Original Articles

Impact of Rainwater Harvesting on Mastic (*Pistacia lentiscus* L. var. *chia*) Plantation in the Semi-Arid Region of Türkiye

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Abstract

The Mediterranean region faces increasing aridity due to climate change, threatening the establishment and growth of drought-sensitive tree species. The ecologically and economically important mastic tree generally exhibits drought resilience but remains vulnerable to heightened water stress due to climate change. This study evaluated the effectiveness of crescent bunds, a rainwater harvesting (RWH) system, in enhancing the growth and survival of young mastic (*Pistacia lentiscus* L. var. *chia*) tree seedlings in a previously established (three-year-old) plantation in the semi-arid Urla-Çeşme Peninsula, Izmir, western Türkiye. Two treatments were compared: traditional pit planting (the control) and crescent bunds. Two-meter-diameter crescent bunds were formed around three-year-old seedlings to capture runoff. The control treatment included the seedlings pit-planted three years ago. No significant differences were observed between the RWH and the control treatments one-year post-treatment. However, two years after treatment, the seedlings with crescent bunds exhibited significantly greater increases in mean height (15%), root-collar diameter (19%), and crown diameter (35%) than the controls. The sturdiness index remained similar between treatments, indicating balanced growth. Relative growth metrics revealed that crescent bunds supported at least a threefold increase in height and crown diameter growth over the control. These findings highlighted the potential of crescent bunds to improve soil moisture availability and enhance long-term seedling performance in water-limited environments. The study underscored the importance of adaptive and sustainable water management techniques, such as RWH systems, for sustaining mastic tree plantations under climate change-induced aridity, offering scalable solutions for Mediterranean afforestation.

Keywords: Mediterranean ecosystems, *Pistacia lentiscus*, crescent bunds, smart forestry.

Introduction

Tree establishment is crucial for restoring fragile ecosystems, as tree seedlings are particularly susceptible to abiotic and biotic stresses during the summer. In the Mediterranean region, poor tree survival during extended droughts is often attributed to inadequate seedling establishment, with insufficient soil moisture recognized as the primary limiting factor. Successful plant establishment correlates closely with increased leaf area, improved photosynthetic activity, and vigorous root growth, all of which significantly enhance seedling survival (Oweis, 2022; Lefi et al., 2023). With the region facing increasing aridity due to climate change, species' ability to rapidly adapt to water stress will be essential for their future distribution and persistence (Sánchez-Gómez et al., 2011; Gratani et al., 2013). In recent years, annual precipitation in the Aegean Region of Türkiye has decreased significantly. The average annual precipitation for the region from 1991 to 2024 was 605 mm, but in 2024 it decreased by 22% (AFAD, 2025).

The mastic tree (*Pistacia lentiscus* L.), an endemic woody species in the Mediterranean region, is a versatile and drought-tolerant tree with significant ecological and economic value (Ak & Parlakçı 2009; Vasques et al., 2016; Lefi et al., 2023). It is naturally distributed throughout the Mediterranean and Aegean regions, with maquis vegetation extending to Hatay, located in southern Türkiye (Zohary, 1952; Davis, 1966; Acar, 1988). While wild forms of the mastic tree are abundant in the maquis formation, its subspecies suitable for mastic production and capable of developing into a tree form (*P. lentiscus* var. *chia*) has a more restricted distribution. This subspecies is endemic to the Greek island of Chios and sporadically appears on the opposite side of the Çeşme Peninsula in Izmir, Türkiye (Browicz, 1987; Acar, 1988; Pericos, 1993).

The mastic tree plays a crucial role in soil conservation and erosion control, as well as in its gum production, which is significant for industry, medicine, and rural livelihoods (Gratani et al., 2013; Vasques et al., 2016; Chehrit-Hacid et al., 2023; Lefi et al., 2023). Its high capacity for vegetative reproduction and fire-resistant properties enable it to adapt to and mitigate dry, fire-prone Mediterranean ecosystems (Vasques et al., 2016). While the mastic tree demonstrates greater tolerance to water stress compared to other resprouting woody species, such as the strawberry tree (*Arbutus unedo* L.) and holm oak (*Quercus ilex* L.), increased water availability during the spring-summer period significantly enhances its survival and growth. Due to climate change, frequent, intense, and prolonged heatwaves and droughts significantly reduce the survival and growth of the mastic tree (Vasques et al., 2016; Tamudo et al., 2024; Camarero et al., 2024).

Despite its drought resilience, worsening soil water conditions caused by climate change pose a significant threat to the successful establishment of mastic tree plantations (Lefi et al., 2023). Mastic trees have demonstrated higher survival rates when planted under the canopy of Aleppo pine (*Pinus halepensis* Miller) stands compared to open or shrub-dominated sites. This indicates that microclimatic conditions play a crucial role in their establishment success (Maestre et al., 2004). Furthermore, a strong positive correlation has been observed between root-collar diameter and seedling survival, highlighting the importance of early growth traits in determining long-term establishment (Lefi et al., 2023). In another study, provenance does not significantly influence the drought tolerance of mastic tree seedlings (Vasques et al., 2016).

In arid and semi-arid regions, supplemental irrigation is essential for planting and establishing tree seedlings (Critchley et al., 1991; Prinz, 2001). However, the cost and distance to water resources often make irrigation unfeasible in these areas, particularly due to climate effects. Rainwater harvesting (RWH) systems offer a sustainable and cost-effective solution for tree plantations. These systems collect and store surface flow after precipitation and direct the harvested water to the crops (Critchley et al., 1991). They have demonstrated considerable success in afforestation efforts in the semi-arid Izmir region of western Türkiye. Six-meter-diameter crescent (i.e., semi-circular) bunds and 6x6-m baklava (i.e., negarim) microcatchments significantly increased mean soil water content over the growing season in the semi-arid Aliaga, Izmir, Türkiye, compared with conventional terraces and pit planting. They greatly improved the survival and growth of young stone pine (*Pinus pinea* L.) and Turkish oak (*Quercus cerris* L.) compared to traditional afforestation methods (Eşen et al., 2024). In a recent study in the region, V-shaped microcatchments significantly enhanced mean soil moisture threefold during the growing season compared to traditional terraces in Izmir, one year after treatment. Young narrow-leaf ash (*Fraxinus angustifolia* Vahl.) seedlings in the microcatchments exhibited significantly greater growth than those in the terraces (Karaşin et al., 2024). In another recent study located very close to the present study (567 m), the V-shaped microcatchments also significantly increased mean soil moisture content by up to 4.5-fold and improved seedling survival and growth of two-year-old mastic tree seedlings in Çeşme, Izmir, two years after treatment, compared to traditional terraces (Koyuncu, 2024). While previous studies have demonstrated the efficacy of RWH systems like V-shaped microcatchments in newly established plantations (Karaşin et al., 2024; Koyuncu, 2024), their applicability to older plantations remains understudied. This study addresses this gap by evaluating crescent bunds in a three-year-old mastic plantation, testing their

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potential to enhance growth in existing afforestation efforts. The present study is particularly significant as it approaches the critical challenges of seedling survival and growth under increasing aridity, worsened by climate change, which prolongs drought periods, intensifies their severity, and increases the frequency and intensity of wildfires. This study also examines regional afforestation policies, such as Türkiye's 2023–2030 Climate Action Plan, to mitigate drought impacts. It utilizes an existing three-year-old mastic tree plantation established using traditional pit planting and crescent bunds two years ago. The study aims to investigate the effects of crescent bunds in established mastic plantations and assess their applicability to older plantations in the region. Therefore, it differs from the Koyuncu (2024) study.

Methods

Description of study site and treatments. The experimental area is situated on the Urla-Çeşme Peninsula in Izmir, along the Aegean Sea in western Türkiye. It is located at the boundary between the Çeşme Chiefship (Compartment No: 53) and the Karaburun Chiefship (Compartment No: 508) of the Gaziemir Directorate of Forestry, under the jurisdiction of the Izmir Regional Directorate of Forestry (38.423280 N- 26.526706 E; 38.418539 N- 26.523595 E) (Figure 1). The study was conducted in a 3-ha mastic tree plantation established in 2020 with 3x3 m spacing along the Ildır-Balıklıova road, adjacent to the experimental sites of Koyuncu (2024).

Izmir Province is on the coast of the Aegean Sea and has a typical Mediterranean climate with hot, dry summers and relatively moist winters. The long-term mean annual temperature and precipitation for the province are approximately 18°C and 697 mm, respectively. According to Aydeniz's Climate Classification, Izmir is classified as semi-arid, with a Drought Index of 0.84 (Semenderoğlu, 1999; AFAD, 2025; Aydın et al., 2025; MGM, 2025). Typically, the growing season in western Türkiye extends from May to September (Arslantaş & Yeşilırmak, 2020), covering the entire summer (June, July, and August) and part of the autumn (September, October, and November) (Kotsias et al., 2021). Summer rainfall accounts for only 9% of the annual mean precipitation, indicating that considerable water stress (i.e., low soil moisture content) occurs for most of the growing season (AFAD, 2025; Aydın et al., 2025; MGM, 2025). Kotsias et al. (2021) reported that climate change has shortened the winter (December, January, and February) and autumn periods, suggesting a recent increase in the duration of water stress in the region.

The long-term (2012-2022) mean annual precipitation recorded at the nearest Çeşme Meteorological Station, located 18.3 km

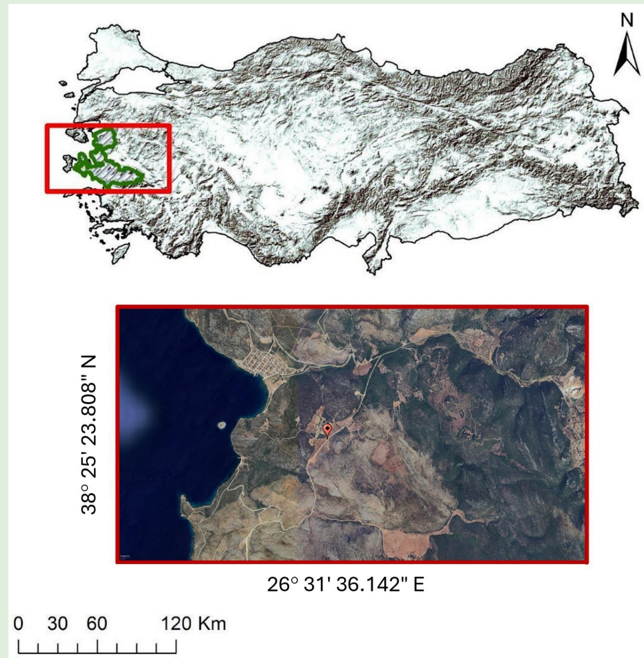

Figure 1. The location of the study site where mastic (*Pistacia lentiscus* L. var. *chia*) seedlings were tested with and without crescent bunds in Izmir, western Türkiye.

from the experimental site, is slightly lower than the mean annual precipitation of Izmir Province 610 mm (MGM, 2025). Drought-resistant plant species, including the mastic tree (P*istacia lentiscus* L. var. *chia*), prevail on the peninsula where the experimental site is located (Semenderoğlu, 1999). The experimental site features stony, clayey soil with a slightly alkaline reaction (pH: 8.07) and an electrical conductivity of 0.05 µS cm^{-1}, containing moderate levels of organic matter (2.55%). The soil at the study site has 0.11% total N, 2.99 ppm available P, 630 ppm available K, and 230 ppm available Mg (Koyuncu, 2024). The average slope and elevation of the study area are 25% and 137 m above sea level, respectively.

Mechanical site preparation was conducted in the fall of 2020 using a ripper, followed by pit planting at a spacing of 3x3 m. One-year-old mastic tree seedlings were obtained from the Izmir-Torbalı Forest Nursery under the Izmir Regional Directorate of Forestry. The nursery's management propagated these seedlings through air-layering from mastic trees collected in the Urla and Çeşme sub-provinces of Izmir, Türkiye.

In the autumn of 2023, two treatments were installed in the study: pit planting (the control) and crescent bunds (Figure 2). For the control treatment, seedlings pit-planted in 2020 received no treatment. They were three years old when the experiment began. For the crescent bunds, two-meter-diameter semi-circular earth bunds were manually constructed around each three-year-old mastic tree seedling in fall 2023, leaving the seedling at the center of each bund (Figure 2 and 3). The bunds were constructed by manual labor, forming 20-30 cm-high berms with their open ends facing perpendicular to the slope to maximize rainwater interception. This arrangement ensured optimal water collection

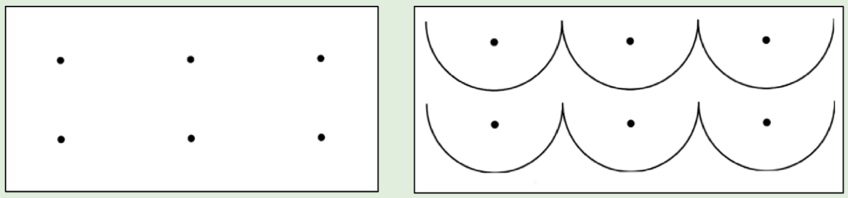

Figure 2. A representative view of an experimental unit including six 2x2-m pit-planted mastic (*Pistacia lentiscus* L. var. *chia*) seedlings as the control (on the left) and a representative view of a rainwater harvesting experimental unit including a 2-m-diameter crescent bund with six 2x2-m pit-planted seedlings (on the right).

Figure 3. Mastic (*Pistacia lentiscus* L. var. *chia*) seedlings with crescent bunds in Izmir Türkiye.

from the upslope catchment area while directing runoff toward the root zone.

Sampling and analysis of plants. Initial seedling height, crown diameter, and root-collar diameter were not recorded at the time of treatment installation in fall 2023 (Year 0). One and two years after treatment, seedling survival (%), height (mm), and crown diameter (mm) were evaluated. Seedling root-collar diameter (RCD, mm) was only measured, and the sturdiness index (height/RCD, mm) was calculated at Year 2.

Statistical design and analysis. A randomized complete block design with four replications was utilized for the study. Each block contained two experimental units (the control and crescent bund treatments), each consisting of six mastic tree seedlings. The data were analyzed using a one-factor analysis of variance (ANOVA) with treatment as the factor. Duncan's mean separation test was employed to distinguish between the treatment means. The ANOVA assumptions were verified, and transformations were applied as necessary to ensure appropriate mean separation for the relevant variables. Actual data values were presented in the figures, and results were deemed significant if the p-value was less than or equal to 0.05.

Results

No seedling mortality (i.e., 100% survival) was observed between the treatments, one and two years after treatment. Although the crescent bund RWH system demonstrated greater height (7%) and crown diameter (10%) than conventional pit planting one year after treatment, these differences were not significant (Figure 4). However, the trend in these variables one year after treatment led to significant differences in the second year of treatment (Figure 5 and 6). Mastic seedlings with crescent bunds averaged a significant increase (19%) in mean RCD compared to those without crescent bunds, as shown in Figure 5. The mean height of the seedlings supported by crescent bunds was also significantly greater (15%) than that of the seedlings using the traditional pit method. There was no significant difference in vigor indicators across the two treatments.

Crescent bunds exhibited the most significant increase in mean seedling crown diameter. The use of crescent bund RWH system resulted in a significant increase (35%) in the mean crown diameter of the seedlings compared to conventional pit planting (Figure 5). Additionally, a significant difference in relative growth over the past year was observed between the treatments. The mean relative height and crown diameter growth of individuals supported by

Figure 4. Mean height and mean crown diameter of mastic (*Pistacia lentiscus* L. var. *chia*) seedlings with and without crescent bunds one year after the treatment. According to the analysis of variance (ANOVA), the treatment factor is not significant ($p>0.05$). Means of letters beside bars indicate the following: **A**: differences in the heights between pit-planting and crescent bunds; and **a**: differences in the crown diameters between pit-planting and crescent bunds.

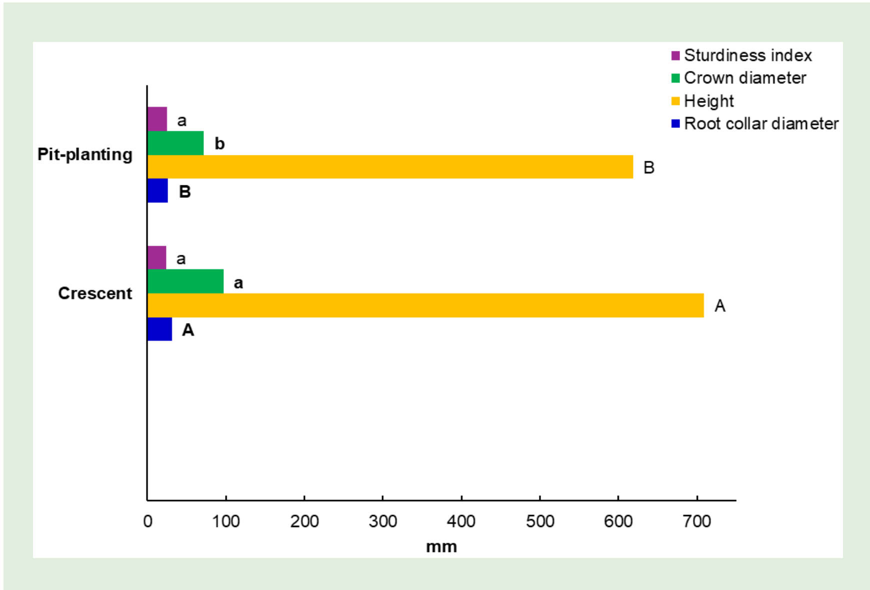

Figure 5. Mean root-collar diameter, height, crown diameter, and sturdiness index of mastic (*Pistacia lentiscus* L. var. *chia*) seedlings with and without crescent bunds two years after the treatment. According to the analysis of variance (ANOVA), the treatment factor is significant ($p<0.05$). Asin-transformed values were employed for the mean separation test of crown diameter whereas actual means were presented in the figure. Means of letters beside bars indicate the following: a: differences in the sturdiness index between pit-planting and crescent bunds; **a**, **b**: differences in the crown diameters between pit-planting and crescent bunds; A, B: differences in the height between pit-planting and crescent bunds; **A**, **B**: differences in the root collar diameter between pit-planting and crescent bunds.

crescent bunds showed at least a threefold increase compared to individuals using the conventional (pit-planting) method (Figure 6).

Discussion

These findings align with global observations regarding the efficacy of RWH systems in semi-arid regions, where water scarcity is a critical limiting factor for afforestation success (Critchley et al., 1991; Prinz, 2001; Tadros et al., 2021; Oweis, 2022). The absence of seedling mortality in both treatments implies that five-year-old mastic trees had established robust root systems prior to the treatments, likely buffering them against drought stress (Lefi et al., 2023). The delayed yet significant growth responses (root-collar diameter, height, and crown diameter, Figure 5) in the second year suggest a gradual but transformative impact of crescent bunds on seedling growth under improved soil moisture dynamics, as noted in similar studies (Critchley et al., 1991; Eşen et al., 2024). The similar sturdiness index between treatments indicates that crescent bunds promote proportional growth without inducing significant structural changes in seedling stability (Aphalo & Rikala, 2003; Ayan et al., 2020).

Previous research confirms that RWH systems, such as crescent bunds and Negarim microcatchments (Critchley et al., 1991; Kelil et al., 2023; Eşen et al., 2024), and V-shaped microcatchments (Karaşin et al., 2024; Koyuncu, 2024) significantly improve soil water retention and, consequently, seedling growth. The present study corroborates earlier findings that RWH techniques significantly enhance seedling performance in water-limited environments. However, the absence of soil moisture measurements in the present study is a limitation. Therefore, it is not possible to link the observed increases in mastic tree seedling growth (root-collar diameter, height, and crown diameter) to soil moisture content. Nevertheless, the significantly greater growth of mastic seedlings with crescent bunds may be attributed to an increased availability of soil moisture, as the crescent bunds likely enhanced water retention in the present study. The sturdiness index remained similar across treatments, indicating balanced growth without structural instability, which is a critical trait for drought resilience (Aphalo & Rikala, 2003; Ayan et al., 2020). Relative growth metrics further demonstrated that crescent bunds supported at least a threefold increase in height and crown diameter growth over traditional pit planting, highlighting their potential to mitigate climate-induced aridity (Gratani et al.,

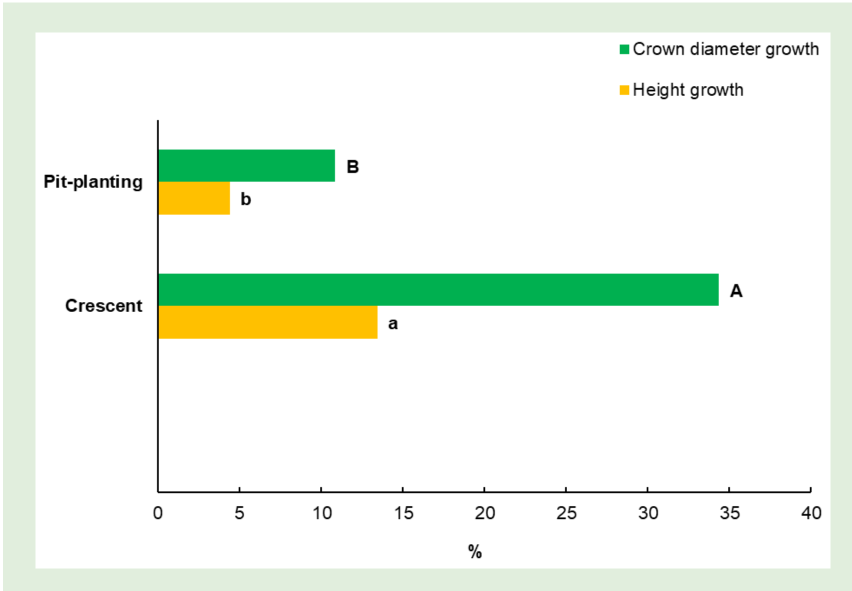

Figure 6. Relative crown diameter growth and height growth of mastic (*Pistacia lentiscus* L. var. *chia*) seedlings with and without crescent bunds two years after the treatment. According to the analysis of variance (ANOVA), the treatment factor is significant ($p<0.05$). Log-transformed values were employed for the mean separation test of height whereas actual means were presented in the figure. Means of letters beside bars indicate the following: **A**, **B**: differences in the crown diameter between pit-planting and crescent bunds; **a**, **b**: differences the height growth between pit-planting and crescent bunds.

2013; Vasques et al., 2016). Unlike previous studies, this research found that the superior performance of crescent bunds in improving soil moisture content and tree seedling survival and growth is not limited to young plantations, and its applicability to older plantations broadens its utility beyond newly established sites. The bunds' semi-circular design likely enhances water infiltration and reduces runoff, gradually increasing plant-available water—a mechanism well-documented in semi-arid afforestation efforts (Critchley et al., 1991; Prinz, 2001; Tadros et al., 2021; Oweis, 2022).

The outcomes of the study particularly tackle broader challenges in Mediterranean afforestation, where only 20% of annual precipitation occurs during the critical growing season (AFAD, 2025). With climate change worsening drought frequency and intensity (Sánchez-Gómez et al., 2011; Gratani et al., 2013), low-cost, sustainable RWH systems, such as crescent bunds, are essential for restoring degraded landscapes (Critchley et al., 1991; Prinz, 2001; Oweis, 2022; Kelil et al., 2023; Eşen et al., 2024). The success of crescent bunds in this study reflects global trends, where similar systems have been crucial in rehabilitating arid and semi-arid ecosystems (Critchley et al., 1991; Prinz, 2001; Tadros et al., 2021; Oweis, 2022).

The findings of Çerçioğlu et al. (2024) on wood-particle mulching provide valuable insights for further enhancing the effectiveness of crescent bunds in semi-arid afforestation. Their study demonstrated that mulching treatments significantly affected the sturdiness index and root-collar diameter in stone pine (*Pinus pinea* L.) seedlings, with 5-cm-thick wood chips increasing the sturdiness index by 18% compared to controls. However, this treatment also led to the lowest diameter, suggesting a trade-off between structural stability and radial growth. These results underscore the potential of mulching as a complementary treatment to crescent bunds, especially in optimizing seedling vigor and drought resilience.

A limitation of this study is the absence of baseline (Year 0) measurements. Consequently, pre-existing differences between plots at the start of the treatment cannot be entirely ruled out and represent a potential source of uncertainty in the one-year results. Additionally, since the root-collar diameter was only measured and the sturdiness index was assessed at Year 1, differences observed between plots may partly reflect pre-existing differences from the previous year, which represents an additional potential source of error.

Conclusions

These findings highlight the potential of crescent bunds to improve soil moisture availability and enhance seedling growth in water-limited environments. The study also underscores the importance of adaptive water management techniques, such as rainwater harvesting systems, for sustaining mastic tree plantations amid climate change-induced aridity, offering practical insights for Mediterranean afforestation and restoration efforts. Long-term data indicate that only 121 mm (20%) of the area's annual precipitation (610 mm) occurs during the growing season (May-September) (Arslantaş & Yeşilırmak, 2020; AFAD, 2025). With increasing aridity and drought frequency, low-cost, sustainable techniques are essential for promoting seedling growth. However, the study's short duration (two years) and focus on a single species limit broader generalizations. Further investigations should assess the efficacy of rainwater harvesting across diverse species and soil types and under varying climatic extremes over longer periods (greater than 5 years), including interactions with other environmental stresses and disturbances such as extreme heat and wildfires. In conclusion, crescent bunds offer a low-cost, sustainable strategy to enhance mastic tree resilience in water-scarce environments. Future studies should evaluate their scalability across diverse Mediterranean landscapes and incorporate cost-benefit analyses to guide policy implementation. A limitation of the study was the absence of baseline (Year 0) measurements, which may have introduced uncertainty into the initial results, as pre-existing differences between plots could not be entirely excluded. Additionally, the lack of first-year data for root-collar diameter and sturdiness index may also introduce potential uncertainty.

Authors contribution

The authors confirm their contribution to the paper as follows: study conception and design: Derya Eşen; data collection: Derya Kamer and Muhammed Ali Aydin; analysis and interpretation of results: Derya Eşen and Melis Çerçioğlu; draft manuscript preparation: Melis Çerçioğlu. All authors have reviewed the results and approved the final version of the manuscript.

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