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Water scarcity under global climate change: Ways of addressing water scarcity in the Amu Darya lower reaches

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Water scarcity under global climate change: Ways of addressing water scarcity in the Amu Darya lower reaches

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Abstract. The global climate changes and their influence on agriculture in Uzbekistan were analyzed, including problems of irrigation water shortage on irrigated lands in the lower reaches of the Amu Darya with the greatest water shortage due to repeated dry years. Additionally, the recommendations for the effective use of water resources in the conditions of meadow alluvial soils salinization and shallow salinized groundwater were proposed to use subirrigation and drip irrigation to irrigate cotton, maintaining the pre-irrigation soil moisture of the lowest soil moisture capacity. The introduction of a science-based regime for cotton using subirrigation and drip irrigation methods provides conservation of water up to 1.596–1.757 (subirrigation) and 1.596–1.757 (drip irrigation) cbm/ha, an increase in cotton yield of up to 6.3 centner/ha.

1. Introduction

Global climate changes, population growth, annual increase in the need for water yearly influence the shortage of water resources in Uzbekistan, located in the Aral Sea basin with the Amu Darya and Syr Darya rivers, inland rivers, groundwaters, whose average long-term annual flow of water is 116.2 billion cubic meters, wherein 67.4 percent belongs to the Amu Darya basin, 32.6 percent to the Syr Darya basin. The total groundwater reserve is 31.2 billion cubic meters, 47.2 percent belongs to the Amu Darya basin, 52.8 percent to the Syr Darya basin with the average annual water withdrawal limit of 64 billion cubic meters [1] whereas in the 1980s, the annual water consumption was within the multi-year limits, which in recent years has become 51–53 billion cubic meters, including the irrigated land area of 4.3 million hectare with 90–91 percent of all water resources used in agriculture [1].

Insufficient natural drainage and a high level of groundwater mineralization have led to primary salinization and secondary salinization of lands in some territories, and global climate change over the past 50–60 years has decreased glaciers by 30 % as a temperature increase by 20C will decrease glaciers by 50 %, by 40ºC by 78 %. By 2050, a decrease in water resources in the Syr Darya basin is up to 5 percent, in the Amu Darya basin up to 15 %, whereas by 2015 the total water shortage was more than 3 billion cubic meters, which could reach 7 billion cubic meters by 2030 [1]. Such climate change will further exacerbate the water shortage in Uzbekistan, increasing the duration and frequency of drought, raising problems in the economy of water resources when water availability per capita has decreased from 3.048 cubic meters to 1.589 cubic meters [2].

By 2030, water consumption in agriculture will increase up to 20 % [3] under the influence of natural factors, with the yield of cotton of 19.45-22.3 c/ha in 2050, and 17.2–19.65 c/ha by 2100.

A. Rachinsky recommends the 900–1200 cbm/ha irrigation of cotton, exceeding the deficit of the root layer by 20–30% in saline soils and ground water depth of 1–2 m in southern Khorezm [4], whereas slightly saline irrigated soils of the Khorezm region for obtaining high and qualitative yields of cotton varieties “Mekhnat” are used in the irrigation scheme of 0–3–1 (the first is 900 cbm/ha, the subsequent is 1000 cbm/ha) [5]. The best regime is 70–80–60 % LSMC [6], when cotton is watered: for light mechanical soils, the scheme is 1–4–1 with irrigation norms of 437–825 cbm/ha, 3641-3676 cbm/ha; for medium loamy soils, the scheme is 1–4–0 with 494–664 cbm/ha and 3090–3133 cbm/ha and for heavy, the scheme is 1–3–0, with 541–753 cbm/ha and 2766–2786 cbm/ha [6]. High yield of cotton of the Bukhara-6 variety on meadow soils of the Bukhara region is provided by 5 vegetation irrigation by the 0–4–1 scheme, with 650–1050 cbm/ha and 4600 cbm/ha [7].

Their studies have shown that irrigation water losses differ with different irrigation methods and technologies: plants do not reach 10–20% of water with drip irrigation, 30–50% with sprinkling, and 50–60% with furrow irrigation [8]. Many scientists have written about the effectiveness of drip irrigation to save water, mineral fertilizers, and other resources [9, 10].

Studies have shown that the loss of irrigation water with different irrigation methods and technologies is different: 10–20% of water does not reach the plants with drip irrigation, 30–50% with sprinkling and 50–60% with furrow irrigation [11]. Many scientists wrote about the effectiveness of drip irrigation for saving water, mineral fertilizers and other resources [12, 13].

The drip irrigation method is a water-saving, anti-erosion method increasing the efficiency of mineral fertilizers, recommending drip irrigation primarily on water deficit lands and a groundwater depth of 2–3 meters [16], whose application on large slopes of the terrain prevents irrigation erosion, saving 45–50% of irrigation water and preventingd soil erosion [14], providing water savings of 35.6–41.5% compared to surface irrigation. At the same time, it is necessary to maintain the pre-irrigation soil moisture at the level of 70-70–60% LSMC with the irrigation rate of 2400 cbm/ha [13].

Many scientists have dealt with the issues of subsurface irrigation – subirrigation. With this method of irrigation, the root layer of the irrigated area is moistened due to nearby fresh or slightly mineralized (in conditions of severe water scarcity) ground water. Comprehensively studied the use of plants, groundwater and concluded that the share of groundwater in total water consumption of lucerne the first year standing at a level of 1 meter is 73–80%, with a level 2 meter is 30% and at level 3 m – 11 to 22% [14].

Subirrigation is recommended for obtaining high cotton yields on meadow layered soils of the Ferghana valley. To do this, drains are closed for 1–1.5 months and artificially raise the ground water level to 1–1.5 m. At the same time, the amount of irrigation will be reduced 1–1.5 times and the saving of river water from each hectare will be 800–1400 cbm [15]. In terms of the Zerafshan valley for irrigation of cotton way subirrigate the number of irrigations will be less than 1–1. 5 times, economy of water resources will be 987–1880 cbm/ha, reduced the number of row cultivation of cotton, respectively, the consumption of fuels and lubricants, will increase, the cotton yields by creating favorable meliorative modes of soils of 1.5–7.0 t/ha will be provided with prevention of environmental pollution by agro chemicals [16]. The optimal irrigation regime and favorable reclamation conditions were created when using the subirrigation method maintaining the pre-irrigation soil moisture of 70–80–60 % LSMC by the 1–2–1 scheme with irrigation norms of 607–889 cbm/ha and 2774–2839 cbm/ha [6].

2. Materials and Methods

In the meadow alluvial heavy loamy soils, the authors used methods for studying the agrophysical, agrochemical and microbiological properties of soil in cotton fields for conducting field experiments, the dispersion method of V. P. Peregudov for mathematical and statistical processing in the Shavat district of the Khorezm region in the Toji-Islom farm according to the 1st option: production control (furrow irrigation); 2nd option: pre-irrigation soil moisture of 70-80-60 % LSMC (subirrigation) and 3-option: pre-irrigation soil moisture of 80-80-60 LSMC (subirrigation). The irrigation rate in the control version was measured, other versions were determined by the moisture deficit in the layer of 0-100 centimeters. Field experiments were carried out according to the 1st option: production control; 2nd option: pre-irrigation soil moisture of 70–80–60 % LSMC (drip irrigation) and 3rd option: pre-irrigation soil moisture of 80–80–60 % LSMC (drip irrigation), when the irrigation rate was measured, other versions were determined by moisture deficit in the 50–70–50-cm layer.

3. Results and Discussion

The mechanical composition of the soils of the experimental plots was determined by the classification of N. A. Kachinsky, which refers to heavy loam lightened downwards [17]; in the experiment, the bulk density of soil in the arable layer of 0-30 cm was 1.34–1.36 g/ccbm, 1.40–1.41 g/ccbm in the layer of 0–100 cm [17]. By the end of the growing season, in the 1st control variant, bulk density increased by 0.03–0.04 g/ccbm, in the 2nd variant by 0.01–0.03 g/ccbm and in the 3rd variant by 0.02–0.03 g/ccbm [17]; at the beginning of the growing season, the water permeability of soils for 6 hours was 853–900 cbm/ha or 0.236–0.250 mm/min [17], which by the end of the growing season decreased [17]. In the 2nd variant, subirrigation with a pre-irrigation soil humidity of 70-80-60% LSMC, the soil water permeability for 6 hours was 697–720 cbm/ha or 0.194–0.200 mm/min, which was 72–128 cbm/ha or 0.02–0.036 mm/min more than that in the 1st control variant.

Table 1 shows the scheme, terms and norms of cotton irrigation for different irrigation methods. In the control, a constant high level of humidity in the active soil layer was provided due to large irrigation norms (1165–1364 cbm/ha) according to the 0-3-0 scheme, the irrigation rate was 3614–3879 cbm/ha. In the 2nd variant, cotton was watered three times, with an irrigation rate of 664–715 cbm/ha by the 0-3-0 scheme with the irrigation rate of 2018–2122 cbm/ha, which is 1596–1757 cbm/ha less than that in the control version.

Table 1. Irrigation regime in the subirrigation method (average years of research).

Options	Irrigation, cbm/ha				Inter- Irrigation period, day	Irrigation scheme	Irrigation rate, cbm/ha
	1	2	3	4			
1	1241–1265	1208–1297	1165–1364		25–27	0–3–0	3614–3879
2	681–709	664–715	673–705		19–22	0–3–0	2018–2122
3	585–682	636–693	650–682	634–690	16–21	1–3–0	2536–2707

The results of studies of the dynamics of groundwater showed that their level during the growing season in the control version was 137–135 cm. During subirrigation due to artificial elevation of their level and maintenance at this level in the pre-flood period due to the blocking structure on the drain was 98–156 cm (Figure1).

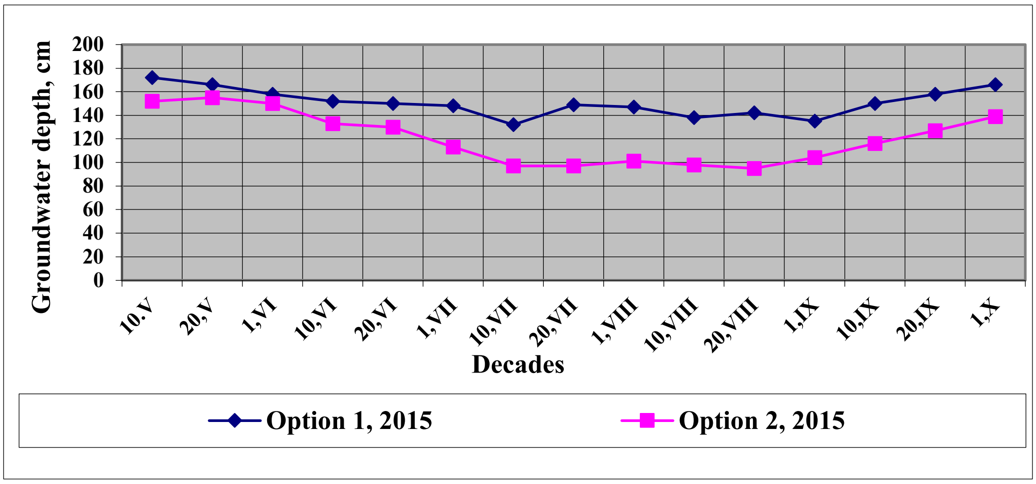

Figure 1. Groundwater level dynamics at the experimental site.

The method and mode of irrigation influenced the salt regime of the soil [6] when in the active soil layer (0–100 cm) of the control at the growing season beginning, chlorine ions were 0.009–0.011% and 0.015–0.020% by the end; the dry residue amount was 0.172–0.190% and 0.296–0.352% by the end with the seasonal salt accumulation coefficient for chlorine ions of 1.67–1.82, 1.72–1.85 for dry residue [6]. In the 3-variant, the amount of dry residue was 0.172–0.190% and 0.231-0.272%, respectively with the seasonal salt accumulation coefficient for chlorine ions of 1.56-1.64, 1.34–1.43 for dry residue. The influence of the irrigation method and regime on cotton yield showed that the best reclamation conditions for the development of cotton were provided and the yield was 38.0–42.8 C/ha, being 4.2–6.3 C/ha more than that in the control version (Figure 2). In this option, the water consumption coefficient was 49.6–53.1 cbm/c.

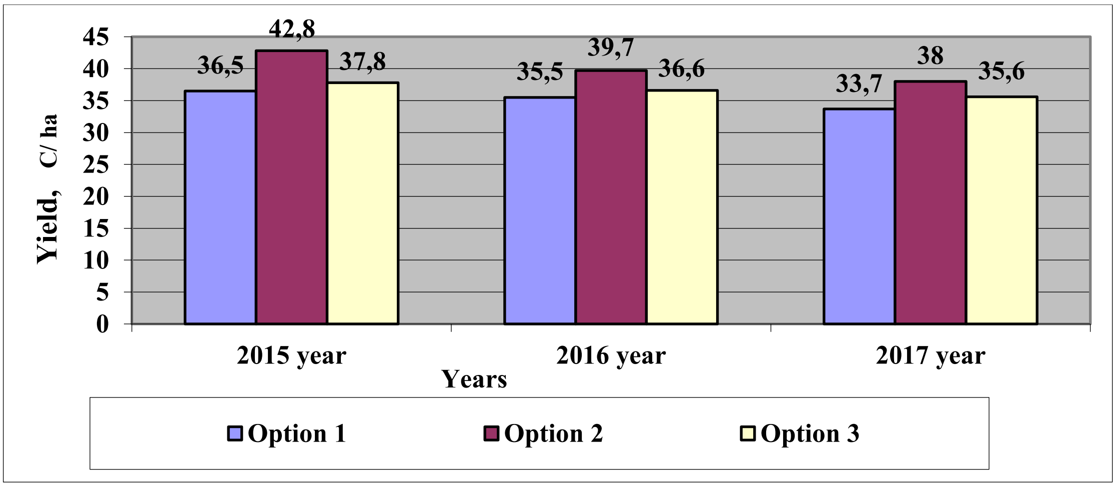

Figure 2. Cotton yield dependence on irrigation modes and methods.

Based on the experience, the volume mass of the soil of the experimental plot at the beginning in the 0–100 cm layer was 1.39–1.40 g/ccbm [6], whereas by the end, the volume mass of the soil in the 0–100 cm layer increased by 0.04–0.05 g/ccbm during drip irrigation (option 2), when the smallest soil compaction was 0.01 g/ccbm; soil water permeability for 6 hours was 970–984 cbm/ha or 0.269–0.273 mm/min. By the end of the growing season, soil water permeability decreased [6] while in the 2nd option with drip irrigation and a pre-irrigation humidity of 70–80–60 % LSMC, the soil water permeability for

6 hours was 816–826 cbm/ha or 0.227–0.229 mm/min, being 106-132 cbm/ha or 0.029–0.037 mm/min more than that in the control [18].

The irrigation regime using drip irrigation showed that in the 2nd option with the pre-irrigation soil moisture of 70–80–60 % LSMC, cotton was irrigated 6 times according to 0–6–0, 436–468 irrigation norms cbm/ha and 2678–2698 cbm/ha irrigation norm, saving 1437–1472 cbm/ha river water in contrast to the control option [6] (Table 2).

Table 2. Irrigation regime using drip irrigation (average research period).

Options	Irrigation, cbm/ha							Inter–Irrigation period, day	Irrigation scheme	Irrigation rate, cbm/ha
	1	2	3	4	5	6	7			
1	1360–1458	1370–1445	1310–1360					22–28	0–3–0	4115–4170
2	436–447	436–456	447–460	436–450	436–460	439–468		7–11	0–6–0	2678–2698
3	318–337	456–468	439–478	436–471	447–457	436–460	439–456	7–11	1–6–0	3015–3057

Table 2 represents the scheme, terms and norms of cotton irrigation with furrow and drip irrigation methods. In the control version of the experiment, a constant high level of humidity in the active soil layer was provided due to large irrigation norms (1310–1458 cbm/ha) by the 0–3–0 scheme, with the irrigation rate of 4115–4170 cbm/ha. In the 2nd option, cotton was watered six times, with an irrigation rate of 436–468 cbm/ha by the 0–6–0 scheme, when the irrigation rate was 2678–2698 cbm/ha, being 1437–1472 cbm/ha less than that in the control.

The study showed that in the 2-variant with drip irrigation, with the pre-irrigation soil moisture of 70–80–60 % LSMC, the cotton growth was 92.5–96.2 cm, with sympodial branches of 11.8–12.3 and bolls of 10.6–11.0 PCs revealing 3.6 to 4.2 units, having 0.4–0.7 sympodial branches, 0.7–0.8 by 0.7 bolls and pieces of split bolls greater than that in controls.

The effect of drip irrigation in the Khorezm region showed that in the first control version, 121.6–129.1 cbm of river water was used to produce one hundred weights of cotton of the Bukhara-102 variety and 32.3–34.2 C/ha of raw cotton was obtained. In the second, with a pre–irrigation soil humidity of 70–80–60% LSMC, a smaller amount of water (66.5–70.1 cbm) was used to produce 1 centner of raw cotton and a 38.5–40.3 C/ha yield of raw cotton being 6.1–6.3 C/ha more than that of the control (Table 3).

Table 3. Influence of drip irrigation on cotton yield (on average).

Options	Average yield, C/ha	Additional yield, relative to control, ± C/ha,	Water consumption per 1 C of raw cotton, cbm/C
1	32.3–34.2	0.0	121.6–129.1
2	38.5–40.3	+(6.1–6.3)	66.5–70.1
3	36.3–38.3	+(4.0–4.6)	78.7–83.7
E = 1.10 C/ha; P = 2.92%			

4. Calculation of the total water consumption of cotton

Atmospheric precipitation did not influence, not exceeding 22-45 mm in April-October, without changing the total water consumption by cotton; moisture reserves were covered by irrigation water and groundwater during the growing season. Irrigation rates change the total water consumption by cotton, which were 30-40% and seepage water was 50-60%. The total water consumption was determined by:

$$E = N - W + T + P + M, \quad m^3/ha; \ [17]$$

where E is total water consumption, m^3/ha; N is moisture reserve at the beginning, m^3/ha; W is soil moisture reserve at the end, m^3/ha; P is precipitation during the growing season, m^3/ha; M is the seasonal irrigation rate, m^3/ha. T is the water use, m^3/ha. The total seepage water evaporation and consumption were determined depending on the seepage depth ($H_{d.r}$) and evaporation:

$$T = K \cdot E_0 \cdot \left(1 - \frac{H_{d.r}}{H_0^1}\right)^2, \ m^3/ha; \ [17]$$

where: K- the coefficient taking into account the characteristics of agricultural crops, K=1; H_0^1 is a parameter representing the depth and natural conditions of seepage waters (according to the results of observation in the experimental field), cm; $H_{d.r}$ - drying standard (drying standard 1.5-1.9 m is recommended when mineralization of seepage water is 1-3 g/l) 1.75 m was accepted for this region; E_0 - monthly evaporation, mm - water consumption for evaporation determined by the correction coefficient (0.8):

$$E_0 = 0{,}0018 \cdot 0{,}8 \cdot (25 + t)^2 \cdot (100 - RH); mm \ [17]$$

where t is average monthly temperature, ^{0}C; RH is average monthly relative humidity, %.

When calculating the total water consumption during subirrigation in the Khorezm region, the best conditions for cotton growing on heavy sandy soils with seepage water located at 1-2 m and mineralization of 1-3 g/l are in option 2, seasonal irrigation norms of 2018-2122 m^3/ha and total water consumption was generated when 6216-6966 m^3/ha. The use of soil moisture in the total water consumption is 7.7%, atmospheric precipitation is 5.3%, irrigation water is 32.4%, and the share of seepage water is 54.6%. In control option 1, the seasonal irrigation norms were 3614-3879 m^3/ha, and the total water consumption was 6476-6970 m^3/ha, 182.4-206.8 m^3/c per centner of cotton yield, that is, 23.5-37.2 m^3/c compared to option 2.

5. Conclusion

Global challenges increase demand for water, reducing water resources in Uzbekistan, exacerbating water scarcity, increasing the duration and frequency of droughts, raising issues of saving water resources. Subirrigation will provide a favorable reclamation regime of soils, increasing the yield of cotton by 4.2–6.3 c/ha and saving river water by 1596–1757 cbm/ha compared to traditional furrow irrigation with the total water consumption of 6216-6966 m^3/ha, when the soil moisture is 7.7%, atmospheric precipitation is 5.3%, irrigation water is 32.4%, and the share of seepage water is 54.6% with the total water consumption per quintal cotton crop of 145.2-183.3 m^3/t.

The introduction of the drip irrigation on meadow alluvial soils of the Khorezm region and the maintenance of pre-irrigation soil moisture at the level of 70–80–60% HB will create the best conditions, ensuring the raw cotton yield of 40.3 c/ha, irrigation rate of 2678–2698 cbm/ha, being 6.1–6.3 c/ha more and 1437–1472 cbm/ha less compared to traditional furrow irrigation. The total water consumption during drip irrigation was 4375-4757 m^3/ha with the soil moisture use of 11.0%, atmospheric precipitation of 7.5%, irrigation water of 53.2%, and the seepage water share of 28.3%.

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