Influence of soil water regime on cotton yield under mole irrigation in southern Russia

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Abstract. Studies on the features of mole irrigation of cotton were conducted at Volgograd State Agrarian University in 2023 on light-chestnut soils of southern Russia. One of the central tasks of our research was to determine the influence of soil water regime on cotton yield under mole irrigation compared with sprinkling and drip irrigation. As a result, it was found that the main component of the cotton soil water regime was the irrigation rate (more than 50 %). Its value at an increase of pre-watering soil moisture from 70-70-65 to 80-80-75 % LWC under mole irrigation increased from 1040 to 1270 m3/ha. As a result, total water consumption increased from 2175 to 2332 m3/ha, which, compared with sprinkling and drip irrigation, was less by 430...673 and 146...245 m3/ha, respectively. It was also found that the highest cotton yields were obtained when moisture availability was maintained at 75-75-70% LWC. Among irrigation methods, at mole irrigation on this variant, the yield occupied an intermediate position of 1.87...3.18 t/ha; at sprinkling, it decreased by 0.04...0.21 t/ha, and at drip irrigation, it increased by 0.10...0.18 t/ha.
Keywords. mole irrigation, cotton, water consumption

1 Introduction

Cotton is an essential agricultural crop. The products of this plant are used in many industries, but primarily in textiles, defense, chemicals, and medicine. Today, cotton is cultivated by about 70 nations, the global production of cotton fiber is about 26,000,000 tons annually, and the planted area covers 30,000,000 ha [1].

In the world, the primary method of cotton irrigation is still furrow irrigation, so, for example, in Central Asian countries, this method of irrigation is used in most cotton farms [2, 3]. However, due to the significant disadvantages of surface irrigation, to increase land use's productivity, it is necessary to switch to more efficient irrigation methods, such as sprinkling, drip, and in-soil irrigation. Today, sprinkling is used to a much lesser extent for cotton irrigation than furrow irrigation, and drip and in-soil irrigation is used only for test crops.

Currently, studies on cotton irrigation techniques and technology under different irrigation methods are carried out in many countries. Sprinkling is actively studied by

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scientists from China [4, 5], USA [6, 7], Republic of Uzbekistan [8], Pakistan [9], Australia [10], and others. Drip irrigation of cotton is being researched in China [11], India [12], Syria [13], USA [14] and others. However, the most promising way to irrigate cotton is subsurface irrigation – mole irrigation, which consists of a network of soil pipes cut annually by a special working body. Unlike those discussed above, this method does not require capital construction or high initial costs but simultaneously contributes to saving irrigation water and increasing crop yields. Such studies were carried out only in Uzbekistan [15, 16]. This is the first time such studies have been conducted in the Russian Federation.

One of the central tasks of our research was to determine the influence of soil water regime on cotton yield under mole irrigation compared with sprinkling and drip irrigation.

2 Materials and methods

The research was conducted in 2023 on the experimental fields of Volgograd State Agrarian University (VSAU). The experimental site was located in the southern part of Russia in the Volgograd Oblast. The climate here is characterized by cold, snowy winters and hot, dry summers.

The hydrothermal coefficient (HTC) of G.T. Selyaninov was used to assess weather conditions during field experiments. According to data from the Internet meteorological station “SOKOL-M” located at the experimental site, it is defined as the precipitation ratio to the average daily air temperatures. According to this indicator, weather conditions in 2023 were acutely dry (HTC was less than 0.4 and equal to 0.28).

Soils on the site are light-chestnut with humus content not more than 1-2%, medium and heavy loamy. Groundwater at the experimental site was at a depth of about 10 m and did not influence the soil water regime. The active soil layer for cotton was assumed to be 0.0-0.5 m since the central mass of roots under irrigation of this crop is located in the upper 40...50 cm layer [17].

The research was carried out with the cotton variety “PGSSH-1”. This variety was obtained by breeding scientists from VSAU together with colleagues from Uzbekistan specifically for the soil and climatic conditions of southern regions of Russia and is characterized by a shorter growing season [18].

In our experiments, 3 factors were studied: factor A – soil water regime, factor B – doses of mineral fertilizers, and factor C – irrigation method.

Since the main component of the soil water regime is the irrigation regime on factor A, 3 variants of differentiated irrigation regimes of cotton with the change of irrigation regime intensity in interphase periods “sprouting – budding”, “budding – fruiting” and “fruiting – beginning of ripening” were studied: 1 variant – maintenance of pre-irrigation soil moisture 70-70-65 % of the lowest water holding capacity (LWC); 2 variant – 75-75-70 % of LWC and 3 variant – 80-80-75 % of LWC.

Factor B (fertilizer doses) included 3 variants of calculated doses of mineral fertilizers: 1 variant – N70P30K23 kg of active ingredient (ai)/ha for 2 t/ha yield; 2 variant – N105P45K34 kg ai/ha for 3 t/ha yield; 3 variant – N140P60K45 kg ai/ha for 4 t/ha yield.

Factor C (irrigation method): 1 variant – sprinkling (E), 2 variant – drip irrigation (DO), 3 variant – mole in-soil irrigation (MISI).

The test was conducted four times.

Moisture reserves were determined in the 0.0-1.5 m layer immediately before sowing and immediately after cotton harvest. The difference between these values was considered when calculating the total water consumption of cotton.

Cotton yield was measured separately for each variant of the experiment by sampling sheaves from a plot of 1 m^2 (length of this plot – 1.1 m and width – 0.9 m) in 4-fold repetition in each variant. Yields per hectare were then recalculated.

3 Results and discussion

The soil water regime in our research was evaluated according to the regularities of changes in the primary constituent elements of total water consumption of cotton, the value of which is shown in Table 1.

Table 1. Structure of total cotton water consumption under different irrigation methods in 2023.

Pre-irrigation soil moisture, % LWC	Irrigation rate (M), m^3/ha	Moisture inflow from precipitation (P), m^3/ha	Soil moisture reserves (ΔW), m^3/ha	Total water consumption (E), m^3/ha	Share in total water consumption, %		
					M	P	ΔW
Sprinkling							
70-70-65 % LWC	1460	941	204	2605	56.0	36.1	7.8
75-75-70 % LWC	1630	941	162	2733	59.6	34.4	5.9
80-80-75 % LWC	1940	941	124	3005	64.6	31.3	4.1
Drip irrigation							
70-70-65 % LWC	1190	941	190	2321	51.3	40.5	8.2
75-75-70 % LWC	1370	941	135	2446	56.0	38.5	5.5
80-80-75 % LWC	1430	941	117	2488	57.5	37.8	4.7
Mole irrigation							
70-70-65 % LWC	1040	941	194	2175	47.8	43.3	8.9
75-75-70 % LWC	1090	941	170	2201	49.5	42.8	7.7
80-80-75 % LWC	1270	941	121	2332	54.5	40.4	5.2

In the absence of moisture inflow from groundwater at a depth of much more than 3 m, the main structural elements of total water consumption were irrigation norm, precipitation, and soil moisture reserves.

The studies showed that the total irrigation water discharge per season and the amount of moisture in the soil varied mainly depending on the level of soil water availability. When pre-watering soil moisture increased from 70-70-65 to 80-80-75 % LWC, the value of irrigation norm increased from 1460 to 1940 under sprinkling, from 1190 to 1430 under drip irrigation, and from 1040 to 1270 m3/ha under mole irrigation.

The primary source of moisture was irrigation. The share of irrigation water in total moisture consumption for cotton was 47.8...64.6 %. Its most significant influence on soil water regime (56.0...64.6 %) was observed under sprinkling irrigation. Under drip and mole irrigation, the share of total irrigation water volume per season decreased to 51.3...57.5 and 47.8...54.5 %, respectively.

On the contrary, the importance of precipitation in total moisture reserves for cotton increased from 31.3...36.1 % under sprinkling to 37.8...40.5 % under drip irrigation and 40.4...43.5 % under mole irrigation.

Soil moisture reserves had a similar effect. Under sprinkling, their share in total water consumption was 4.1...7.8 %. It increased to 4.7...8.2 % at drip irrigation and mole irrigation – to 5.2...8.9 %.

Thus, the conducted studies have shown that under mole irrigation, in comparison with sprinkling and drip irrigation, the influence of precipitation and soil moisture reserves on the soil water regime under cotton growing significantly increased.

The field experiments allowed to establish that the total irrigation water consumption per season and the soil's moisture volume varied mainly depending on the level of soil water availability. When pre-watering soil moisture increased from 70-70-65 to 80-80-75 % LWC, the value of soil moisture reserves decreased from 204 to 124 under sprinkling, from 190 to 117 under drip irrigation, and from 194 to 121 m3/ha under mole irrigation.

Irrigation water supply varied according to another pattern. The value of irrigation norm increased under sprinkling from 1460 to 1940, under drip irrigation – from 1190 to 1430, under mole irrigation – from 1040 to 1270 m3/ha.

Since the volume of irrigation water per season was the main component in total water use, it too increased from 2605 to 3005 under sprinkling, from 2321 to 2488 under drip irrigation, and from 2175 to 2332 m3/ha under mole irrigation.

At the same time, the highest total moisture consumption of 2605...3005 m3/ha was required when irrigating cotton with sprinkler equipment. Then it decreased to 2321...2488 m3/ha under drip irrigation, reaching minimum values of 2175...2332 m3/ha under mole irrigation.

Further analysis of the results showed that the soil water regime significantly affected cotton yield (Figure 1).

Thus, with the increase of pre-watering soil moisture from 70-70-75 to 75-75-70 % LWC, the cotton yield increased, reaching the highest values: from 1.6...2.47 to 1.8...2.97 t/ha under sprinkling, from 1.76...2.78 to 2.05...3.31 t/ha under drip irrigation and from 1.66...2.66 to 1.87...3.18 t/ha under mole irrigation. And then, on the variant with the most intensive irrigation regime of 80-80-75 % LWC, the yield decreased to 1.72...2.69, to 1.87...2.95, and 1.76...2.82 t/ha under sprinkling, drip, and mole irrigation, respectively.

A comparison of irrigation methods showed that yields under mole irrigation occupied an intermediate position, amounting to 1.66...3.18 t/ha. Under sprinkling, it decreased to 1.6...2.97 t/ha; under drip irrigation, it reached the highest value of 1.76...3.31 t/ha.

Since the irrigation regime on all agronomic backgrounds was the same, for example, the mathematical processing on the variants of the experiment with fertilizer doses N140P60K45 kg ai/ha is given.

In the course of statistical processing of the results, the equation of functional dependence of cotton yield on total water consumption under mole irrigation was obtained (Figure 2), describing the regularity of change quite reliably (approximation reliability coefficient $R^2 = 0.53$):

$$Y = -0.000145*E^{2} + 0.654049*E - 734.464812$$

This polynomial regression equation predicts the value of cotton yield under mole irrigation to be 2.5 to 3.2 t/ha (average of the four sires).

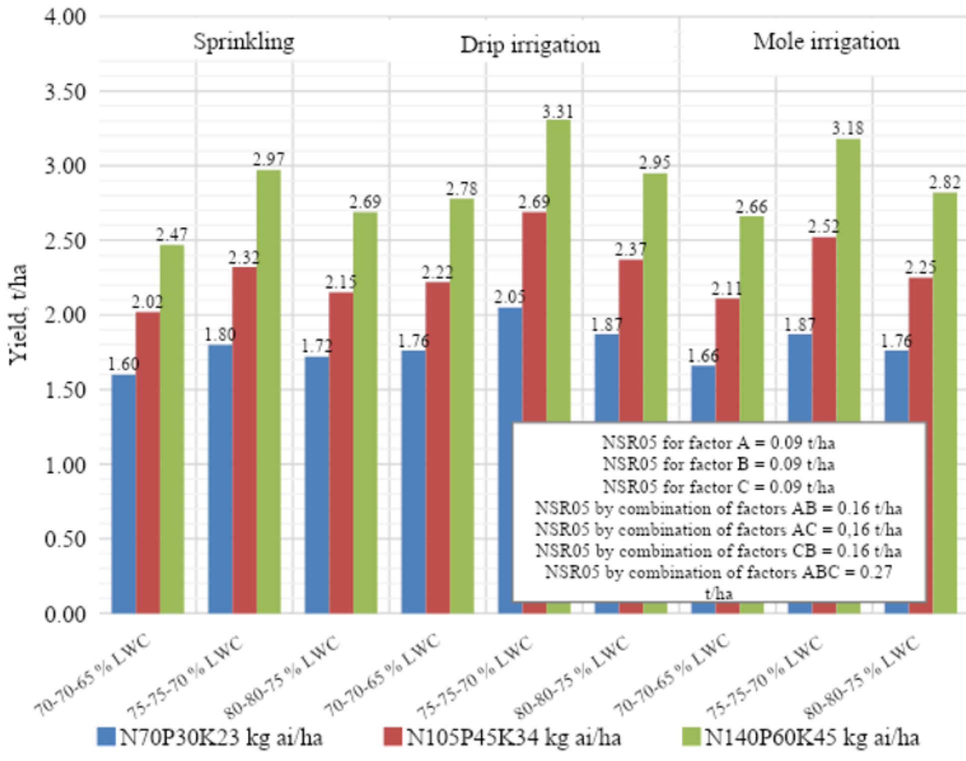

Fig. 1. Cotton yield under different irrigation methods in 2023.

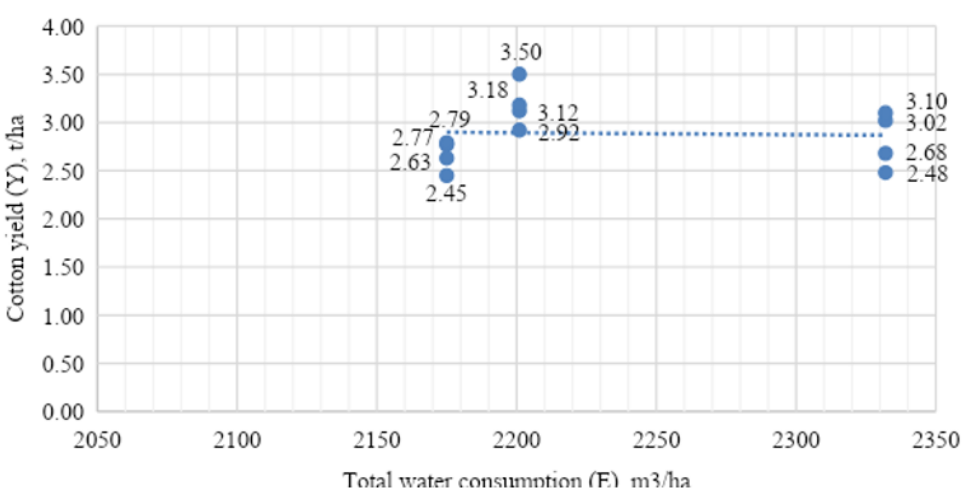

Fig. 2. The functional dependence of cotton yield on total water consumption under mole irrigation.

4 Conclusion

Thus, studies conducted in 2023 to study the peculiarities of mole irrigation of cotton on light-chestnut soils in southern Russia showed that the total irrigation water consumption per season and the amount of moisture in the soil varied mainly depending on the level of soil water availability. When pre-watering soil moisture increases from 70-70-65 to 80-80-75 % LWC, the value of irrigation norm increased from 1460 to 1940 under sprinkling, from 1190 to 1430 under drip irrigation, and from 1040 to 1270 m3/ha under mole irrigation, while soil moisture reserves on the contrary decreased from 204 to 124, from 190 to 117, and from 194 to 121 m3/ha, respectively. Moisture inflow from precipitation remained unchanged and amounted to 941 m3/ha.

The main component of total cotton water consumption was irrigation water. Its most significant influence on soil water regime (56.0...64.6 %) was observed under sprinkling irrigation. Under drip and mole irrigation, the share of irrigation water from the total volume per season decreased to 51.3...57.5 and 47.8...54.5 %, respectively.

Consequently, under mole irrigation, in comparison with other irrigation methods, the influence of precipitation and soil moisture reserves on soil water regime during cotton growing increased significantly, as they totaled 45.6...52.2 %.

Since irrigation water was the main component of total water consumption, it also increased with increasing pre-irrigation soil moisture from 70-70-65 to 80-80-75 % LWC, reaching the highest values under sprinkling – from 2605 to 3005; from 2321 to 2488 – under drip irrigation and from 2175 to 2332 m3/ha under mole irrigation, where it was the lowest.

It was also found that the highest cotton yields were obtained when moisture availability was maintained at 75-75-70% LWC. Among irrigation methods, at mole irrigation at this variant of irrigation regime, the yield occupied an intermediate position of 1.87...3.18 t/ha; at sprinkling, it decreased by 0.04...0.21 t/ha, and at drip irrigation, it increased by 0.10...0.18 t/ha.

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