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Original Research Paper

Phenology-based irrigation management in guava orchards

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ABSTRACT

An investigation was carried out on 7 to 10 years old guava var. Arka Mridula trees to standardize the irrigation scheduling across different stages of crop, in RBD with five replications during 2018 o 2021.Results revealed that irrigation scheduled to meet 60% evaporation during both vegetative and reproductive phases demonstrated superior outcomes. This approach resulted in higher mean fruit weight (104.5 g), increased productivity (29.84 t/ha), and consistent water use efficiency (11.86 kg/m^3), saving 24% of irrigation water. Despite observing a higher number of fruits (524/plant/year) when irrigation met 80% of the evaporation rate, the treatment with 60% evaporation replenishment showcased equally commendable returns of Rs.8,31,788/ha and Rs.5,55,731/ha for gross and net returns, respectively. Furthermore, this strategy recorded a higher benefit-cost ratio of 3.01, emphasizing its economic efficiency in guava cultivation compared to the marginally superior returns associated with the 80% evaporation scheduling. These results highlight the importance of phenology-based irrigation management in optimizing guava cultivation, emphasizing that 60% ER is a viable alternative that delivers substantial yields with less water usage.

Keywords: Irrigation scheduling, irrigation water, net returns, productivity, water use efficiency

INTRODUCTION

Ensuring adequate, timely, and reliable irrigation is imperative for achieving optimal growth, yield, and quality in guava fruit cultivation. Guava (*Psidium guajava* L.), a widely grown tropical fruit, is known for its nutritional value and economic importance. In India, the area under guava cultivation has reached approximately 3,00,000 hectares, with an annual production of around 4.6 million tonnes, reflecting the fruit's significant contribution to the agricultural sector (Ministry of Agriculture & Farmers Welfare, 2022). The increasing demand for high-quality guava fruits has led to the exploration of advanced cultivation techniques to maximize productivity and profitability. While, guava is inherently resilient to moisture stress, its vegetative phase and fruit development stages are recognized as critical periods for soil moisture management, impacting nutrient availability and metabolic processes. Guava cultivation often faces challenges such as uneven rainfall distribution, water scarcity, and inefficient irrigation practices, which can adversely affect fruit yield and quality (Bhargava & Singh, 2020; Patel et al., 2021). Nationwide reports confirm guava's responsiveness to irrigation, with drip irrigation emerging as the optimal system. Drip irrigation not only conserves water and nutrients but also ensures the desired fruit quality, making it one of the most efficient methods, saving 30-70% of irrigation water and boosting yields by 25-80%. Its precision in water application maintains uniform fruit growth, unaffected by moisture stress, and allows water to be supplied only as needed (Sharma et al., 2022). The efficiency of drip irrigation is attributed to reduced surface evaporation, minimal surface runoff, and limited deep percolation. Additionally, this method facilitates effective flowering regulation (Singh & Singh, 2007). Uniform moisture and nutrient conditions within the rhizosphere zone reduce the plant's energy expenditure compared to fluctuating growing conditions (Shirgure et al., 2001).

Earlier studies emphasize a consistent increase in guava fruit yield with replenishment of rising evapotranspiration (ET). While maximum fruit yield and water productivity were evident under drip irrigation at 100% ET, a higher benefit-cost ratio was achieved with 75% irrigation relative to cumulative pan evaporation. This approach also resulted in maximum yield, quality fruits, optimal leaf nutrient status, fertilizer use efficiency, and the highest net returns (Sharma et al., 2012; Ramniwas et al., 2013). Water application depends significantly on climatic conditions, soil type, and plant growth stage. Since, guava is yielding twice a year, phenology-based irrigation management, which tailors irrigation schedules to the specific developmental stages of the plant, is essential for optimizing water use and enhancing fruit quality. By adopting a phenology-based approach, we seek to improve water use efficiency, enhance fruit quality and contribute to the sustainable intensification of guava cultivation (Kumar et al., 2023).

MATERIALS AND METHODS

A field experiment was conducted at ICAR-Indian Institute of Horticultural Research, Hesaraghatta, Bengaluru, situated at latitude 13°82 122 2 N and longitude 77°292 452 2 E, spanning four years from 2018 to 2021. The experimental site featured sandy loam soil with a pH (5.10), EC (0.41 dSm^{-1}) and organic carbon content (0.99%). Initial nutrient levels in the soil included 359.3 kg available N/ha, 76.6 kg available phosphorus/ha, and 593.6 kg available potassium/ha. The field experiment centered on seven to ten-year-old guava var. Arka Mridula trees, aimed at standardizing irrigation scheduling across different stages of the crop throughout the year. Employing a randomized block design with five replications. The experiment featured varied levels of pheno-phase-based irrigations, meeting evaporation replenishment at different ratios. The control, representing 80% evaporation replenishment during both the vegetative and reproductive phases, was established for comparison (Table 1). Standard recommended practices were followed for crop management, except for irrigation.

Table 1 : Treatment details

Treatment	Vegetative phase	Reproductive phase
T_1	0.4 ER	0.6 ER
T_2	0.4 ER	0.8 ER
T_3	0.6 ER	0.6 ER
T_4	0.6 ER	0.8 ER
T_5	0.8 ER	0.8 ER

Irrigation scheduling was based on crop evapotranspiration (ET), calculated using the Penman equation and local meteorological data (Allen et al., 1998). The ET was adjusted weekly based on the phenological stage of the guava plants (vegetative and fruiting). The 100% ET treatment received irrigation equivalent to the full ET, while, the 80% and 60% ET treatments received proportionally less water. The efficiency of water application was monitored by measuring soil moisture content before and after irrigation using gravimetric methods. Observations were systematically recorded at intervals, encompassing plant growth and physiology, yield and quality. Physiological parameters were assessed using an IRGA portable photosynthetic system. Plant canopy volume was calculated using the formula 2/3 π H (A/2 x B/2), where H represents plant height, and A and B signify the East-West (EW) and North-South (NS) plant canopy spread, respectively, as described by Mark et al. (2002). Water use efficiency was determined based on plant yield and water consumption. The experimental data of four years were pooled and analyzed statistically using OPSTAT software, following the methods outlined by Panse & Sukhatme (1985), with differences in means assessed at a 5% level of significance.

RESULTS AND DISCUSSION

Growth parameters

Analysis of pooled mean revealed significant impact of irrigation treatments on canopy spread. The highest plant canopy spread was evident when irrigation was scheduled at 80% evaporation replenishment (ER) throughout the crop's growth and development stages, registering at 4.04 and 3.97 m^2, respectively. This trend was followed by scheduling irrigation at 40% ER during the vegetative phase and 80% ER during the reproductive phase, resulting in canopy spreads of 3.95 and 4.17 m^2, respectively. Similar pattern was observed in plant height, canopy volume, and collar girth. The data suggest that irrigation levels significantly influenced the growth parameters of guava plants. Treatments with higher irrigation levels (T_2) generally resulted in taller plants, wider canopy spreads, larger canopy volumes, thicker collar girths and more extensive branching patterns. Conversely, treatments with lower irrigation levels (T_4) exhibited comparatively lower growth parameters. These findings underscore the importance of appropriate irrigation management in optimizing guava plant growth and development (Sharma et al., 2022).

Table 1 : Growth parameters in ten years old guava as influenced by irrigation treatments

Treatment	Plant height (m)	Plant canopy spread (m^2) E-W	Plant canopy spread (m^2) N-S	Plant canopy volume (m^3)	Collar girth (cm)	Primary branches/ plant	Secondary branches/ plant
T_1	2.50	3.50	3.51	65.52	33.56	3.08	2.41
T_2	2.72	3.95	4.17	99.37	39.90	2.28	2.31
T_3	2.60	3.87	3.88	84.89	36.79	2.53	2.66
T_4	2.43	3.28	3.44	59.97	33.61	2.77	2.25
T_5	2.63	4.04	3.97	89.93	37.77	2.25	2.26
S.E.m±	0.17	0.52	0.52	15.23	2.71	0.32	0.19
C.D. (P=0.05)	0.54	0.17	0.17	46.93	8.34	0.97	0.59

Physiological parameters

Analysis of pooled mean results concerning physiological parameters in guava revealed noteworthy trends (Table 2). Scheduling irrigation at 40% ER during the vegetative phase and 80% ER during the reproductive phase resulted in lower physiological parameters, including photosynthesis (8.14 µ mol m^{-2} s^{-1}), stomatal conductance (0.063 mmol m^{-2} s^{-1}), and transpiration rate (1.62 mmol m^{-2} s^{-1}) indicating compromised plant physiological activity and potential stress conditions. This suggests that scheduling irrigation to meet only 40% of ER during the vegetative phase is insufficient to fulfill the physiological requirements of the guava crop (Ramniwas et al., 2012). The data suggest that treatments with higher proportions of irrigation water during both the vegetative and reproductive phases (T_5) tend to exhibit higher photosynthetic rates, stomatal conductance, and transpiration rates. Conversely, treatments with lower irrigation levels during specific phases (T_2 during the vegetative phase) may result in reduced physiological activity. Overall, the treatment details provide insights into how irrigation management influences key physiological processes in guava plants.

Fruit yield

The fruit number in guava consistently demonstrated higher values when irrigation was scheduled at 80% ER over the four years of the study, as well as in the pooled mean analysis. Notably, the highest number of fruits (524/plant/year in the 10th year, at 4 m x 4 m spacing) was observed when irrigation met 80% of ER during both the vegetative and reproductive phases. Correspondingly, elevated fruit yield (49.81 kg/plant, equivalent to 31.13 t/ha) was recorded with irrigation scheduled at 80% ER throughout the crop stages. This was followed closely by scheduling irrigation at 60% ER during both vegetative and reproductive phases, resulting in a slightly lower yield (47.75 kg/plant, equivalent to 29.84 t/ha), with differences of 2.06 kg/plant and 1.29 t/ha, respectively (Table 3 & Fig. 1). The crop responded positively to the increased amounts of irrigation water but with corresponding decline in the rate of increase, clearly indicating the higher water economic response for 60% replenishment of ET. Singh et al. (2015) reported

Table 2 : Pooled mean physiological parameters as influenced by irrigation treatments

Treatment	Photosynthetic rate (µ mol m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})	Transpiration rate (m mol m^{-2} s^{-1})
T_1	9.59	0.0700	1.75
T_2	8.14	0.0628	1.62
T_3	9.45	0.0721	1.79
T_4	9.21	0.0750	1.94
T_5	9.86	0.0748	1.76
S.E.m±	0.62	0.007	0.14
C.D. (P=0.05)	1.91	0. 022	0.42

Table 3 : Fruit yield in guava as influenced by different irrigation treatments

Treatment	No. of fruits/plant					Fruit yield (kg/plant)				
	2018	2019	2020	2021	Mean	2018	2019	2020	2021	Mean
T_1	149.50	536.50	382.00	428.65	374.16	14.40	45.68	33.46	48.96	35.62
T_2	258.75	712.75	515.75	523.65	502.73	23.13	58.80	47.38	56.17	46.37
T_3	189.75	629.00	480.00	579.75	469.63	19.08	58.05	49.68	64.18	47.75
T_4	168.50	505.25	361.50	400.63	358.97	16.63	44.50	33.69	38.63	33.36
T_5	224.75	764.50	551.00	555.30	523.89	22.08	62.68	48.48	66.02	49.81
S.E.m±	50.32	94.54	108.08	66.99	83.13	4.52	7.30	9.00	7.89	7.37
C.D. (P=0.05)	155.07	291.31	333.02	206.44	256.14	13.93	22.50	27.75	24.33	22.71

higher fruit number, weight, and yield with irrigation at 80% Potential Evapotranspiration (PE) per day per plant. Goswami et al. (2012) recorded significant increases in guava fruit yield with higher ET and nitrogen fertilization, achieving the best results under drip irrigation at 100% ET. Sharma et al. (2012) found the highest guava yields at 100% ET under drip irrigation, reaching 18.7 tons/hectare. Kumawat et al. (2017) observed improvements in fruit weight, pulp weight, and yield per tree with 75% irrigation of PE level.

Fruit quality

The average fruit weight exhibited a higher value when irrigation met 60% evaporation replenishment (104.5 g), followed by the treatment where irrigation met 80% of evaporation replenishment (99.53 g) (Table 4). While, there were no significant differences in the total soluble solids (TSS) of the fruit, the replenishment of 60% evaporation during both vegetative and reproductive phases generally resulted in marginally higher TSS levels (13.3 ºB). This trend persisted consistently across different years. These results align with Mandal et al . (2007), who found that drip-irrigated guava plants produced fruits with higher weight (161.3 g), TSS (11.7 ºB), total sugars (10.71%), and vitamin C content compared to flood-irrigated plants. The findings suggest that applying 60% ER during both phases can enhance fruit weight and slightly improve TSS, contributing to better overall fruit quality. Both 60% and 80% ER treatments significantly improved fruit weight, indicating the importance of maintaining higher irrigation levels during critical growth phases. Although, TSS differences were marginal, the consistent trend of higher TSS in the 60% ER treatment suggests potential benefits in taste and sweetness, which are important quality attributes for marketability.

Table 4 : Fruit quality in guava as influenced by irrigation during different phenophases during different years

Treatment	Fruit weight (g)					T.S.S. (˚B)				
	2018	2019	2020	2021	Mean	2018	2019	2020	2021	Mean
T_1	95.16	87.50	89.29	112.53	96.12	13.93	14.38	10.38	12.15	12.70
T_2	95.73	84.10	103.33	112.62	98.94	14.03	12.55	11.35	12.69	12.70
T_3	98.48	92.14	108.11	119.42	104.54	13.45	14.70	12.28	12.86	13.30
T_4	97.84	90.64	92.96	100.42	95.46	13.95	13.33	10.80	12.38	12.60
T_5	100.63	81.93	89.25	126.30	99.53	12.20	12.40	11.50	11.85	12.00
S.E.m±	6.07	3.68	8.99	18.35	5.84	0.36	0.97	0.67	0.47	0.66
C.D. (P=0.05)	18.71	11.34	27.71	56.54	15.62	1.12	3.00	2.05	1.44	2.03

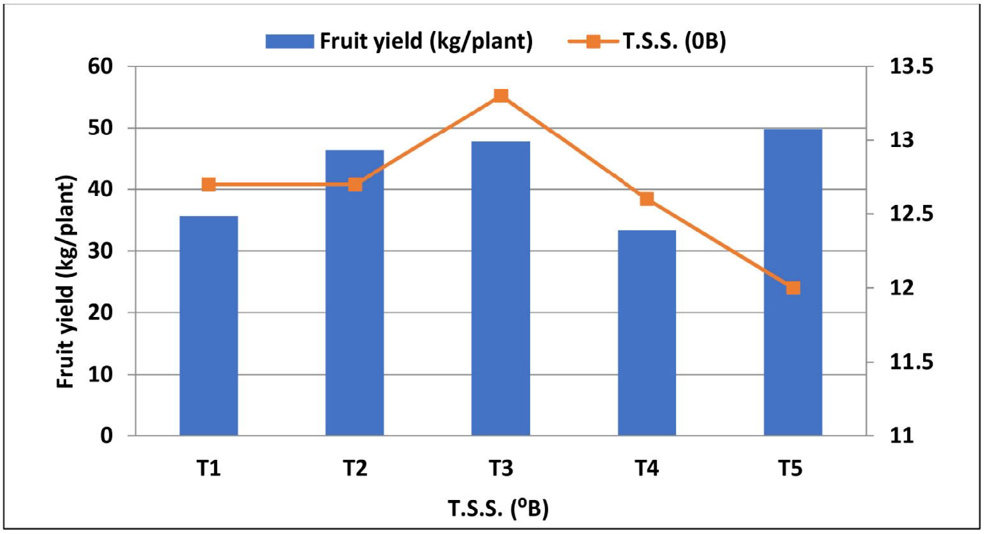

Fig. 1: Fruit yield in guava as influenced by different irrigation treatments

Water productivity and water saving

While replenishing 80% evaporation during both vegetative and reproductive phases resulted in a higher yield of 31.13 t/ha, it also incurred a greater total irrigation usage (3571 mm) (Table 5). In contrast, replenishing 60% evaporation during both vegetative and reproductive phases showcased substantial water savings of 2729.10 m^3/ha, reflecting a remarkable 23.57% reduction in water usage. This treatment not only demonstrated efficient water utilization but also achieved the highest water use efficiency (WUE) at 11.86 kg/m^3, indicating its suitability for water-scarce regions. This consistent trend across all three years underscores the reliability of this treatment. The rationale behind this efficiency is further supported by the principle that a plant exposed to a consistent moisture and nutrient regime within the rhizosphere zone expends less energy compared to conditions that vary over time. This has contributed to an increase in both fertilizers use efficiency (FUE) and water use efficiency, as reported by Shirgure et al. (2001). Furthermore, Kumawat et al. (2017) recorded the highest WUE under 50% irrigation of PE level, highlighting the benefits of strategic irrigation practices in optimizing water use efficiency.

The economic assessment of different phenophase-based irrigation strategies revealed that, while the gross and net returns marginally favored scheduling irrigation to meet 80% of evaporation during both the vegetative and reproductive phases (Rs.8,62,688/ha and Rs.5,57,592/ha, respectively), the treatment meeting 60% evaporation replenishment demonstrated equally commendable returns (Rs.8,31,788/ha and Rs.5,55,731/ha, respectively). Notably, the latter also boasted a higher benefit-cost ratio of 3.01, along with a significant 23.6% reduction in irrigation water usage.

Table 5 : Effect of irrigation schedules on water use/ha, water productivity and water saving by guava

Irrigation schedule	Effective rainfall (mm)	Irrigation water (m^3)	Water use (m^3)	Savings in water (%)	Pooled mean fruit yield (t/ha)	Water productivity (kg/m^3)
T_1	657	5256	2609.51	50	22.26	9.28
T_2	657	5256	3331.76	37	28.98	9.40
T_3	657	5256	2729.10	48	29.84	11.86
T_4	657	5256	3451.36	34	20.85	6.65
T_5	657	5256	3570.94	32	31.13	9.51
S.E.m±	-	-	-	-	4.60	1.56
C.D. (P=0.05)	-	-	-	-	14.19	4.80

Table 7 : Economics of different irrigation treatments in guava

Treatment	Yield (t/ha)	Gross returns (Rs./ha)	Total cost (Rs./ha)	Net returns (Rs./ha)	B:C ratio
T_1	22.26	6,25,975	2,66,242	3,59,733	2.35
T_2	28.98	7,75,663	2,86,877	4,88,786	2.70
T_3	29.84	8,31,788	2,76,057	5,55,731	3.01
T_4	20.85	5,48,688	2,95,322	2,53,366	1.86
T_5	31.13	8,62,688	3,05,096	5,57,592	2.83

This aligns with findings of Sharma & Mursaleen (2014), where 100% irrigation of cumulative pan evaporation through drip resulted in maximum fruit weight (163.71 g), while 75% irrigation of cumulative pan evaporation produced the highest fruit yield per plant (5.87 kg) and a superior benefit-to-cost ratio of 2.62. Additionally, Kumawat et al. (2017) concluded that maintaining 75% irrigation of PE level, coupled with fertigation, is recommended for achieving higher yields, maintaining fruit quality, and ensuring economically viable guava production under ultra-high-density planting. This economic analysis underscores the critical role of strategic irrigation planning in maximizing returns and sustainability in guava cultivation. The study reveals that reduced irrigation levels can lead to significant water savings and substantial economic gains without sacrificing productivity.

CONCLUSION

The findings from the comprehensive four-year field trial on seven to ten-years-old guava var. Arka Mridula conclusively recommend scheduling irrigation to meet 60% evaporation during both vegetative and reproductive phases. This strategy enhances productivity (29.84 t/ha), improves profitability (Rs.5,55,731/ha), and achieves notable water use efficiency (11.86 kg/m^3), facilitating a significant 24% reduction in irrigation water usage. While 80% ER treatments consistently demonstrated higher fruit yield, they required more water. In contrast, the 60% ER treatment provided substantial water savings without compromising yield, exhibiting higher water productivity and economic returns, making it suitable for water-scarce regions. These results highlight the importance of phenology-based irrigation management in optimizing guava cultivation, emphasizing that 60% ER is a viable alternative that delivers substantial yields with less water usage. This allows farmers to choose between 60% and 80% ER based on water availability and cost considerations without significantly compromising productivity.

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