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Assessing the Response of Bael (*Aegle marmelos* Correa L.) to Varying Irrigation Frequencies: Implications for Growth and Yield

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ABSTRACT

An experiment was carried out in 2023–24 at the Horticulture Research Centre, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) to determine the effect of irrigation frequency on shoot development and yield of bael (*Aegle marmelos* Correa L.). The experiment was set up in Randomized Block Design (RBD) with five irrigation levels, including one check level, replicated three times. Irrigation scheduling was based on different intervals during Winter and Summer seasons. Shoot lengths were measured at 15-day intervals until 180 days, and shoot growth rates were calculated accordingly. It was found that irrigation frequency had a strong impact on shoot length as well as production. Treatment T1, comprising an irrigation frequency of 15 days in Winter and 5 days in Summer, resulted in the highest shoot length and growth rate. The maximum yield (100.32 kg plant^{-1}) was also recorded in treatment T1, while minimum growth and yield were recorded for treatment T4 (irrigation interval of 30 days in Winter and 11 days in Summer). These results indicate that frequent irrigation improves vegetative growth and yield, particularly during the Summer season when moisture stress is prevalent.

Keywords Bael, Irrigation interval, Shoot growth rate, Subtropical climate, Water management, Yield.

INTRODUCTION

Bael (*Aegle marmelos* Correa L.) is a highly valued native fruit species in India, well known for its nutritional, medicinal, and spiritual importance. Bael fruits contain appreciable amounts of vitamins, minerals, and phytochemicals, making them useful in both diet and medicine. Bael trees grow naturally in South and Southeast Asia, especially the Eastern part of the Gangetic plains of India, including Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh, and Chhattisgarh. Despite good resistance to harsh conditions and drought tolerance, this fruit species largely remains underutilized (Peter 2007; Meena

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et al. 2022; Khanal *et al*. 2023). The fruit is rich in carbohydrates, minerals, vitamins and phytonutrients. The pulp of bael is high in moisture content, proteins, carbohydrates, carotene, thiamine, riboflavin, niacin, and vitamin C (Singh *et al.* 2018). In addition, bael fruit possesses several therapeutic properties and has been widely reported for its medicinal importance due to the presence of phytochemicals and antioxidants (Baliga *et al.* 2011).

The bael tree is recognized for its capacity to tolerate drought and high temperatures. Mature plants can withstand water stress through leaf fall during summer months, thereby reducing transpiration loss. Nevertheless, water availability at crucial growth stages is necessary for maximum shoot growth, flowering, fruiting and yield. Water stress adversely affects physiological functions such as stomatal conductance, photosynthesis, nutrient uptake, and cell growth (Hsiao 1973; Taiz *et al.* 2015). Therefore, proper irrigation scheduling is an important agronomic practice to improve bael growth and fruit yield, especially in subtropical regions.

The concept of irrigation scheduling through evapotranspiration has been recommended by researchers for effective water use (Allen *et al.* 1998). Estimation of crop water requirements using climatic parameters is also central to FAO guidelines for irrigation planning (Doorenbos and Pruitt 1977). Furthermore, inadequate moisture during critical growth stages results in significant yield losses (Doorenbos and Kassam 1979). Studies have shown that soil moisture availability strongly influences the growth and canopy development of perennial fruit crops (Singh *et al.* 2006). Bael is also considered to perform better under improved soil moisture availability even in rainfed conditions (Ghosh and Mathew 2002; Kumar *et al.* 2015).

Keeping these facts in view, the present investigation was undertaken to study the effect of different irrigation frequencies on shoot growth and yield of bael under the subtropical climatic conditions of the Ayodhya region. The results will help in developing suitable irrigation schedules for improving bael productivity.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at the Horticulture Research Centre of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during November 2023 to April 2024.

Experimental Design and Treatments

The experiment was laid out in a Randomized Block Design (RBD) with five irrigation treatments, including one check, replicated three times. Irrigation was applied at different intervals during Winter and Summer seasons. The treatments were as follows: T1 – 15-day interval in winter and 5-day interval in Summer; T2 – 20-day interval in winter and 7-day interval in Summer; T3 – 25-day interval in Winter and 9-day interval in Summer; T4 – 30-day interval in Winter and 11-day interval in Summer; and T5 (Check) – 12-day interval in both Winter and Summer seasons.

The experiment was laid out in a Randomized Block Design (RBD) with five treatments (T1–T5) and three replications, giving 15 experimental units (5 treatments × 3 replications). Each replication formed one block containing all five treatments, which were randomly allocated within the block using [randomization method, e.g., random number table]. Each experimental unit consisted of three 24-year-old bael (*Aegle marmelos*) trees of cultivar NB-9, planted at a spacing of 10 × 10 m. The experimental site has a subtropical climate and sandy loam soil. Observations began on 1 November 2023. Winter irrigation intervals were applied from November to February (0-120 days after the start of observations) and Summer intervals during March and April (120–180 days). Each irrigation delivered 6 cm of water, and five shoots per plant were tagged for observation.

Irrigation Water Calculation

The amount of irrigation water applied per plant was calculated using the basin method. The radius of the basin was maintained at 1.20 m. The quantity of water applied was estimated as: Quantity of water (liter) =

Basin area (m²) × Depth of irrigation (mm). With a basin radius of 1.20 m, the basin area (πr²) was 4.52 m², and since 1 mm of water over 1 m² equals 1 liter, the volume per irrigation was 4.52 liters for each millimeter of depth applied.

Observations Recorded

Shoot length (cm) was measured at 15-day intervals from 1 November 2023 onwards using a measuring tape, from the node to the shoot tip. Shoot growth rate (SGR) was calculated as: $SGR = (L_2 – L_1) / (D_2 – D_1)$, where L_1 = shoot length at time D_1, L_2 = shoot length at time D_2, and $(D_2 – D_1)$ = time interval in days. Yield per plant was calculated as: Yield (kg plant^{-1}) = Number of fruits plant^{-1} × Average fruit weight (kg).

RESULTS AND DISCUSSION

Effect of Irrigation Frequencies on Shoot Length

Irrigation frequency had a significant impact on shoot growth of bael trees. As time progressed from 0 to 180 days, an increasing trend in shoot length was recorded across all treatments; however, the magnitude of increase differed with irrigation frequency. The maximum shoot length was observed in treatment T1 (15-day winter interval and 5-day summer interval), where shoot length increased from 65.8 cm at day 0 to 77.8 cm at 180 days, indicating that frequent irrigation promotes greater vegetative growth. The check treatment (T5) also performed well for shoot elongation in comparison to the remaining treatments. The shoot length data across all observation dates and treatments are presented in Table 1.

Seasonal Variation in Shoot Growth Rate

The season played an important role in the shoot growth rate of bael. Growth rate was comparatively high during winter (0–120 days), while a significant decline was recorded during Summer (120–180 days). During March and April, shoot growth was near-zero across all treatments. This general decline was common to all treatments, but plants receiving more frequent irrigation performed consistently better than those under wider irrigation intervals. The reduction in growth rate during Summer can be attributed to high temperatures, increased evaporative demand, and rapid soil moisture depletion in the subtropical environment (Doorenbos and Pruitt 1977; Allen *et al.* 1998). These findings align with Meena *et al.*

Table 1. Shoot length (cm) of bael under different irrigation frequencies at 15-day intervals.

Treatment	0	15	30	45	60	75	90	105	120	135	150	165	180
T1	65.8	68.0	70.2	72.3	73.8	75.2	76.1	76.9	77.2	77.5	77.7	77.8	77.8
T2	59.5	61.8	63.2	64.6	65.6	66.4	67.3	67.9	68.3	68.4	68.6	68.6	68.6
T3	51.8	53.2	54.3	55.6	56.4	57.2	57.9	58.4	58.5	58.5	58.5	58.5	58.5
T4	65.1	66.5	67.5	68.5	69.2	69.7	70.1	70.4	70.4	70.4	70.4	70.4	70.4
T5 (Check)	63.17	65.33	67.13	68.89	70.07	70.82	71.46	72.10	72.42	72.65	72.74	72.92	72.9
SEm±	1.15	1.03	0.49	1.06	0.86	1.17	0.78	0.85	1.37	0.73	0.50	0.68	1.43
CD (5%)	3.96	3.57	1.68	3.67	2.98	4.06	2.71	2.93	4.74	2.52	1.73	2.35	4.95

Table 2. Shoot growth rate (cm day^{-1}) of bael under different irrigation frequencies.

Treatment	0–15	15–30	30–45	45–60	60–75	75–90	90–105	105–120	120–135	135–150	150–165	165–180
T1	0.153	0.145	0.136	0.102	0.091	0.063	0.063	0.025	0.018	0.013	0.010	0.000
T2	0.149	0.099	0.092	0.063	0.057	0.057	0.057	0.023	0.010	0.007	0.000	0.000
T3	0.092	0.075	0.083	0.054	0.055	0.047	0.047	0.005	0.000	0.000	0.000	0.000
T4	0.091	0.069	0.063	0.046	0.036	0.023	0.023	0.002	0.000	0.000	0.000	0.000
T5 (Check)	0.144	0.120	0.117	0.079	0.050	0.043	0.043	0.021	0.015	0.006	0.012	0.000

Table 3. Yield attributes of bael fruit crop under different irrigation frequencies.

Treatment	No. of Fruits (plant^{-1})	Weight per Fruit (kg)	Total Yield (kg plant^{-1})
T1	66	1.52	100.32
T2	63	1.50	93.87
T3	62	1.48	91.76
T4	59	1.46	86.14
T5 (Check)	65	1.51	98.79
CD at 5%	3.01 (S)	0.09 (NS)	3.97 (S)

(2022), who reported that climate change, through more frequent drought and rising temperatures, intensifies abiotic stress in arid and semi-arid regions and threatens the productivity of fruit crops.

Effect of Irrigation Frequencies on Shoot Growth Rate (SGR)

Shoot Growth Rate (SGR) showed a decreasing trend from early to later growth stages across all irrigation treatments (Table 2), indicating that vigorous shoot elongation predominantly occurred during the initial growth phase. The highest SGR was recorded at the 0–15 day interval under treatment T1 (0.153 cm day^{-1}), followed by T5 (0.144 cm day^{-1}). This demonstrates that timely water availability during initial growth stages promotes vigorous cell division and elongation. By contrast, the lowest SGR was recorded under treatment T4 (0.091 cm day^{-1}) at the initial interval, attributed to the negative effect of long irrigation intervals on vegetative growth. Reduced soil moisture during longer irrigation periods limits physiological activities, thereby reducing shoot growth. These findings are consistent with Hsiao (1973), who reported that water stress adversely affects stomatal conductance and plant growth, and with Taiz *et al.* (2015), who emphasized the critical role of water availability in cell expansion and vegetative development. Similarly, Ezzat *et al*. (2021) reported that seasonal shoot growth of apricot trees declined as water deficit increased, with the lowest growth under continuous deficit irrigation.

Effect of Irrigation Frequencies on Yield

Fruit yield characteristics of bael were significantly influenced by different irrigation regimes, confirming the importance of adequate soil moisture for fruiting. The maximum fruit yield was achieved in treatment T1 (100.32 kg plant^{-1}), with the next highest yield recorded in T5 (98.79 kg plant^{-1}), demonstrating that frequent irrigation contributes to improved yields. Treatment T4 showed the minimum yield (86.14 kg plant^{-1}), indicating that wider irrigation intervals adversely affected fruit yield. Similarly, the maximum number of fruits per plant (66) was obtained in T1, while the lowest (59 fruits plant^{-1}) was recorded in T4. Notably, no significant differences in individual fruit weight were observed across treatments, suggesting that irrigation frequency primarily influenced fruit set and retention rather than individual fruit development. These data are presented in Table 3.

These findings are consistent with Doorenbos and Kassam (1979), who reported that crop yield is strongly dependent on water availability and that moisture deficit during reproductive stages substantially reduces productivity. Similarly, Fereres and Soriano (2007) emphasized that efficient irrigation scheduling plays a vital role in minimizing water stress and maintaining crop yield under limited water conditions. Ezzat *et al.* (2021) likewise found that continuous deficit irrigation significantly reduced fruit number per tree and yield in apricot, in line with the lower fruit number and yield recorded here under the longest irrigation interval (T4). The results also corroborate Singh *et al.* (2018), who indicated that although bael is drought tolerant, adequate irrigation during critical growth and fruit development stages is essential for achieving higher productivity under subtropical and semi-arid conditions.

CONCLUSION

The present study provides clear evidence of the important role of irrigation frequency in regulating shoot growth and fruit yield of bael. Significant differences in growth characteristics and yield were recorded between treatments. Treatment T1 (15-day winter interval + 5-day Summer interval) was the best-performing treatment, recording the highest shoot length, shoot growth rate, number of fruits per plant, and total fruit yield. Treatment T4, with the longest irrigation interval, showed the poorest growth

and fruit yield, confirming the negative effect of moisture stress on bael productivity. These results indicate that maintaining adequate soil moisture, particularly during summer when temperatures and evaporative demand are high, is critical for achieving optimum yields. Proper irrigation scheduling can therefore be recommended as an effective management strategy for enhancing bael fruit productivity under subtropical conditions.

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