Alternate bearing in olive – mitigation with properly timed foliar-applied naphthaleneacetic acid or pruning

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Abstract

Climate events causing floral bud abortion, poor pollination or abscission of reproductive structures result in alternate bearing (AB) in olive (*Olea europaea* L.). Alternating low-yield years (OFF crops) following high-yield years (ON crops) have negative economic impacts on orchard management, harvesting, marketing, production of value-added products, and consumer prices, which destabilize the sustainability of olive commodity-based industries. In this research, AB severity for 'Manzanillo' olive, based on alternate bearing index (ABI), where 0 equals no AB and 1 is complete AB (crop one year, no crop the next), ranged from 0.35 to 0.94. Non-bearing shoots (NBS) on OFF-crop trees produced 20-fold more inflorescences the following spring than bearing shoots (BS) of ON-crop trees, whereas NBS on ON-crop trees produced 15-fold more inflorescences than BS. To increase flowering and yield following an ON-crop year, the number of NBS needs to be increased. Flower removal at full bloom (FB) with naphthaleneacetic acid (NAA) or fruit removal 28 days after full bloom (DAFB) by pruning were imposed on one side of commercial 'Manzanillo' olive trees and then the other side annually versus every other year (biennially). Over a 4-year period starting with an ON crop, for untreated ON-/OFF-crop control trees, ABI for total yield was 0.94 and ABI for yield of commercially valuable medium plus large (M+L) size fruit was 0.80. Foliar-applied NAA at FB or pruning 28 DAFB to one side of the tree annually reduced the ABI for total yield to 0.75 and 0.72, respectively, and ABI for yield of M+L size fruit to 0.70 and 0.61, respectively. In contrast, foliar-applied NAA at FB or pruning 28 DAFB to one side of the tree biennially reduced the ABI for total yield to 0.58 and 0.47, respectively, and ABI for yield of M+L size fruit to 0.46 and 0.37, respectively. There were no differences in 4-year cumulative total yields among treatments, whereas cumulative yields of M+L size fruit were 20 and 40% greater for trees treated with NAA or pruned biennially than trees treated annually for the same 3-year period (*P*<0.01).

Keywords: alternate bearing index, climate, commercially valuable size fruit, flower and fruit thinning, OFF-crop trees/years, ON-crop trees/years, total yield

INTRODUCTION

Globally, alternate bearing (AB), repeating biennial cycles of a low yield OFF crop followed by a high yield ON crop, is a serious economic problem for olive growers and allied industries. In OFF years, trees produce a greater proportion of valuable size fruit than in ON years, but there are too few to provide a good income. In ON years, trees produce a large number of small fruit of reduced commercial value that take longer to mature, attain size, and accumulate oil. Alternate bearing can be asynchronous among individual trees in an orchard or synchronized throughout an orchard and even across a large geographic area (Monselise and Goldschmidt, 1982). The absence of fruit in the OFF year and the negative effects of AB on fruit size that occur in each ON-/OFF-crop cycle have a negative economic impact on every step in the production chain from farm to consumer. This destabilizes olive commodity-based industries and threatens their sustainability.

Alternate bearing is typically initiated by an adverse climatic event (e.g., low or high temperatures, lack of rain or flooding) during bloom, which affects not only the crop-bearing trees, but also the pollinizer trees, causing low flower number, reduced pollination, and low fruit set (Sibbett, 2000; Lavee, 2007; Fichtner and Lovatt, 2018). This results in an OFF crop, which is typically followed by an ON crop the next year, depending on how long it takes the trees to recover. Conversely, optimal conditions during bloom and fruit set that preclude natural flower and fruit thinning result in an ON crop that is followed by an OFF crop. Cultural management practices can also initiate AB. Excessive pruning resulting in low flower or fruit number and vigorous vegetative shoot growth can initiate an OFF crop followed by heavy flowering on the new vegetative shoots and an ON crop. Once initiated, AB continues until reset by a climate event or a crop reduction strategy is imposed.

Fichtner et al. (2021) documented four physiological mechanisms in olive (*Olea europaea* 'Manzanillo') by which crop load influences return bloom. They are listed here as the negative effects of the ON crop (note that the effect of the OFF crop is limited and thus, appears opposite to the effect of the ON-crop):

- ON years reduce summer vegetative shoot growth, with fewer, shorter vegetative shoots resulting in fewer nodes to bear buds that can produce inflorescences the following spring, first demonstrated by Sibbett (2000);
- ON years result in abscission of floral buds in summer for next spring's bloom;
- ON years show repression of key genes required for floral development and inflorescence and flower formation;
- ON years have an inhibition of spring bud break, which further decreases flowering in the spring following the ON-crop year.

Presently, knowledge of the physiology underlying each mechanism is limited. Due to the whole tree effect of crop load combined with the localized effect of fruit set on a shoot, the negative effects of the ON crop are more severe for bearing shoots (BS) than non-bearing shoots (NBS) on ON-crop trees. Thus, by default NBS are the major source of inflorescences at spring bloom following an ON-crop year (Fichtner and Lovatt, 2018). Non-bearing shoots on OFF-crop trees produced 20-fold more inflorescences the following spring than BS of ON-crop trees, whereas NBS on ON-crop trees produced 15-fold more inflorescences than BS (Fichtner and Lovatt, 2018). Thus, it is the fewer NBS compared to BS on ON-crop trees that contribute the majority of inflorescences at return bloom the following spring. In an ON-crop orchard, it is necessary to manage the trees to create more NBS with properly timed flower or fruit thinning by hand, chemical treatment, or pruning to overcome the effects of the ON crop and stimulate summer vegetative shoot growth, prevent floral bud abscission, restore floral gene expression, and promote spring bud break to increase return bloom and yield in the year following the ON-crop. In addition, properly timed crop thinning treatments also increase olive fruit size (Kour et al., 2018).

Climate events repeat in a random manner, creating a reoccurring need for a strategy to mitigate AB. Thus, the overall goal of the research presented herein was to reduce the severity of AB and achieve total yields that maximize the yield of commercially valuable size (CVS) fruit (medium plus large (M+L), 3.5-4.9 g fruit^{-1}) annually. The specific objective was to test the efficacy of two crop reduction strategies under two different application schedules. The following treatments were initiated in the ON-crop year: 1) foliar-applied NAA to remove flowers at FB, and 2) pruning imposed 28 DAFB to remove young developing fruit. Both treatments were applied to one side of the tree and then the other side (1) annually versus (2) biennially over a 4-year period starting with an ON-crop. Treatment effects on total yield, yield of CVS fruit, and ABI were quantified. The relationship between total yield and yield of CVS fruit was calculated. In addition, for each data tree in the orchard, estimates of floral intensity were made at FB, one day before the first treatment was applied, with the objective to determine the relationship between estimated floral intensity on treated and untreated trees, total yield and yield of CVS fruit. The goal was to maximize yield of CVS fruit by using estimated floral intensity to identify when to use or not use a crop reduction strategy and to guide grower pruning practices in an AB orchard.

MATERIALS AND METHODS

Plant material and experimental plan

The research was conducted in a commercially bearing 'Manzanillo' olive orchard located in Exeter, California, USA (latitude 36.3°N; longitude 119.2°W; elevation 106 m a.s.l.). The 27-year-old trees on their own roots were planted at 156 trees ha^{-1}, with 'Sevillano' pollinizer trees at a ratio of 1 to 7. Trees were maintained according to grower standard practice. There were six treatments: 1) annual foliar-applied NAA at FB to one side of a tree and then the other side the following year (years 1, 2, 3 and 4); 2) annual pruning (28 DAFB) to one side of the tree and then the other side of the tree (years 1, 2, 3, and 4); 3) biennial foliar-applied NAA at FB to one side of a tree and then the other side every other year (years 2 and 4); 4) biennial pruning on one side of the tree and then the other side every other year (years 2 and 4); 5) ON-crop control trees selected in year 1; and 6) OFF-crop control trees selected in year 1. A randomized complete block design with 16 individual tree replicates per treatment was used. At FB NAA (162.5 mg active ingredient L^{-1}) (Olive-Stop® Concentrate, ammonium salt, American Vanguard Corporation) was applied as a foliar spray, containing 0.025% WideSpead Max® (non-ionic organosilicone wetting agent, Loveland Products) to one side of a tree in sufficient volume to provide good canopy coverage, but not to the point of runoff. Trees were hand-pruned 28 DAFB on one side of the tree along the tree line to maintain the width between rows. Trees were topped to a height of 4.27 m in late May or early June each year and skirted in June of year 4.

In years 2 through 5, one day prior to the initiation of treatments at FB, floral intensity was estimated on the east and west sides of each data tree (trees were planted in rows running north-south), using a scale from 0 to 3, with 0 equal to no inflorescences and 1 through 3 indicating a low, medium and high number of inflorescences. The values for the east and west sides of each data tree were added to give the estimated floral intensity per tree, reported on a scale from 0 to 6, with 0 equaling no inflorescences and 6 equaling maximum flowering. At standard harvest in September, total yield (kg $tree^{-1}$) was determined for years 1-5. In addition, a sample of 50 fruit was randomly collected at a height of 1.2 m above the ground around each data tree one day before harvest. Each fruit in the 50-fruit sample was weighed and, on the basis of weight, each fruit was assigned to one of nine US. Standard and marketing order fruit size categories. Based on weight, the proportion of fruit in each size category was used to calculate fruit size distribution as kg $tree^{-1}$ for years 2 through 5. For each 2-year ON/OFF cycle, ABI was calculated for total yield and yield of M+L size fruit: ABI = (year 1 yield – year 2 yield)/(year 1 yield + year 2 yield), in which yield is kg of fruit $tree^{-1}$ and the difference in yield between years 1 and 2 is expressed as an absolute value. An ABI of zero means no AB, whereas an ABI of one is complete AB, i.e., crop one year, no crop the other year (Pearce and Dobersek-Urbanc, 1967).

Statistical analysis

Analysis of variance (ANOVA) was used to test for treatment effects on estimated floral intensity at bloom, fruit size distribution, and total yield, using the general linear model procedure of SAS (version 9.3; SAS Institute, Cary, NC). When ANOVA output indicated significant differences, post-hoc comparisons were run using Fisher's least significant difference (LSD) test with a family error rate of $\alpha \leq 0.05$. Pearson's product moment correlation coefficients were calculated to identify significant relationships ($r > 0.5$, $P \leq 0.05$) among estimated floral intensity, total yield and yield of CVS fruit, respectively.

RESULTS

Effects of ON/OFF tree status and crop reduction treatments on annual total yield

ON-crop control trees (104 kg $tree^{-1}$) selected in year 1 exhibited a classic AB pattern, with ON-crops in years 1, 3 and 5 and OFF-crops in years 2 and 4. The OFF-crop total yields (kg $tree^{-1}$) in years 2 and 4 following the ON-crops in years 1 and 3 were 74 and 95% lower than the ON-crop yields, respectively (Table 1). Conversely, the ON-crop total yields in years 3 and 5 were 6.8- and 10.5-fold greater than the OFF-crop yields in years 2 and 4, respectively. In contrast, the OFF-crop control trees (25 kg tree^{-1}) selected in year 1 were irregular bearing, rather than alternate bearing, having two successive ON crops (years 2 and 3) followed by two OFF crops (years 4 and 5), in which total annual yield decreased 41% from year 3 to 4 and 39% from year 4 to 5 (Table 1). Treating ON-crop trees with NAA or pruning in year 1 reduced total yield by 33% compared to the ON-crop control trees ($P \leq 0.01$). Continuing treatments annually resulted in total annual yields equal to the low (OFF) yields of the ON-crop control trees in years 2 and 4 and intermediate to the ON- and OFF-crop control trees in year 3 (Table 1). For trees treated biennially, treating ON-crop trees with NAA or pruning starting in year 2 resulted in total yields 31 and 17% lower than the high ON yields of OFF-crop control trees but 3.0- and 3.7-fold greater than the ON-crop control trees, respectively. Additionally, application of NAA or pruning to ON-crop trees in year 2 produced total yields 52% greater than trees receiving these treatments annually. Continuing to treat trees with NAA or pruning biennially resulted in total annual yields equal to the OFF-crop control trees in year 3. In year 4, trees pruned biennially had total annual yields equal to the greater yield of the OFF-crop control trees with both having greater yields (≥50%) than trees in all other treatments ($P \leq 0.01$) (Table 1).

Table 1. Effects of naphthaleneacetic acid (NAA) foliar spray at full bloom and pruning 28 days after full bloom applied to one side of ON-crop 'Manzanillo' olive trees and then the other side annually or biennially on annual total yield.

Tree status and treatments	Year 1	Year 2	Year 3	Year 4	Year 5
	(kg tree^{-1})				
ON control	104 A[a]	27 C	211 A	10 B	115 A
OFF control	-	122 A	135 D	79 A	48 C
Annual[b]					
NAA	71 B	40 C	180 B	24 B	-
Pruning	69 B	48 C	161 BC	20 B	-
Biennial[c]					
NAA	-	84 B	156 BCD	29 B	70 B
Pruning	-	101 AB	142 CD	60 A	49 C

[a]Means in a vertical column followed by different uppercase letters are significantly different at $P \leq 0.01$ by Fisher's LSD test.
[b]Treatments were initiated in year 1 with ON-crop trees and applied again in years 2-4.
[c]Treatments were initiated in year 2 with ON-crop trees and applied again in year 4.

Effects of ON/OFF tree status and crop reduction treatments on yield of M+L size fruit

The AB ON-crop control trees had yields that were too low in OFF-crop years 2 and 4 and too high in ON-crop year 3 (Table 1) to produce high yields of M+L size fruit (Table 2). In contrast, the total annual yields of the irregular bearing OFF-crop control trees resulted in consistently higher yields of M+L size fruit than the ON-crop control trees (Table 2), except in year 5. Treating the trees with NAA or pruning annually resulted in lower yields of M+L size fruit that were equal to the ON-crop control trees and significantly less than the OFF-crop control trees, with the single exception of the use of NAA in Year 3, which produced yields of M+L size fruit equal to the higher yields of the OFF-crop control trees. In comparison, treating trees biennially with NAA or pruning resulted in yields of M+L size fruit that were equal to the higher yields of the OFF-crop control trees in years 2, 3 and 4 and the ON-Crop control trees in year 5. However, the yields of M+L size fruit for trees treated with NAA biennially were also not significantly different from the low yield of M+L size fruit of the ON-crop control trees in years 3 and 4. Trees pruned biennially tended to have greater yields of M+L size fruit (44, 48 and 46%) across years 2 through 4, respectively, than trees pruned annually (Table 2).

Table 2. Effects of naphthaleneacetic acid (NAA) foliar spray at full bloom and pruning 28 days after full bloom applied to one side of ON-crop 'Manzanillo' olive trees and then the other side annually or biennially on annual yield of commercially valuable medium plus large size fruit (M+L, 3.5-4.9 g $fruit^{-1}$).

Tree status and treatments	Year 2	Year 3	Year 4	Year 5
	(kg $tree^{-1}$)			
ON control	17 B[a]	19 c	7 c	48 a
OFF control	37 A	48 a	34 a	34 b
Annual[b]				
NAA	26 B	55 a	16 bc	-
Pruning	25 B	23 bc	16 bc	-
Biennial[c]				
NAA	40 A	36 abc	18 abc	42 a
Pruning	44 A	44 ab	29 ab	34 a

[a]Means in a vertical column followed by different uppercase or lowercase letters are significantly different at $P\leq0.01$ or $P\leq0.05$, respectively, by Fisher's LSD test.

[b]Treatments were initiated in year 1 with ON-crop trees and applied again in years 2-4.

[c]Treatments were initiated in year 2 with ON-crop trees and applied again in year 4.

Effects of ON/OFF tree status and crop reduction treatments on cumulative yields and alternate bearing index

There were no significant differences in 4-year cumulative total yields between the ON- and OFF-crop control trees at the end of years 1 to 4 or years 2 to 5, respectively (Table 3). Additionally, treating trees with NAA or pruning annually or biennially had no significant effect on 4-year cumulative total yields relative to the ON- and OFF-crop control trees. Major effects of the treatments on annual total yields were reflected in the significant differences in ABI averaged across each 2-year ON-/OFF-crop cycle during the 4 years of treatment (Table 3). The ABI for total yield for the alternate bearing ON-crop control trees was 0.85 for years 1 through 4 and 0.94 for years 2 through 5. Note that an ABI of 1.0 is complete AB with crop one year, no crop the other. In contrast, the irregular-bearing OFF-crop control trees had the lowest ABI for total yield, 0.35 for years 1 through 4 and 0.32 for years 2 through 5. Treating one side of the tree and then the other side with NAA or pruning annually resulted in an ABI equal to that of the ON-crop control trees and significantly greater than that of the OFF-crop control trees (Table 3). In contrast, treating trees biennially with NAA reduced the ABI for total yield to a value intermediate to the ON- and OFF-crop controls trees. Pruning biennially reduced ABI to a value significantly lower than the ON-crop control trees and equal to that of the OFF-crop control trees (Table 3). A lower ABI indicates that annual total yields were more uniform across years and that the severity of AB was reduced.

Cumulative yields of CVS M+L size fruit were significantly different between the ON- and OFF-crop control trees (Table 3). The AB ON-crop control trees had the lowest 3-year cumulative yield for Years 2 to 4 of CVS fruit (43 kg $tree^{-1}$), and the irregular bearing OFF-crop control trees had the greatest (119 kg $tree^{-1}$). For the same 3 years between years 2 through 4, annually treating trees with NAA or pruning resulted in 3-year cumulative yields of M+L size fruit intermediate to the ON- and OFF-crop control trees, whereas, treating trees biennially with NAA or pruning resulted in 3-year cumulative yields of M+L size fruit that were not significantly different from the higher yields of the OFF-crop control trees and significantly greater than those of the ON-crop control trees (Table 3). During this 3-year period, the cumulative yield of M+L size fruit was greater for trees treated biennially with NAA (20%) or pruned (40%) than trees treated with NAA or pruned annually, respectively. For the 4-years between years 2 through 5, cumulative yields of M+L size fruit were greater for the OFF-crop control trees than ON-crop control trees. Yields of M+L size fruit for trees treated biennially with NAA or pruned during this 4-year period were equal to the greater yield of the OFF-crop control trees (Table 3).

Table 3. Effects of naphthaleneacetic acid (NAA) foliar spray at full bloom and pruning 28 days after full bloom applied to one side of ON-crop 'Manzanillo' olive trees and then the other side annually or biennially on 4-year cumulative total yields and alternate bearing index (ABI) averaged across the 4 years of the study and 3-year cumulative yields of commercially valuable medium plus large size fruit (M+L, 3.6-4.9 g fruit^{-1}) and ABI averaged across 3 years of the study.

Tree status and treatments	Cumulative yield and average alternate bearing index (ABI) for the years specified							
	Years 1-4		Years 2-5		Years 2-4		Years 2-5	
	Total yield (kg tree^{-1})	ABI	Total yield (kg tree^{-1})	ABI	Yield M + L (kg tree^{-1})	ABI	Yield M + L (kg tree^{-1})	ABI
ON control	380 a[a]	0.85 a	363 a	0.94 A	43 C	0.80 A	91 B	0.80 A
OFF control	352 a	0.35 b	384 a	0.35 C	119 A	0.23 C	152 A	0.32 C
Annual[b]								
NAA	314 a	0.75 a	-	-	81 B	0.70 A	-	-
Pruning	298 a	0.72 a	-	-	68 BC	0.61 AB	-	-
Biennial[c]								
NAA	-	-	347 a	0.58 B	102 A	0.46 BC	144 A	0.56 ABC
Pruning	-	-	349 a	0.47 BC	116 A	0.37 C	156 A	0.48 ABC

[a]Means in a vertical column followed by different uppercase or lowercase letters are significantly different at $P\leq0.01$ or $P\leq0.05$, respectively, by Fisher's LSD test.

[b]Treatments were initiated in year 1 with ON-crop trees and applied again in years 2-4.

[c]Treatments were initiated in year 2 with ON-crop trees and applied again in year 4.

The ABI for yield of M+L size fruit for the 3-year period between years 2 through 4 was highest (0.85) for the ON-crop control trees, whereas the OFF-crop control trees had a low ABI (0.23) (Table 3). For trees treated with NAA or pruned annually, the ABI for years 2 through 4 for M+L size fruit was statistically equal to the high ABI of the ON-crop control trees, whereas the ABI for years 2 through 4 for the yield of M+L size fruit for trees treated with NAA or pruned biennially was low and equal to that of the OFF-crop control trees. This result is significant. The lower average ABI for trees treated with NAA or pruned biennially compared to trees treated annually means that annual yield of M+L size fruit was less variable from year to year, which stabilized grower income.

Relationship between total yield and yield of M+L size fruit

In order to maximize yield of CVS fruit while reducing ABI, the relationship between total yield and yield of M+L size fruit was quantified to determine at what total yield (kg tree^{-1}), the greatest yield of M+L size fruit (kg tree^{-1}) was obtained (Table 4). Median yield for the data set comprised of more than 500 tree-years for this orchard was 110 kg tree^{-1}, indicating 50% of the trees produced more than 110 kg tree^{-1} and 50% produced less. At 110 kg tree^{-1}, yield of M+L size fruit averaged 55 kg tree^{-1} (Table 4). More than 20% of the trees produced less than 20 kg tree^{-1} due to AB. This interpretation is based on the fact that yields for the preceding and following years were ON-crops rather than consecutive low yields typical of unhealthy poor-yielding trees. These trees produced ≤5.6 kg tree^{-1} of M+L size fruit (Table 4). Total yields from >50 to 60 kg tree^{-1} were characterized by an average of 18 kg tree^{-1} M+L size fruit (32% of total yield) with a greater proportion (56%) of harvested fruit extra-large and > extra-large (>4.9 g fruit^{-1}) and only 12% ≤ small fruit (<3.5 g fruit^{-1}) (Table 4). At total yields >100 to 120 kg tree^{-1}, yields of M+L size fruit were the majority of fruit tree^{-1} (approximately 50%). As total yield increased, the yield of medium size fruit continued to increase with the yield of large size fruit unchanged up to 120 kg tree^{-1}. Thus, at total yields >130 to 140 kg tree^{-1}, yield of M+L size fruit increased to 60.3 kg tree^{-1} but decreased to 45% of the total yield due to the increase in the yield of ≤ small fruit (<3.5 g fruit^{-1}) to 63.6 kg tree^{-1} (47% of the total yield). In contrast, for trees producing total yields >170 to 180 kg tree^{-1}, yield of M+L size fruit decreased to 53 kg tree^{-1}, only 30% of total yield, whereas yield of ≤ small fruit increased to 118 kg tree^{-1} (68% of total yield) (Table 4). The data document that increases in total yield beyond 130 kg tree^{-1} resulted in increased yields of fruit ≤ small (<3.5 g fruit^{-1}) of limited commercial value (Table 4). In addition, trees yielding >130 kg tree^{-1}

produced lower yields the following year. For example, in a separate experiment, trees yielding 149 to 155 kg tree^{-1} produced 74 to 81 kg tree^{-1} M+L size fruit, but the following year yielded less than 45 kg tree^{-1} and only 13 kg tree^{-1} M+L size fruit. Taken together, the results suggested that total yields between 100 to 120 kg tree^{-1} maximized the yield of CVS M+L fruit with less risk of AB than trees producing more than 120 kg tree^{-1}. Thus, yields have to be sufficiently high to provide a good yield of M+L size fruit, but not so high that fruit size is reduced and the risk of AB is increased (Table 4).

Table 4. Relationship between total yield (kg tree^{-1}) and yield by fruit size category (as kg tree^{-1} and percent (%) total yield) for 'Manzanillo' olive trees.

Total yield (kg tree^{-1})	Yield by fruit size category[a]					
	≤Small (<3.5 g fruit^{-1})		M+L (3.5-4.9 g fruit^{-1})		≥Extra large (>4.9 g fruit^{-1})	
	kg tree^{-1}	%	kg tree^{-1}	%	kg tree^{-1}	%
0-20	<1	<2	<6	<39	<8	<16
>50-60	7	12	18	32	32	56
>90-100	30	31	43	46	22	23
>100-110	33	32	54	52	17	17
>110-120	38	33	56	48	21	19
>120-130	53	43	55	44	16	12
>130-140	64	47	60	45	12	8
>170-180	118	68	53	30	4	2

[a]For each fruit size category, yield as kg tree^{-1} and percent total yield are the average values for trees within specific total yield ranges in the 400 tree-year data set derived from this research for years 2-5.

Relationship between estimated floral intensity, total yield, and yield of M+L size fruit

There was a strong positive relationship between estimated floral intensity at full bloom and total yield at harvest in September (r=0.79, P<0.0001). The estimated floral intensity for the ON-crop control trees was only 1.1 in the OFF-crop year (year 2), increased to 5.4 in Year 3, an ON-crop year, dropped to 1.5 in the subsequent OFF-crop year (year 4), and increased again to 5.8 in year 5, the final ON-crop year (Table 1). In addition, estimated floral intensity at FB, before any treatments were applied, reflected the effects of the previous year's treatments and were useful for interpreting in hindsight whether or not a crop reduction treatment should have been applied. For example, comparison of the year 2 bloom estimates for trees treated with NAA or pruning annually were low, 2.0 and 1.5, respectively, compared to trees treated biennially, which had bloom estimates of 4.5 and 5.2, respectively. Despite the low bloom estimates, the trees treated annually were treated with NAA and pruned in year 2, resulting in 50% lower total yields and an average 40% decrease in yield of M+L size fruit for both treatments compared to trees treated biennially, which were also treated in year 2 (Tables 1 and 2). Additionally, in Year 3, ON-crop control trees had an estimated bloom of 5.4, whereas the OFF-crop control trees had an estimated bloom of 3.1. At harvest, the total yield of the ON-crop control trees was 50% greater than the OFF-crop control trees, but the OFF-crop control trees yielded 60% more M+L size fruit. The relationship between total yield and yield of M+L size fruit was not linear at higher yields, making the relationship between estimated floral intensity and yield of M+L size fruit less strong (r=0.60, P<0.0001). A plot of average total yield and the corresponding yield of M+L size 'Manzanillo' olive fruit as a function of estimated floral intensity for years 3 through 5 illustrates this point (Figure 1). In Figure 1, it is clear that bloom estimates of 1.5 and 2.0 resulted in total yields that were too low to result in good yields of CVS fruit, whereas an estimated floral intensity greater than 5.0 resulted in total yields that were too high to produce good yields of M+L size fruit. Bloom estimates of 4.5±0.25 were associated with maximum yields of M+L size fruit. The corresponding total yields ranged from >120 to 130 kg tree^{-1} (see Table 4 for yield by fruit size category). The results suggest that trees with an estimated floral intensity below this range should not be treated with a crop reduction strategy, whereas those with bloom estimates above this range would be treated with NAA or pruned on one side of the tree.

Future research will test the utility of this model as a tool to sustain high yields of M+L size fruit with a low ABI across orchards.

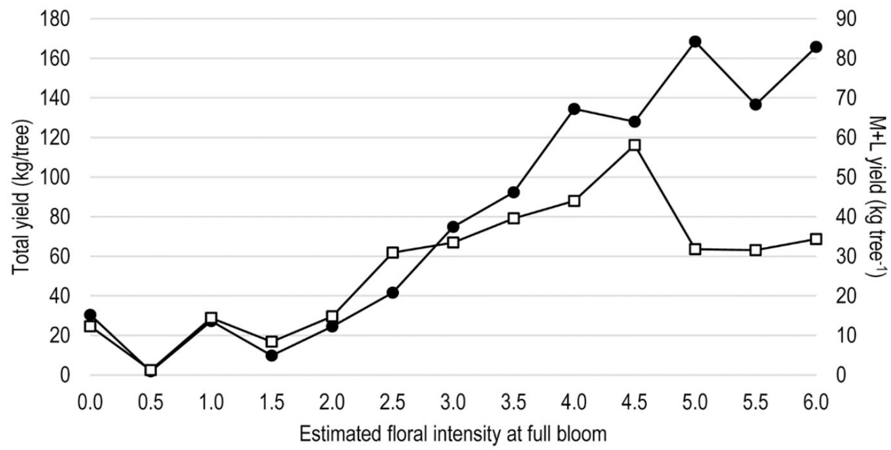

Figure 1. Relationship between total yield (•), yield of commercially valuable medium plus large size fruit (M+L; 3.5-4.9 g fruit^{-1}) (□), and the estimated floral intensity of 'Manzanillo' olive trees.

DISCUSSION

The results of the research presented herein provided evidence that reducing crop load with NAA foliar spray at FB to reduce floral intensity per tree or pruning 28 DAFB to reduce fruit number per tree applied to one side of the tree starting in the ON-crop year and then to the other side of the tree biennially is more effective in mitigating AB than applying these same treatments annually. There were no statistically significant differences in 4-year cumulative total yields among treatments, including the alternate bearing ON- and irregular bearing OFF-crop control trees. However, the severity of AB based on ABI was significantly reduced when these treatments were applied biennially, but not when they were applied annually. Having more uniform annual total yields improves the economics of all steps in the supply chain from farm to consumer. In addition, application of NAA or pruning to one side of the tree and then the other side biennially reduced the ABI for the yield of CVS M+L size fruit in years 2 through 4 to the low value of the OFF-crop control trees, whereas the ABI for yield of M+L size fruit for trees treated annually over this same period was equal to the high ABI of the ON-crop control trees. The lower ABI for the yield of M+L size fruit provides growers with more uniform yields and hence, more reliable annual revenues. For this same period, 3-year cumulative yields of CVS M+L size fruit were greater (20 and 40%) for trees treated with NAA or pruned, respectively, on one side of the tree and then the other biennially compared to trees receiving these same treatments annually. The results of this research taken together with the fact that the cost of applying the NAA or pruning treatments is reduced by half when used biennially compared to annually make implementation of crop reduction strategies using NAA or pruning in the ON-crop year and repeating them biennially the more economically practical approach to mitigating AB in 'Manzanillo' olive.

Foliar-application of NAA at FB to only one side of the tree significantly reduces the potential for over-thinning associated with the use of whole tree sprays of NAA to reduce fruit number later in spring when temperatures can spike (Krueger et al., 2014). Moreover, it is relatively easy to visually identify a heavy ON bloom versus a moderate bloom to decide whether to treat or not. The major problem with the use of NAA at FB is the inability to predict the effect of subsequent adverse climate events on fruit set on the untreated side of the tree, which could result in low yields on both sides of the tree. In this regard, pruning 28 DAFB provides a window of time sufficient to evaluate final fruit set and decide to treat one side of the tree or not. In addition, this timing for pruning in an ON-crop year is optimal for increasing fruit size and stimulating summer vegetative shoot growth necessary for a good return bloom without creating competition between fruit and shoot growth that occurs when pruning is performed later in the summer. Pruning is essential for tree fruit production. Pruning one side of the tree to mitigate the negative effects of a heavy ON crop when AB is initiated and continuing the treatment biennially to maintain uniform annual total yields that maximize yields of M+L size fruit can be integrated with standard pruning practices essential for keeping rows open for orchard management, controlling tree height to facilitate harvest, raising tree skirts to allow cold air to drain through the orchard and prevent sprinklers from wetting low hanging fruit, and opening the canopy for better light penetration – no light, no flowers, no fruit (Kour et el., 2018).

Maintaining annual total yields that maximize yields of CVS 'Manzanillo' olive fruit requires knowledge of the relationship between total yield and fruit size. The results of this research provided preliminary evidence suggesting that total yields between 100 to 120 kg tree^{-1} maximize the yield of CVS fruit with a lower risk of perpetuating AB compared to total annual yields >120 to 140 kg tree^{-1}, which result in greater yields of M+L size fruit, with greater yields of small size fruit and a higher ABI. The relationship between total yield and yield of M+L size fruit was expanded to include estimated floral intensity. The preliminary results of this research suggest that an estimated floral intensity of 4.5±0.25 was related to 50 to 60 kg tree^{-1} M+L size fruit (total yields >120 to 130 kg tree^{-1}). Trees with floral intensity estimates below this range would not be treated with a crop reduction strategy; those with bloom estimates above this range would be treated. The results of the preliminary investigation into the relationships among total yield, yield of M+L size fruit and estimated floral intensity are reported here for their heuristic value. Additional research is required to develop the utility of these relationships for mitigating AB and managing olive production to maximize yield of CVS fruit. Additional research is being conducted to confirm the greater efficacy of NAA sprays and pruning applied biennially versus annually and using estimated bloom to decide when treatments should be used to mitigate AB or ceased to maintain maximum yields of CVS fruit.

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