



Fertilization, cover cropping and measurement period: Their effects on the annual growth of trees in an olive farm in Southwestern Buenos Aires

Mariano Busso¹⁺

**Roberto
Rodríguez**²

Liliana Suner³

^{1,2,3}Department of Agronomy, National University of the South, San Andrés
800, (8000) Bahía Blanca, Province of Buenos Aires, Argentina.

¹Email: mariano.busso29@gmail.com

²Email: rrodrig@uns.edu.ar

³Email: lsuner@criba.edu.ar

³Scientific Research Commission of the Province of Buenos Aires, (1900), La
Plata, Province of Buenos Aires, Argentina.



(+ Corresponding author)

ABSTRACT

Article History

Received: 3 April 2026

Revised: 8 May 2026

Accepted: 13 May 2026

Published: 22 May 2026

Keywords

Argentina

Crown area and volume

Olea europaea L.

Tree height

Trunk circumference.

The objective of this study was to determine the effect of fertilization in areas with or without a cover crop on the annual growth of irrigated olive trees (*Olea europaea* L.) during two growing seasons (2020/2021 and 2021/2022) in southwestern Buenos Aires Province, Argentina. Fertilization treatments included (1) organic fertilizer applied to the soil beneath the tree trunk; (2) inorganic fertilizer applied to the soil or (3) to the leaves of the olive trees; and (4) an unfertilized control. Vetch (*Vicia sativa* L.) and oats (*Avena sativa* L.) sown between the tree rows constituted the cover crop areas. Unsown areas corresponded to the control treatment. Annual growth variables were height, trunk circumference, and canopy area and volume. There were no significant differences ($p > 0.05$) between fertilization treatments or areas with or without cover crops for any of the annual growth parameters studied. However, the annual growth of these variables was greater ($p < 0.05$) in 2020/2021 than in 2021/2022. Furthermore, the difference in annual growth between the 2020/2021 and 2021/2022 periods was greater ($p < 0.05$) in the organic and inorganic soil fertilization treatments than in the inorganic foliar fertilization treatment. Moreover, this difference was greater ($p < 0.05$) in areas without cover crops compared to those with. This study determined that the annual growth of irrigated olive trees was not affected by different fertilization treatments in areas with or without inter-row cover crops in the studied region.

Contribution/Originality: The originality of this study was to determine the effect of various fertilization sources in areas with or without a cover crop on the annual growth of irrigated olive trees in southwestern Buenos Aires, Argentina. Annual tree growth was not affected by the evaluated treatments in the studied region.

1. INTRODUCTION

Currently, Argentina is the leading producer and exporter of olive oil in South America [1]. The main olive-producing provinces are Catamarca, La Rioja, San Juan, Mendoza, and Córdoba. These provinces have approximately 90,000 hectares planted with olive trees (*Olea europaea* L.) [2] and account for more than 95% of the country's total production. The southwestern region of the Province of Buenos Aires, Argentina, comprises the semi-arid, arid, and sub-humid-dry Pampas, with 6.5 million hectares divided into 12 districts [3]. Given that the soil and climate conditions of this region are very different from those of the northwestern provinces [4], farmers in the southwestern region of Buenos Aires are very interested in developing olive management techniques suited to the area. This region is ecologically ideal for olive cultivation [5], which helps to mitigate the advance of regional desertification [6]. It is

worth noting that the region has competitive advantages, as it possesses the deepest-draft port in the country (Puerto Ingeniero White), adequate transportation systems, and the provision of associated services necessary for marketing and the overall development of the industry [7].

Many olive growers in some provinces of Argentina, such as San Juan, use foliar fertilization with macronutrients (N, P, and K) as a method to increase production [8]. However, Fernández et al. [9] reported that foliar fertilization in olive trees should serve as a supplement to correct specific micronutrient deficiencies, since foliar absorption of most elements is low and cannot replace soil fertilization to meet macronutrient demands. Furthermore, several foliar applications should be made throughout the growing cycle, considering that: (1) foliar fertilization depends on the amount of nutrients the olive tree needs; if the amount is high, root absorption is necessary, (2) the very low efficiency of fertilizer absorption through the leaves due to the presence of pubescent undersides, and (3) the large quantities of fertilizer that are not absorbed due to runoff, evaporation, drift, etc. Many regional producers apply no more than two or three foliar applications per year, assuming the crop is well-nourished. In this context, more efficient fertilization methods must be found that not only incorporate inorganic nutrients into the olive grove but also contribute organic matter to the soils where this species is cultivated. This is important not only for current fertility, which involves inorganic nutrients that are immediately available, but also for potential fertility, where inorganic nutrients are slowly released by organic matter.

Das et al. [10]; Oliveira et al. [11]; Sanchez et al. [12] and Sarwar et al. [13] reported an increase in growers' interest in including cover crops between olive tree rows due to the benefits they provide in improving and conserving the soil's biological and physicochemical properties. Among these benefits, which depend on the quantity and quality of the residue, the soil type, fertility, acidity, biological activity, moisture, and temperature, an increase in organic matter, nitrogen (N), and carbon (C) content was reported, resulting in a net reduction in the C/N ratio and an increase in the phosphorus (P) and potassium (K) concentrations in the soil. Legume cover crops have been used as green fertilizers on organic farms [14, 15]. The main characteristic of legumes as nitrogen-fixing plants makes them economically and ecologically friendly compared to other types of cover crops [16]. This characteristic is essential for sustainable agriculture in the future, which will seek to limit the use of mineral nitrogen and energy in agriculture [17].

Several studies evaluating the effects of different organic and inorganic fertilization sources applied to leaves or soil on height, trunk circumference, and canopy area and volume in olive trees have yielded inconsistent results. Mazeh et al. [18] showed that both organic and inorganic fertilization significantly increased the growth of young olive trees, with increases in tree height and trunk cross-sectional area observed compared to unfertilized controls, attributable to the nutrients and biological components of the applied fertilizers. Sotiropoulos et al. [19] compared organic and conventional (inorganic) fertilization strategies applied to the soil and leaves of mature olive trees, finding that fertilization positively influenced crop variables related to tree growth and physiological status compared to unfertilized practices. Other studies, however, found no increases in height, trunk circumference, or canopy area and volume in olive trees fertilized with different fertilizer sources. Roussos et al. [20] determined the impact of fertilization with two commercial organic fertilizers plus inorganic fertilizer, with inorganic fertilizer alone serving as a control, on several morphological characteristics in two new olive cultivars under Mediterranean conditions. These authors showed that the simultaneous use of organic and inorganic fertilizers yielded similar results to the control in both cultivars studied with respect to trunk growth, plant height, and canopy diameter after two years of treatment application. In a trial with *Olea europaea* L. cv. Picual, Sánchez-Zamora, and Fernández-Escobar [21] reported that urea (N) application at different levels and methods (soil vs. soil + foliar) did not result in increases in tree height and trunk circumference with increasing N from 0 to 1 kg tree⁻¹ year⁻¹ when foliar N levels were above the deficiency threshold. In field experiments lasting up to 13 years with Picual olive groves and different doses of nitrogen fertilization with urea applied to the soil (0; 0.12; 0.25; 0.5 or 1.0 kg N tree⁻¹ year⁻¹) or to the soil plus the leaves (50% soil and 50% leaf combination), Fernández-Escobar et al. [22] found no significant effects on canopy

volume growth despite differences in foliar and soil N levels. This was observed even when foliar N concentrations exceeded the critical levels considered sufficient (1.5%: Beutel et al. [23]), suggesting fertilization was not a determining factor for growth under these conditions. These authors and Fernández-Escobar et al. [24] recommended practice for optimizing N, P, and K fertilization in olive groves is to apply these nutrients only when the previous season's foliar analysis indicates that the concentration of these nutrients in the leaves is below their deficiency thresholds. The deficiency thresholds for foliar concentrations in olive trees are 1.4% for N [23] and < 0.05% for P and < 0.4% for K [25].

Previous studies, however, have not considered the effects of fertilization in conjunction with the use of cover crops between olive groves. Therefore, the objective of this study was to compare the combined effects of organic or inorganic soil fertilization or foliar fertilization in areas with and without a cover crop on the annual growth of olive trees in a grove in southwestern Buenos Aires Province, Argentina. The novelty of this work lies in its ability to compare the effects of (1) a specific organic fertilizer with those of traditional foliar or soil fertilization treatments, and (2) organic or traditional fertilization treatments in combination with cover crops (including a legume) on the annual growth of olive trees.

2. MATERIALS AND METHODS

2.1. Study Site

The study was conducted in the district of Bahía Blanca, Buenos Aires Province (38°34'S, 61°59'W) on an irrigated olive grove (*Olea europaea* L.) belonging to the "Nobles Caciques" agricultural establishment during the 2020/2021 and 2021/2022 growing seasons.

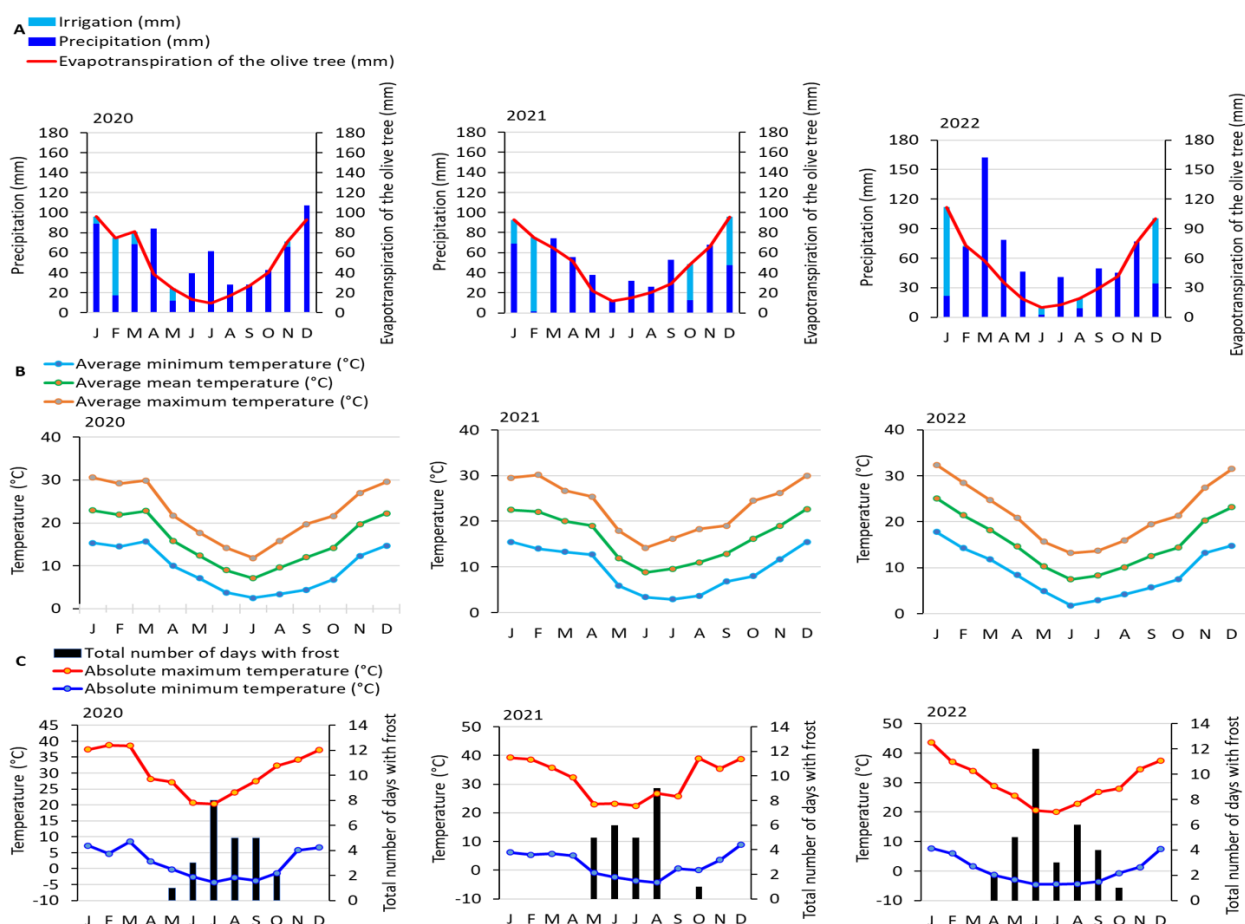


Figure 1. Monthly values of various climatic variables determined during the growth periods of 2020, 2021 and 2022.

Figure 1 shows the values of various climatic variables recorded during the studied growing seasons by a meteorological station located at the Regional Center for Basic and Applied Research in Bahía Blanca (CRIBABB). This institution, part of CONICET, is located 10 km from the study site. Monthly evapotranspiration of the olive crop was calculated following [26]. The soils are classified as Kastanozems petrocalcic soils according to the World Reference Base System [27].

2.2. Experimental Design and Treatments

The experimental design used to determine annual growth in tree height, trunk circumference, and canopy area and volume during the 2020/2021 and 2021/2022 growing seasons was a split-plot design with time-subdivided plots (Figure 2). The main experimental units were six large plots where the two levels of the cover crop factor [with cover (WCC), without cover (NCC)] were applied (Table 1, Figure 2). The secondary experimental units were four subplots where the four fertilization treatments were applied (one treatment per subplot) (Table 1, Figure 2). The last level of the factor corresponded to the study periods (years) 2020/2021 and 2021/2022 (there were two periods or growth cycles within the same plot) (Figure 2). The unit of measurement to determine the annual growth in height, trunk circumference, and canopy surface and volume was 8 trees/subplot in each studied growing season (2020/2021 and 2021/2022).

In addition, the difference in the total annual growth of these variables between the first and second growing seasons (i.e., 2020/2021 – 2021/2022) was obtained. The experimental design was a split-plot design and had the same main and secondary experimental units as Figure 2, and the measurement unit was 8 trees per subplot.

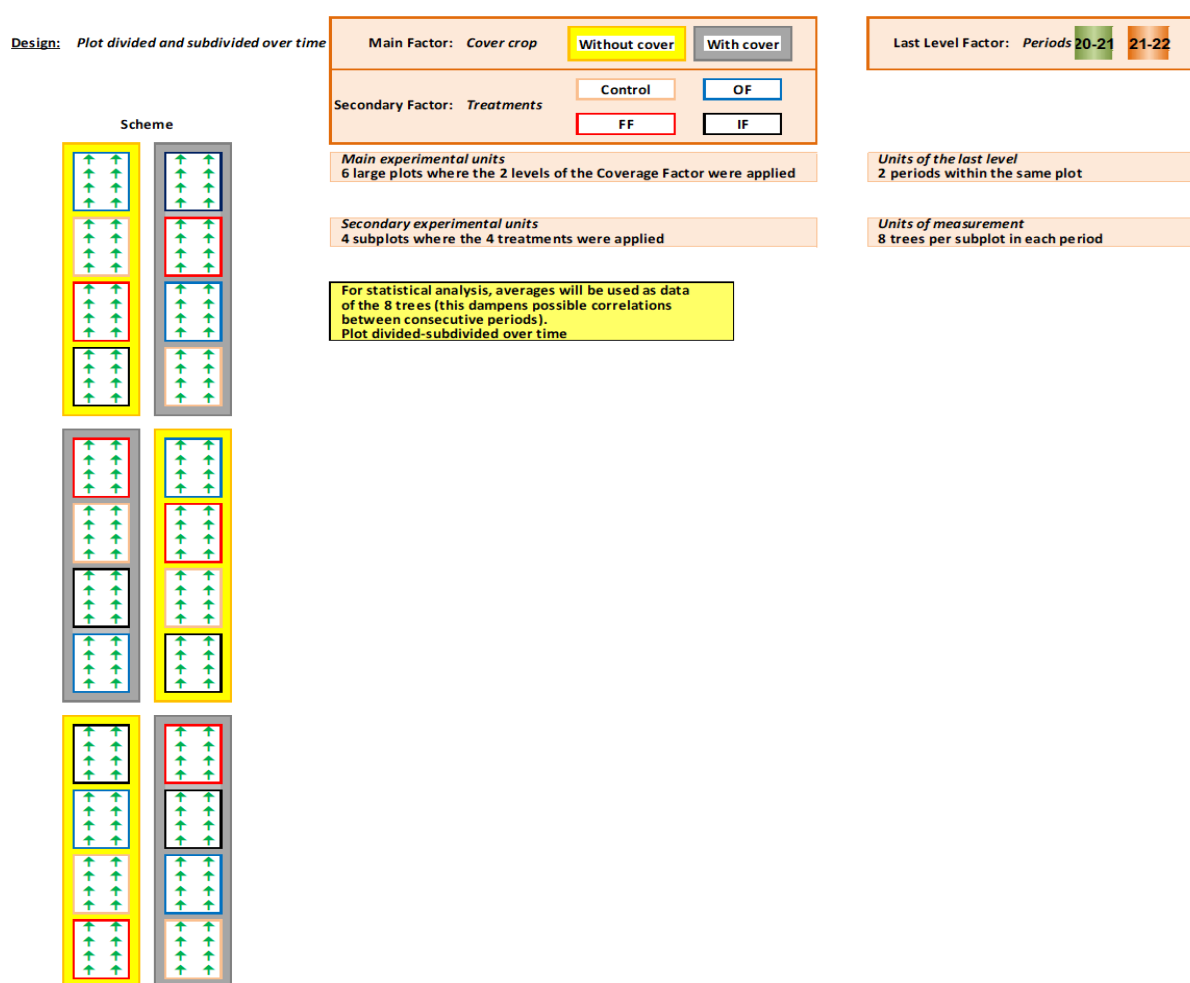


Figure 2. Experimental design to determine the annual growth of the tree (height, trunk circumference and canopy surface and volume) in the 2020/2021 and 2021/2022 growth cycles.

The fertilization treatments, which included an unfertilized control (C), a commercial organic fertilizer (BioOrganutsa) applied to the soil (OF), and inorganic fertilizers applied to the leaves (FF) and soil (IF), are detailed in Table 1.

Table 1. Treatments to be applied during the study in each of the studied periods (growth cycles) (2020/2021 and 2021/2022).

WCC				NCC			
C	OF	FF	IF	C	OF	FF	IF

References:

WCC: With cover crop between subplots within each large plot.

NCC: No cover crop between subplots within each of the 6 large plots.

C: Control (without fertilizer application).

OF: Organic soil fertilization (BioOrganutsa).

FF: Inorganic fertilization of the leaves.

IF: Inorganic fertilization of the soil.

A total of 192 trees (8 trees/subplot x 24 subplots: Figure 2) were randomly selected and distributed in 4 trees/row in each of 2 rows/subplot x 24 subplots, totaling 192 trees (Figure 2). Three replicates per fertilization treatment were used in areas with or without a cover crop.

Details regarding fertilization treatments (i.e., control, organic and inorganic soil fertilization, inorganic foliar fertilization), the planting or non-planting (control) of a cover crop, and the timing of these treatments in 2020/2021, 2021/2022, and 2022/2023 have already been reported by Bueno et al. [8] and Busso et al. [28], who also provided details on the irrigation system.

2.3. Sampling and Measurements

2.3.1. Annual Growth of Trees

A measuring tape was used to quantify variables related to annual size growth in each tree [i.e., height (cm), trunk circumference at 20 cm from the ground surface (cm), canopy area (m²), and volume (V, m³)] between September 21, 2020, and September 21, 2021, and between September 21, 2021, and September 21, 2022. On these dates, measurements of the tree canopy diameter (D) and height (H) were taken. To obtain V, the foliage diameters (D, m) were measured parallel and perpendicular to the crop rows, and an average D was calculated. The formula $V = \pi/6 D^2 H$ [29] was then used. The differences in tree height, trunk circumference, canopy area, and volume at the beginning and end of the 2020/2021 and 2021/2022 growing seasons provided the annual growth figures for these variables during those seasons. In addition to the total annual growth of these variables, the difference in total annual growth between the first and second growing seasons was also calculated. This growth could not be quantified for the third season (2022/2023) because the trees were mechanically pruned before the start of spring 2023, having exceeded the hedgerow dimensions for super-intensive systems (2 m wide and 2.5 m high). It is important to respect these dimensions for the proper functioning of the straddle harvester used in this type of olive grove.

2.4. Statistical Analysis

For the annual growth variables (trunk height and circumference, and tree canopy area and volume), the averages of the 8 trees per subplot were used as data, thus mitigating potential correlations between consecutive growing seasons. The variance table for each annual growth variable was a 3-way ANOVA [2 types of cover crop (with, without) x 4 fertilization treatments x 2 periods (2020/2021, 2021/2022)]. Furthermore, the difference in total annual growth between these growing seasons was obtained by subtracting the values of total annual growth in 2020/2021 and 2021/2022. To determine these differences in total annual growth for all the growth variables investigated, a 2-

way ANOVA table [2 types of cover crop (with, without) x 4 fertilization treatments] was used. From the ANOVA tables, the eta-squared values [30] (which are similar to the regression R^2) were calculated for each source of variation. This term represents the sum of squares of a given source of variation divided by the sum of squares of all sources (excluding error). It is the percentage that this source of variation represents relative to the others.

The tests for each factor [cover crop, treatment, or period (sampling year in each of the two studied growth cycles)] and for the interactions should be tested using their corresponding mean square errors included in the General Variance Table. However, when all mean square errors were very similar in that table, Bartlett's test was used to determine whether these mean square errors were statistically equal. When the mean square errors were statistically equal ($p > 0.05$) for all factors, a weighted mean square error (i.e., an average of all mean square errors) was used for all factors, considering the total number of degrees of freedom (the sum of degree of freedom for all mean square error terms), to perform a new 3-way ANOVA. When the F-tests were significant in the ANOVA table, the means were compared using Fisher's least significant difference (LSD) test at a significance level of 5%.

3. RESULTS

3.1. Tree height (cm year^{-1})

There were no significant ($p > 0.05$) two-way or three-way interactions in the ANOVA table (Table 2) for annual tree height growth among the studied sources of variation: cover crop, fertilization treatments, and periods (or growing seasons).

Table 2. ANOVA table for annual growth in height, trunk circumference, and tree canopy area and volume in the 2020/2021 and 2021/2022 growing periods. Each data point was the average of 8 trees.

Source of variation	df	Annual growth of the olive tree							
		Height (cm)		Trunk circumference (cm)		Surface area of the canopy (m^2)		Canopy volume (m^3)	
		MS	p	MS	p	MS	p	MS	p
Cover crop	1	154.5316	0.2189	0.6888	0.5821	0.3907	0.3080	0.1034	0.2536
Error 1	4	72.8246		1.9271		0.2868		0.0583	
Treatments	3	8.4430	0.5427	0.0557	0.8802	0.0364	0.3239	0.0016	0.8741
Cover crop x Treatments	3	6.4448	0.6435	0.2533	0.4246	0.0485	0.2169	0.0170	0.1155
Error 2	12	11.2473		0.2523		0.0283		0.0070	
Period	1	2769.8206	0.0001	89.3802	0.0000	1.4396	0.0112	0.2388	0.0002
Cover crop x Period	1	61.5967	0.4546	6.2894	0.0034	0.0798	0.5092	0.0247	0.1475
Treatment x Period	3	11.2408	0.9547	1.9629	0.0344	0.0182	0.9564	0.0040	0.7721
Cover crop x Treatment x Period	3	20.3623	0.8988	0.0218	0.9885	0.0084	0.9856	0.0015	0.9321
Error 3	16	104.8506		0.5328		0.1751		0.0107	
Total	47								

Note: p-values only correspond to the sources of variation (i.e., cover crops, treatments, period). P-values are not valid for the error terms.

There were no significant differences ($p > 0.05$) between fertilization treatments or areas with or without cover crops (Table 2). Significant differences ($p = 0.0001$) were only found between the study periods, which accounted for more than 88% of all analyzed sources of variation (Table 2). Annual height growth was significantly greater ($p < 0.05$) in 2020/2021 than in 2021/2022 (Figure 3).

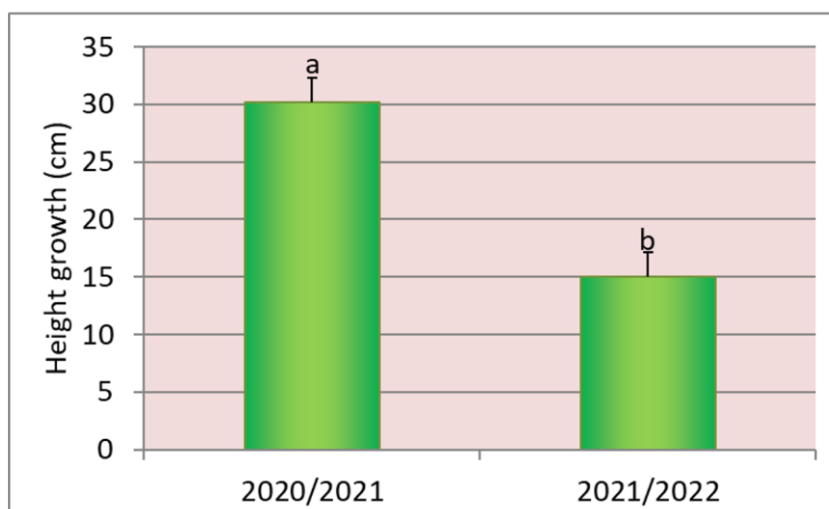


Figure 3. Annual height growth (cm) of the tree during the 2020/2021 and 2021/2022 growing seasons.

Note: Each histogram is the average of $n=24$. The vertical lines represent the standard error of each average. The average standard error for both periods was 2.09 cm. Different lowercase letters above the histograms indicate significant differences ($p<0.05$) in tree height growth during the studied periods.

For the variable difference in total annual tree height growth between the 2020/2021 and 2021/2022 periods, no significant differences were found for either the main factors of cover crop and fertilization treatment or for the interaction of these factors in the ANOVA table (Table 3). The average among the fertilization treatments ($n=6$) was 15.19 cm with a mean standard error of 3.03 cm. The average among the areas with and without a cover crop ($n=12$) was also 15.19 cm with a mean standard error of 7.49 cm.

Table 3. ANOVA table for the difference in total annual growth in height (cm), trunk circumference (cm), canopy area (m^2), and volume (m^3) between the periods 2020/2021 and 2021/2022. Each data point was the average of 8 trees.

Source of variation	df	Difference in annual growth between 2020/2021 and 2021/2022							
		Height (cm)		Trunk circumference (cm)		Surface area of the canopy (m^2)		Canopy volume (m^3)	
		MS	p	MS	p	MS	p	MS	p
Cover crop	1	123.1900	0.6909	12.5788	0.0210	0.1596	0.7318	0.0493	0.4320
Error 1	4	673.4600		0.9245		11,8060		0.0647	
Treatments	3	22.4800	0.7502	3.9258	0.0486	0.0365	0.6910	0.0080	0.3615
Cover crop x Treatment	3	40.7200	0.5489	0.0436	0.9891	0.0168	0.8742	0.0030	0.7262
Error 2	12	55.1100		11.1260		0.0733		0.0068	
Total	23								

3.2. Trunk circumference ($cm\ year^{-1}$)

The interactions between cover crop x period and fertilization treatment x period were significant ($p<0.05$) in the ANOVA table for annual trunk circumference growth in the 2020/2021 and 2021/2022 growing seasons (Table 2). Annual trunk circumference growth in the different fertilization treatments in areas with or without soil cover in the 2020/2021 and 2021/2022 growing seasons ranged from 1.08 cm (inorganic soil fertilization, areas without a cover crop, 2021/2022 growing season) to 5.35 cm (organic soil fertilization, areas without a cover crop, 2020/2021 growing season) (Figure 4).

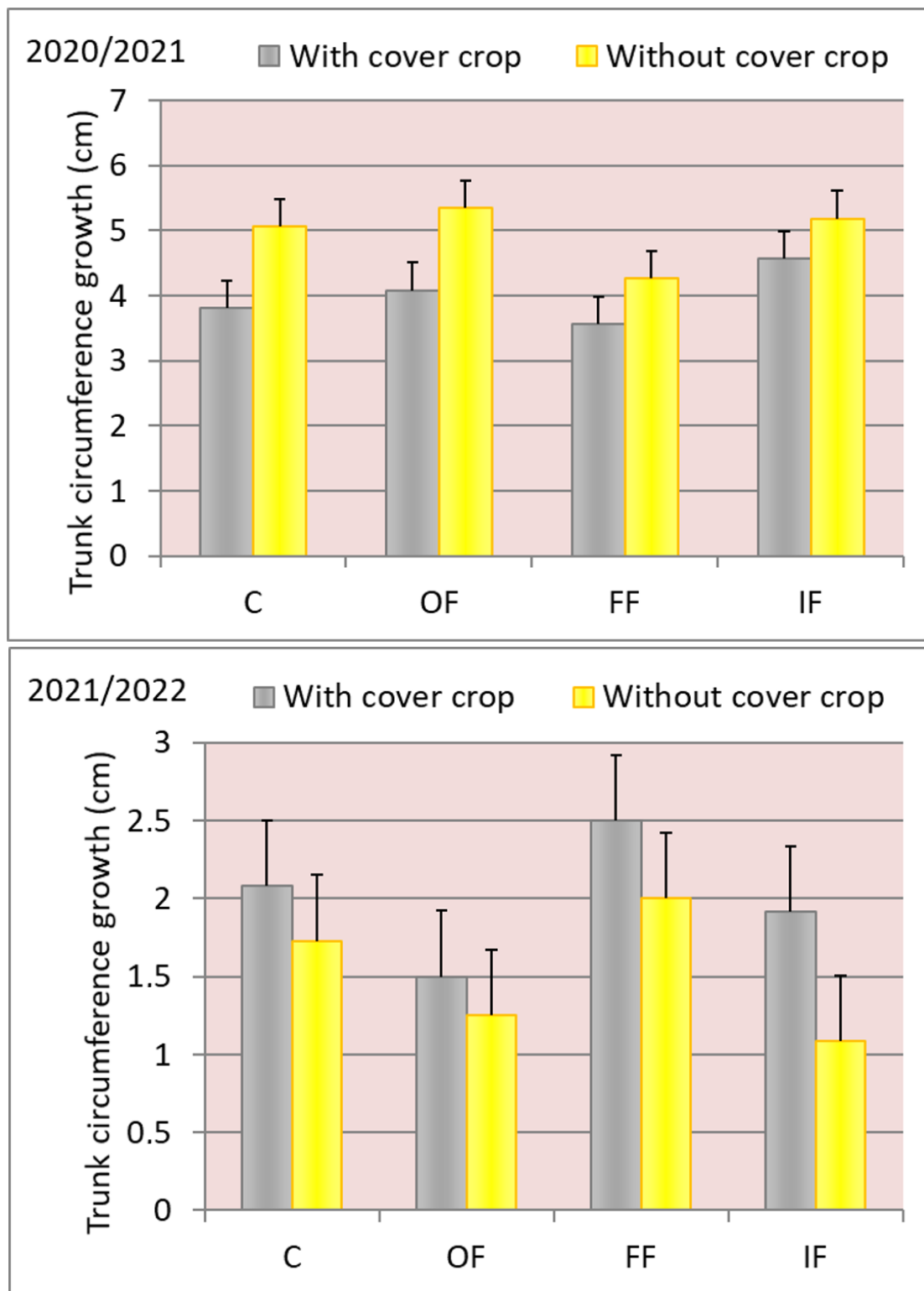


Figure 4. Annual growth in tree trunk circumference (cm) in the different fertilization treatments in areas with or without a cover crop in the periods 2020/2021 and 2021/2022.

Note: Each histogram is the average of $n=3$. The vertical lines represent the standard error of the means. The average standard error of each mean was 0.42 cm.

The annual trunk circumference growth between the study periods accounted for more than 86% of the total variation in the ANOVA table. Therefore, this difference is not invalidated by the significant interactions shown in the ANOVA table (Table 2). As a result, there were highly significant differences ($p=0.0000$) between the evaluated periods; the annual trunk circumference growth was greater in 2020/2021 than in 2021/2022 (Figure 5).

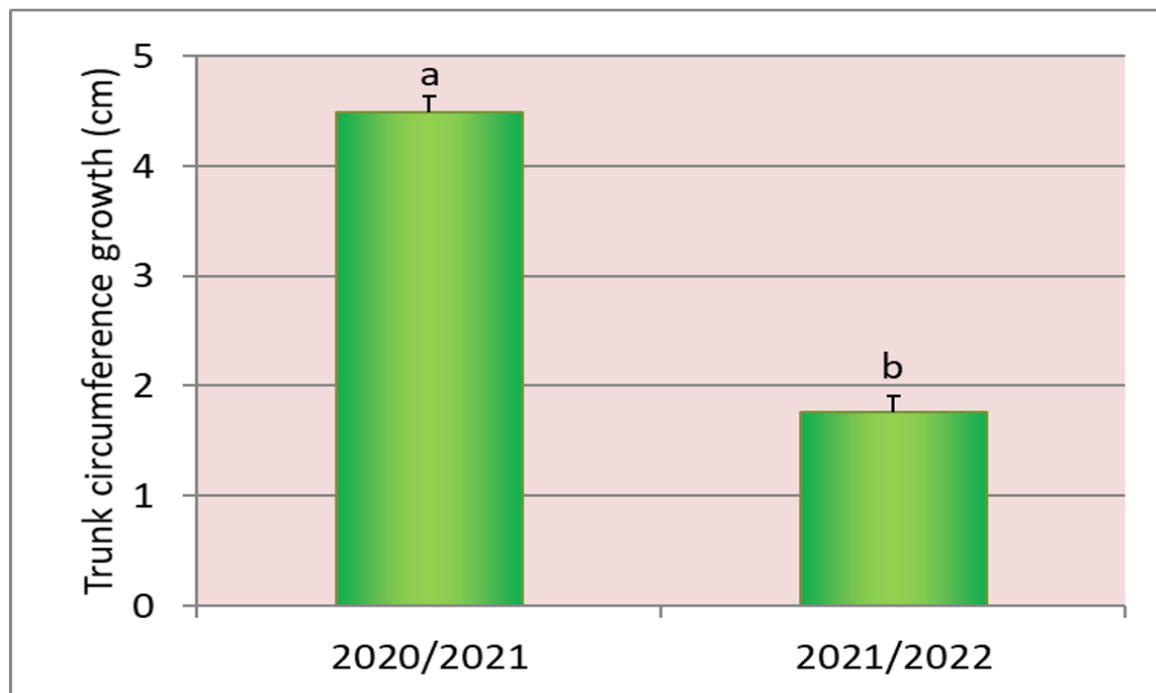
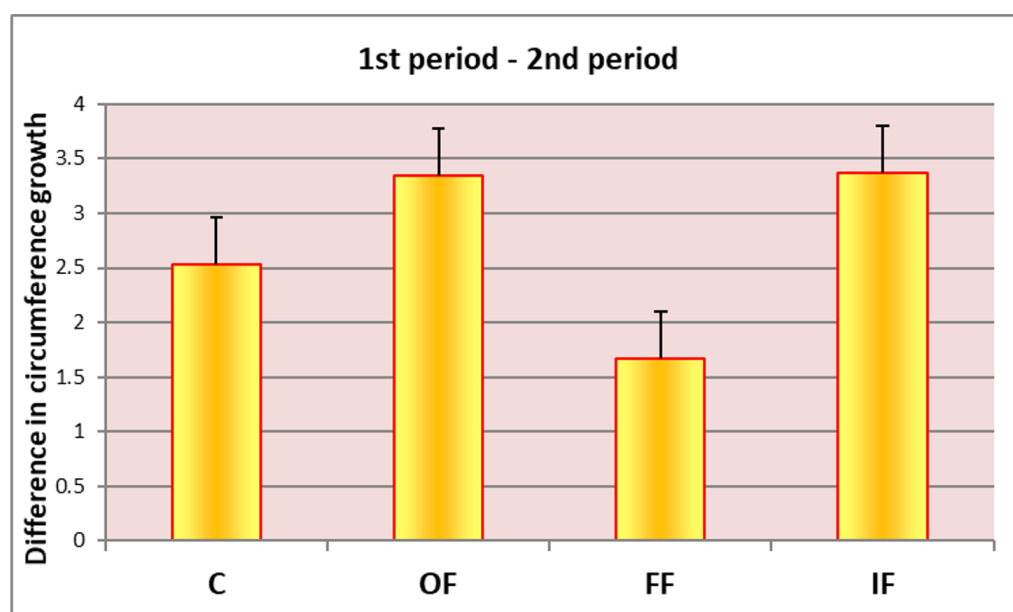


Figure 5. Annual growth in tree trunk circumference (cm) during the 2020/2021 and 2021/2022 growing seasons.
Note: Each histogram is the average of $n=24$. Vertical lines represent the standard error of each average. The average standard error for both periods was 0.15 cm. Different lowercase letters above the histograms indicate significant differences ($p<0.05$) in tree trunk circumference growth during the studied periods.

For the variable difference in total annual growth in tree trunk circumference between the 2020/2021 and 2021/2022 periods, significant differences were found for the main factors of cover crop and fertilization treatment (Table 3). The interaction between these two factors was not significant (Table 3). The organic and inorganic soil fertilization treatments showed a greater difference ($p<0.05$) than the inorganic foliar fertilization treatment in total annual growth in tree trunk circumference between the 2020/2021 and 2021/2022 periods (Figure 6). Furthermore, the difference in total annual growth in tree trunk circumference between these periods was similar ($p>0.05$) in the unfertilized control and inorganic foliar fertilization treatment (Figure 6A). However, the difference in total annual growth in tree trunk circumference between 2020/2021 and 2021/2022 was greater (<0.05) in areas without than with cover crops (Figure 6 B).



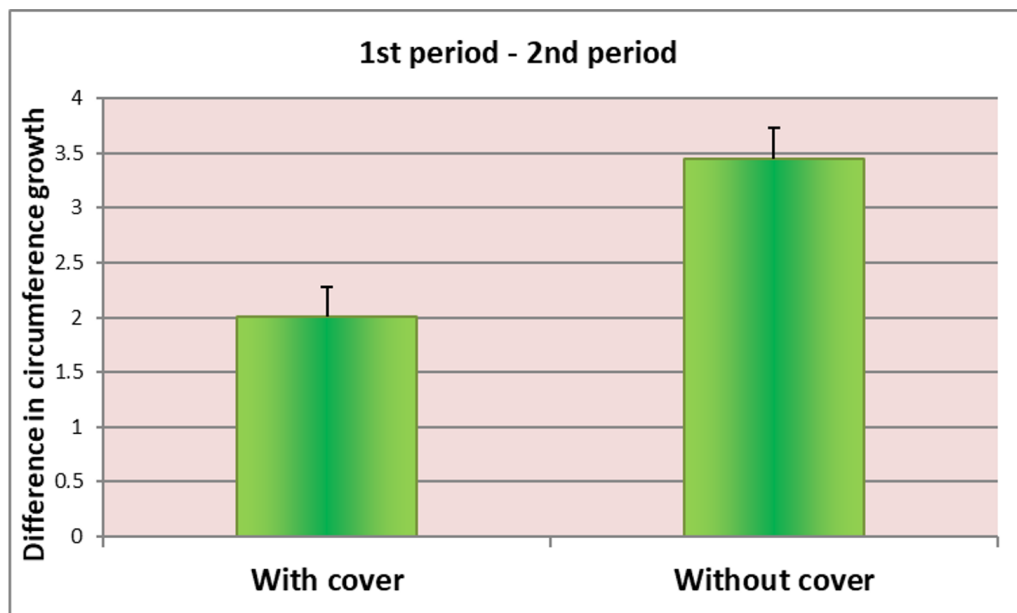


Figure 6. Difference in trunk circumference growth between the 2020/2021 and 2021/2022 periods in the different fertilization treatments (A) and in areas with or without a cover crop (B).

Note: The histograms are the average of $n=6$ in (A) and $n=12$ in (B). The standard errors of the averages were 0.431 in (A) and 0.278 in (B). The vertical lines indicate the standard error of the averages.

3.3. Tree Canopy Area ($M^2 \text{ Year}^{-1}$)

There were no significant ($p>0.05$) two-way or three-way interactions in the ANOVA table for annual tree canopy area growth among the sources of variation: cover crop, fertilization treatments, and growing seasons (Table 2). There were also no significant differences ($p>0.05$) among fertilization treatments or between areas with and without cover crops for this variable (Table 2). Significant differences ($p=0.0112$) were found only among the growing seasons, which accounted for more than 64% of all analyzed sources of variation. Annual canopy area growth was significantly greater in 2020/2021 than in 2021/2022 (Figure 7).

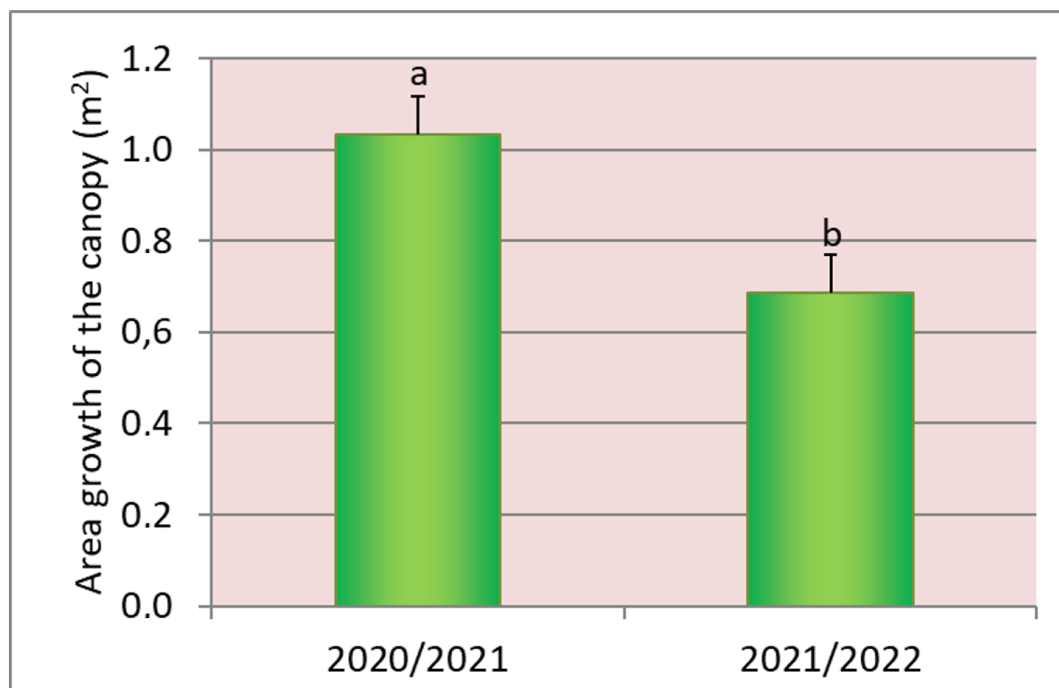


Figure 7. Annual growth in tree canopy area (m^2) during the 2020/2021 and 2021/2022 growing seasons.

Note: Each histogram is the average of $n=24$. Vertical lines represent the standard error of each average. The average standard error for both periods was 0.085 m^2 . Different lowercase letters above the histograms indicate significant differences ($p<0.05$) in tree canopy area growth during the studied periods.

For the variable difference in total annual growth of tree canopy area between the 2020/2021 and 2021/2022 periods, no significant differences were found for either the main factors of cover crop and fertilization treatment or for the interaction of these factors in the ANOVA table (Table 3). The average across the fertilization treatments ($n=6$) was 0.35 m^2 with a mean standard error of 0.11 m^2 . The average across the areas with and without a cover crop ($n=12$) was 0.35 m^2 with a mean standard error of 0.31 m^2 .

3.4. Volume of the Tree Canopy ($\text{M}^3 \text{ Year}^{-1}$)

The two- and three-way interactions for the factors of cover crop, fertilization treatments, and study periods (2020/2021 and 2021/2022) were not significant ($p>0.05$) in the ANOVA table for the annual volume growth (m^3) of the tree canopy (Table 2). Growth in different fertilization treatments in areas with or without a cover crop during periods 2020/2021 and 2021/2022 ranged from 0.36 (organic soil fertilization, areas with a cover crop, period 2021/2022) to 0.65 m^3 (control, areas without a cover crop, period 2020/2021) (Figure 8).

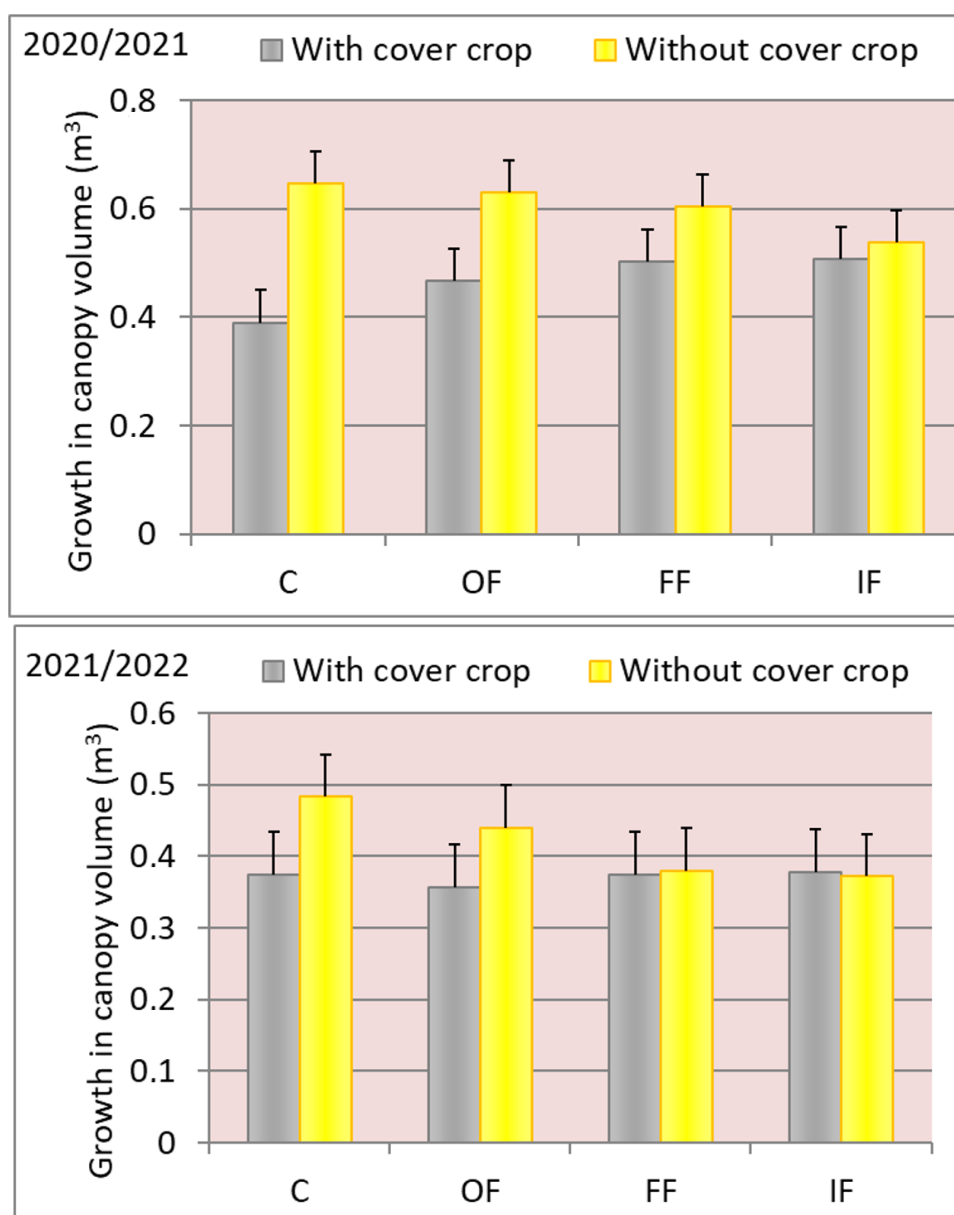


Figure 8. Annual growth in tree canopy volume (m^3) in the different fertilization treatments in areas with or without a cover crop in the periods 2020/2021 and 2021/2022.

Note: Each histogram is the average of $n=3$. The vertical lines represent the standard error of the averages. The average standard error of each mean was 0.06 m^3 .

The annual growth in tree canopy volume between the studied periods accounted for more than 54% of the total variation in the ANOVA table. As a result, there were highly significant differences ($p=0.0002$) between the evaluated periods; the annual growth in tree canopy volume was greater in 2020/2021 than in 2021/2022 (Figure 9).

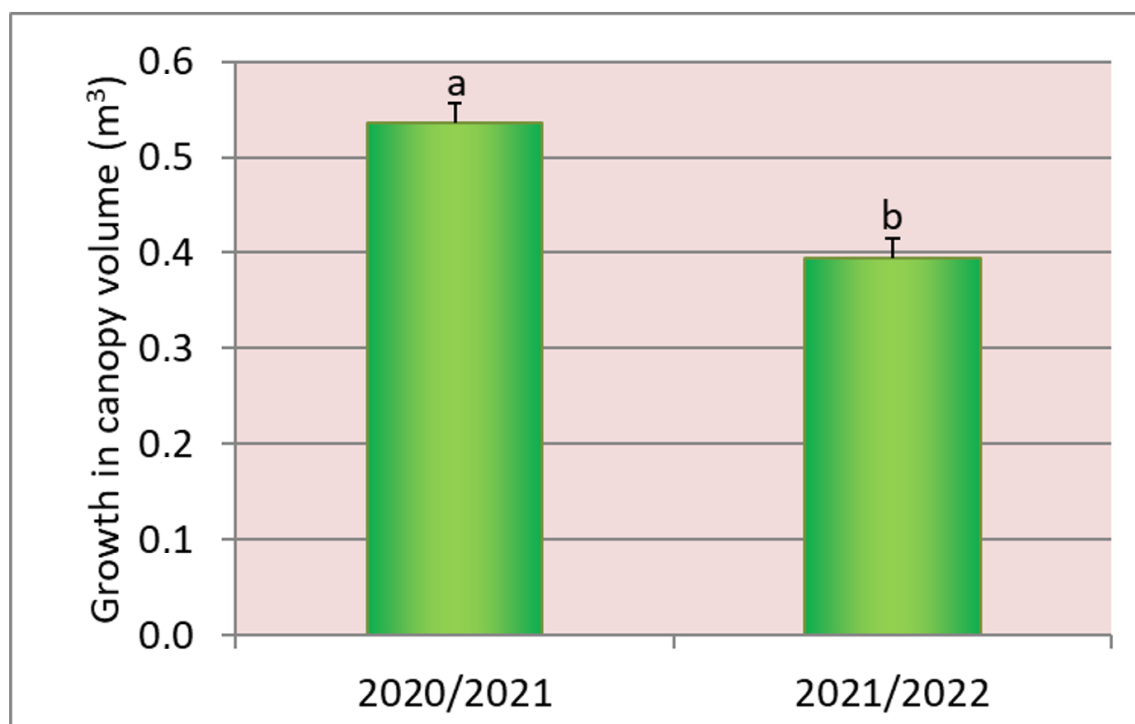


Figure 9. Annual growth in tree canopy volume (m³) during the 2020/2021 and 2021/2022 growing seasons.

Note: Each histogram is the average of $n=24$. Vertical lines represent the standard error of each average. The average standard error of each mean was 0.02 m³. Different lowercase letters above the histograms indicate significant differences ($p<0.05$) in tree canopy volume growth between the studied periods.

For the variable difference in total annual growth in tree canopy volume between the 2020/2021 and 2021/2022 periods, no significant differences were found for either the main factors of canopy cover and fertilization treatment or for the interaction of these factors in the ANOVA table (Table 3). The average among the fertilization treatments ($n=6$) was 0.14 m³, with an average standard error of 0.03 m³. The average between areas with or without a cover crop ($n=12$) was 0.035 m³, with an average standard error of 0.073 m³.

4. DISCUSSION

In the present study, there were no significant differences between fertilization treatments or areas with or without a cover crop for annual growth in tree height, circumference, canopy area, and volume in the 2020/2021 and 2021/2022 growing seasons (Table 2). This was probably because, in a parallel study, the concentrations of N, P, and K in olive leaves were above 2%, 0.15%, and 0.60%, respectively, in the different fertilization treatments during spring, summer, autumn, and winter in the three studied growing seasons. Fernández-Escobar et al. [22] and Fernández-Escobar et al. [24] recommended that fertilization of olive trees with N, P, and K should only be carried out when the previous season's foliar analysis indicates that the concentration of these nutrients in the leaves is below the deficiency threshold. These authors indicated that routine fertilization of olive trees with N, P, and K is not necessary if the concentration of these nutrients in the leaves is within the appropriate ranges. Their approach helps to optimize olive fertilization with N, P, and K, reducing unnecessary fertilizer use without affecting growth or yield, and minimizing environmental impacts and cost increases. Sánchez-Zamora and Fernández-Escobar [21] reported that when foliar N levels were above the deficiency threshold, urea (N) application at different levels and methods (soil vs. soil + foliar) did not result in increases in tree height and trunk circumference with increasing N from 0 to 1 kg tree⁻¹.

year⁻¹ in a 6-year trial with *Olea europaea* L. cv. Picual. These results are consistent with those reported by Elalakmy et al. [31], who reported no significant differences in tree canopy height and volume between the control [fertilized with N (ammonium sulfate), P (superphosphate), and K (potassium sulfate)] and the combination of various organic soil fertilizers and biofertilizers in olive trees cv 'Kalamata' over two consecutive years of study. However, the control treatment had the lowest values compared to the combination of other organic soil fertilizers and biofertilizers in their study. Furthermore, the control treatment had the lowest tree canopy circumference values in both seasons compared to the combination of various organic soil fertilizers and biofertilizers [31].

The difference in trunk circumference growth between the 2020/2021 and 2021/2022 growing seasons was greater in the organic and inorganic soil fertilization treatments than in the inorganic foliar fertilization treatment (Figure 6). Busso et al. [32] reported no significant differences in trunk circumference growth in olive trees when exposed to organic and inorganic soil fertilization and inorganic foliar fertilization during a growth cycle. However, their results showed a trend toward organic and inorganic soil fertilization in areas with or without a cover crop producing greater trunk circumference growth compared to the inorganic foliar fertilization treatment. These authors showed that trunk circumference growth varied between approximately 3.6 cm in the inorganic foliar fertilization treatment and 5.4 cm in the organic soil fertilization treatment, suggesting a greater vegetative effect of soil-applied fertilizations compared to foliar fertilization.

There were no significant differences between areas with and without cover crops in relation to annual trunk circumference growth (Figure 4) and canopy volume (Figure 8) across all fertilization treatments in 2020/2021 and 2021/2022. However, these variables tended to have higher values in areas without cover crops compared to those with cover crops in the different fertilization treatments in 2020/2021 (Figures 4 and 8). Furthermore, the difference in trunk circumference growth between the 2020/2021 and 2021/2022 growing seasons was significantly greater in areas without cover crops compared to those with cover crops (Figure 6B). This result agrees with that reported by Hindersmann et al. [33], who found that the cover crop *Paspalum notatum* showed a strong ability to compete with olive trees for available mineral forms of nitrogen in the soil. This suggests that competition for soil nutrients between the cover crop and the trees' needs may have been more intense where a cover crop was sown in the spaces between the rows of olive trees than where it was not. The same irrigation regime was provided in all treatments in our study; that is, abundant water was allowed in all of them. Plant density in a community determines the intensity of competition and the efficiency of exploiting available resources [34]. As plant density increases, competition among plants and their underground root systems for water and soil nutrients is expected to increase [35].

Shoot growth in length, number of internodes, and basal diameter were significantly lower in the 2020/2021 growing season than in the 2021/2022 season in a study conducted concurrently with the one reported here. In that study, olive production could not be measured at the end of the 2020/2021 growth cycle because it was extremely low, as the trees were in the early stages of production. Olive production was determined at the end of the 2021/2022 growing season, with an average yield of 5.5 kg per tree⁻¹ across fertilization treatments and areas with and without cover crops in 8-year-old trees [28]. Conversely, the growth in tree height (Figure 3), trunk circumference (Figure 5), and canopy area (Figure 7) and volume (Figure 9) was significantly greater in 2020/2021 than in 2021/2022. These results suggest that the plants likely allocated a greater partitioning of photoassimilates to annual growth in height, trunk circumference, canopy area, and volume than to shoot growth and olive production during the 2020/2021 season, and the opposite may have occurred in 2021/2022. Rosati et al. [36] manipulated fruit presence (flowering vs. normal production) in young olive trees and quantitatively demonstrated that increased fruit production (greater partitioning of photoassimilates to the reproductive organ) was closely correlated with reductions in vegetative growth, measured as an increase in trunk cross-sectional area. Thus, their results indicated that the allocation of resources to fruit reduced the partitioning of assimilates to vegetative growth structures and tree vigor. Scariano et al. [37] described the partitioning of dry matter (photosynthetic assimilates) in young olive plants among different organs (leaves, shoots, trunk, roots) during a period of growth and development. These authors showed that

the greater accumulation of dry matter in actively growing organs (e.g., leaves and shoots) was associated with a lower accumulation in other secondary organs. On average, 31% of the total dry mass in their study was allocated to the roots (20% coarse and 11% fine), 28% to the leaves, 14% to the branches, 7% to the two-year-old wood, and 14% to the main trunk.

5. CONCLUSIONS

Annual growth in height, trunk circumference, and canopy area and volume in olive trees was similar across the fertilization treatments investigated and in areas with or without cover crops in this study conducted in southwestern Buenos Aires Province. This was likely due to the fact that foliar concentrations of N, P, and K were above the levels considered optimal for olive tree growth in all fertilization treatments and areas with or without cover crops reported in this study. This information was provided by research conducted concurrently with that reported in the present study on the same plants. However, the difference in annual trunk circumference growth between the consecutive studied periods was significantly greater in the organic and inorganic soil fertilization treatments beneath the plants than in the foliar fertilization treatment. Annual growth of all the aforementioned variables was significantly higher in 2020/2021 than in 2021/2022. Most likely, the plants allocated a greater partitioning of photoassimilates to the annual growth of the trees in the first season compared to the second season of growth and development evaluated. Another study conducted in parallel with the one reported in this manuscript on the same olive trees determined that the seasonal growth of the shoots was significantly lower in 2020/2021 than in 2021/2022.

Funding: This study received financial support from the Agronomy Department/National University of the South, Argentina (Grant number: 401_AV PGI TIR 2023).

Institutional Review Board Statement: Not applicable.

Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

Competing Interests: The authors declare that they have no competing interests.

Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

REFERENCES

- [1] Presidency of the Argentine Nation, *Buenos Aires strengthens its position as a producer of high-quality olive oil*. Buenos Aires, Argentina: Presidency of the Argentine Nation, 2023.
- [2] S. Tagarelli, "Olive cultivation. Regions, olive trees and currencies," *Alimentos Argentinos*, no. 72, pp. 39-43, 2017.
- [3] E. M. Abraham, J. C. Guevara, R. J. Candia, and N. D. Soria, "Dust storms, drought and desertification in the Southwest of Buenos Aires Province, Argentina," *Revista De La Facultad de Ciencias Agrarias. Universidad Nacional De Cuyo*, vol. 48, no. 2, pp. 222-241, 2016.
- [4] G. González, L. Tedesco, and M. S. Picardi, "Evolution of the business environment and economic analysis of extra virgin olive oil production in Southwest Buenos Aires," *Faces*, vol. 22, no. 47, pp. 63-79, 2016.
- [5] B. Lupín and S. Picardi, "Sharing an experience of collaboration with olive oil producers in Southwestern Buenos Aires," presented at the V National Conference on University Social Commitment and IV University Social Commitment Conference "Mariano Salgado", Mar Del Plata, Argentina, 2016.
- [6] S. R. Elias and A. C. Barbero, "The situation of olive oil tourism and guidelines for its development in the Southwestern region of Buenos Aires, Argentina," *Revista interamericana de ambiente y turismo*, vol. 13, no. 1, pp. 91-104, 2017. <https://doi.org/10.4067/S0718-235X2017000100091>
- [7] C. Cincunegui *et al.*, "Consumption and territory: Olive oil produced in Southwestern Buenos Aires Province," presented at the II Argentine Pre-Congress on Territorial Development and I Patagonian Conference on Disciplinary Exchange on Development and Territory, San Carlos de Bariloche, Argentina, 2019.

- [8] L. A. Bueno, E. Sánchez, and P. S. Searles, "Nutrient reference levels for fertigation scheduling in olive groves of an arid region of Argentina (San Juan)," *Acta Horticulturae*, vol. 1057, pp. 369–373, 2014. <https://doi.org/10.17660/ActaHortic.2014.1057.44>
- [9] V. Fernández, T. Sotiropoulos, and P. H. Brown, *Foliar fertilization: Scientific principles and field practices*. Paris, France: International Fertilizer Association, 2013.
- [10] K. Das, N. Biswakarma, R. Zhiipao, A. Kumar, P. C. Ghasal, and V. Pooniya, *Significance and management of green manures*. In B. Giri & A. Varma (Eds.), *Soil health: Soil biology*. Cham, Switzerland: Springer, 2020.
- [11] M. C. Oliveira, L. Butts, and R. Werle, "Assessment of cover crop management strategies in Nebraska, US," *Agriculture*, vol. 9, no. 6, p. 124, 2019. <https://doi.org/10.3390/agriculture9060124>
- [12] E. E. Sanchez, A. Giayetto, L. Cichón, D. Fernández, M. C. Aruani, and M. Curetti, "Cover crops influence soil properties and tree performance in an organic apple (*Malus domestica* Borkh) orchard in Northern Patagonia," *Plant and Soil*, vol. 292, no. 1, pp. 193–203, 2007. <https://doi.org/10.1007/s11104-007-9215-7>
- [13] G. Sarwar, H. Schmeisky, M. A. Tahir, Y. Iftikhar, and N. U. Sabah, "Application of green compost for improvement in soil chemical properties and fertility status," *Journal of Animal and Plant Sciences*, vol. 20, no. 4, pp. 258–260, 2010.
- [14] A. Freidenreich, S. Dattamudi, Y. Li, and K. Jayachandran, "Influence of leguminous cover crops on soil chemical and biological properties in a no-till tropical fruit orchard," *Land*, vol. 11, no. 6, p. 932, 2022. <https://doi.org/10.3390/land11060932>
- [15] R. Ordóñez-Fernández, M. A. Repullo-Ruibérriz de Torres, J. Márquez-García, M. Moreno-García, and R. M. Carbonell-Bojollo, "Legumes used as cover crops to reduce fertilisation problems improving soil nitrate in an organic orchard," *European Journal of Agronomy*, vol. 95, pp. 1–13, 2018. <https://doi.org/10.1016/j.eja.2018.02.001>
- [16] K. Koudahe, S. C. Allen, and K. Djaman, "Critical review of the impact of cover crops on soil properties," *International Soil and Water Conservation Research*, vol. 10, no. 3, pp. 343–354, 2022. <https://doi.org/10.1016/j.iswcr.2022.03.003>
- [17] M.-B. Magrini *et al.*, "Why are grain-legumes rarely present in cropping systems despite their environmental and nutritional benefits? Analyzing lock-in in the French agrifood system," *Ecological Economics*, vol. 126, pp. 152–162, 2016. <https://doi.org/10.1016/j.ecolecon.2016.03.024>
- [18] M. Mazeh *et al.*, "Use of an organic fertilizer also having a biostimulant action to promote the growth of young olive trees," *Agriculture*, vol. 11, no. 7, p. 593, 2021. <https://doi.org/10.3390/agriculture11070593>
- [19] S. Sotiropoulos *et al.*, "Enhancing the yield of mature olive trees via comparative fertilization strategies, including a foliar application with fulvic and humic acids, in non-irrigated orchards with calcareous and non-calcareous soils," *Horticulturae*, vol. 10, no. 2, p. 167, 2024. <https://doi.org/10.3390/horticulturae10020167>
- [20] P. A. Roussos, D. Gasparatos, K. Kechrologou, P. Katsenos, and P. Bouchagier, "Impact of organic fertilization on soil properties, plant physiology and yield in two newly planted olive (*Olea europaea* L.) cultivars under Mediterranean conditions," *Scientia Horticulturae*, vol. 220, pp. 11–19, 2017. <https://doi.org/10.1016/j.scienta.2017.03.019>
- [21] M. A. Sánchez-Zamora and R. Fernández-Escobar, "The effect of foliar vs. soil application of urea to olive trees," *Acta Horticulturae*, vol. 594, pp. 675–678, 2002. <https://doi.org/10.17660/ActaHortic.2002.594.91>
- [22] R. Fernández-Escobar, L. Marin, M. A. Sánchez-Zamora, J. M. García-Novelo, C. Molina-Soria, and M. A. Parra, "Long-term effects of N fertilization on cropping and growth of olive trees and on N accumulation in soil profile," *European Journal of Agronomy*, vol. 31, no. 4, pp. 223–232, 2009. <https://doi.org/10.1016/j.eja.2009.08.001>
- [23] J. Beutel, K. Uriu, and O. Lilleland, *Leaf analysis for California deciduous fruits*. In H. M. Reisenauer (Ed.), *Soil and plant tissue testing in California*. Berkeley, CA: University of California, 1983.
- [24] R. Fernández-Escobar, M. A. Parra, C. Navarro, and O. Arquero, "Foliar diagnosis as a guide to olive fertilization," *Spanish Journal of Agricultural Research*, vol. 7, no. 1, pp. 212–223, 2009.
- [25] S. Sotiropoulos *et al.*, "Inorganic and organic foliar fertilization in olives," *Horticultural Science*, vol. 50, no. 1, pp. 1–11, 2023. <https://doi.org/10.17221/69/2022-HORTSCI>

- [26] P. Alegre Fidalgo, *Inventory and characterization of groundwater in fractured rock masses: Cíes Islands*. In J. Samper, T. Leitão, L. Fernández, & L. Ribeiro (Eds.), *Groundwater in the Northwest of the Iberian Peninsula*. Madrid, Spain: Geological and Mining Institute of Spain, 2000.
- [27] IUSS Working Group WRB, *World reference base for soil resources: International soil classification system for naming soils and creating legends for soil maps*, 4th ed. Vienna, Austria: International Union of Soil Sciences, 2022.
- [28] M. A. Busso, R. A. Rodríguez, and L. Suñer, "Effects of fertilization, cover crop and harvest time on olive characteristics cultivated under irrigation in Bahía Blanca," *Horticultura Argentina*, vol. 44, no. 113, pp. 54–78, 2025.
- [29] M. Pastor *et al.*, "Responses of traditional olive groves to different irrigation strategies and water doses," *Agricultural Research: Plant Production*, vol. 14, pp. 393–404, 2016.
- [30] J. Cohen, *Statistical power analysis for the behavioral sciences*. New York: Routledge, 1988.
- [31] D. A. Elalakmy, M. A. Nagaty, M. M. Sourour, and M. D. ElDeep, "Effects of bio and organic fertilizers on vegetative growth and leaf mineral content of Kalamata olive trees under North Sinai conditions," *Sinai Journal of Applied Sciences*, vol. 7, no. 3, pp. 197–206, 2018.
- [32] M. A. Busso and R. A. Rodríguez, and L. G. Suñer, "Quantitative responses to fertilization with or without a cover crop in an olive orchard under irrigation in Southwestern Buenos Aires," *Argentinian Horticulture / Horticultura Argentina*, vol. 43, no. 112, pp. 40–62, 2024.
- [33] J. Hindersmann *et al.*, "Soil-applied nitrogen uptake by young olive cultivars intercropped or not with *Paspalum notatum*," *Scientia Horticulturae*, vol. 318, p. 112100, 2023. <https://doi.org/10.1016/j.scienta.2023.112100>
- [34] X. Li *et al.*, "Response of cotton fruit growth, intraspecific competition and yield to plant density," *European Journal of Agronomy*, vol. 114, p. 125991, 2020. <https://doi.org/10.1016/j.eja.2019.125991>
- [35] L.-C. Zhai, R.-Z. Xie, B. Ming, S.-K. Li, and D.-L. Ma, "Evaluation and analysis of intraspecific competition in maize: A case study on plant density experiment," *Journal of Integrative Agriculture*, vol. 17, no. 10, pp. 2235–2244, 2018. [https://doi.org/10.1016/S2095-3119\(18\)61917-3](https://doi.org/10.1016/S2095-3119(18)61917-3)
- [36] A. Rosati, A. Paoletti, R. Al Hariri, A. Morelli, and F. Famiani, "Partitioning of dry matter into fruit explains cultivar differences in vigor in young olive (*Olea europaea* L.) trees," *HortScience*, vol. 53, no. 4, pp. 491–495, 2018. <https://doi.org/10.21273/HORTSCI12739-17>
- [37] L. Scariano, R. Lo Bianco, L. Di Marco, and M. Policarpo, "Dynamics of dry matter partitioning in young 'Nocellara Del Belice' olive trees," *Acta Horticulturae*, vol. 791, pp. 397–401, 2008. <https://doi.org/10.17660/ActaHortic.2008.791.58>

Views and opinions expressed in this article are the views and opinions of the author(s). Current Research in Agricultural Sciences shall not be responsible or answerable for any loss, damage or liability etc. caused in relation to/arising out of the use of the content.