



Article

Deflowering as a Tool to Accelerate Growth of Young Trees in Both Intensive and Super-High-Density Olive Orchards

Franco Famiani ^{1,*}, Nicola Cinosi ^{1,†}, Andrea Paoletti ¹, Daniela Farinelli ¹, Adolfo Rosati ^{2,*} and Enrico Maria Lodolini ³

¹ Dipartimento di Scienze Agrarie, Alimentari e Ambientali, Università degli Studi di Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy

² Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Centro di Ricerca Olivicoltura, Frutticoltura e Agrumicoltura, Via Nursina 2, 06049 Spoleto, Italy

³ Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Centro di Ricerca Olivicoltura, Frutticoltura e Agrumicoltura, Via Fioranello 52, 00134 Roma, Italy

* Correspondence: franco.famiani@unipg.it (F.F.); adolfo.rosati@crea.gov.it (A.R.)

† These authors contributed equally to this work.

Abstract: In 2019–2020, trials were carried out in both intensive (cultivar Moraiolo) and super-high-density (cultivar Sikitita) young olive orchards to drastically reduce early production and, consequently, accelerate tree growth. Different concentrations of naphthaleneacetic acid (NAA) (0 ppm–control, 20 ppm, 40 ppm, 80 ppm, 160 ppm and 250 ppm) were applied at full bloom (open flowers > 80%), using a shoulder sprayer, and their effects on vegetative growth and reproductive behavior were evaluated, also compared to manually deflowered trees. The treatments with NAA reduced fruit set (down to values close to zero) compared to the control, and the reduction was correlated with the NAA concentration. In particular, 160 ppm virtually eliminated fruit set and thus production in both Moraiolo and Sikitita cultivars. In Moraiolo, 160 ppm NAA and manual deflowering determined similar shoot and trunk growths, which were greater than in control trees. Application of 160 ppm NAA for two consecutive years gave a progressively higher increase in trunk growth compared to the control. In conclusion, in young olive trees, the treatment with 160 ppm NAA at full bloom practically eliminated fruit set and production, with a parallel great increase in vegetative growth. This can be exploited as a powerful technique to accelerate the growth of young olive trees in both intensive and super-high-density orchards, as well as in nurseries. A more rapid transition to the adult stage/size of the trees and to full production of the orchard allows us to anticipate the use of mechanical harvesting and the recovery of the planting investment.

Keywords: production; *Olea europaea*; deflowering; early bearing



Citation: Famiani, F.; Cinosi, N.; Paoletti, A.; Farinelli, D.; Rosati, A.; Lodolini, E.M. Deflowering as a Tool to Accelerate Growth of Young Trees in Both Intensive and Super-High-Density Olive Orchards. *Agronomy* **2022**, *12*, 2319. <https://doi.org/10.3390/agronomy12102319>

Academic Editor: José Casanova Gascón

Received: 31 August 2022

Accepted: 23 September 2022

Published: 27 September 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

In the last 30 years both olive-oil production and consumption worldwide have doubled (IOC, 2020). This is primarily due to the establishment of new olive orchards. The main models adopted for new orchards in all olive-producing countries are the intensive (200–400 trees ha^{−1}) and super-high-density (SHD, >1200 trees ha^{−1}) ones, as well as those with an intermediate number of trees [1,2].

The intensive models are very flexible and can be established in both plain and hilly areas (up to a slope of 20–25%). The trees are usually trained to a vase system, and olives are harvested with trunk shakers, usually combined with a reversed umbrella interceptor for collecting the fruit [1–3]. The SHD orchards have a high tree density, with canopies arranged in a continuous hedgerow. They require plain or slightly sloping terrain and, especially, low-vigor cultivars with a compact vegetative habit [1–3].

The main advantage of intensive olive orchards is that any cultivar can be used, thus enabling the production of all kinds of olive oils (PDO and PGI, organic, etc.). The main

disadvantage is the length of time required (7–10 years) to reach final tree size (adult stage) and therefore full fruit production [1]. Moreover, in the first years after planting, the yield is low and the trunk diameter is too small to use trunk shakers for mechanical harvesting. A reduction in the time required to reach 10–15 cm of trunk diameter, the minimum size for trunk shakers, and, more in general, to reach final tree size and, therefore, full production, would have a significant positive effect on the economical sustainability of intensive orchards.

The main advantages of SHD orchards are the relatively short time required to reach full production (3–6 years) and the complete and rapid mechanization of harvesting with straddle machines. An important disadvantage is the low number of cultivars suitable to this system [1]. These cultivars are characterized by high fertility and low vigor. This means that they often flower and produce even in the first year of planting, and the competition caused by the fruit reduces the vegetative growth of young trees. This is problematic, as it is important to have high vegetative growth in the first two years after planting to develop the continuous hedgerow and reach the full production stage in order to use straddle harvesters.

Taking these factors into account, it is clear that, in the first years after planting in both intensive and SHD orchards, it is very important to promote the vegetative growth of the trees, thus reducing the time required to reach the stage when harvesting machines can be used and, more in general, the final tree size and, thus, the full production.

Several practices can be used to promote tree growth. Among them, irrigation determines significant increases in tree growth [4], especially in the first years after planting [5–7]. Nitrogen fertilization can also significantly speed up the growth of young trees [8,9]. Higher growth can also be obtained by improving the availability of nutrients, including by using pruning residues [10]. Moreover, an increase in early growth has been obtained by using arbuscular mycorrhizal fungi [11,12] or biostimulants [13,14].

Fruiting is another factor that can strongly affect tree growth. Indeed, it has been observed that once reproduction starts, the crop will compete with and reduce vegetative growth [15]. This competition has been well recognized in mature trees of several species [16–18], including olive [19–24]. It is especially prominent in young fruit trees, where the removal of all blossoms or fruit results in dramatic increases in growth with respect to the fruiting trees [25–29]. In olive trees, a negative correlation was found between production efficiency and vegetative growth across different cultivars [30]. Furthermore, in young olive trees, it has been shown that the differences in vigor between cultivars are due to differences in early fruiting and that the elimination of blossoms in early fruiting cultivars promotes a significant increase in vegetative growth [29,31]. This suggests the possibility of using deflowering (i.e., preventing fruit formation) as a tool to promote the growth of young trees.

Up to now, reducing fruiting by fruit thinning has been used to control crop load and consequently alleviate alternate bearing in several fruit-tree species [32]. In many species, fruit thinning is performed manually, and only in some cases it can be performed chemically, such as in apple and olive [32,33]. In olive, chemical thinning has been found to be an effective practice to control fruit yield and, consequently, reduce alternate bearing [21,33,34]. Chemical fruit thinning has been used in olives since the 1950s in California [35]. Thinning in the early stages of fruit development increases the quality of the remaining crop, mainly in terms of fruit size [36].

Among the compounds used for chemical thinning, naphthaleneacetic acid (NAA) is an exogenous hormone that has been very effective in many fruit species [32] and has been the most used and effective hormone in olive [33,34,36,37]. Post-bloom application of NAA improves fruit quality, as well as shoot elongation [33]. However, the main aim of these studies was to reduce the fruit number in order to increase the size and quality of the remaining fruits. Therefore, the effect on yield was partial. In fact, although fruit thinning usually reduces the total yield (alleviating alternate bearing), the reduction is less than proportional to the reduction in fruit number, due to partial compensation with increased

fruit size. If the purpose of de-fruiting is to maximize the vegetative growth of the trees, then the maximum effect should be achieved when fruits are completely eliminated before their formation. No studies have evaluated the potential use of NAA to achieve complete deflowering with the aim of achieving maximum vegetative growth in the initial stages of tree growth. Additionally, using chemical treatments to deflower trees might induce possible side effects on tree behavior, and these side effects might compromise growth; however, these possible effects have not been studied.

The aim of this study was to assess the effectiveness and feasibility of using NAA applications to drastically reduce early fruit production and, consequently, accelerate growth in young olive trees of both intensive and SHD olive orchards. To do this, different concentrations of NAA were applied as a single application at flowering, and their effects on the vegetative and reproductive activities of the trees were evaluated in comparison to untreated and manually deflowered trees.

2. Materials and Methods

Three experiments were carried out, using two different orchard systems: an intensive system (spacing: 6×5 m; 333 trees ha^{-1}) with trees of the cultivar Moraiolo trained to a vase system, and a SHD system (spacing: 5×1.8 m; 1111 trees ha^{-1}) with Sikitita. The two systems were adjacent in the same experimental field, located in Central Italy ($42^{\circ}59'23''$ N, $12^{\circ}41'47''$ E, 260 m a.s.l.), and the pedoclimatic conditions were therefore nearly identical. The soil, at the beginning of the experiments, had the following characteristics: medium-clayey texture; pH, 7.9 ± 0.1 ; organic matter content, 1.4 ± 0.1 (%); active limestone, 3.6 ± 0.1 (%); cation-exchange capacity, 25.6 ± 0.5 (meq/100 g); exchangeable potassium, 273 ± 43 (mg/kg); and assimilable phosphorus, 31.9 ± 2.5 (mg/kg). For both systems, trees were established in the autumn of 2016. In all experiments and treatments, NAA was applied at fool bloom (fully open flowers > 80%), with a single application of an aqueous NAA (Fixormone, Cifo, Bologna, Italy) solution, using a shoulder sprayer. Each treatment included 4 trees (replications). The weather during and after NAA application was uniformly warm (2019) or uniformly cool (2020), and dry, with no precipitation occurring within 10 days from treatment application, and daily average temperature ranging from 24.1 to 27.3 °C in 2019 and from 15.0 to 19.2 °C in 2020 (except for one day with some precipitation and average temperature of 12.8). Weather data were obtained from the nearest station (Foligno) of the Umbria Region's weather station network (Servizio Idrografico Regionale).

2.1. Experiment 1—Effects of Different NAA Concentrations on the Vegetative and Reproductive Activities of the Cultivar Moraiolo

The trial was carried out in 2019 in the Moraiolo system. Before flowering (beginning of June), 28 trees with uniform vegetative–productive characteristics were selected and labeled. NAA treatments included the following concentrations: 0.0 ppm (control), 20 ppm, 40 ppm, 80 ppm, 160 ppm, and 250 ppm. An additional treatment consisted of the manual elimination of all inflorescences during flowering.

At the beginning of the vegetative season, before applying the treatments, and at the end of the season, the diameter of the trunk was measured at 30 cm from ground level, and the trunk cross-sectional area (TCSA) was calculated from the diameter. Before treatment, 16 fruiting branches per treatment (4 per tree) were labeled, and the length of the growing shoots and the number of inflorescences were recorded. After the treatments, until the end of the vegetative–productive season, the number of fruits on the labeled branches was periodically recorded, and the final length of the growing shoots was measured at the end of the vegetative season. At the end of the year, the yield per tree was also recorded.

2.2. Experiment 2—Effects of Different NAA Concentrations on the Reproductive Activity of the Cultivar Sikitita

The trial was carried out in 2019 in the Sikitita system. Before flowering (beginning of June), 20 trees with uniform vegetative–productive characteristics were selected and

labeled. NAA treatments included the following concentrations: 0.0 ppm (control), 40 ppm, 80 ppm, and 160 ppm. An additional treatment consisted in the manual elimination of all inflorescences during flowering.

At the end of the year, the yield per tree was recorded.

2.3. Experiment 3—Effects of NAA Treatments on the Cultivar Moraiolo for Two Consecutive Years

The trial was carried out in 2019 and 2020. Before flowering (beginning of June in 2019), 8 trees with uniform vegetative–productive characteristics were selected and labeled, and NAA applications were repeated on the same trees in both years. NAA treatments included the following concentrations: 0.0 ppm (control) and 160 ppm, using a shoulder sprayer.

From the beginning of 2019 to the end of 2020, the diameter of the trunk was periodically measured, and the trunk cross-sectional area (TCSA) was calculated.

2.4. Statistical Analysis

Data are presented as means $\pm$ standard error and, in some cases, were statistically analyzed by one-way ANOVA according to a randomized block design. The relationships between some of the parameters were evaluated by calculating the coefficients of determination (R^2).

3. Results

3.1. Experiment 1—Effects of Different NAA Concentrations on the Vegetative and Reproductive Activities of the Cultivar Moraiolo

The treatments with NAA, compared to the control (untreated trees), resulted in a reduction in fruit set, and this reduction was positively correlated to the concentration of NAA: the concentrations of 160 ppm and 250 ppm eliminated virtually all the fruits (Figures 1 and 2) and, thus, the production (Figure 3).

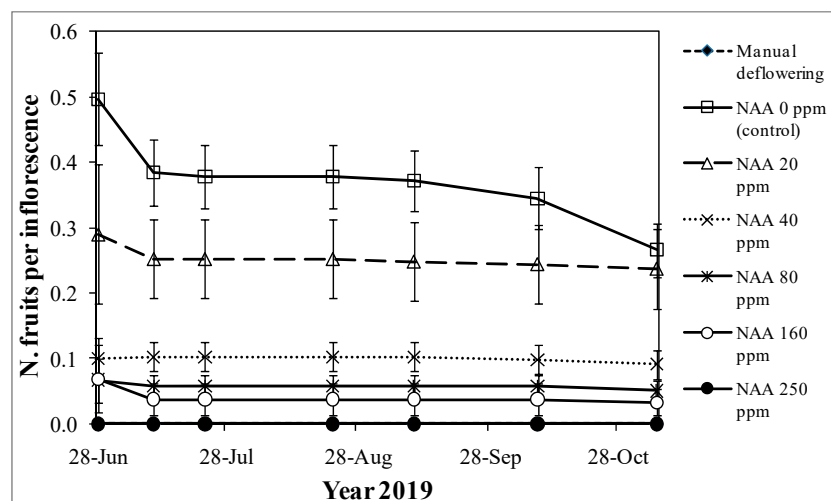


Figure 1. Fruit set and drop during the growing season (2019) in control, different NAA concentrations, and manually deflowered trees in a young intensive olive orchard of the cultivar Moraiolo. The bars represent the standard error of 16 replicates per treatment. The dashed line for manual deflowering is difficult to see because it overlaps with the solid line for the NAA 250 treatment.

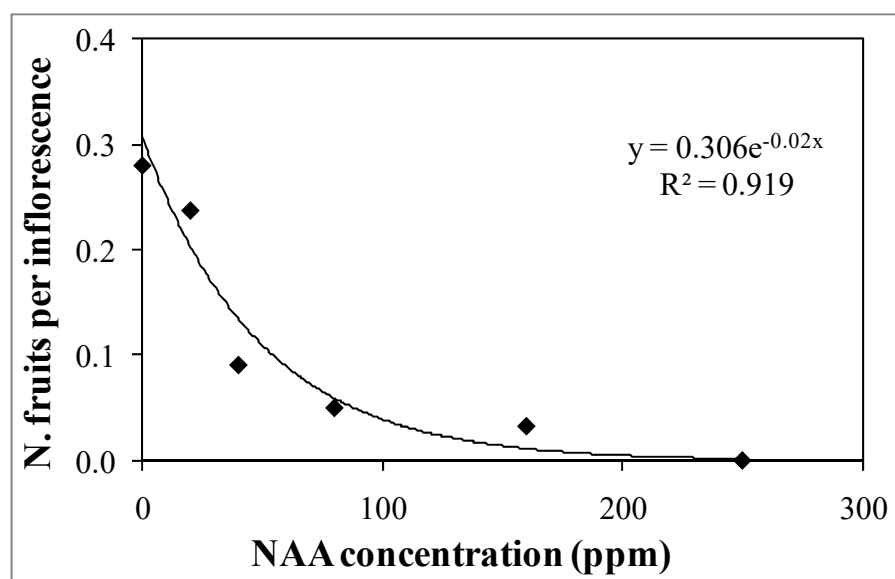


Figure 2. Relationship between used NAA concentrations and the number of fruits per inflorescence at the end of the vegetative season (2019) in a young intensive olive orchard of the cultivar Moraiolo. Values are means of 16 replicates per treatment.

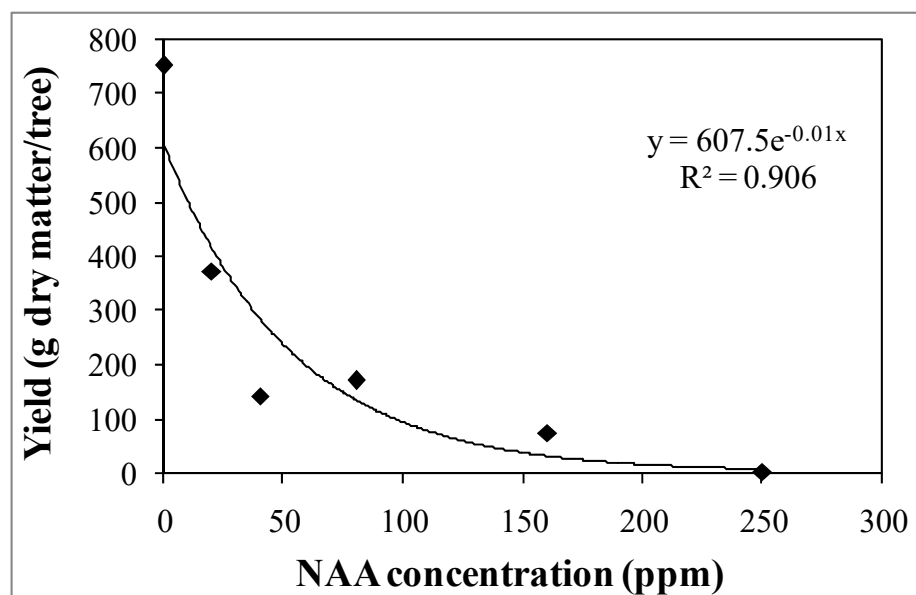


Figure 3. Relationship between NAA concentrations and the yield per tree at the end of the vegetative season (2019) in a young intensive olive orchard of the cultivar Moraiolo. Values are means of 4 replicates per treatment.

NAA at 160 ppm and manual deflowering determined similar shoot growth, which was greater than the control (Figure 4). Treatments with NAA at concentrations of 80, 160, and 250 ppm resulted in a very large increase in both the annual and the June-to-December increment in trunk cross-sectional area (Figure 5). A similar increment was observed in manually deflowered trees. The increase in trunk cross-sectional area was positively correlated to the NAA concentration (Figure 6) and negatively correlated to the yield efficiency of the trees (Figure 7).

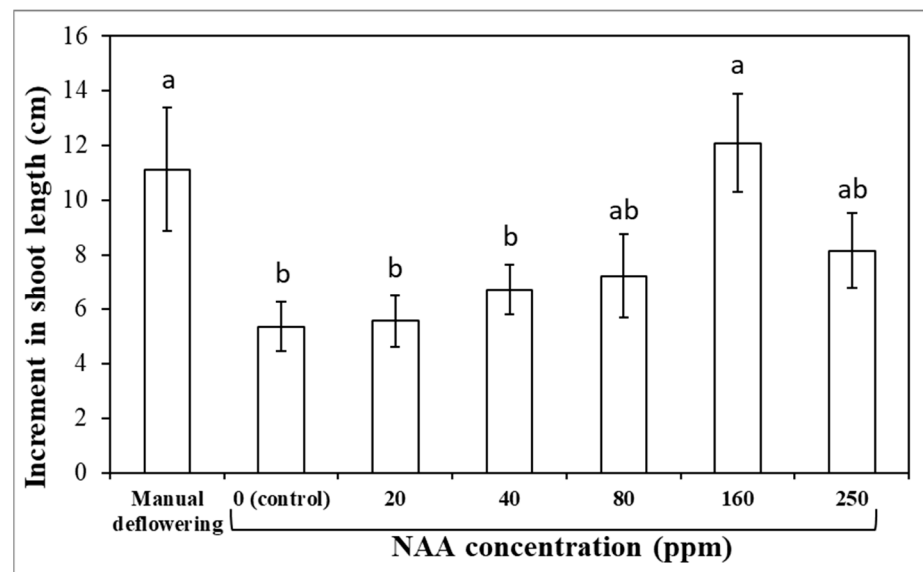


Figure 4. Increment of shoot length in control, different NAA concentrations, and manually deflowered trees in a young intensive olive orchard of the cultivar Moraiolo. Values are means of 16 replicates per treatment, and bars represent standard errors. Different letters indicate significant differences between treatments according to the Student–Newman–Keuls Test ($p < 0.05$).

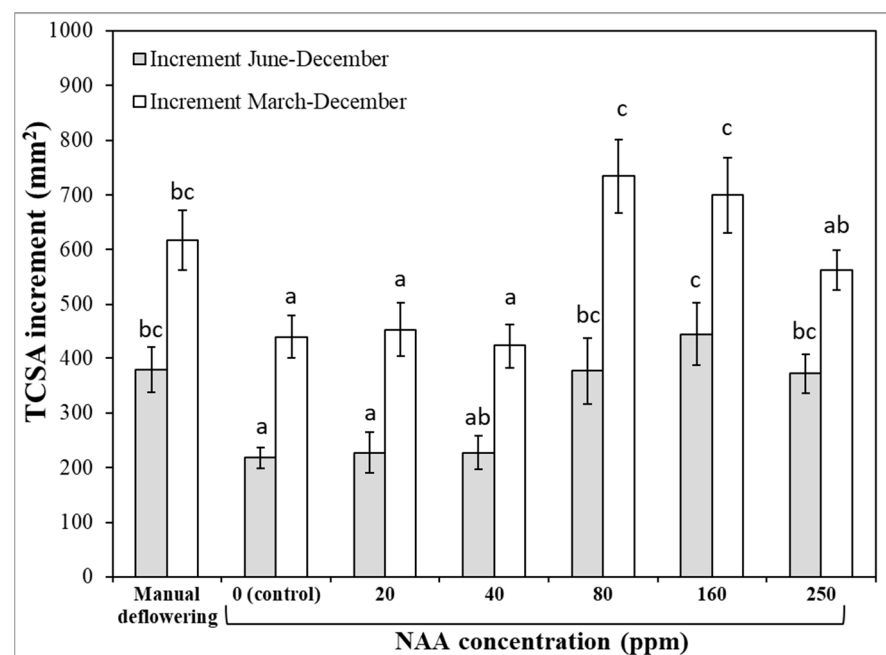


Figure 5. Increment in trunk cross-sectional area (TCSA) from the time of application of the NAA treatments (June) to the end of the season (December) and for the whole vegetative season (March–December) in control, different NAA concentrations, and manually deflowered trees in a young intensive olive orchard of the cultivar Moraiolo. Values are means of 4 replicates per treatment, and bars represent standard errors. Different letters indicate significant differences between treatments within each period (June–December and March–December, respectively) according to the Student–Newman–Keuls Test ($p < 0.05$).

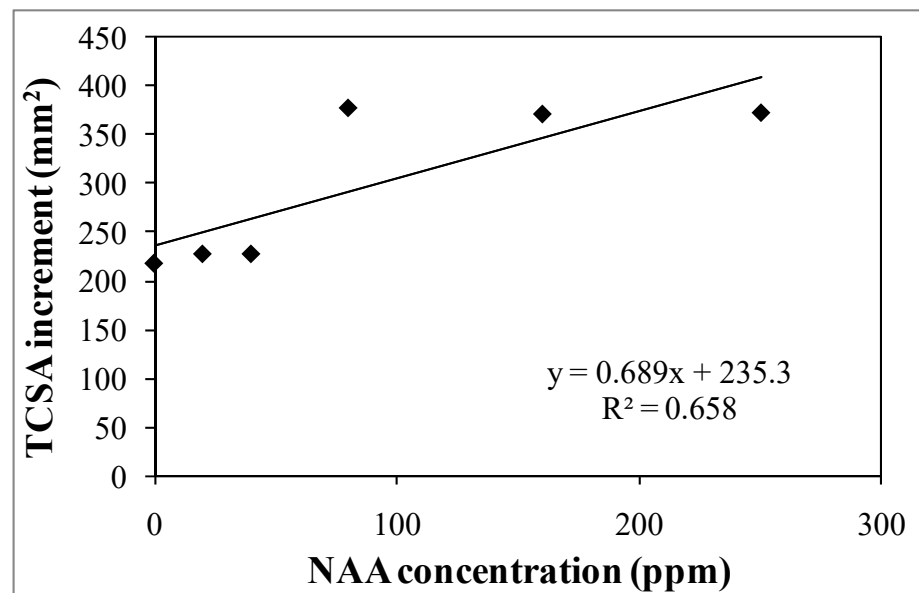


Figure 6. Relationship between NAA concentrations and increments in trunk cross-sectional area (TCSA) from the time of application of the NAA treatments (June) to the end of the season (December) in a young intensive olive orchard of the cultivar Moraiolo. Values are means of 4 replicates per treatment.

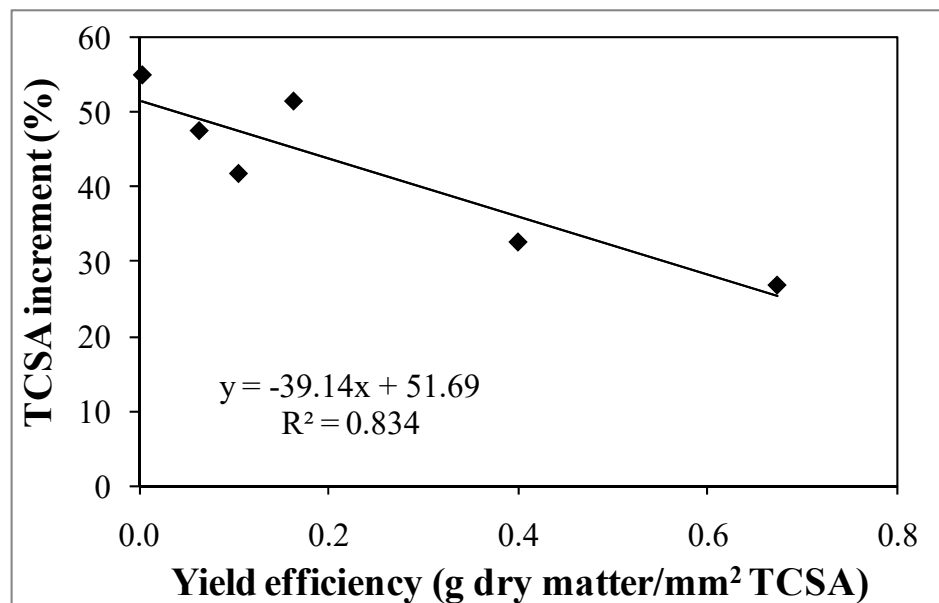


Figure 7. Relationship between the yield efficiency and the increment of the trunk cross-sectional area (TCSA) from the time of application of the NAA treatments (June) to the end of the season (December) in a young intensive olive orchard of the cultivar Moraiolo. Values are means of 4 replicates per treatment.

3.2. Experiment 2—Effects of Different NAA Concentrations on the Reproductive Activity of the Cultivar Sikitita

The treatments with NAA reduced fruit set in the SHD orchard (Sikitita cultivar). There was a negative correlation between the NAA concentration and fruit yield, with a reduction of more than the 80% from 0 ppm NAA to 160 ppm NAA (Figure 8).

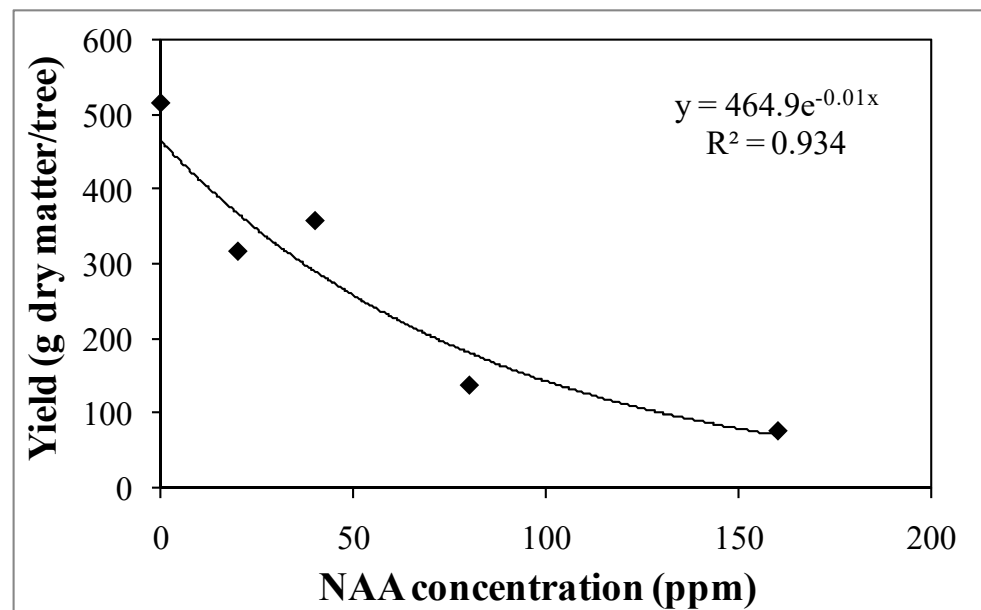


Figure 8. Relationship between NAA concentrations and the yield per tree at the end of the vegetative season (2019) in a young SHD olive orchard of the cultivar Sikitita. Values are means of 4 replicates per treatment.

3.3. Experiment 3—Effects of NAA Treatments on Cultivar Moraiolo for Two Consecutive Years

In 2019, at the beginning of the experiment, the TCSA of Moraiolo trees was about 700 mm². The 160 ppm NAA application, both in 2019 and 2020, determined a progressive higher increase in tree growth compared to the control, as shown by the TCSA rate of increment (Figure 9).

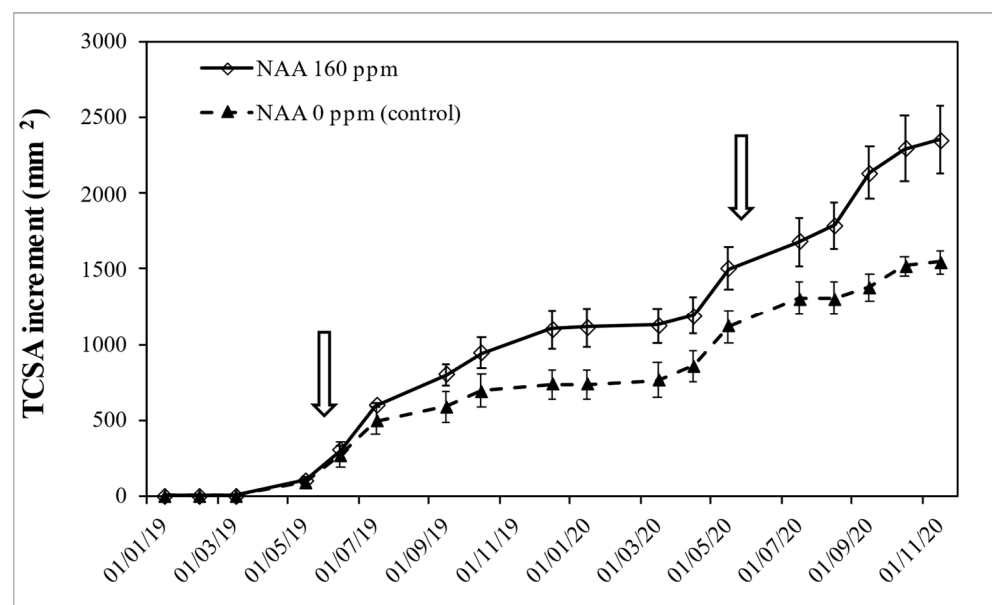


Figure 9. Increment in trunk cross-sectional area (TCSA) over two consecutive years (2019–2020) in control (NAA 0 ppm) and NAA 160 ppm trees in a young intensive olive orchard of the cultivar Moraiolo. The arrows indicate the time of NAA treatments. The bars represent the standard error of 4 replicates per treatment.

4. Discussion

The application of NAA at full bloom was very effective in reducing fruit set, with a dose-related intensity (Figures 1 and 2). The dosages of 160 and 250 ppm were able to

virtually eliminate it. Up to now, NAA applications at flowering have only been used to reduce fruit set and improve the fruit size and quality of the remaining fruits, or to eliminate yield in ornamental trees, where ripe olives dropping to the ground can be a nuisance [33,38]. No previous studies have been carried out to test the use of NAA to prevent fruit set and promote the growth of young trees. Our results show that this may be a viable strategy, because, with suitable concentrations, the crop can be completely removed, with significant positive effects on the vegetative growth of young trees (Figures 4 and 5).

Up to now, NAA has mainly been used in post-bloom applications for fruit thinning and, in this case, the fruit size compensated, at least in part, for the reduction in fruit number. Therefore, the fruit yield was less affected by fruit thinning and, consequently, also vegetative growth was not, or only slightly, influenced, because the demand of assimilates by the growing fruits was not eliminated [34,36]. In the present study, the crop load was reduced down to zero, using increasing doses of NAA, determining a significant increase in the vegetative growth of the trees. The increase in growth was significantly and positively related to the NAA concentration (Figure 6) and, hence, inversely related to fruit set and yield efficiency (Figure 7). Likewise, early and complete de-fruiting [22] or deflowering performed by hand [31,39] resulted in an increase in vegetative growth of the trees.

The greater vegetative growth of NAA-treated trees, where the crop was completely removed (NAA 160–250 ppm), is mostly likely due to the fact that fruit and vegetative growths compete for the available resources, and, in fruit trees, these two activities occur simultaneously for several months [27,40,41]. This is especially true for olives, which are normally harvested in autumn. This competition is well-known in both mature and young trees of several species, including olive [16–23,42–45]. In young apple trees, removing flowers/fruits results in very large increases in vegetative growth [25–28]. Recently, also in olive, deflowering young trees by hand gave a very significant increase in the vegetative growth, demonstrating that, in young trees, competition for resources plays a major role in determining vegetative growth, which is, therefore, source limited [29,31]. This agrees with the great increase in the vegetative growth due to NAA treatments, which eliminated fruit set (160–250 ppm).

Comparable results were obtained with the cultivar Sikitita in a super-high-density orchard, indicating that the effect of NAA was similar with different cultivars and conditions. Considering our results and those from the above-cited literature, it is important to emphasize that significant effects on tree growth are achieved when all fruits are prevented, and not just thinned.

De-fruiting exerts its effects from the time of fruit removal to the end of the growing season. In the present work, treatments were applied when flowers were fully open (end of May to beginning of June). From this time to the end of the season, 160 ppm NAA and manual deflowering more than doubled shoot growth compared to the control (trees with crop load; see Figure 4). The increase was marked also for the trunk's cross-sectional area: about 100% (from treatment application to the end of the season) and 60% (calculated over the whole season; see Figure 5). These results indicate a great increase in tree growth, which was confirmed by the trial on trees treated with 160 ppm NAA for two consecutive years, where the difference in TCSA increased further in the second year, compared to control (Figure 9). A similar behavior was observed in a previous study in which potted trees of the cultivars Arbequina and Frantoio were deflowered manually for the first 4 years [39]. The increments in growth determined by preventing fruit set in young olive trees depends on the fruiting potential of the trees. In the present study, deflowered trees after one year had a growth similar to that of fruiting trees after 1.5 years. Similarly, in the study of Paoletti et al. [39], two-year-old deflowered trees of the cultivar Arbequina reached the TCSA of three-year-old fruiting trees; in the case of the cultivar Frantoio, three-year-old deflowered trees had the size of four-year-old fruiting trees. Overall, our results agree with the literature on the effects of manual deflowering [39] and suggest that chemical deflowering enables young olive trees to gain one year of growth for every two or three years of cultivation, with the highest increase (one year every two years of cultivation)

being with cultivars having an early and high production of flowers/fruits. Considering that tree growth in young trees is exponential, it can be assumed that, with continuous deflowering over the years, the improvement in growth becomes greater and greater.

Our results suggest that, in SHD orchards, where very fertile cultivars are normally used, NAA might be best applied during the first and, possibly, second year in the case of abundant flowering in order to accelerate the transition to a hedgerow and to full production and the use of mechanical harvesting.

In intensive olive orchards, the repeated use of NAA to prevent fruit set in the first few years may be a strategy to promote a significant reduction in the time required by trees to reach the trunk dimension that enables trunk shakers to be used (minimum diameter of 10–15 cm) and the time required to reach final tree size and full production.

Previous studies showed that deflowering determines higher vegetative growth in the current year and greater flower induction and differentiation in the following year, which, in turn, causes a reduction in vegetative growth [29,39]. Therefore, if de-fruiting is performed, it should be performed continuously until the target is achieved. In both SHD and intensive orchards, this is when tree size and yield enable the use of mechanical harvesting. This will also shorten the time to reach full size and the full production of the trees.

NAA is a synthetic form of auxin; therefore, it could also affect tree growth through a hormonal effect. However, the lack of differences in shoot and trunk growth between trees deflowered by hand vs. 160 ppm NAA (Figures 4 and 5) suggests that the positive effects on tree growth are only due to the fruit removal and not to other effects. Moreover, it also indicates the absence of negative side effects caused by 160 ppm NAA.

5. Conclusions

In young olive trees, applications of NAA at concentrations of 160 ppm or 250 ppm at full bloom allowed complete or nearly complete prevention of fruit set and production, with a consequent increase in vegetative growth, in terms of both greater shoot elongation and trunk growth, an effect comparable to that achieved with manual (i.e., complete) deflowering. NAA treatments were effective in preventing fruit set in both cultivars tested. This can be exploited as a powerful technique to accelerate the growth of young olive trees in both intensive and SHD olive orchards, leading to a more rapid transition to the adult stage when mechanization of harvesting can be applied and, consequently, reduction in the time to reach full tree size and full orchard production. Finally, this technique is also potentially profitable in nurseries to accelerate initial tree growth.

The present findings provide the first quantitative assessment of the potential of using chemical deflowering as a tool to prevent reproductive growth in young olive orchards, thus shifting the balance toward increased vegetative activity, with evident advantages in terms of orchard management and economics.

Author Contributions: Conceptualization, F.F., A.P., N.C., D.F., E.M.L. and A.R.; methodology, F.F., A.P., N.C., D.F., E.M.L. and A.R.; validation, F.F., A.P., N.C., D.F., E.M.L. and A.R.; formal analysis, F.F., A.P., N.C., D.F., E.M.L. and A.R.; investigation, A.P., N.C. and D.F.; data curation, A.P., N.C., D.F. and E.M.L.; writing—original draft preparation, F.F., A.P. and N.C.; writing—reviewing and editing, F.F., N.C., E.M.L. and A.R.; supervision, F.F.; project administration, F.F.; funding acquisition, F.F. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out in the frame of the MOLTI project (Decree n. 13938/7110/2018) funded by the Italian Ministry of Agricultural Food and Forestry Policies.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Famiani, F.; Gucci, R. *Moderni Modelli Olivicoli*; Collana divulgativa dell'Accademia Vol VII; Accademia Nazionale dell'Olio e dell'Olio: Spoleto, Italy, 2011; p. 32.
2. Lo Bianco, R.; Proietti, P.; Regni, L.; Caruso, T. Planting systems for modern olive growing: Strengths and weaknesses. *Agriculture* **2021**, *11*, 494. [\[CrossRef\]](#)
3. Rallo, L.; Barranco, D.; Castro-Garcia, S.; Connor, D.J.; Gomez del Campo, M.; Rallo, P. High-density olive plantations. *Hortic. Rev.* **2013**, *41*, 303–384.
4. Tognetti, R.; d'Andria, R.; Lavini, A.; Morelli, G. The effect of deficit irrigation on crop yield and vegetative development of *Olea europaea* L. (cvs. Frantoio and Leccino). *Eur. J. Agron.* **2006**, *25*, 356–364. [\[CrossRef\]](#)
5. Pérez-López, D.; Ribas, F.; Moriana, A.; Olmedilla, N.; de Juan, A. The effect of irrigation schedules on the water relations and growth of a young olive (*Olea europaea* L.) orchard. *Agric. Water Manag.* **2007**, *89*, 297–304. [\[CrossRef\]](#)
6. Gucci, R.; Lodolini, E.M.; Rapoport, H.F. Productivity of olive trees with different water status and crop load. *J. Hortic. Sci. Biotechnol.* **2007**, *82*, 648–656. [\[CrossRef\]](#)
7. Martín-Vertedor, A.I.; Pérez Rodríguez, J.M.; Losada, H.P.; Castiel, E.F. Interactive responses to water deficits and crop load in olive (*Olea europaea* L., cv. Morisca) I.—Growth and water relations. *Agric. Water Manag.* **2011**, *98*, 941–949. [\[CrossRef\]](#)
8. Rodrigues, M.; Lopes, J.; Pavão, F.; Cabanas, J.; Arrobas, M. Effect of soil management on olive yield and nutritional status of trees in rainfed orchards. *Commun. Soil Sci. Plant Anal.* **2011**, *42*, 993–1007. [\[CrossRef\]](#)
9. Leskovar, D.; Othman, Y.A. Nitrogen management for improving root and shoot components of young 'Arbequina' olives. *HortScience* **2019**, *54*, 175–180. [\[CrossRef\]](#)
10. Endeshaw, S.T.; Lodolini, E.M.; Neri, D. Effects of olive shoot residues on shoot and root growth of potted olive plantlets. *Sci. Hortic.* **2015**, *182*, 31–40. [\[CrossRef\]](#)
11. Soriano-Martín, M.L.; Azcón, R.; Barea, J.M.; Porras-Soriano, A.; Marcilla-Goldaracena, I.; Porras-Piedra, A. Reduction of the juvenile period of new olive plantations through the early application of mycorrhizal fungi. *Soil Sci.* **2006**, *171*, 52–58. [\[CrossRef\]](#)
12. Porras-Soriano, A.; Soriano-Martín, M.L.; Porras-Piedra, A.; Azcón, R. Arbuscular mycorrhizal fungi increased growth, nutrient uptake and tolerance to salinity in olive trees under nursery conditions. *J. Plant Physiol.* **2009**, *166*, 1350–1359. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Almadi, L.; Paoletti, A.; Cinosi, N.; Daher, E.; Rosati, A.; Di Vaio, C.; Famiani, F. A biostimulant based on protein hydrolysates promotes the growth of young olive trees. *Agriculture* **2020**, *10*, 618. [\[CrossRef\]](#)
14. Mazeh, M.; Almadi, L.; Paoletti, A.; Cinosi, N.; Daher, E.; Tucci, M.; Lodolini, E.M.; Rosati, A.; Famiani, F. Use of organic fertilizer also having a biostimulant action to promote the growth of young olive trees. *Agriculture* **2021**, *11*, 593. [\[CrossRef\]](#)
15. Smith, H.M.; Samach, A. Constraints to obtaining consistent annual yields in perennial tree crops. I: Heavy fruit load dominates over vegetative growth. *Plant Sci.* **2013**, *207*, 158–167. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Stevenson, M.T.; Shackel, K.A. Alternate bearing in pistachio as a masting phenomenon: Construction cost of reproduction versus vegetative growth and storage. *J. Am. Soc. Hortic. Sci.* **1998**, *123*, 1069–1075. [\[CrossRef\]](#)
17. Costes, E.; Fournier, D.; Salles, J.C. Changes in primary and secondary growth as influenced by crop load in 'Fantasme' apricot trees. *J. Hortic. Sci. Biotechnol.* **2000**, *75*, 510–519. [\[CrossRef\]](#)
18. Berman, M.E.; DeJong, T.M. Seasonal patterns of vegetative growth and competition with reproductive sink in peach. *J. Hortic. Sci. Biotechnol.* **2003**, *78*, 303–309. [\[CrossRef\]](#)
19. Obeso, J.R. The cost of reproduction in plants. *New Phytol.* **2002**, *155*, 321–348. [\[CrossRef\]](#) [\[PubMed\]](#)
20. Connor, D.J.; Fereres, E. The physiology of adaptation and yield expression in olive. *Hortic. Rev.* **2005**, *31*, 155–229.
21. Lavee, S. Biennial bearing in olive (*Olea europaea*). *Ann. Ser. Hist. Nat.* **2007**, *17*, 101–112.
22. Dag, A.; Bustan, A.; Avni, A.; Tzipori, I.; Lavee, S.; Riov, J. Timing of fruit removal affects concurrent vegetative growth and subsequent return bloom and yield in olive (*Olea europaea* L.). *Sci. Hortic.* **2010**, *123*, 469–472. [\[CrossRef\]](#)
23. Castillo-Llanque, F.; Rapoport, H.F. Relationship between reproductive behavior and new shoot development in 5-year-old branches of olive trees (*Olea europaea* L.). *Trees* **2011**, *25*, 823–832. [\[CrossRef\]](#)
24. Fernández, F.J.; Ladux, J.L.; Searles, P.S. Dynamics of shoot and fruit growth following fruit thinning in olive trees: Same season and subsequent season responses. *Sci. Hortic.* **2015**, *192*, 320–330. [\[CrossRef\]](#)
25. Chandler, W.H.; Heinicke, A.J. The effect of fruiting on the growth of Oldenburg apple trees. *Proc. Amer. Soc. Hort. Sci.* **1926**, *23*, 36–46.
26. Verheij, E.W.M. Competition in Apple as Influenced by Alar Sprays, Fruiting, Pruning and Tree Spacing. Ph.D. Thesis, Agricultural University, Wageningen, The Netherlands, 1972; 54p.
27. Forshey, C.G.; Elfving, D.C. The relationship between vegetative growth and fruiting in apple trees. *Hortic. Rev.* **1989**, *11*, 229–287.
28. Embree, C.G.; Myra, M.T.; Nichols, D.S.; Wright, A.H. Effect of blossom density and crop load on growth, fruit quality, and return bloom in 'Honeycrisp' apple. *HortScience* **2007**, *42*, 1622–1625. [\[CrossRef\]](#)
29. Rosati, A.; Paoletti, A.; Al Hariri, R.; Morelli, A.; Famiani, F. Partitioning of dry matter into fruit explains cultivar differences in vigor in young olive (*Olea europaea* L.) trees. *HortScience* **2018**, *53*, 491–495. [\[CrossRef\]](#)
30. Rosati, A.; Paoletti, A.; Pannelli, G.; Famiani, F. Growth is inversely correlated with yield efficiency across cultivars in young olive (*Olea europaea* L.) trees. *HortScience* **2017**, *52*, 1525–1529. [\[CrossRef\]](#)

31. Rosati, A.; Paoletti, A.; Al Hariri, R.; Morelli, A.; Famiani, F. Resource investments in reproductive growth proportionately limit investments in whole-tree vegetative growth in young olive trees with varying crop loads. *Tree Physiol.* **2018**, *38*, 1267–1277. [[CrossRef](#)] [[PubMed](#)]
32. Costa, G.; Botton, A.; Vizzotto, G. Fruit thinning: Advances and trends. *Hortic. Rev.* **2018**, *46*, 185–226.
33. Krueger, W.H.; Maranto, J.; Sibbett, G.S. Olive fruit thinning. In *Olive Production Manual*; Sibbett, G.S., Ferguson, L., Eds.; University of California, Agriculture and Natural Resources, Publication 3353: Oakland, CA, USA, 2005; pp. 101–104.
34. Dag, A.; Bustan, A.; Avni, A.; Lavee, S.; Riov, J. Fruit thinning using NAA shows potential for reducing biennial bearing of ‘Barnea’ and ‘Picual’ oil olive trees. *Crop. Pasture. Sci.* **2009**, *60*, 1124–1130. [[CrossRef](#)]
35. Krueger, W.H.; Heat, Z.; Mulqueeney, B. Effect of spray solution concentration, active ingredient, additives and sequential treatments of Naphthalene Acetic Acid for chemical thinning of Manzanillo table olives (*Olea europaea*). *Acta Hort.* **2002**, *586*, 267–271. [[CrossRef](#)]
36. Barone, E.; La Mantia, M.; Marchese, A.; Marra, F.P. Improvement in yield and fruit size and quality of the main Italian table olive cultivar ‘Nocellara del Belice’. *Sci. Agric.* **2014**, *71*, 52–57. [[CrossRef](#)]
37. Crous, J.J.; Steyn, W.J. Chemical thinning of ‘Barouni’ and ‘Manzanilla’ olives with naphthalene acetic acid under South African conditions. *S. Afr. J. Plant Soil* **2015**, *32*, 47–54. [[CrossRef](#)]
38. Hegazi, E.S.; Hegzi, A.A.; ElKoly, D.M. Effect of some chemical thinning agents on fruit set of Manzanillo and Eggezi Shgami olive cultivars. *J. Hortic. Sci. Ornam.* **2015**, *7*, 117–123.
39. Paoletti, A.; Rosati, A.; Famiani, F. Effects of cultivar, fruit presence and tree age on whole-plant dry matter partitioning in young olive trees. *Heliyon* **2021**, *7*, e06949. [[CrossRef](#)]
40. DeJong, T.M. Development and environmental control of dry-matter partitioning in peach. *HortScience* **1999**, *34*, 1037–1040. [[CrossRef](#)]
41. Wunsche, J.N.; Ferguson, I.B. Crop load interactions in apple. *Hortic. Rev.* **2005**, *31*, 231–290.
42. Monselise, S.P.; Goldschmidt, E.E. Alternate bearing in fruit trees. *Hortic. Rev.* **1982**, *4*, 128–173.
43. Rallo, L.; Suarez, M.P. Seasonal distribution of dry matter within the olive fruit-bearing limb. *Adv. Hort. Sci.* **1989**, *3*, 55–59.
44. Lodolini, E.M.; Neri, D. How growth and reproduction cycles affect alternate bearing in olive. *Acta Hort.* **2012**, *949*, 191–198. [[CrossRef](#)]
45. Di Vaio, C.; Nocerino, S.; Paduano, A.; Sacchi, R. Characterization and evaluation of olive germplasm in southern Italy. *J. Sci. Food Agric.* **2013**, *93*, 2458–2462. [[CrossRef](#)] [[PubMed](#)]