	Irrigation Method	Distance Between Irrigation Pipes, m	Dripper Water Flow Rate, l/h	Distance Between Drippers, sm	Pre-Irrigation Soil Moisture Relative to Field Capacity, %
1 (control)	Furrow	Production control			
2	Томчилатиб	to each furrow, 0.6 m	1,6	30	70-80-60
3		every other furrow, 1.2 m	1,6		
4		to each furrow, 0.6 m	1,8		
5		every other furrow, 1.2 m	1,8		

Conclusion and Recommendations

In 2023, the total volume of drainage water discharged from the irrigated areas of the region was 1,177.84 million m³, with 3,333.29 thousand tons of salt removed through the collector water system.

In 2023, the average depth of groundwater in the region was 183 cm, compared to 178 cm in 2022, indicating a 5 cm decrease due to water scarcity.

Analysis of the water flow regime in the inter-republican "Daryolik" and "Ozyorny" collectors over the last 20 years shows that during the non-vegetation period (soil leaching period), the flow is maximal (250 million m³), while during the vegetation period, the average flow is 50–100 million m³.

Conclusions from Research on Drip Irrigation Technology

On light sandy soils, where cotton was planted with 60 cm row spacing and drip irrigation technology was applied—using drippers with a water flow of 2 L/h, 25 cm

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spacing between drippers, and 60 cm spacing between irrigation pipes, with an irrigation rate of 173–227 m^3/ha and seasonal irrigation rate of 2,810 m^3/ha under a 4-7-3 irrigation scheme applied 14 times—favorable conditions for cotton growth were achieved, resulting in a yield of 42.2 c/ha.

For light sandy soils, water saving per ton of yield compared to the production control was:

- Variant 2: 852 m^3
- Variant 3: 885 m^3
- Variant 4: 914 m^3
- Variant 5: 913 m^3

The highest result was in Variant 4, with 4.22 tons/ha yield, which is 1.11 tons higher than the control.

On medium sandy soils with 60 cm row spacing, using drip irrigation with drippers of 1.8 L/h, 30 cm spacing between drippers, and 60 cm spacing between pipes, with 180–230 m^3/ha irrigation per event and 2,765 m^3/ha seasonal irrigation under a 3-7-3 scheme applied 13 times, cotton yield reached 42.8 c/ha.

Water saving per ton of yield compared to the control was:

- Variant 2: 702 m^3
- Variant 3: 755 m^3
- Variant 4: 765 m^3
- Variant 5: 764 m^3

The highest result was in Variant 4, with 4.28 tons/ha, which is 0.97 tons higher than the control.

On heavy sandy soils with 90 cm row spacing, drip irrigation using 1.6 L/h drippers, 40 cm spacing between drippers, and 180 cm spacing between pipes under a 3-6-3 scheme applied 12 times, with single irrigation rates of 196–204 m^3/ha and seasonal irrigation of 2,403 m^3/ha, cotton yield reached 41.4 c/ha.

Water saving per ton of yield compared to the control was:

- Variant 2: 672 m^3
- Variant 3: 809 m^3
- Variant 4: 714 m^3
- Variant 5: 729 m^3

The highest yield was in Variant 4, 4.14 tons/ha, which is 0.85 tons higher than the control.

Overall, applying drip irrigation technology, including optimized irrigation equipment and scheduling, allowed 40–43% savings of river water under different soil and melioration conditions.

Effect of Drip Irrigation on Soil Mechanical Properties

According to pilot plot studies, the soil of the first experimental plot was physically loamy (<0.01 mm) and classified as light sandy soil according to N.A. Kachinsky. The second experimental plot had medium sandy soil, and the third experimental plot had heavy sandy soil.

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For medium sandy soil (0–40 cm plow layer):
- Humus: 0.61%
- Total nitrogen: 0.073%
- Phosphorus: 0.197%
- Nitrogen available to cotton: 20.3 mg/kg
- Available phosphorus: 18.3 mg/kg
- Exchangeable potassium: 140 mg/kg

Cotton absorbed:
- Nitrogen: 15.5 mg/kg
- Phosphorus: 11.0 mg/kg
- Potassium: 97 mg/kg

Soil bulk density by mechanical type:
- Light sandy soils (0–30 cm): 1.20 g/cm³; 1 m layer: 1.25 g/cm³
- Medium sandy soils (0–30 cm): 1.39 g/cm³; 1 m layer: 1.41 g/cm³
- Heavy sandy soils (0–30 cm): 1.48 g/cm³; 1 m layer: 1.49 g/cm³

Results from experiments in Gurlan, Khonka, and Yangibazar districts:
- Light sandy soil: 4-8-3 scheme, 15 irrigations, irrigation 200–250 m³/ha, seasonal irrigation 3,400 m³/ha
- Medium sandy soil: 3-7-3 scheme, 13 irrigations, irrigation 200–240 m³/ha, seasonal irrigation 2,900 m³/ha

Analysis showed that cotton yield on light sandy soils was higher under drip irrigation compared to heavy sandy soils. For instance:
- Control (traditional method, Variant 1): 35.7 c/ha
- Drip irrigation (Variant 2): 41.7 c/ha
- With inter-row drip hoses (Variant 3): 37.5 c/ha

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