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Comparative Study of the Phenological and Physiological Characteristics of Olive Trees (*Olea europaea* L.) under Irrigation and Rainfed Conditions in the Bordj-Bou-Arreridj Region, Algeria

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ABSTRACT

Background: The region of Bordj Bou Arreridj, Algeria, has recently witnessed a remarkable development in olive cultivation.

Methods: This study, focusing on the Chemlal variety, examined the effects of drip irrigation compared to rainfall irrigation. Conducted in the municipality of El Anasser, Bordj Bou Arréridj province, it explored various morphological, physiological and phenological aspects.

Result: The results highlight the advantages of irrigated trees, particularly in terms of shoot growth, leaf surface area, number of flower clusters per branch, number of flower buds per cluster, chlorophyll content and stomatal density. Additionally, irrigation led to a precocity of 4 to 7 days across various phenological stages.

Key words: Behavior, Characteristics, Chemlal, Irrigation, Olive.

INTRODUCTION

Irrigation, the process of artificially supplying water to cultivated plants to enhance their yield and ensure their normal development, is crucial, especially in arid regions. Irrigation periods extend from late winter (end of March) through to autumn (end of September), with quantities adjusted according to soil type and climate, based on evapotranspiration.

Irrigation techniques vary depending on crop density, farming practices and available resources, ranging from traditional methods like gravity-fed irrigation to advanced techniques such as drip irrigation (Singh *et al.,* 2023; Ugwu *et al.,* 2023). Traditionally, olive production relies on rainfall, allowing the olive tree to survive intense drought periods while still producing acceptable yields (Silva *et al.*, 2010).

Generally, irrigation has a favorable quantitative effect on tree biology by increasing yields. However, it is challenging to definitively conclude the impact of water on reducing alternation, especially considering the significant role of cultivar (Le Bourdelle, 1975). Olive yield and oil quality are influenced by a combination of factors, including genotype and the plant's nutritional and water status. Traditional olive groves exhibit high adaptability to local conditions, whereas modern intensive systems require substantial water and nutrient inputs to maintain high yields and optimal oil quality. However, such intensification can lead to drawbacks, such as deteriorated oil quality from excess nitrogen, affecting phenolic compounds, saturated fatty acids, bitterness and oil stability.

The aim of this study is to examine the impact of irrigation on the behavior of the Chemlal olive variety by analyzing various phenological, morphological and physiological parameters to understand how irrigation can influence the growth, development and physiological characteristics of this olive variety.

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MATERIALS AND METHODS

The experiment was conducted on a private agricultural estate of Mr. Benouilli Ammar, located in the municipality of El Anasser, Wilaya of Borj-Bou-Arréridj. The study site is situated along National Road No. 5, 5 km from the center of Bordj-Bou-Arréridj city, with geographical coordinates of 36.04°N and 4.50°E.

The plant material consists of several trees of the Chemlal olive variety, primarily cultivated in Grande Kabylie where it holds significant economic importance. It represents about 40% of the olive trees cultivated in Algeria. The trees are vigorous, large, with a spherical and semi-weeping habit. Their fruiting branches are long and flexible. The fruits are small and oval-shaped and the variety is intended for oil production, with a yield of 18-22% (Chaouadi and Smaili, 2017).

The experiment was conducted during the year 2024, between March and June, in this study, six trees were tested to compare the behavior of olive trees under irrigation and rainfed conditions, planted in two plots, one irrigated and the other non-irrigated, with three trees in each plot. The characteristics studied include morphological and phenological traits.

The olive tree, which requires a mild and sunny climate, can tolerate drought well but is sensitive to excess water and overwatering. It needs an intake of 30 to 40 liters of water per week, once or twice in July and August (Anonymous, 2006). The olive tree can tolerate up to 3 g of salt per liter of water, provided that a rainfall exceeding 500 mm annually ensures leaching (Anonymous, 2006).

In our experiment, a drip irrigation system was used for the tested variety (Lalichetti *et al.,* 2025, Gowdra Gangana *et al.*, 2025). To meet the tree's water needs optimally, we supplied approximately 4.5 liters/hour for 8 hours/day, starting from the beginning of the vegetative awakening in April and May. During February and March, the same amount of water was applied for 8 hours once a month to prevent tree desiccation.

According to Bedbabis, (2002), the olive tree has two types of shoots: a wood shoot, which represents a vigorous shoot where bud development into floral buds does not occur and a fruiting shoot, which bears both floral and vegetative buds. New branch growth occurs on branches of one year or other branches of different ages (Boulouchа, 1995).

The length of annual shoots was measured to track their growth, starting from March. Four shoots per tree were selected, with measurements taken every ten days from March 3, 2024, to April 25, 2024.

Olive leaves are simple, entire, with a short petiole and lanceolate blade ending in a mucro (Ruby, 1918; Argenson *et al*., 1999). They often contain herbs, waxes, chlorophylls, acids (gall and malic), gums and fibers (Amouretti, 1985). We sampled nine leaves per variety, three per tree for each plot and calculated leaf area using the "Pétiole" application on April 28, 2024. "Pétiole" processes images to estimate leaf area through calibration using a "pad."

The number of clusters per shoot was measured for each tree and treatment to assess the inflorescence rate and estimate the effect of irrigation on this parameter.

The number of floral buds per cluster was measured for each shoot and treatment to evaluate flowering rate and the impact of irrigation. The length of the shoot bearing floral buds was calculated, followed by counting the number of buds to assess floral intensity and the effect of irrigation.

The number of floral buds that developed into set fruits was measured across all clusters to evaluate the fertilization rate and the impact of irrigation. We sampled 15 leaves, five per tree for each plot, with stomatal density determined by the epidermal imprint method on April 28, 2024. Stomates, covered by trichomes, were exposed by applying transparent varnish, peeling it off with tape and observing under a microscope. Stomatal density was calculated by counting the number per square millimeter of epidermis and their diameter was measured in micrometers (Cheroura and Mihoubi, 2023).

Nine leaves per variety, three per tree for each plot, were sampled. We ground 0.25 g of olive leaves in a mortar with sand, macerated in 20 ml of acetone, filtered to remove solids and measured chlorophyll content spectro photo metrically at 645 nm and 663 nm. Chlorophyll content is reported in µg/ml.

Phenology studies the periodic annual events in living organisms, determined by seasonal climate variations. In plants, these events include leaf development, flowering and fruit maturation (Bloesch, 2013). The annual vegetation cycle of the olive tree is closely linked to the local climate, reaching stages when more than 50% of vegetative organs appear (Colbrant and Fabre, 1981).

The reproductive cycle begins with rising temperatures, usually observed in late February or early March. This stage, known as bud break, marks the start of new leaf and bud development, influenced by local climatic conditions.

To assess flowering rate, we measured the number of floral buds before blooming, using six trees (three per treatment) and counting buds on four shoots from the previous year per tree on May 15, 2024. The same shoots used for fertilization measurement were kept to evaluate the rate of flowers developing into set fruits. Fertilization rate estimation was performed on June 2, 2024.

Statistical analysis was performed using JMP® version 10 (SAS Institute Inc., Cary, NC, USA). Analysis of variance was used, with the t-Student test for means separation, with a significance probability of $P \leq 0.05$.

RESULTS AND DISCUSSION

Leaf area

The data reveal a significant difference in leaf area between trees under different irrigation regimes. Trees irrigated using drip irrigation showed an average leaf area of 4.6 cm^2 compared to an average of 3.01 cm^2 for non-irrigated trees (Fig 1).

This increase in leaf area in the irrigated trees can be attributed to more vigorous growth and optimal leaf development, resulting from adequate water and nutrient supply. These observations highlight the positive impact of irrigation on leaf development, which can have important implications for overall plant health and productivity.

Irrigation likely supports better photosynthetic efficiency and overall plant vigor, contributing to enhanced growth and potentially improved yield and fruit quality. The results align with previous studies showing that irrigation can significantly improve leaf development and overall crop performance (Cheroura and Mihoubi, 2023). This suggests that managing water resources effectively can be crucial for maximizing the growth potential and productivity of olive trees.

The analysis of variance indicates a highly significant effect of the treatment on leaf area (P = 0.0014**).

Length of annual shoots

Fig 2 highlights a notable difference in the length of annual shoots between irrigated and non-irrigated trees, with a clear advantage for trees receiving drip irrigation compared to those that are not irrigated.

The length of annual shoots was significantly greater in the trees under drip irrigation. This result suggests that adequate water supply through irrigation supports more robust shoot growth, which can lead to improved overall plant development. The increased shoot length in irrigated trees indicates better access to essential resources, such as water and nutrients, facilitating enhanced growth and potentially greater fruiting potential.

These findings underscore the importance of effective irrigation practices in promoting healthy growth and optimizing the productivity of olive trees. By ensuring that trees receive sufficient water, particularly in arid or semi-arid conditions, growers can enhance vegetative growth and support the development of higher-quality and more productive olive crops.

Both figures show a similar trend, with initially slow growth observed from March 3 to March 31, where shoot growth was around 1 cm. From March 31 to April 7, shoot growth began to accelerate, reaching approximately 1.5 cm for non-irrigated trees and 3 cm for irrigated trees. This acceleration is likely due to more favorable environmental conditions, such as increased water and

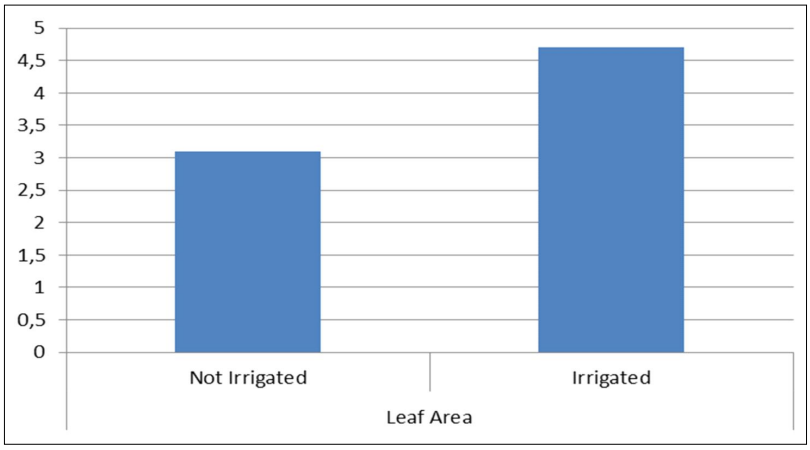


Fig 1: Leaf area of chemlal variety under different treatments.

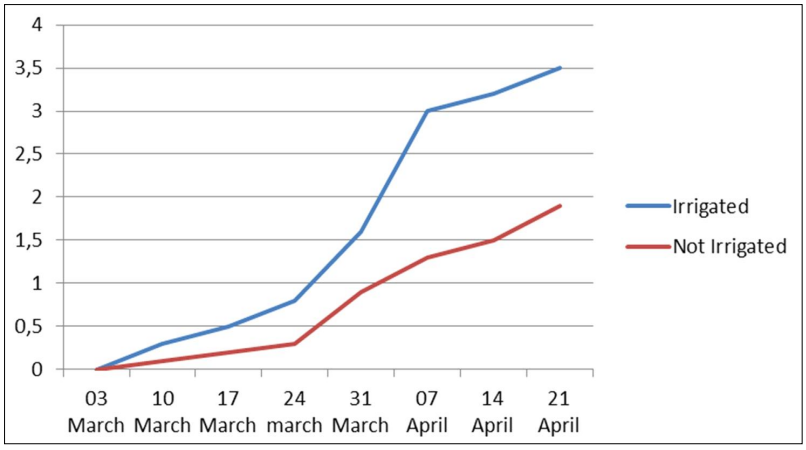


Fig 2: Length of shoots under different treatments.

nutrient availability, which stimulate shoot growth. These observations highlight the significant impact of irrigation on tree growth, showing apparent benefits in shoot length for irrigated trees compared to non-irrigated ones (Fig 2).

At the end of the growth period, there is a noticeable slowdown in growth, characterized by a very slight increase in shoot length. Between April 7 and April 21, trees under irrigation show a total shoot length of 3.5 cm, while non-irrigated trees have a length of 2 cm. This phase of slowed growth could be attributed to various environmental or physiological factors, such as depletion of nutrient reserves or less favorable climatic conditions (Fig 2).

The observed results demonstrate a clear difference in shoot growth favoring irrigated trees over non-irrigated ones. This finding underscores the importance of irrigation in promoting optimal vegetative growth of trees. By providing sufficient water and nutrients to the tree roots, irrigation helps stimulate shoot growth, leading to robust vegetative development and overall tree health.

These results support the argument for irrigation as an essential practice for optimizing growth and productivity in tree crops, potentially leading to positive implications for agricultural yields and the sustainability of production systems.

Number of flower clusters per shoot

Olive flowers are small, white and produced in dense clusters. Each flower consists of four sepals, four petals, two stamens and a pistil composed of a stigma, style and an ovary with two ovules (Loussert and Brousse, 1978).

The results show a significant disparity in the number of flower clusters per branch between irrigated and non-irrigated trees. Irrigated trees have an average of 24 flower clusters per branch, while non-irrigated trees have only 14. This substantial difference highlights the positive impact of irrigation on flowering, with a notable increase in flower clusters observed in trees with adequate water supply (Table 1).

The variance analysis indicates a significant effect of irrigation on the number of flower clusters per branch (P = 0.0111*).

Number of floral buds per flower cluster

The number of floral buds per flower cluster varies significantly between irrigated and non-irrigated trees. Irrigated trees show a much higher average of 22 floral buds per cluster, compared to just 9 in non-irrigated trees. This substantial difference emphasizes the significant impact of irrigation on floral bud formation, with a notable increase in blooming potential in trees with adequate water. These findings underscore the importance of irrigation for promoting abundant and regular flowering, which can have major implications for fruit yield and quality.

The variance analysis indicates a highly significant effect of irrigation on the number of floral buds per flower cluster (P = 0.0000***).

Number of floral buds per linear meter (Floral intensity)

There is a marked difference in the number of floral buds per linear meter between irrigated and non-irrigated trees. For irrigated trees, floral intensity is measured at 11.78 floral buds per linear meter, while non-irrigated trees have only 4.9 floral buds per linear meter. This divergence suggests a significant link between irrigation and floral bud production, highlighting the positive impact of irrigation on tree flowering (Table 2).

The variance analysis indicates a highly significant effect of irrigation on the number of floral buds per linear meter (P = 0.0000***).

Fertilization rate

Tracking the number of floral buds per branch and the number of fertilized flowers per branch, the data suggest a clear distinction in fertilization rates between irrigated and non-irrigated trees. For irrigated trees, the fertilization rate is approximately 5.79% of flowers fertilized per branch, while for non-irrigated trees, this rate is significantly lower, around 2.28%. This difference again highlights the positive impact of irrigation on tree health and reproduction, resulting in a higher fertilization rate in trees with adequate water supply. The observed low fertilization rate for both varieties is linked to water scarcity and subsequent hydric stress, which can affect fruit formation through pistil abortion (Fig 3).

Table 1: Number of flower clusters per shoot and number of floral buds per flower cluster for chemlal variety.

Variety	Irrigation type	Number of flower Clusters/Branch	Variance analysis	Number of floral buds/Flower Cluster	Variance analysis
Chemlal	Non-Irrigated	14	0.0111*	9	0.0000 ***
	Irrigated	24		22	

Table 2: Number of floral buds per linear meter and fertilization rate for the chemlal variety.

Variety	Irrigation type	Number of floral buds per linear meter (Floral intensity)	Variance analysis	Number of floral buds per branch	Number of fertilized flowers per branch	Fertilization rate (%)	Variance analysis
Chemlal	Non-Irrigated	4.90	0.0000***	1094	25	2.28	0.0000***
	Irrigated	11.78		4261	247	5.79	

Variance analysis indicates a highly significant effect of the treatment on the fertilization rate (P = 0.0000***).

Chlorophyll content

The results reveal a clear difference in chlorophyll a and b levels between the leaves of irrigated and non-irrigated trees. Irrigated trees exhibit significantly higher levels of chlorophyll a (21.78 µg/ml) and chlorophyll b (14.66 µg/ml) compared to non-irrigated trees, which have chlorophyll a and b levels of 17.03 µg/ml and 10.02 µg/ml, respectively. These data suggest that irrigation supports optimal physiological activity in trees, demonstrating a beneficial effect on their ability to perform photosynthesis, produce energy and maintain growth and health (Table 3).

The combined chlorophyll a and b content also shows a significant difference between irrigated and non-irrigated trees, with irrigated trees having a higher total chlorophyll a + b content (50.11 µg/ml) compared to non-irrigated trees (39.36 µg/ml) (Table 3). Chlorophyll content can be influenced by many factors, including leaf age, leaf position and environmental factors such as light, temperature and water availability (Hikosaka *et al.*, 2006).

Adequate irrigation ensures a constant supply of water, promoting optimal photosynthesis and chlorophyll production. Olive trees respond positively to well-managed irrigation, which can enhance leaf growth and health. The effects of irrigation on chlorophyll content may vary based on soil type, climate, olive variety and agricultural management practices. Effective irrigation management, tailored to the specific needs of olive trees and local conditions, can contribute to a significant increase in total chlorophyll content, thus improving the health and productivity of olive groves.

The variance analysis for chlorophyll content does not show a significant difference between the treatment groups, as the p-value is greater than 0.05 (P = 0.1366 ns).

Stomatal density

Increased stomatal density supports plant survival in particularly harsh environments.

The results show that irrigated trees have higher stomatal densities, with 312 stomata/mm^2 compared to non-irrigated trees, which have 171 stomata/mm^2. Indeed, leaves from the irrigated plots exhibit higher stomatal values, while the non-irrigated plots show lower values (Fig 4).

Variance analysis indicates a highly significant effect of the treatment on stomatal density (P = 0.0002***).

Phenological traits

Phenology studies the biological cycles of plants and their relationship with climatic conditions. This study recorded the different stages of growth and development of trees under two irrigation types (Table 4).

Bud burst

The development cycle of the olive tree begins with the first signs of growth, typically in response to increasing temperatures. The initial key stage is bud burst, occurring around the end of February or early March. This stage marks the beginning of active growth of new shoots and leaves from dormant buds. It is noteworthy that the exact timing of bud burst can vary depending on the olive variety and the specific climatic conditions of the region.

The data indicate that bud burst began around March 15 for irrigated trees, while a slight delay was observed for non-irrigated trees, with bud burst starting around March 19. This slight discrepancy in bud burst timing

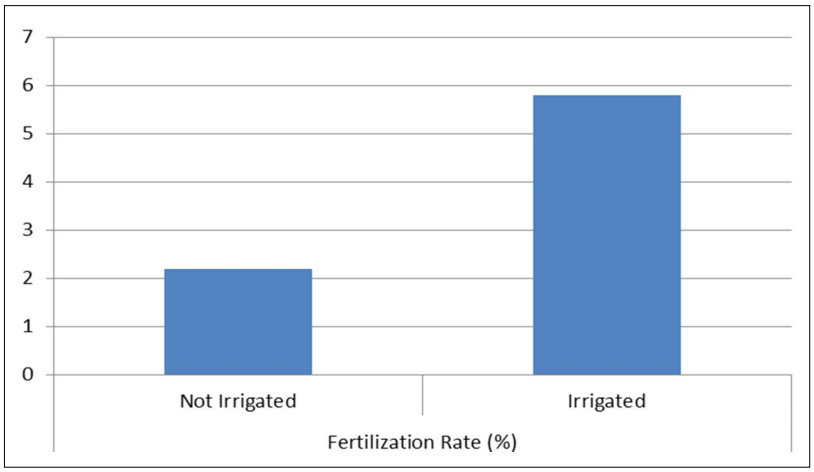


Fig 3: Fertilization rate for the two treatments.

Table 3: Chlorophyll content in leaves of irrigated and non-irrigated trees.

	Chlorophyll a (µg/ml)	Chlorophyll b (µg/ml)	Total Chlorophyll a + b (µg/ml)	Variance analysis
Tree leaf irrigated	21.78	14.66	50.11	0.1366 ns
Tree leaf non-irrigated	17.03	10.02	39.36	

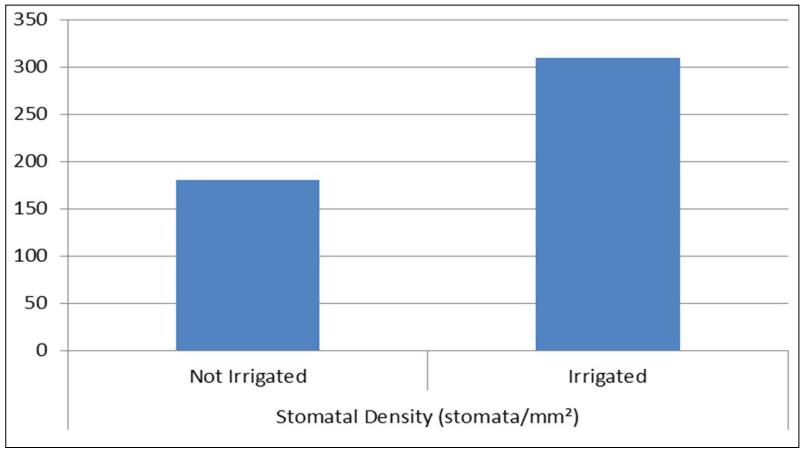


Fig 4: Stomatal density (stomata/mm²) of chemlal variety under two treatments.

Table 4: Dates of phenological phases for the chemlal variety under two treatments.

Variety		Bud burst date	Floral bouquet formation date	Blooming date	Fertilization date
Chemlal	Irrigated	15/03/2024	25/04/2024	15/05/2024	30/05/2024
	Non-Irrigated	19/03/2024	30/04/2024	21/05/2024	04/06/2024

between the two tree groups may be attributed to differences in soil water availability. Irrigated trees benefit from a regular water supply, potentially leading to a quicker response to favorable environmental conditions. In contrast, non-irrigated trees may experience water stress, slightly delaying the onset of their active growth phase. These observations highlight the impact of irrigation on tree development and underscore the importance of water management in olive cultivation (Table 4).

Floral bouquet formation

Inflorescences consist of long clusters that can have 4 to 6 secondary branches. The number of flowers varies depending on the cluster's position on the branch (Ouksili, 1983).

It is interesting to note that floral bouquet formation is the second phenological stage after bud burst. Data indicate that irrigated trees present floral bouquets first compared to non-irrigated trees, with appearance around April 25 for irrigated trees and April 30 for non-irrigated trees. This delay in floral bouquet formation between the two tree groups may also be attributed to the impact of irrigation on tree vigor and health (Table 4).

Blooming

The blooming stage is characterized by the visible formation of more than 50% of the flowers from the floral buds. This stage typically occurs about 15 days after floral bouquet formation. For irrigated trees, blooming is observed around April 15, while for non-irrigated trees, it occurs around April 21. This difference between the two tree groups confirms the significant impact of irrigation on the olive tree development cycle, influencing the speed and regularity of growth and blooming phases (Table 4).

Fertilization

Water plays a crucial role in the synthesis of carbohydrates in the presence of carbon dioxide and light, accelerating growth and fruiting in olive trees (Braham, 1997; Bedbabis, 2002).

The same flowering shoots were used to assess the fertilization stage. This stage was reached on April 30 for irrigated trees, with a 4-day advance compared to non-irrigated trees, which reached this stage around June 4 (Table 4).

CONCLUSION

Olive cultivation plays a crucial role in the national economy, representing 15% of the agricultural product. Although most olive orchards in Algeria are rain-fed, the introduction of irrigation systems is becoming essential to meet the water needs of this crop and stimulate olive oil production and yield.

The work conducted on a private farm in the municipality of El Annasser aimed to compare the effect of irrigation on the morphological, physiological and phenological development of Chemlal olive trees. This study provided the following results:

Regarding morphological traits, measurements of annual shoot growth reveal that irrigated trees exhibit more promising results, with a noticeable increase in vegetative mass. Additionally, the leaf area of irrigated trees is significantly larger, reaching 4.6 cm^2, compared to only 3.01 cm^2 for non-irrigated trees.

The number of floral bouquets per branch and the number of floral buds per bouquet are significantly higher in irrigated trees, as well as floral intensity and fertilization rate. The fertilization rate reaches 5.79% for irrigated trees, while it is only 2.28% for non-irrigated trees.

For physiological traits such as chlorophyll content and stomatal density, higher values are recorded in the leaves of irrigated trees. The chlorophyll content reaches 50.11 in irrigated leaves, compared to only 39.36 in non-irrigated leaves. Similarly, stomatal density is notably higher in leaves of irrigated trees, with a stomatal count of 312 stomata/mm², compared to 171 in non-irrigated leaves.

Irrigation also affects phenological stages, with an advance of 4 to 7 days for irrigated trees observed throughout different phases, from bud burst to flower fertilization. The latter stage occurred on April 30 for irrigated trees, whereas it happened on June 4 for non-irrigated trees.

This study highlighted the significant effect of irrigation on olive tree behavior, with results consistently favorable to irrigated trees. These observations underscore the critical importance of irrigation, which should be further generalized and developed.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal Care and Handling Techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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