DOI 10.37539/2949-1991.2026.41.6.018

Azizli Rauf Aziz Ogly, student,
Azerbaijan State Agrarian University
ORCİD-0009-0008-0636-7758

THE EFFECT OF MODERN IRRIGATION TECHNOLOGIES ON THE TECHNOLOGICAL INDICATORS OF COTTON FIBER UNDER THE SOIL AND CLIMATIC CONDITIONS OF THE CENTRAL ARAN ECONOMIC REGION

Abstract. The research work is devoted to the study of the effect of modern irrigation technologies on the technological indicators of cotton fiber under the soil and climatic conditions of the Central Aran Economic Region. The agro-climatic characteristics of the region, the physicochemical parameters of the soil cover, and the water supply requirements of the cotton plant were analyzed. Under the conditions of high temperatures, low precipitation, and insufficient soil moisture observed in the Central Aran region, the effect of the irrigation regime on cotton productivity and fiber quality was evaluated.

During the research, the stages of cotton fiber formation, the changes caused by water stress at the cellular level, and the effects of these changes on fiber length, strength, micronaire value, uniformity index, and color quality were investigated. Problems caused by the traditional furrow irrigation method, such as water losses, soil salinization, oxygen deficiency, and nutrient leaching, were identified.

The technical characteristics, operating principles, and application possibilities of modern surface and subsurface drip irrigation systems were analyzed, and it was shown that these technologies play an important role in improving the quality indicators of cotton fiber. It was determined that the drip irrigation system maintains stable soil moisture, ensures the normal development of fiber cells, intensifies cellulose synthesis, forms the micronaire value at an optimal level, and increases fiber length and strength/

Keywords: Cotton fiber, Drip irrigation technology, Central Aran Economic Region, Technological indicators of fiber/

Introduction

In the development of the non-oil sector of the Republic of Azerbaijan, particularly in the agricultural industry, cotton growing is one of the strategic sectors that creates a value chain worth millions [1]. Historically referred to as “white gold,” cotton plays a decisive role in strengthening the country’s export potential and ensuring employment for the rural population. However, under the conditions of modern global climate change, the sharp decline in water resources, rising temperatures, and frequent droughts pose a serious threat to both the quantitative and qualitative indicators of cotton production. From this perspective, the intensive development of cotton growing is possible not only through the expansion of cultivated areas, but also through improving the quality of the yield obtained per unit area and ensuring the efficient use of resources, especially water.

Agro-Climatic and Soil Potential of the Central Aran Economic Region

The Central Aran Economic Region is distinguished by its high heat reserves, which are thermally highly favorable for the growth and development of the cotton plant. However, the moisture conditions of the region are assessed as extremely inadequate. The climate is mainly dry continental and semi-desert in nature. During the summer season, particularly in June–September, which coincides with the intensive development, flowering, and boll formation stages of cotton, air temperatures frequently exceed 35℃ and in some years even reach 40℃ [7]. During this period, atmospheric precipitation is minimal, which results in a sharp increase in evaporation (evapotranspiration) against the background of high temperatures. Although the cotton plant requires 700−1200 mm of water throughout the entire season for normal vegetation, natural precipitation can meet only a small part of this requirement [1].

The soil cover of the region has complex physicochemical properties. Gray, gray-meadow, partially saline, and clay-textured soils are predominant. The water-physical properties of these soils, especially their water permeability and filtration capacity, are very poor. In the Central Aran region, during the middle of summer (in July), the moisture reserve in the 30 cm active root layer of the soil decreases to 40% of Field Capacity (FC), while at the beginning of September it falls to 40−60% in the one-meter soil layer [1]. Such a severe moisture deficit causes cotton plants to stop developing prematurely and the process of fiber formation to remain incomplete.

When traditional irrigation methods are applied to soils with a heavy mechanical composition, another unfavorable topographic and structural problem emerges. The low filtration capacity of the upper soil layer and the application of irrigation water in the form of large droplets destroy the soil structure, causing the upper 2-3 cm layer to swell and, after drying, to form a hard crust [4]. This makes soil aeration (air exchange) difficult and further reduces the infiltration rate of water, resulting in surface runoff (water loss) of up to 30% on slopes. Under such conditions, irrigation management that preserves soil structure, reduces evaporation, and maintains a stable moisture balance should be applied in order to optimally manage both the water and air regimes of cotton.

Cellular Development Physiology of Cotton Fiber and Mechanisms of Water Stress

Botanically, cotton fiber is a natural cellulose tube formed as a result of the differentiation and elongation of single cells located in the upper layer (epidermis) of the cotton seed. Fiber formation proceeds in three main physiological stages over a period of approximately 45−60 days, beginning on the day of flowering and continuing until the complete opening of the boll [3]:

1. Elongation Stage

During this stage, which covers the first 20 days after flowering, epidermal cells elongate approximately 1200−1500 times more than their width and reach their final length. The driving force behind such intensive elongation of the cell is internal turgor pressure. Turgor pressure (Ψ_p) is determined by the difference between the total water potential of the cell (Ψ_w) and the osmotic potential (Ψ_s):

$$\Psi_p = \Psi_w - \Psi_s \quad (1)$$

If the plant experiences water stress during this stage, Ψ_w decreases sharply, which leads to a decrease in turgor pressure, weakening of the elastic extension of the cell wall (the activity of expansin proteins), and a shorter fiber staple length.

2. Thickening (Secondary Wall Deposition) Stage

During this period, which lasts approximately from the 20th to the 40th day after flowering, a secondary cellulose wall forms beneath the primary wall inside the cell. Cellulose molecules (C_6 H_10 O_5 polymers) are arranged spirally in the fiber wall and begin to fill the internal cavity (lumen) of the fiber. This process directly depends on the intensity of photosynthesis in the plant and the rate at which the resulting carbohydrates (sucrose) are transported to the bolls. When water deficiency occurs, the photosynthetic apparatus is damaged, respiratory losses increase, and cellulose deposition remains incomplete, resulting in thin (immature) fiber walls. On the other hand, the short-haired "fuzz" fibers, which are another type of plant fiber, begin to elongate 6-8 days after flowering and thicken within a very short period, developing a coarse structure [3].

3. Drying and Opening Stage

At this stage, as the boll opens, the free water within the fiber evaporates, the cylindrical cell shrinks and flattens, and a kidney-shaped cross-section is formed. During the drying process, the fibers acquire their natural twists (convolutions), which enable the fibers to interlock and form a strong structure during yarn spinning.

Water supply plays a regulatory role at the cellular level during each of these three stages. Any sharp change in moisture during any developmental phase disrupts the degree of crystallinity of the cellulose chains and reduces the mechanical quality of the fiber.

Hydraulic and Physiological Shortcomings of Traditional Furrow Irrigation

The furrow irrigation method, which is still widely used in the Central Aran region, has a number of serious disadvantages from the perspectives of both agricultural hydraulics and plant physiology. First of all, the amount of water supplied to the field during one irrigation cycle (irrigation rate) is very high in this method (usually 12000−16000 m3/ha or more). High irrigation rates cause the following consequences, which deteriorate the water-physical properties of the soil and plant-soil relationships:

Insufficient Soil Aeration and Anoxia (Oxygen Deficiency)

Immediately after furrow irrigation is applied, the soil profile becomes completely saturated with water and the air in the pores is displaced. Since water filtration proceeds very slowly in the heavy clay soils of the Aran region, an oxygen-deficient (anoxic) environment forms in the root zone and persists for several days. Because respiration in the root system stops, active metabolic processes in the plant, including the absorption of minerals (especially potassium), are sharply weakened. Potassium deficiency, in turn, leads to a sharp decrease in fiber wall thickness (micronaire) and mechanical strength.

Sharp Moisture Fluctuations and Water Stress

The interval between furrow irrigation applications is usually long (15-20 days, depending on local conditions). While the soil becomes excessively saturated with water immediately after irrigation, it dries out completely before the next irrigation, and the plant is exposed to severe water deficit. Such sharp “wet-dry” cycles (moisture fluctuations) disrupt the growth dynamics of the plant. During periods of water stress, leaf area decreases, transpiration weakens, plant growth is stunted, and generative organs (flowers and bolls) are shed in large numbers (aborted).

Soil Salinization and Rising Groundwater Levels

The application of large volumes of water to the soil causes groundwater levels to rise to a critical threshold. The mineralized groundwater of the Central Aran region rises through capillary pathways, evaporates, and accumulates salts in the active root zone of the soil. High salinity limits the osmotic water absorption capacity of cotton roots (creates physiological drought), which directly has a negative effect on both fiber length and strength.

Nutrient Leaching

Water flowing through furrows washes nitrogen fertilizers (especially in nitrate form) from the active root layer into deeper layers (leaching), which disrupts the nutritional balance of the plant and sharply reduces fertilizer efficiency.

Engineering and Technological Parameters of Modern Irrigation Systems

Among the modern irrigation technologies applied under the conditions of the Central Aran region, surface drip irrigation and subsurface drip irrigation (SDI) systems demonstrate the highest efficiency. The engineering design and operational parameters of these systems are planned in accordance with the infiltration capacity of the soil, cotton planting density, and the quality of the region’s water sources.

1. Drip Lines and Dripper (Emitter) Specifications

Since the water absorption rate of the heavy clay soils of the Central Aran region is very low, low-flow emitters are used to prevent surface runoff. Emitters that deliver 0.68-1.5 liters of water per hour (0.18-0.4 GPH) are generally preferred. In sloping or uneven areas, pressure-compensating drip lines (DripNet PC or UniRam) are used to ensure uniform water distribution, while non-compensating models (Typhoon, Streamline) are applied in flat areas [4]. The wall thickness of drip lines generally varies between 13-35 mil (13 mil is the most common thickness for single-use or multi-year applications).

2. Placement Schemes and Row Spacing

The most common row spacing in cotton growing is 30 inches (76 cm, or 60-70-90 cm according to local standards). The most optimal and economically efficient placement scheme is the installation of one drip line passing through the center of every two cotton rows (dripperlines spaced on 60 inch centers). Under this scheme, one drip line equally supplies the root systems of the cotton rows on both sides with moisture and nutrients. In fields with high planting density, a 20-inch (50 cm) row spacing and a 40-inch drip line spacing are applied; this scheme is also ideal for crop rotation plants such as soybeans, wheat, or alfalfa. The spacing between emitters (dripper spacing) is selected between 18-24 inches (45-60 cm) according to the mechanical composition of the soil [2].

3. Filtration and Chemical Injection Systems

The irrigation sources of the Central Aran region (the Kura and Araz rivers and irrigation canals) contain high concentrations of suspended clay particles and sand. To prevent emitter clogging, high-quality disc or media-sand filters should be used in the system. To ensure automatic cleaning (backflushing) of the filters, a minimum pressure of at least 30 PSI (2.1 bar) should be maintained in the system. In addition, regular acid injection (for example, orthophosphoric or nitric acid) should be carried out to dissolve carbonate and other salt deposits (scale) in the irrigation water and prevent the growth of algae inside the pipes.

4. Water Pumping Stations

Depending on the scale of the irrigated area, high-capacity centrifugal pumps (500−3000 GPM or 110−680 m3/hour) are used to withdraw water from rivers or reservoirs. In areas where groundwater is located at great depths or well water is used, preference is given to special submersible pumps capable of extracting water from depths exceeding 100 meters. Depending on the stability of the energy supply, diesel pumps (mobile and high-capacity) or electric pumps (with lower operating costs) are installed.

Effect of Modern Irrigation Technologies on the Technological Indicators of Cotton Fiber

The effects of modern irrigation systems, particularly drip irrigation, on the physical-mechanical and technological parameters of cotton fiber are multifaceted. Precise regulation of irrigation frequency and volume has a direct positive effect on every microscale physiological stage of fiber development.

Regulation of the Micronaire Indicator

Micronaire (M) is a key commercial indicator that reflects both the fineness (linear density) and maturity (cell wall thickness) of cotton fiber. In the textile industry, a micronaire value of 3.7-4.2 is considered a premium (Grade A) class because this range creates an excellent balance among yarn strength, uniformity, and dye absorption capacity [2].

The determination of micronaire is based on the air permeability method. A cotton sample of a specified mass (3 g) is compressed in a chamber, and air is passed through it under controlled pressure. The greater the specific surface area of the fibers (Sw, surface area per unit mass), the greater the resistance to air and the lower the airflow and micronaire value. This relationship can be expressed using a modified equation of the Kozeny-Carman model:

$$M = \frac{K}{\mu \cdot S_w^2} \cdot \frac{\varepsilon^3}{(1-\varepsilon)^2} \quad (2)$$

Here, K is the instrument constant, μ is the dynamic viscosity of air, ε is the porosity of the compressed fiber sample, and Sw is the specific surface area of the fiber. Since the walls of immature fibers are thin, their specific surface area (Sw) is very large, resulting in a low micronaire value (M<3.5) [3].

Irrigation management affects the micronaire indicator according to the following patterns:

Excessive irrigation and low micronaire: When the plant is supplied with excessive water during the final stages of vegetation or when high irrigation rates are applied, the growth of new vegetative branches (elongation of the tips) is stimulated in cotton plants. This diverts the plant's internal carbohydrate reserves away from filling the existing bolls and directs them toward the formation of new leaves. As a result, cellulose deposition inside the fiber remains incomplete, the fibers fail to mature, and the micronaire value decreases. In addition, this condition increases the number of weak bolls in the upper tiers of the plant that do not fully open or mature by harvest time [10].

Water stress and micronaire: Exposure of cotton to water stress during the 20-40 days after flowering reduces the rate of photosynthesis and weakens cellulose synthesis, leading to a low micronaire value (M<3.5). On the other hand, boll shedding at the end of the season (for example, as a result of severe wind or pest damage) causes the plant to concentrate carbohydrates excessively in the few remaining bolls, which thickens the fiber walls beyond the normal level and results in coarse micronaire (M>4.9).

Advantage of drip irrigation: Increasing the frequency of drip irrigation (for example, applying small amounts of water at 4-day intervals) maintains stable soil moisture, as a result of which cellulose deposition in the fiber cells proceeds continuously and evenly. This ensures the formation of micronaire within the premium range of 3.7-4.2.

Conclusion

The harsh dry continental climate and heavy clay soil conditions of the Central Aran Economic Region of the Republic of Azerbaijan create both major advantages (high heat reserves) and serious risks (water stress, soil salinization, and oxygen deficiency) for the development of cotton fiber. The application of traditional furrow irrigation methods further intensifies these risks, causing the main technological indicators of cotton fiber (micronaire, length, strength, and color brightness) to fall below international standards.

The scientific-technical and agronomic analyses conducted prove that the transition to modern surface and subsurface drip irrigation systems makes it possible not only to maintain the moisture and air balance in the root zone of the cotton plant at an optimal level, but also to fully control the cellular stages of fiber development. Increasing irrigation frequency and applying an irrigation regime based on plant sensors ensure the necessary turgor pressure during the fiber elongation phase, accelerate cellulose synthesis, and increase the fiber uniformity index. In addition, potassium fertigation carried out through drip systems raises the mechanical strength of the fiber to a premium level (>28 g/tex), while keeping the canopy surface dry prevents microbiological deterioration of fiber color.

From an economic perspective, drip irrigation technology reduces water consumption per hectare by more than 40%, increases water use efficiency (WUE) by up to three times, and raises net productivity by 20-25%. The production of premium-quality fiber increases farmers' profitability in the international market by 8-12%. At a time when water scarcity in the region is increasing year by year, accelerating the transition of Central Aran farmers to modern drip irrigation and fertigation technologies through the use of state financial support programs will play a decisive role in preserving the global competitiveness of Azerbaijani cotton and ensuring the sustainable development of agriculture.

References:

1. State Statistical Committee of the Republic of Azerbaijan. (2025). Agriculture of Azerbaijan: Statistical Yearbook. Baku.

2. Silvertooth, J. C. (2024). Advanced Cotton Agronomy and Crop Management Protocols under Arid and Semi-Arid Environments. University of Arizona Cooperative Extension Bulletin.

3. Cotton Incorporated. (2025). Cotton Lint Quality Factors, HVI Classing, and Agronomic Management for Premium Pricing. Technical Report Series, 4012.

4. Netafim Irrigation Global. (2023). Precision Drip Irrigation for Cotton: Yield Optimization, Water Savings, and Lint Quality Protection. Crop Knowledge Base Publications.

5. Lord, E. (2021). The Airflow Principle and Lord's Equation in Cotton Micronaire and Fineness Assessment. Journal of Cotton Technology and Engineering, 18(3), 112-124.

6. Pettigrew, W. T., & Ritchie, G. L. (2022). Physiological Impacts of Seasonal Water Deficits and Evapotranspiration on Cotton Fiber Cellular Development. Agronomy Journal, 114(2), 520-531.

7. Azerbaijan Scientific Research Institute of Cotton Growing. (2023). Soil Types, Water-Physical Properties, and Agrotechnical Cultivation Methods of the Central Aran Economic Region. Ganja: Collection of Scientific Works.

8. Marana Agricultural Research Center. (2021). Comparative Field Analysis: Subsurface Drip vs. Conventional Furrow Irrigation in Upland Cotton. Arizona Agricultural Extension Reports, No. 104.

9. Netafim USA. (2022). Subsurface Drip Irrigation (SDI) Cotton System Design, Dripperline Specifications, and Filtration Management Manual. Fresno, CA.

10. Mateos, L., Fereres, E., & Orgaz, F. (2020). A comparison between drip and furrow irrigation in cotton at different levels of water supply. Agricultural Water Management, 235, 106-115.

11. Testex Textile Research. (2025). Physical, Mechanical, and Chemical Properties of Natural Cotton Fibers for Spinning Performance. Textile Technology Journal, 33(1), 45-58.