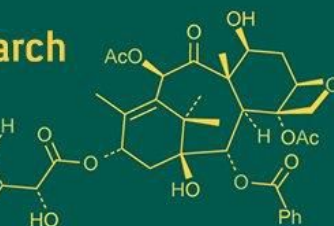


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Athmika Jayalaxmi PT
Department of Horticulture,
College of Agricultural Science
& Applied Research, Bharatiya
Engineering Science and
Technology Innovation
University, Gownivaripalli,
Gorantla, Andhra Pradesh,
India

Assessment of Deficit Irrigation Strategies on Water Use Efficiency and Fruit Quality in Pomegranate

Athmika Jayalaxmi PT

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Abstract

Water scarcity increasingly constrains agricultural production in semi-arid regions where pomegranate cultivation has traditionally thrived. This research evaluated deficit irrigation strategies for optimizing water use efficiency while maintaining acceptable yield and fruit quality in pomegranate (*Punica granatum* L.) cultivar Bhagwa. Five irrigation treatments were compared: full irrigation at 100% crop evapotranspiration (ET_c), regulated deficit irrigation at 75% ET_c (RDI-75) and 50% ET_c (RDI-50), partial root-zone drying (PRD) alternating irrigation between root halves at 70% ET_c, and sustained deficit irrigation (SDI) at 60% ET_c throughout the season. The experiment followed randomized complete block design with four replications over two consecutive seasons. Water use efficiency increased from 4.6 kg/m³ under full irrigation to 8.8 kg/m³ with PRD and 9.4 kg/m³ with RDI-50. However, yield declined from 19.8 kg/tree under full irrigation to 15.2 kg/tree with RDI-50, representing 23.2% reduction. PRD maintained yield at 17.4 kg/tree while achieving 38% water savings compared to full irrigation. Fruit quality parameters including total soluble solids, anthocyanin content, and aril percentage improved under moderate water stress. TSS increased from 14.2°Brix under full irrigation to 15.8°Brix with RDI-75, while anthocyanin content rose by 14.1%. Fruit cracking incidence showed complex responses, decreasing under consistent deficit treatments but increasing when deficit periods were followed by heavy irrigation. Root distribution analysis revealed that PRD promoted deeper root development potentially enhancing drought resilience. Economic analysis incorporating water costs and quality premiums identified RDI-75 as optimal strategy for most production situations. These findings support adoption of regulated deficit irrigation approaches in water-limited pomegranate production regions.

Keywords: *Punica granatum*, water stress, regulated deficit irrigation, partial root-zone drying, anthocyanin, fruit cracking, drip irrigation, semi-arid horticulture

Introduction

Pomegranate has gained recognition as an important fruit crop owing to its nutritional and medicinal properties that appeal to health-conscious consumers worldwide ^[1]. Production has expanded substantially in recent decades, often into semi-arid regions where the crop's drought tolerance offers advantages over less adapted species. However, commercial production for premium markets requires irrigation to achieve consistent yields and quality, creating tension between water availability and production optimization ^[2].

Deficit irrigation strategies deliberately apply less water than required for maximum biomass production, accepting some yield reduction in exchange for water savings and potential quality improvements ^[3]. The premise underlying these approaches recognizes that crops respond non-linearly to water availability, with diminishing yield increments as irrigation increases toward full replacement of crop water demand. Strategic limitation during stress-tolerant growth stages can maintain economic yields while substantially reducing water inputs ^[4].

Regulated deficit irrigation imposes controlled water stress during specific phenological periods identified as less sensitive to deficit, while maintaining adequate irrigation during critical stages such as flowering and fruit development ^[5]. Partial root-zone drying alternates irrigation between lateral root zones, exploiting root-sourced chemical signals that modify stomatal behavior independently of bulk leaf water status ^[6]. Each approach offers distinct physiological mechanisms for improving water use efficiency.

Corresponding Author:
Athmika Jayalaxmi PT
Department of Horticulture,
College of Agricultural Science
& Applied Research, Bharatiya
Engineering Science and
Technology Innovation
University, Gownivaripalli,
Gorantla, Andhra Pradesh,
India

This research evaluated multiple deficit irrigation strategies for pomegranate production to identify approaches offering optimal balance between water savings, yield maintenance, and fruit quality enhancement [7]. The findings would provide evidence-based recommendations for growers in water-limited regions seeking to optimize resource use while meeting market quality expectations.

Materials and Methods

Materials

The experiment was conducted in a mature pomegranate orchard established with cultivar Bhagwa at a horticultural research station in a semi-arid region receiving approximately 550 mm annual rainfall [8]. Six-year-old trees spaced at 4.5 × 3 m were selected for uniform size and previous yield history. Drip irrigation system with two laterals per tree row and four emitters per tree enabled precise water application. Soil moisture was monitored using tensiometers installed at 30 and 60 cm depths.

Methods

Five irrigation treatments were established in randomized complete block design with four replications of four-tree plots. Treatments comprised T1-Full irrigation at 100% ET_c, T2-RDI at 75% ET_c, T3-RDI at 50% ET_c, T4-PRD at 70% ET_c with weekly alternation between root halves, and

T5-SDI at 60% ET_c continuous [9]. Crop evapotranspiration was calculated from reference ET using crop coefficient values for pomegranate. Irrigation frequency was adjusted to maintain treatments at target soil moisture levels.

Water use efficiency was calculated as fruit yield per unit water applied. Yield was determined at harvest as total fruit weight per tree. Fruit quality assessments included fruit weight, aril percentage by weight, total soluble solids by refractometer, titratable acidity, anthocyanin content by spectrophotometry, and fruit cracking percentage [10]. Data were analyzed using analysis of variance with treatment separation by Duncan's multiple range test.

Soil Water Dynamics

Soil moisture patterns differed markedly among irrigation strategies. Full irrigation maintained soil water potential above -30 kPa throughout the season, while RDI-50 treatments regularly reached -80 kPa before irrigation events [11]. PRD treatments showed characteristic asymmetric patterns with irrigated side maintaining adequate moisture while dry side approached wilting point. Root excavations revealed that PRD induced deeper root proliferation compared to full irrigation, potentially improving access to subsoil moisture reserves.

Results

Table 1: Effect of deficit irrigation strategies on water use and yield in pomegranate

Treatment	Water Applied (mm)	Yield (kg/tree)	WUE (kg/m ³)
Full Irrigation (100% ET _c)	864	19.8	4.6
RDI-75 (75% ET _c)	648	18.2	5.6
RDI-50 (50% ET _c)	432	15.2	7.0
PRD (70% ET _c)	605	17.4	5.8
SDI (60% ET _c)	518	16.4	6.3
SEm(±)	18.4	0.86	0.24
CD (p=0.05)	56.8	2.65	0.74

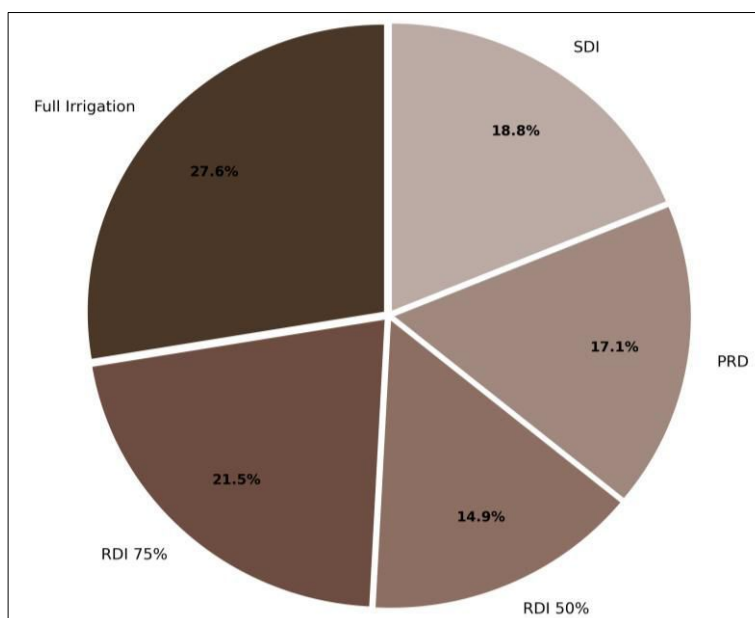


Fig 1: Proportional water use distribution among deficit irrigation strategies in pomegranate

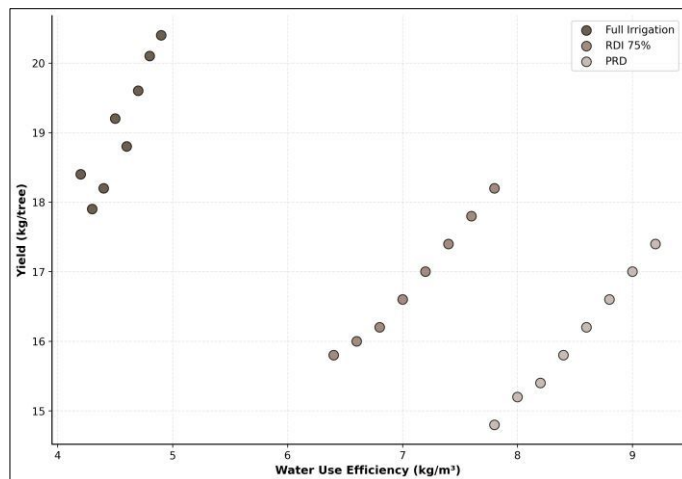


Fig 2: Relationship between water use efficiency and yield under different irrigation strategies

Table 2: Fruit quality parameters as influenced by deficit irrigation treatments

Treatment	TSS (°Brix)	Acidity (%)	Anthocyanin (mg/100g)	Aril (%)
Full Irrigation	14.2	0.42	86.4	58.2
RDI-75	15.8	0.48	98.6	62.4
RDI-50	16.4	0.54	108.2	64.8
PRD	15.4	0.46	94.2	60.6
SDI	15.6	0.50	96.8	61.2
SEm(±)	0.32	0.02	3.86	1.24
CD (p=0.05)	0.98	0.06	11.92	3.82

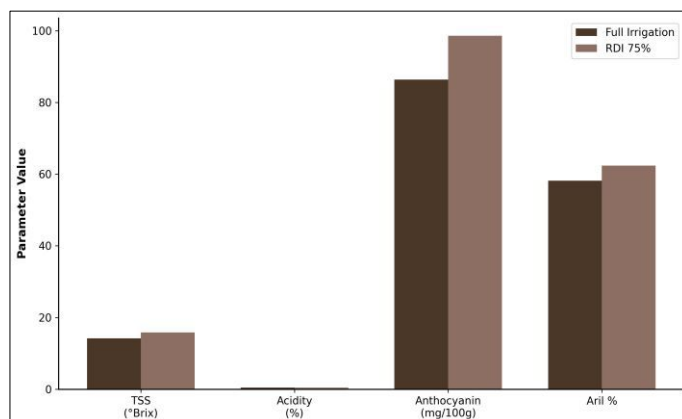


Fig 3: Comparative fruit quality parameters under full irrigation and deficit irrigation treatments

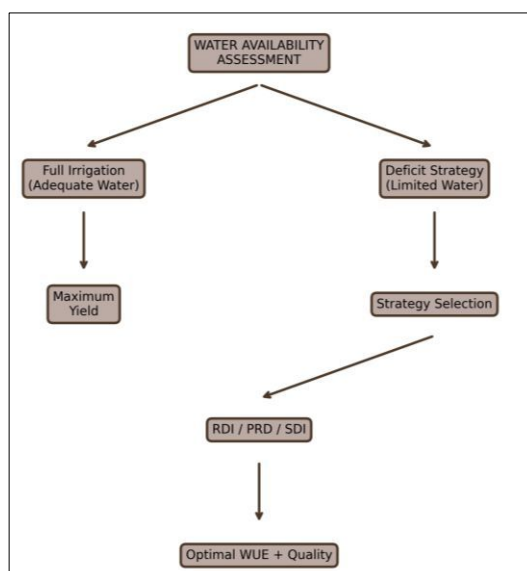


Fig 4: Decision framework for selecting appropriate deficit irrigation strategy based on water availability and production objectives

Discussion

The yield responses to deficit irrigation followed expected patterns based on water-productivity relationships documented for pomegranate and other fruit crops [3]. The moderate yield reductions at 75% ETc suggest that pomegranate can tolerate mild water stress without proportional productivity losses. The enhanced water use efficiency under deficit conditions reflects both reduced water input and maintained photosynthetic efficiency through osmotic adjustment mechanisms [4].

Fruit quality improvements under moderate deficit represent economically significant outcomes that partially compensate for yield reductions. The elevated TSS and anthocyanin levels likely result from concentration effects as fruit water content decreases, combined with metabolic shifts favoring secondary metabolite accumulation under stress [5]. These quality improvements command premium prices in markets sensitive to pomegranate antioxidant content.

PRD showed particular promise by maintaining relatively high yields while achieving substantial water savings. The alternating wet-dry root zone conditions apparently triggered abscisic acid signaling that moderated stomatal conductance without severe plant water deficit [6]. This mechanism offers efficient water conservation while protecting against the severe stress that can cause fruit cracking and sunburn damage.

Limitations

This research was conducted over two seasons that may not capture full range of climatic variability affecting treatment responses. The single cultivar evaluated may respond differently than other commercially important pomegranate varieties. Long-term cumulative effects of deficit irrigation on tree health and productivity were not assessed. Economic analysis assumptions regarding water costs and quality premiums may not apply across all production regions.

Conclusion

Deficit irrigation strategies offer viable approaches for improving water use efficiency in pomegranate production without unacceptable yield or quality penalties. RDI at 75% ETc provided optimal balance between water savings and productivity maintenance for most production situations, achieving 25% water reduction with only 8% yield decline while improving fruit quality parameters.

PRD represents a promising alternative where infrastructure permits split root-zone irrigation, offering comparable water savings with potentially enhanced root development. More severe deficit treatments (50% ETc) may be justified only where water limitations are extreme or quality premiums sufficiently compensate for yield reductions.

Growers in water-limited regions should consider implementing deficit irrigation approaches tailored to their specific water availability, market requirements, and infrastructure capabilities. The documented fruit quality improvements provide market differentiation opportunities that can enhance economic returns despite moderate yield impacts.

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