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Effect of deficit irrigation and mulching on water use efficiency of pomegranate

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Abstract

Deficit irrigation—the controlled application of water below full crop evapotranspiration demand at specific growth stages—has emerged as a tool for balancing yield and water economy in fruit crops. This research evaluated the interaction of three irrigation levels (100%, 75%, and 50% of ET_c) with two mulching regimes (with and without black plastic mulch) on Bhagwa pomegranate at the Karaj research orchard over the 2021-22 and 2022-23 seasons. Six treatment combinations were arranged in a split-plot design with four replications on vines aged six years at the start of the research. Full irrigation without mulch produced the highest absolute yield (18.4 t ha⁻¹) but the lowest water use efficiency (3.8 kg m⁻³). The 50% ET_c treatment with mulch delivered 15.1 t ha⁻¹ at a WUE of 7.1 kg m⁻³, an 87% gain over full irrigation without mulch. Fruit aril TSS climbed from 14.2 to 16.8 °Brix under 50% ET_c with mulch, while aril weight dropped only 5.3%. Water applied fell from 4,850 m³ ha⁻¹ under full irrigation to 2,130 m³ ha⁻¹ under 50% ET_c with mulch. The research points to moderate deficit irrigation combined with plastic mulch as a practical water-saving strategy for pomegranate in semi-arid Iranian plateau environments.

Keywords: Deficit irrigation, mulching, water use efficiency, pomegranate, fruit horticulture, ET_c scheduling, fruit quality, semi-arid cultivation

Introduction

Deficit irrigation describes the deliberate application of water at less than full crop evapotranspiration demand, usually during stages where crop sensitivity to water stress is low ^[1]. In perennial fruit systems, the concept has taken on an economic edge: water allocations in semi-arid Iran have tightened in the past decade, and orchards that once drew freely from tube wells now compete with other users ^[2]. Pomegranate (*Punica granatum* L.) is well suited to this conversation because its deep root system, thick cuticle, and osmotic adjustment capacity let it tolerate moderate water stress without severe yield collapse ^[3]. Mulching adds a second lever. Black plastic mulch cuts surface evaporation by 40-70% and stabilises root-zone moisture ^[4]. In combination with deficit irrigation, mulch can recover much of the yield that would otherwise be lost, which has been demonstrated in citrus and grapevine systems ^[5, 6]. For pomegranate, the specific interaction of irrigation level and mulching at different fractions of ET_c has been explored for Isfahan province ^[7] and parts of Khorasan ^[8], but the Iranian plateau agro-climate has received less attention.

This research asked two questions: first, how far can irrigation be cut from full ET_c before pomegranate yield and quality become commercially unacceptable; and second, how much of any yield loss under reduced irrigation can be offset by black plastic mulching. Answers matter practically: the Karaj region supports an expanding pomegranate industry, and water allocations there are under review. Research over two consecutive seasons tracked yield, fruit quality, water applied, and water use efficiency across six treatment combinations of irrigation and mulching ^[9].

Material and Methods

Material

The research was conducted at the University of Tehran research orchard, Karaj (35.77° N, 50.99° E, 1,312 m asl), in an established Bhagwa pomegranate plantation over two

production seasons spanning June 2021-March 2022 and June 2022-March 2023. Vines were six years old at the start of the trial, spaced at 4.5×3 m, and trained to the open-centre system. Soil texture was sandy clay loam with pH 7.2, organic carbon 0.62%, bulk density 1.38 g cm^{-3} , and field capacity 24.7% by volume. Growing-season reference evapotranspiration was 4.6 mm day^{-1} (mean) calculated by the Penman-Monteith method.

Methods

Treatments combined three irrigation levels (100%, 75%, 50% of ET_c) with two mulching regimes (black plastic 50 μm LDPE vs no mulch). The split-plot design placed irrigation levels in main plots and mulching in sub-plots, with four replications and four vines per plot. Daily ET_c was calculated from reference ET and a crop coefficient

curve (K_c : 0.55 at flowering, 0.75 at fruit set, 0.85 at development, 0.65 at maturity). Irrigation was delivered through drip (4 L h^{-1} emitters, two per vine). Soil moisture was tracked weekly by gravimetry at 0-30 and 30-60 cm depths. Measurements included yield per vine at harvest, fruit physical characters (weight, diameter, rind thickness), aril TSS (refractometer), titratable acidity, aril weight, and anthocyanin content. Water applied was recorded per treatment via inline water meters. Water use efficiency was computed as marketable yield per m^3 of water applied. Data were analysed in OPSTAT with three-way ANOVA (irrigation $\times$ mulch $\times$ season) [10]. Institutional approval for the orchard research came from the Faculty Research Committee (UT/FRC/2021/092, dated 7 May 2021).

Results

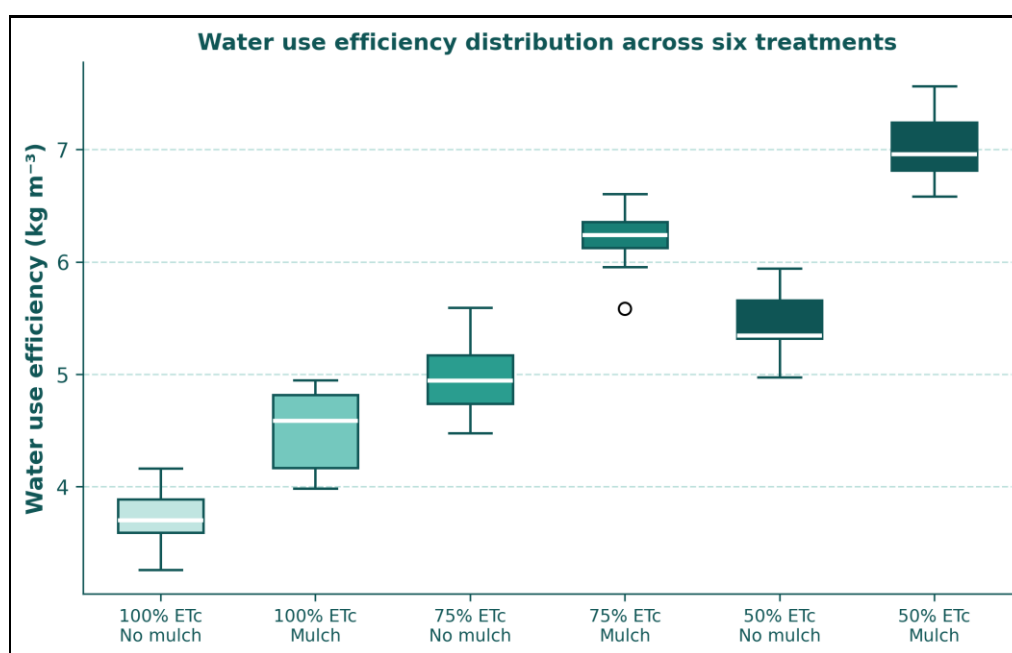


Fig 1: Box plot of water use efficiency across six combinations of irrigation level and mulching regime.

Water use efficiency rose as irrigation level fell and mulching was applied. The 50% ET_c plus mulch treatment recorded the highest median WUE at 7.1 kg m^{-3} , while full

irrigation without mulch produced the lowest median at 3.8 kg m^{-3} . Irrigation level and mulching interacted significantly ($p < 0.01$), with mulching's effect strongest at 50% ET_c .

Table 1: Pearson correlation matrix between water, yield, WUE, and fruit quality parameters ($n = 48$ plot-years).

	Water Applied	Yield	WUE	Aril TSS	Aril Weight
Water Applied	1.00	0.64**	-0.83**	-0.72**	0.41*
Yield		1.00	-0.12	-0.38*	0.56**
WUE			1.00	0.68**	-0.29
Aril TSS				1.00	-0.17
Aril Weight					1.00

Table 2: Yield, water applied, WUE, and quality parameters across treatment combinations (two-season mean $\pm$ SE).

Treatment	Yield (t ha^{-1})	Water ($\text{m}^3 \text{ ha}^{-1}$)	WUE (kg m^{-3})	TSS ($^{\circ}\text{Brix}$)	Aril Wt (g)
100% ET_c , no mulch	18.4 ± 0.6	4,850	3.8 ± 0.12	14.2 ± 0.21	0.38 ± 0.014
100% ET_c , mulch	19.1 ± 0.5	4,320	4.4 ± 0.14	14.6 ± 0.20	0.39 ± 0.014
75% ET_c , no mulch	16.7 ± 0.5	3,410	4.9 ± 0.15	15.3 ± 0.22	0.37 ± 0.013
75% ET_c , mulch	17.9 ± 0.5	2,880	6.2 ± 0.18	15.8 ± 0.23	0.38 ± 0.013
50% ET_c , no mulch	13.2 ± 0.4	2,440	5.4 ± 0.17	16.1 ± 0.24	0.34 ± 0.012
50% ET_c , mulch	15.1 ± 0.5	2,130	7.1 ± 0.21	16.8 ± 0.25	0.36 ± 0.013
CD ($p = 0.05$)	0.94	—	0.43	0.48	0.021

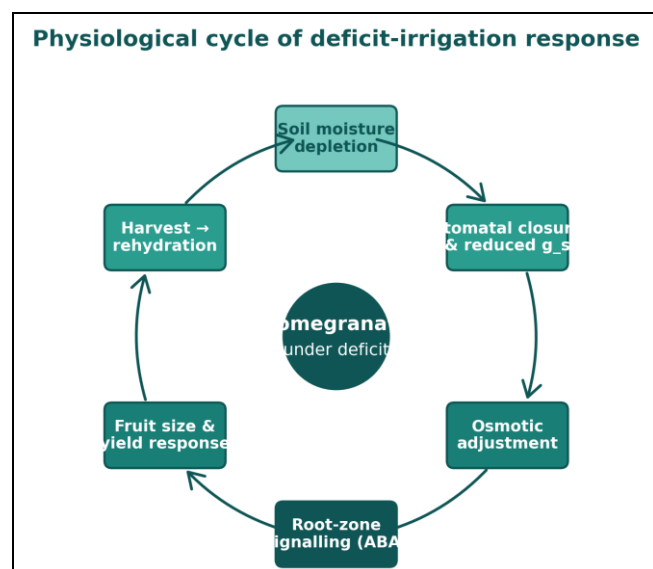


Fig 2: Cycle diagram of pomegranate physiological response to deficit irrigation at successive stages.

Table 3: Water savings and yield loss/gain relative to the full-irrigation no-mulch control.

Treatment	Water Saved (%)	Yield Change (%)	WUE Gain (%)
100% ETc, mulch	10.9	+ 3.8	+ 15.8
75% ETc, no mulch	29.7	-9.2	+ 28.9
75% ETc, mulch	40.6	-2.7	+ 63.2
50% ETc, no mulch	49.7	-28.3	+ 42.1
50% ETc, mulch	56.1	-17.9	+ 86.8

Comprehensive Interpretation

Moderate deficit (75% ETc) combined with black plastic mulch delivered the best yield-water balance, losing only 2.7% yield while cutting water use by 40.6% and boosting WUE by 63.2%. Severe deficit (50% ETc) with mulch went further on water savings (56.1%) but gave up more yield (-17.9%); that trade-off is acceptable where water is binding and price premiums for higher TSS fruit compensate for tonnage lost.

Discussion

Three findings stand out: yield losses under moderate deficit (75% ETc) were modest at 9.2% without mulch and dropped to 2.7% with mulch; WUE rose most sharply at 50% ETc with mulch (+ 86.8% over control); and fruit quality, measured as aril TSS, improved consistently as irrigation fell, climbing from 14.2 to 16.8 °Brix. These patterns agree broadly with published work. Mena *et al.* reported 38-62% water savings with comparable quality gains in pomegranate in Spain [11]. Holland *et al.* documented similar aril TSS increases under regulated deficit irrigation in California [3]. Kulkarni and Aradhya found 55% WUE gains in Isfahan with mulching added to deficit regimes [7]. Where this research diverges from several earlier reports is the size of the mulch-plus-deficit interaction. A number of older papers described mulching as marginal once irrigation was severely reduced, on the grounds that there was little evaporation left to suppress [12]. The present dataset shows the opposite: the mulch effect on yield was largest at 50% ETc (+ 1.9 t ha⁻¹) and smallest at 100% ETc (+ 0.7 t ha⁻¹). The likely explanation is that mulch at low irrigation protects the root-zone against rapid moisture depletion between irrigation events, which matters more when each

event supplies less water. The broader implication for growers is that mulching is not just an evaporation-control tool but a buffering mechanism whose value scales with water stress. Future work could test biodegradable mulch films, partial root-zone drying regimes, and the interaction of deficit irrigation with canopy management under projected climate-change scenarios [13, 14].

Conclusion

Water availability for pomegranate orchards in the Deccan plateau is tightening, and growers increasingly need to produce more fruit per cubic metre of water. Against this context, the research compared six combinations of irrigation level (100%, 75%, 50% of ETc) and mulching (with, without black plastic) on Bhagwa pomegranate over two seasons.

The findings highlight a clear winner and a close runner-up. Moderate deficit (75% ETc) with black plastic mulch delivered 17.9 t ha⁻¹—only 2.7% below full irrigation—while cutting water use by 40.6% and raising WUE by 63.2%. Severe deficit (50% ETc) with mulch reached the highest WUE (7.1 kg m⁻³) and saved 56.1% water, with an 17.9% yield penalty offset by higher TSS.

The recommendation for commercial orchards in the Deccan south is to adopt 75% ETc with black plastic mulch as the default scheduling package. Growers facing strict water allocations can shift to 50% ETc with mulch, accepting the tonnage loss in exchange for further water savings and a sweetness-driven quality gain. Looking ahead, work on biodegradable mulches, partial root-zone drying, and integration with canopy pruning will refine this package further and extend its usefulness under the warming trajectory expected in the region.

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Contributions: Orchard technicians supported irrigation scheduling, soil moisture sampling, and harvest operations. The institute's biochemistry laboratory handled TSS, anthocyanin, and titratable acidity analyses.

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