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Efficiency of irrigation water discharged to furrows in combating irrigation erosion

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Abstract. In this paper, the approach to reduce the risk of irrigation erosion in the irrigated areas where ‘Andijan 37’ and ‘Namangan 77’ varieties of cotton were sowed, in which the topsoil is formed by typical gray soils and which are vulnerable to erosion, was validated. In cotton irrigation, while watering with a device with a 15 mm of irrigation hollow, the cotton water-demand was improved and an optimal and favorable condition to uptake the potential moisture and nutrient for cotton breeding was created. This enabled to harvest 3.6 quintals more cotton yield per ha in contrast to the usual condition, to gain the net profit accounted for 700,309 sums per ha, and to improve the profitability by 38%.

1. Introduction

Today, over 1 billion ha or 56% of arable land worldwide suffer from irrigation erosion percent, including 81% in Australia, 74% in Central America, 63% in North America, 50.6% in South America, 52.3% in Europe, 59.0% in Asia and 46.0% in Africa [10, 13, 15]. Also, due to irrigation erosion around the world, 75 billion tons of topsoil is lost annually in agriculture. Irrigation erosion leads to a deterioration of plant nutrition and soil reclamation, agrochemical and agrophysical properties of soil and plant, crop yields, and product quality [12, 17, 18, 24].

In the world's cotton industry, drip and rain pipe irrigation and irrigation with flexible plastic tubes have been revealed to save irrigation water by 50-60% and to increase the yield of cotton by 8 to 10 quintals per ha due to the efficient use of irrigation water and preservation of the fertile soil layer [19, 20]. In this regard, additional studies are needed to undertake to improve intensive methods of agricultural production, up-to-the-date water and resource-saving agro-technologies in the context of deteriorating land reclamation in the process of water scarcity and irrigation erosion.

Considering all the above, the government of Uzbekistan decided in the policy-making to endorse the urgent scientific studies in the country dedicated to saving irrigation water, a reduction of the erosion risk in agriculture, keeping the living environment clean and safe, and maintaining the fertile soil layer after watering the cotton fields in irrigated lands [1, 2, 3].



Several local and international scientists have investigated and scrutinized a number of approaches to reduce the risk of irrigation erosion, maintain and increase soil fertility, improve the yield and technological properties of cotton, protect the environment from (non-)point-source pollution, inspect the origin of irrigation erosion and its negative consequences in saving irrigation water, mineral fertilizers, and soil fertility [11, 14, 16, 21, 22, 23]. As a result, they recommended probing several existing sustainable furrow irrigation methods through additional fieldwork since the water-saving irrigation technologies have almost failed to irrigate the cotton fields which is prone to irrigation erosion. In regards to this recommendation, this paper aims to save irrigation water in the cotton fields susceptible to erosion and to determine the effectiveness of sustainable furrow irrigation system in combating erosion, excessive water consumption, mitigation of erosion processes, maintaining soil fertility, and cotton quality. Aligned with and achieving the research goal, numerous research objectives were formulated below:

- determination of the slope level of cotton fields prone to irrigation erosion;
- by means of saving irrigation water on the identified slopes, to ascertain the adequate norms and conditions to reduce erosion processes and to irrigate the cotton fields;
- to calculate the amount of water discharged to irrigate cotton (in each irrigation, water delivered, sewage water, water infiltration);
- to study of the irrigation erosion impact on the growth and yield of cotton;
- determination of the effectiveness of irrigation by using a cotton irrigation system in soils susceptible to irrigation erosion.

2. Materials and methods

2.1. Study area

In typical irrigated gray soils of the Tashkent province, a device for calculating the amount of irrigation water consumption in the cotton fields, where the medium-fiber cotton varieties ‘Andijan 37’ and ‘Namangan 77’ were sowed, was examined.

Scientific research on the basis of the working program for 2011 and 2014 years in the experimental farms named ‘Akkavak’ of the Scientific Research Institute of Cotton Breeding, Seed Production and Cultivation Agrotechnology (SRICBSPCA) under Uzbekistan Academy of Sciences in the Kibray administrative district of Tashkent province with 1.5° slope, for the 2012 year in the farmyard ‘Buviniso Bakht’ with 2.5° slope in the Yangiyul administrative district of Tashkent province, and for the 2013 year in ‘Kulakhmat ota’ farmyard in the Chinaz administrative district of Tashkent province with 3.5° slope was conducted. These study areas have the typical gray and mechanically heavy sandy soils suffering irrigation erosion, low groundwater level, and non-salinated soils.

Due to climatic conditions, Tashkent province is located in the arid zone and is the north-eastern part of the cotton-growing region. Winters are much colder, and in spring, air temperature rises rapidly, but spring frosts often return, causing a moderate damage to agricultural crops. Summers are dry, almost without precipitation, with high air temperatures, reaching 40–43 °C in July and August. Autumn is warm and continental, and the first frosts are usually observed on October 20. In all years of research, optimal growth and development of cotton and favorable conditions for timely harvesting were observed in summer and autumn.

2.2. Research subjects

In the conditions of typical gray soils, which have been irrigated for a long time and are vulnerable to irrigation erosion, the efficiency of using a water-saving furrow irrigation device is to reduce water consumption and soil erosion processes, maintain soil fertility, and grow high-quality raw cotton from cotton fields.

2.3. Methodology

Conducting field experiments and all in-situ measurements, observations, and calculations were carried out according to the 'Methods of field experiments' [7, 8, 9]. Besides that the analyses were conducted to determine the amount of soil nutrients and vegetation with respect to the 'Methods of agrochemical and agrophysical research in irrigated cotton fields' [4, 5, 6]. The primary data derived from the in-situ field work were then analysed according to Dospekhov's dispersion mathematical-statistical analysis method entitled 'Methodology of field experiment' [7] and SPSS (Statistical Package for Social Science) software.

Factors leading to soil leaching are usually determined by equations. During the research, the slope of the area, the length of the slope, and the degree of slope in the prevention of soil erosion were determined according to scientific recommendations developed by Professor Kuznetsov, Academician Mirzajonov [13, 14]. Theoretical calculations on the flow speed and irrigation norms of irrigation water in the field were developed, and on the basis of these calculations, Professor Arifjanov, Academician Mirzajonov and Senior researcher Rakhmonov developed an equation to calculate the flow of water through the irrigation hollow considering the laws of flow motion, widely used in hydraulics, and to measure the flow of water from the irrigation device [20].

Equation 1 below shows the general equation for determining the water discharge from the irrigation hollows:

$$Q = \mu \times \omega \times \sqrt{2 \times g \times H} \quad (1)$$

Where:

Q – water discharge; ω – surface of the hole; g – gravitational constant; H – pressure in the hole; and, μ – discharge coefficient (for circled holes, $\mu = 0,61$).

Furrow technical sizes are determined depending on the amount of water discharged. To prevent erosion processes in the study areas during the research, water discharge was determined depending on the slope of the cropyard. In this regard, the pressure in the irrigation hollow of the device was determined, and the discharge coefficient was calculated with respect to Equation 2 below:

$$\omega = \frac{Q}{\mu \times \sqrt{2 \times g \times H}} \quad (2)$$

After having calculated and determined the required values, the diameter (d) of the irrigation hollow of the device was determined as follows in Equation 3:

$$d = \sqrt{\frac{\omega}{0.785}} \quad (3)$$

In cotton irrigation, water delivery devices used in this study were prepared on-site and experiments were carried out in the study areas.

2.4. Scientific and practical significance of the research

The scientific significance of the results of the study is to theoretically justify the determination of the effectiveness of the use of a new sustainable furrow irrigation device in typical gray soils, irrigated eroded soils, and cotton irrigation and the improvement of the cotton growth and development by saving irrigation water and preventing erosion processes which result in increased and high quality cotton yield.

The practical significance of the research output is to validate the determination of the careless use of irrigation water, the prevention of soil fertile layer leaching, the improvement of cotton yield, and the reduction of labor by applying a tested sustainable furrow irrigation device and ensuring that the device is delivering the parallel amount of irrigation water to each furrow in typical gray soils subject to irrigation erosion.

3. Results and Discussion

According to the results of this study, the agrochemical properties of typical gray soils in the experimental fields of the 'Akkavak' experimental farm of SRICBSPCA suffering irrigation erosion, are as follows: humus content accounted for 0.928% in the 0-30 cm soil layer and 0.774% in the 30-50 cm layer, following nitrogen 0.7% in the 0-30 cm soil layer and 0.059% in the 30-50 cm layer; and, phosphorus 0.098% in the 0-30 cm soil layer and 0.085% in the 30-50 cm layer. Nitrate nitrogen outnumbered 9.36 mg/kg in the 0-30 cm layer and 9.05 mg/kg in the 30-50 cm, following propellant phosphorus 30.32 mg/kg and 26.76 mg/kg, and exchangeable potassium 165 mg/kg and 128 mg/kg respectively.

'Buviniso Bakht' farmyard of the Yangiyul district, where typical irrigated gray soils are widespread, has 0.922% of humus in the 0-30 cm cultivation layer and 0.773% in the 30-50 cm layer, following nitrogen 0.073% in the 0-30 cm soil layer and 0.058% in the 30-50 cm layer; and, phosphorus 0.097% in the 0-30 cm soil layer and 0.087% in the 30-50 cm layer. Nitrate nitrogen outnumbered 9.35 mg/kg in the 0-30 cm layer and 9.07 mg/kg in the 30-50 cm, following propellant phosphorus 30.33 mg/kg and 26.77 mg/kg, and exchangeable potassium 164 mg/kg and 127 mg/kg respectively.

In the farm with irrigated typical gray soils named after 'Kulakhmat ota' in the Chinoz district, humus accounted for 0.633% in the layer 0-30 cm and 0.548% in the 30-50 cm layer, following nitrogen 0.057% in the 0-30 cm soil layer and 0.043% in the 30-50 cm layer; and, phosphorus 0.106% in the 0-30 cm soil layer and 0.1% in the 30-50 cm layer. Nitrate nitrogen constituted 9.62 mg/kg in the 0-30 cm layer and 9.12 mg/kg in the 30-50 cm, following propellant phosphorus 29.62 mg/kg and 25.56 mg/kg, and exchangeable potassium 150 mg/kg and 120 mg/kg respectively.

The study areas were found to be low in humus, nitrogen and potassium, and moderately supplied with phosphorus, and in the harvest of increased yield and high-quality crops, it is necessary to use mineral fertilizers rich in nitrogen and potassium and moderately in phosphorus.

The data on the volume mass of the soil showed that 1.26 g/cm³ in the plowing layer of 0-30 cm and 1.32 g/cm³ in the 30-50 cm layer of typical irrigated gray soils of the experimental fields prone to irrigation erosion of the 'Akkavak' experimental farm of SRICBSPCA were determined, following 1.29 g/cm³ in the 0-30 cm layer and 1.37 g/cm³ in the 30-50 cm soil layer of the farm 'Buviniso Bakht' of the Yangiyul district, 1.28 g/cm³ in the 0-30 cm layer and 1.37 g/cm³ in the 30-50 cm soil layer of the farm 'Kulakhmat ota' of the Chinoz district.

The soil water permeability in the 'Akkavak' experimental fields with the eroded typical irrigated gray soils of SRICBSPCA was studied. At the beginning of the irrigation period, an average of 183.3 m³ of irrigation water per ha discharged for six hours, and at the end of the period, the irrigation device with a hollow diameter of 15 mm was found to discharge an average of 7 m³ of irrigation water per ha within an hour. In regards to the the farm 'Buviniso Bakht' of the Yangiyul district, at the beginning of the period, an average of 198.2 m³ of irrigation water per ha discharged for six hours, and at the end of the period, the irrigation device with a hollow diameter of 15 mm was found to discharge an average of 8.5 m³ of irrigation water per ha within an hour.

In the study of soils of the farm 'Kulakhmat ota' in the Chinaz district, at the beginning of the operation period, an average of 198.2 m³/ha of water poured for six hours, at the end of the irrigation, the irrigation device with a hollow diameter of 15 mm was determined to discharge an average of 8.5 m³ of irrigation water per ha within an hour.

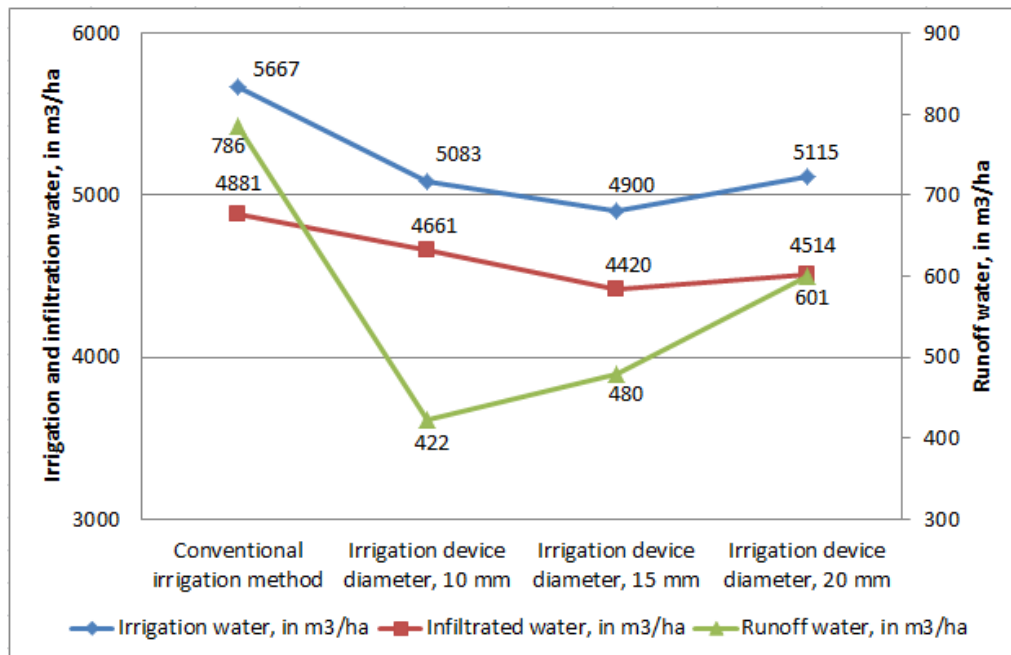
Since the 65-75-65% of the Field Moisture Holding Capacity (FMHC) was used as an optimal regime for typical gray soils through the traditional irrigation method for determining the amount of water per hectare of irrigated land in previous years, this regime was also selected and the following results were obtained (Table 1).

In determining the irrigation duration of cotton, the correlation between the refractometer and the cell sap concentration (CSC) of the cotton leaf was to be close to the actual 65-75-65% in the FMHC, and on the basis of these data cotton fields were irrigated according to the CSC values.

Table 1. Correlation of the FMHC and refractometer in determining the amount and duration of cotton irrigation in soils affected by irrigation erosion

Options	Pre-flowering	Flowering and blooming	Ripening
Irrigation schedule is 65–75–65% of the plan compared to the FMHC			
During observations	Average during the season		
	66	74	67
	Refractometer readings		
Conventional irrigation method	12.5	16.5	12.4
Irrigation device diameter, 10 mm	11.8	15.5	12.0
Irrigation device diameter, 15 mm	12.1	16.0	12.2
Irrigation device diameter, 20 mm	12.3	16.4	12.3

During the experiments conducted in the ‘Akkavak’ fields with the slope of 1.5⁰ of SRICBSPCA with the traditional method of irrigating cotton and the consecutive 10, 15, and 20 mm hollow diameters of irrigation devices, cotton was irrigated five times, and the seasonal irrigation water norm (in 2011) in the option 1 (traditional irrigation method) was 5,667.0 m³/ha (Figure 1). Irrigation water infiltrated into the soil was 4,881 m³/ha and the runoff accounted for 786 m³/ha by irrigating with a 10 hollow diameter of irrigation device (option 2), the total amount of irrigation water discharged to each furrow through the option 2 constituted 5,082 m³/ha. In accordance with the above indicators, 4661 and 422 m³/ha, and 4900 m³/ha water discharged when the hollow diameter of irrigation device in the option 3 was 15 mm. Moreover, 4420 and 480 m³/ha, and 5115 m³/ha as the seasonal irrigation norm, irrigation water discharged when the hollow diameter of irrigation device in the option 4 was 20 mm.

**Figure 1.** Irrigation norms for cotton and runoff water in soils affected by irrigation erosion (source: ‘Akkavak’ Experimental Fields under PSUEAITI, 2011)

In experiments on soils vulnerable to irrigation erosion of the farm 'Buviniso Bakht' of the Yangiyul district with the slope of 2.5° , and on the soil of the farm 'Kulakhmat ota' in the Chinoz district with a slope of 3.5° , cotton was irrigated five times and the seasonal water norm was $5,776-6,293 \text{ m}^3/\text{ha}$ in the option 1 (traditional irrigation method), following water infiltrated into the soil (net) $4,869-4,737 \text{ m}^3/\text{ha}$, and runoff $897-1,556 \text{ m}^3/\text{ha}$. While irrigating with the irrigation device with a 10 mm hollow diameter, the irrigation water norm was equal to $5,175-4,622 \text{ m}^3/\text{ha}$ and for infiltration and runoff, $4,674-4,585 \text{ m}^3/\text{ha}$ and $501-661 \text{ m}^3/\text{ha}$ of water discharged. In accordance with the above parameters, when water is delivered to each field with a hollow diameter of 15 mm of the irrigation device, $5,246-5,273$, $4,585-4505$, and $661-768 \text{ m}^3/\text{ha}$ of irrigation was used respectively, following in option 4, the seasonal irrigation norm $5,394-5,831 \text{ m}^3/\text{ha}$, the infiltrated water $4,530-4,550 \text{ m}^3/\text{ha}$, and the runoff water $688-1,281 \text{ m}^3/\text{ha}$.

Figure 2 below represents the amount of fertile soil leached when irrigating cotton in eroded fields with the conventional irrigation method and 10, 15, and 20 hollow diameter of irrigation devices on irrigated areas. In the 'Akkavak' experimental fields of SRICBSPCA, when cotton was irrigated five consecutive times with a hollow diameter of 10, 15, 20 mm irrigation device, 18.3, 19.2, and 22.1 tons of fertile soil per ha were lost.

In experiments on the farms 'Buviniso Bakht' in the Yangiyul district with a slope of 2.5° and 'Kulakhmat ota' in the Chinoz district with a slope of 3.5° suffering irrigation erosion, compared to the traditional method of cotton irrigation in which cotton was irrigated five times, 18.7-19.5, 20-20.9, and 22.4-24.1 tons of soil leached per ha when the hollow diameter of the irrigation device was 10, 15, and 20 mm respectively.

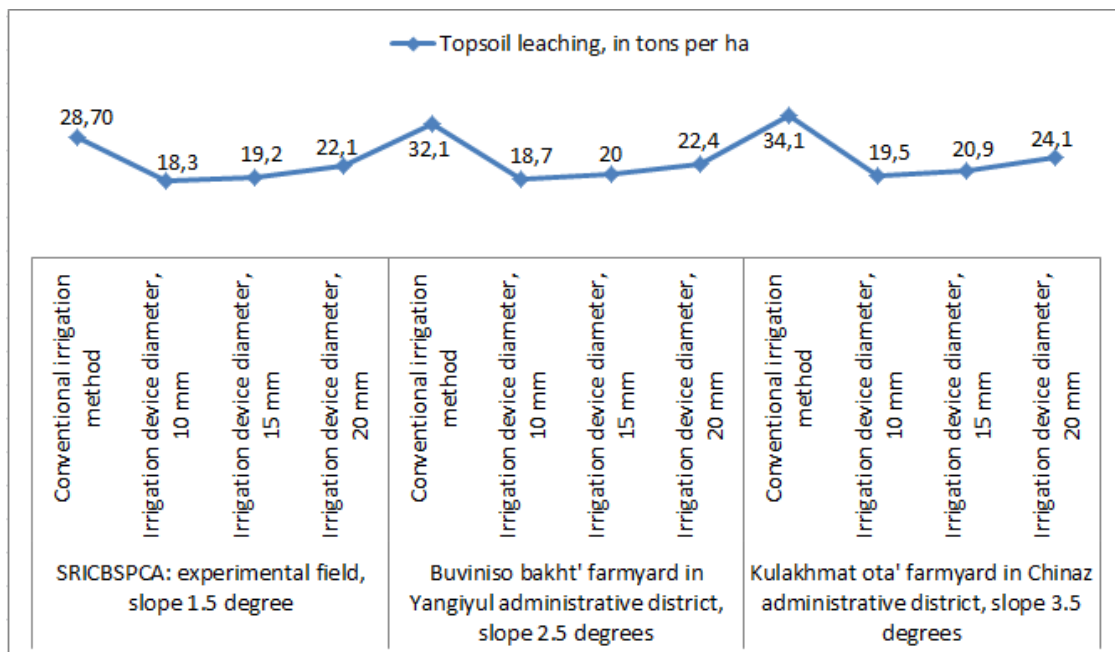


Figure 2. Influence of irrigation methods on the amount of topsoil leaching in cotton fields subject to irrigation erosion

In the cotton fields with irrigation erosion to prevent leaching of fertile soil layer, the same amount of water is distributed to each field to irrigate. So that when irrigating in slopes with an irrigation device with a hollow diameter of 15 mm, 9.5, 12.1, and 13.2 tons of fertile soil per ha were preserved, which in turn created an optimal environment for the growth and development of cotton.

It was noted that the growth and development of cotton depends on many factors, including local habitat, air temperature, soil moisture and its agrochemical, agrophysical, microbiological properties, as well as the severity of erosion. During the experiments, the effects of the traditional irrigation

method and irrigation devices on the growth and productivity of cotton were studied in the fields subject to irrigation erosion. The results of SRICBSPCA experiments on a 1.5° slope field in the 'Akkavak' farmyards were presented in Table 2, which provided optimal conditions for the growth of cotton when irrigated with a 15 mm hollow diameter of an irrigation device compared to the traditional irrigation method.

Table 2. Influence of irrigation method on cotton growth, development and yield in soils affected by irrigation erosion (*SRICBSPCA*, 2011).

Options, irrigation method, device hollow diameter	June 1, 2011		July 1, 2011			August 1, 2011			September 1, 2011		Cotton yield, quintal/sha	Additional yield, quintals/ha	
	Height, cm	Number of leaves	Height, cm	Number of bloomed branches	Number of flowers	Height, cm	Number of bloomed branches	Number of flowers	Cocoons	Number of live cocoons			Number of bloomed cocoons
Conventional irrigation method	11.5	4.5	25.1	4.2	4.4	70.0	10.3	5.3	3.8	7.5	5.0	23.8	–
Irrigation device diameter, 10 mm	12.4	5.0	28.9	4.9	5.1	70.6	11.6	6.5	4.2	9.3	4.8	24.9	1.1
Irrigation device diameter, 15 mm	12.6	5.2	30.0	5.0	5.5	82.4	12.5	7.2	4.5	10.7	6.0	27.0	3.2
Irrigation device diameter, 20 mm	11.7	4.8	26.7	4.8	4.9	78.0	12.2	6.8	4.0	8.2	5.5	25.8	2.0
$HCP_{05} =$												0.19 q/ha	
$HCP_{05} =$												0.76 %	

In such experiments conducted in the farm 'Buviniso Bakht' located in the Yangiyul district, with a slope of 2.5° and the farm 'Kulakhmat ota' in the Chinoz district with a slope of 3.5°, during irrigating with a 15 mm hollow diameter of an irrigation device, favorable conditions for the growth and development of cotton were created, and additional 4.2-4.6 more quintals per ha of cotton yield were harvested.

The efficient use of water in such fields susceptible to irrigation erosion when irrigated by a 15 mm hollow diameter of an irrigation device was found to reduce the erosion risk and its processes, and provide adequate results in the cultivation of high-quality cotton yield.

In eroded soils of Tashkent province, cotton irrigation with an irrigation device allows to harvest a high-quality cotton yield due to the preservation of fertile soil layer. The acme point of cotton fibering was 37.5% while watering with a 15 mm hollow diameter of an irrigation device, and the weight of

1000 cotton seeds accounted for 110 g. In comparison with other cotton varieties, these results above mainly dedicated to the 'Andijan-37' cotton variety.

The experiments carried out in cotton production in 2016-2017 in the conditions of the irrigated gray soils of the farm 'Abduvali Muhriddin Agro' located in the Urta Chirchik district of Tashkent province on eroded soils with a slope of 3.5°. Such experiments were undertaken in the fields where the medium-fiber cotton variety 'Namangan-77' was planted, and soil agro-technical measures were carried out on the basis of agricultural techniques adopted by the farm. In the traditional method of irrigation, the norm of seasonal irrigation water was 6,499 m³/ha, with a runoff of 2,070 m³/ha, and 36.7 tons of dusty and muddy soil particles were washed away from the furrows per ha. When irrigating cotton with a 15 mm hollow diameter of an irrigation device, the seasonal irrigation norm was 5,600 m³/ha, with a runoff of 1,124 m³/ha, and it was validated in the observations and analyzes that 20.9 tons of muddy soil particles per ha were leached.

Phenological observations on the growth and development of cotton plant in production were given according to the data of August 2016. The farm was irrigated using the traditional method, which affected the length of cotton to be 74.5 cm, the number of branches to be 9.7, the number of cocoons to be 6.6. When irrigating cotton using a 15 mm hollow diameter of an irrigation device, the same above-mentioned indicators were 87.1 cm, 13.3, and 9.0 respectively. As of September, the total number of cocoons in the cotton field was 7.8, of which 5.9 matured as a result of the traditional irrigation method, and the total number of cocoons was 12.4, of which 5.6 opened when irrigating cotton with a 15 mm irrigation device. The yield was 30.0 quintals per ha when irrigating with a traditional method, while the yield accounted for 34.2 quintals per ha when cotton was irrigated with a 15 mm irrigation device.

The agro-technical measures taken in the care of cotton were the same for both, the traditional method of irrigation and a 10 mm hollow diameter of an irrigation device. When using irrigation devices with 15 hollow diameter, compared to the traditional method, 640 m³/ha of irrigation water was saved; the amount of fertile soil leached reduced by 50%, and an average of 3.6 quintal per ha of additional cotton yield was grown, enabling to profit 700,309 soums (about \$70 per ha) and the level of profitability was 38.0%.

4. Conclusion

To reduce erosion processes in the typical gray soils of Tashkent province, to use water efficiently, to grow high-quality cotton, to protect the environment from agrochemicals, by using a 15 mm hollow diameter of an irrigation device, the irrigation water flow speed to be 0.15 liter per second and fertilizing soil with reference to the norm of mineral fertilizers N₂₀₀, P₁₄₀ K₁₀₀ kg/ha when the slope is 1.5° and N₂₅₀, P₁₇₅, K₁₂₅ kg/ha with a slope of 2.5° and 3.5° are recommended. Besides that the use of a rapid refractometer method to determine the water demand of cotton is advised.

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