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COTTON YIELD AND IRRIGATION WATER PRODUCTIVITY UNDER DRIP AND SURFACE IRRIGATION REGIMES IN CALCISOLS OF UZBEKISTAN

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ABSTRACT

Water scarcity constrains cotton production in Central Asia, where irrigation strategies must balance yield with water conservation. A three-season field experiment (2018–2020) in Qibray District, Tashkent Region, compared surface and drip irrigation at three pre-irrigation soil-moisture threshold regimes: 65–65–60%, 70–70–65%, and 75–75–65% of field capacity across sequential crop-development periods. The experiment was reported as a randomized block design with three replications and 120 m² plots. Because the available analytical record contained treatment-level summaries rather than replicate- and year-level observations, results were evaluated descriptively and no inferential significance claims were retained. Drip irrigation used 2,900–3,560 m³ ha⁻¹ compared with 5,264–5,996 m³ ha⁻¹ under surface irrigation, corresponding to 40.6–44.9% less irrigation water for matched moisture regimes. Cotton yield was 3.06–3.49 t ha⁻¹ under drip irrigation and 2.66–3.07 t ha⁻¹ under surface irrigation, a 13.7–15.0% increase for matched regimes. Irrigation water productivity was highest under drip irrigation at 65–65–60% field capacity (1.06 kg m⁻³), whereas the highest yield occurred at 75–75–65% field capacity (3.49 t ha⁻¹). The findings indicate a trade-off: the wetter drip regime favored yield, while the drier drip regime maximized output per unit of irrigation water.

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Keywords: *cotton; drip irrigation; irrigation scheduling; irrigation water productivity; field capacity; Calcisols; Uzbekistan.*

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Introduction

Agriculture is the largest global user of freshwater, and improving the productivity of irrigation water is central to food production in water-limited regions (Food and Agriculture Organization of the United Nations [FAO], 2017). The distinction between water-use efficiency based on evapotranspiration and productivity based on irrigation water applied is important because the two measures answer different management questions (Howell, 2001). At the field scale, drip irrigation can reduce non-beneficial surface losses and improve control over the timing and location of water delivery, although the magnitude of any saving depends on system design, scheduling, soil conditions, and the accounting boundary used (Ayars et al., 1999; Playán & Mateos, 2006).

Cotton is a major irrigated crop in Uzbekistan, and its production is closely linked to the availability and management of irrigation water. Previous field research in Uzbekistan reported that drip irrigation

could reduce applied water and increase cotton yield relative to furrow irrigation under locally calibrated soil-moisture schedules (Ibragimov et al., 2007). A later study showed that improved irrigation termination using wetting-front detectors could further reduce water losses and improve irrigation crop water productivity (Ibragimov et al., 2021). A review of water-management practices in Uzbekistan likewise identified drip irrigation as one of the most promising approaches for increasing cotton water productivity, while emphasizing that technical performance and farm-level feasibility must be evaluated together (Mirshadiev et al., 2018).

Soil properties also influence the response to irrigation scheduling. The experimental site in the present study was described as typical gray soil corresponding to Calcisols, with carbonate accumulation and a deep groundwater table. Because water movement and storage in calcareous soils may differ from those in coarser or non-calcareous soils, locally derived treatment comparisons remain useful for irrigation planning. The present study therefore compared three pre-irrigation moisture-threshold regimes under drip and surface irrigation over three growing seasons. The objectives were to quantify treatment-level differences in seasonal irrigation water applied, cotton yield, and irrigation water productivity, and to distinguish the regime associated with the highest yield from the regime associated with the highest output per unit of irrigation water.

Materials and Methods

Study Site

Field experiments were conducted during the 2018, 2019, and 2020 cotton-growing seasons at the Central Experimental Farm of the Research Institute of Plant Genetic Resources in Qibray District, Tashkent Region, Uzbekistan. The site lies in the foothill zone and has a semi-arid continental climate with hot summers. The field record described growing-season air temperatures of approximately 18–32 °C, precipitation of 260–340 mm, and reference evapotranspiration of 850–950 mm across the study period. The soil was described as an automorphic typical gray soil corresponding to Calcisols. Groundwater depth was approximately 15 m, so direct groundwater contribution to root-zone water was considered negligible.

Experimental Design and Irrigation Treatments

The experiment used a randomized block design with three replications. Each plot covered 120 m². Two irrigation methods were compared: conventional surface irrigation and drip irrigation. Within each method, three pre-irrigation soil-moisture threshold regimes were evaluated: 65–65–60%, 70–70–65%, and 75–75–65% of field capacity. The three values in each treatment code represent sequential crop-development periods in the field protocol. Cotton was planted at 60 cm between rows and 20 cm between plants. For drip-irrigated plots, emitters were spaced at 30 cm and had a nominal discharge of 2 L h^{-1}. All treatments received the same general crop-management program so that irrigation method and threshold regime were the intended treatment contrasts.

Measurements and Derived Indicators

Soil moisture was monitored gravimetrically to determine when the assigned pre-irrigation threshold had been reached. The number of irrigation events and the seasonal volume of irrigation water applied were obtained from field irrigation records. Cotton yield was measured at harvest and reported in tonnes per hectare. Because the denominator available in the field record was irrigation water applied rather than crop evapotranspiration, the efficiency metric was defined as irrigation water productivity (IWP), not evapotranspiration-based water-use efficiency.

$$IWP\ (kg\ m^{-3}) = cotton\ yield\ (kg\ ha^{-1}) / seasonal\ irrigation\ water\ applied\ (m^3\ ha^{-1})$$

Water saving for each drip treatment was calculated relative to the surface-irrigated treatment with the same moisture-threshold regime: water saving (%) = 100 × [1 − (drip water applied / surface water applied)]. The percentage yield difference was calculated in the same matched-treatment manner.

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Statistical Treatment and Verification Scope

The supplied analytical record contained one summary value per irrigation-method × moisture-regime combination and did not include replicate-level or year-level observations, variance estimates, model output, or reproducible statistical files. Consequently, analysis of variance, Tukey multiple-comparison groupings, p values, and error bars could not be independently reconstructed and are not reported. The present analysis is therefore limited to internally verified arithmetic and descriptive comparisons of the six treatment summaries. All water-saving percentages, yield differences, and IWP values were recalculated directly from the reported water and yield totals.

Ethical Considerations

The study involved field-grown cotton and did not include human participants or vertebrate animals; human-subject or animal-research ethical approval was therefore not applicable.

Results

Seasonal Irrigation Water Application

Surface-irrigated treatments received 5,264–5,996 $m^3\ ha^{-1}$ over five to seven irrigation events, whereas drip-irrigated treatments received 2,900–3,560 $m^3\ ha^{-1}$ over seven to ten events (Table 1). Thus, drip irrigation applied smaller volumes more frequently. For matched moisture-threshold regimes, the reduction in seasonal irrigation water was 44.9% at 65–65–60%, 43.8% at 70–70–65%, and 40.6% at 75–75–65%. Absolute water saving ranged from 2,364 to 2,516 $m^3\ ha^{-1}$.

Table 1

Seasonal irrigation water applied and water saving by treatment

Irrigation method	Threshold regime (% FC)	Irrigation events	Water applied ($m^3\ ha^{-1}$)	Water saving (%)
Surface	65–65–60	5	5,264	—
Surface	70–70–65	6	5,746	—
Surface	75–75–65	7	5,996	—
Drip	65–65–60	7	2,900	44.9
Drip	70–70–65	8	3,230	43.8
Drip	75–75–65	10	3,560	40.6

Note. FC = field capacity. Water saving for each drip treatment was calculated relative to the surface treatment with the same threshold regime.

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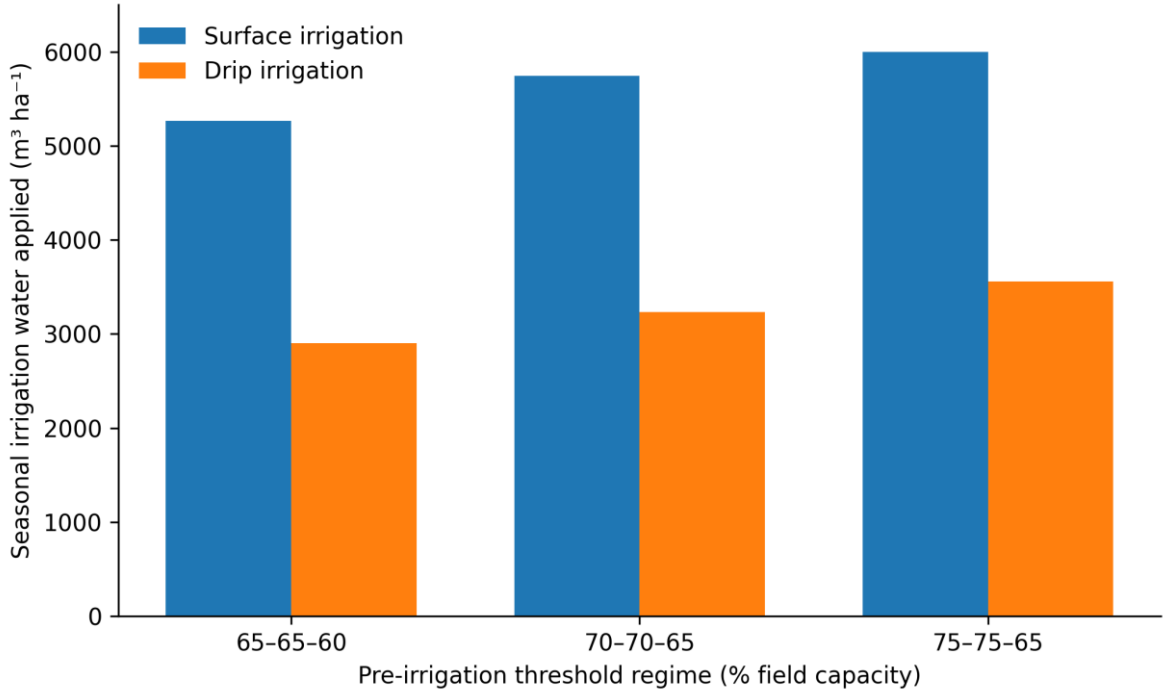


Figure 1. Seasonal irrigation water applied under surface and drip irrigation at three pre-irrigation threshold regimes. Values are treatment-level summaries; no error bars are shown because replicate-level variance estimates were not available.

Cotton Yield and Irrigation Water Productivity

Cotton yield increased across the three moisture-threshold regimes under both irrigation methods (Table 2). For matched regimes, drip-irrigated yield exceeded surface-irrigated yield by 15.0%, 14.0%, and 13.7%, respectively. The highest reported yield was 3.49 t ha^{-1} under drip irrigation at 75–75–65% field capacity (Figure 2). However, this treatment did not have the highest IWP. Because water application rose more rapidly than yield across the drip regimes, IWP declined from 1.06 kg m^{-3} at 65–65–60% to 0.98 kg m^{-3} at 75–75–65%. Surface-irrigated IWP remained near 0.50–0.51 kg m^{-3}. Thus, all drip treatments approximately doubled output per unit of irrigation water, but the driest drip regime produced the greatest IWP.

Table 2

Cotton yield, matched-treatment yield difference, and irrigation water productivity

Irrigation method	Threshold regime (% FC)	Yield (t ha^{-1})	Yield difference (%)	IWP (kg m^{-3})
Surface	65–65–60	2.66	—	0.51
Surface	70–70–65	2.85	—	0.50
Surface	75–75–65	3.07	—	0.51
Drip	65–65–60	3.06	15.0	1.06
Drip	70–70–65	3.25	14.0	1.01
Drip	75–75–65	3.49	13.7	0.98

Note. FC = field capacity; IWP = irrigation water productivity. Yield difference compares each drip treatment with the surface treatment at the same threshold regime. IWP was recalculated as yield in kg ha^{-1} divided by seasonal irrigation water applied in m^3 ha^{-1}.

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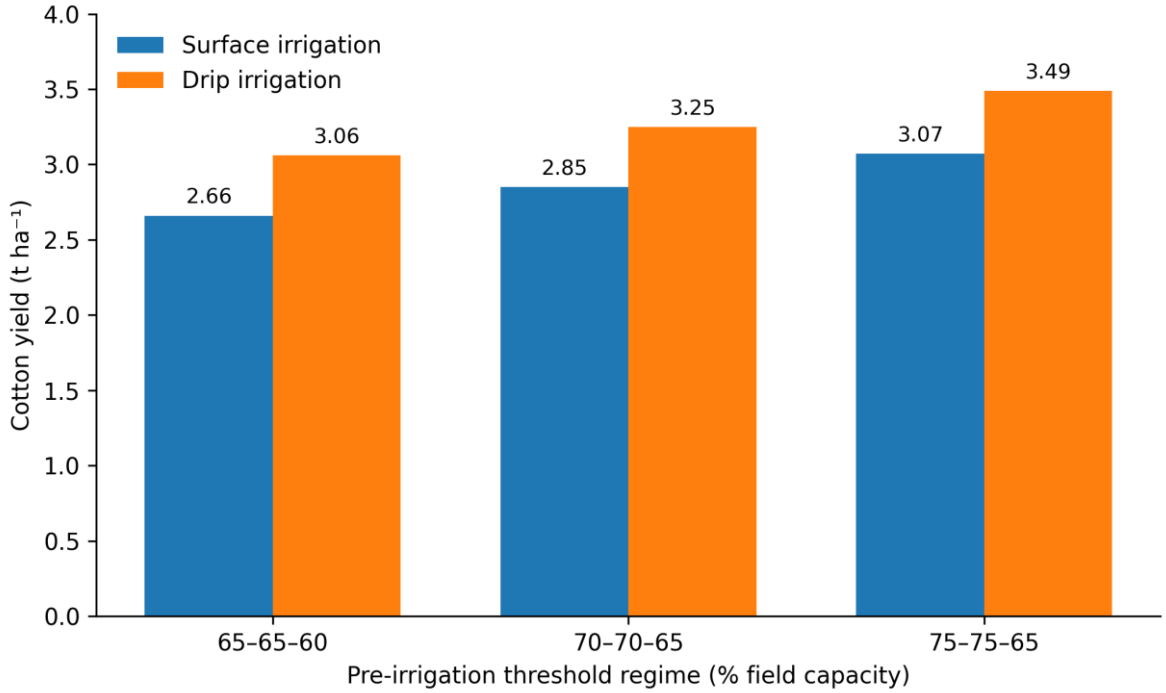


Figure 2. *Cotton yield under surface and drip irrigation at three pre-irrigation threshold regimes. Values are treatment-level summaries; inferential group letters and error bars are not shown because the underlying replicate-level data were not available for verification.*

Discussion

The treatment summaries show a consistent descriptive advantage of drip irrigation over surface irrigation in both seasonal water application and cotton yield. The 40.6–44.9% reduction in applied irrigation water is at the upper end of the 18–42% range reported in an earlier Uzbekistan field study, whereas the 13.7–15.0% yield increase falls within that study's reported 10–19% range (Ibragimov et al., 2007). The agreement in direction and approximate magnitude strengthens the practical plausibility of the present treatment summaries, although it does not replace statistical verification of the current experiment.

The main agronomic result is not a single universal optimum but a clear yield–water-productivity trade-off. The 75–75–65% drip regime produced the highest yield, but the 65–65–60% drip regime produced the highest IWP. This pattern is expected when additional irrigation continues to raise yield but with diminishing output per unit of applied water. Deficit-irrigation literature similarly shows that maximizing yield and maximizing water productivity can require different schedules (Cheng et al., 2021; Fereres & Soriano, 2007; Geerts & Raes, 2009). Accordingly, the preferred treatment depends on the management objective: maximizing harvested output favors the wetter drip regime, whereas maximizing output per cubic metre of irrigation water favors the drier drip regime.

The use of IWP rather than a generic water-use-efficiency label is also consequential. The reported denominator was seasonal irrigation water applied, not measured crop evapotranspiration. Therefore, the values quantify farm-level output per unit of supplied irrigation water and should not be interpreted as physiological efficiency or evapotranspiration-based crop water productivity (Howell, 2001; Pereira et al., 2002). This distinction improves comparability and prevents an overstatement of true consumptive water savings, particularly because reductions in field application do not necessarily translate one-for-one into basin-scale water savings.

Higher irrigation frequency under drip irrigation was accompanied by lower total seasonal application. This is consistent with the operational purpose of drip systems: smaller, localized applications can maintain the assigned soil-moisture threshold while reducing excess surface wetting and uncontrolled percolation. However, the present summary data cannot isolate the mechanisms responsible for the

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observed differences. Detailed measurements of evapotranspiration, drainage, salinity, and root-zone water distribution would be required to quantify the water balance and to evaluate whether the apparent field-scale saving is sustained over longer periods.

Limitations

Several limitations constrain interpretation. First, only pooled treatment summaries were available; replicate-level and year-specific data were not supplied. Consequently, year-to-year variability, block effects, uncertainty intervals, and inferential significance could not be assessed. Second, the field record did not provide a complete description of the exact crop-development stages represented by the three moisture thresholds, fertilizer rates, cultivar, planting dates, harvest protocol, or instrument calibration. Third, the yield measure was reported generically as cotton yield and was not explicitly distinguished as seed cotton or lint yield. Fourth, the available water accounting covered irrigation water applied rather than a complete evapotranspiration or soil-water balance. Finally, economic claims were excluded because the original cost and return values did not include reproducible price assumptions and were internally inconsistent with the stated additional income. These limitations mean that the results should be treated as descriptive treatment evidence rather than a fully reproducible optimization analysis.

Conclusions

Across three reported growing seasons in Calcisols of the Tashkent Region, drip irrigation used 40.6–44.9% less seasonal irrigation water than the corresponding surface-irrigation regimes while producing 13.7–15.0% higher cotton yield. The 75–75–65% field-capacity regime under drip irrigation produced the highest yield (3.49 t ha^{-1}), whereas the 65–65–60% drip regime produced the highest irrigation water productivity (1.06 kg m^{-3}). The results therefore support drip irrigation as a promising field-level water-management approach at the study site, but they do not justify naming one regime as universally optimal. Selection should depend on whether the production objective prioritizes maximum yield or maximum output per unit of irrigation water. Future work should report year- and replicate-level data, complete crop and soil protocols, full water-balance measurements, and transparent economic assumptions.

Data Availability

The corrected analysis is based on the treatment-level water-application and yield summaries contained in the study record. Replicate-level and year-level datasets were not available with the supplied manuscript.

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