Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees

Article *in* Crop and Pasture Science · January 2009

DOI: 10.1071/CP09090

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CSIRO PUBLISHING
www.publish.csiro.au/journals/cp *Crop & Pasture Science*, 2009, **60**, 1124–1130

Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees

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Abstract. Biennial bearing is a major horticultural and economic drawback of olive (*Olea europaea* L.) cultivation, which particularly affects the olive oil industry under intensive production systems. The number of fruits per tree in an on-year is a primary determinant of the biennial cycle. While fruit thinning using NAA shortly after full bloom is commonly practiced to increase fruit size in table olives, the extent of its influence on biennial bearing is unknown. In the present study, the ability of that common naphthaleneacetic acid (NAA) treatment (100 mg/L, 10 days after full bloom) to alleviate biennial bearing in two oil olive cultivars, Picual and Barnea, was poor, although significant influence on the number of fruit was evident solely in Barnea. Picual seemed less susceptible than Barnea to biennial bearing. Consequently, the effect of a broad range of NAA concentrations (0–320 mg/L, 10 days after full bloom) on various yield parameters was investigated during a biennial cycle of Barnea trees. There was a gradual proportional decline in the on-year number of fruits from ~50 000 to 10 000/tree in response to increasing NAA concentrations. The number of return fruits in the off-year was reciprocal to the on-year fruit load, but remained relatively small, below 15 000/tree. The dynamic relationship between fruit load and fruit size in both on- and off-years was a significant compensation factor in fruit and oil yields. In both cultivars, an on-year fruit load smaller than 20 000/tree is likely to provide consistent yearly oil yields ranging from 10 to 12 kg/tree. The results demonstrate the possibility of using NAA post-bloom spraying to balance biennial bearing in oil olives.

Additional keywords: alternate bearing, fruit load, fruit size, NAA (naphthalenacetic acid), oil content, *Olea europaea*.

Introduction

Biennial or alternate bearing is a widespread phenomenon in many fruit tree species, which brings about severe instability in management inputs (e.g. labour) and marketing. Although the metabolic processes, their induction, and the signals involved are only partially understood, they clearly differ among various fruit tree species (Goldschmidt 2005). Different horticultural practices are used to minimise alternate bearing in many species, but in most cases, they are only partially effective (Monselise and Goldschmidt 1982).

Olive (*Olea europaea*) has a very high tendency of alternate fruit production. Being an industry-dependent commodity, the economic problems arising from biennial bearing are especially serious in the production of olive oil, where the consequences of unstable yields on labour distribution, oil-mill capacity, storage requirements, and produce quality are dramatic. For instance, an intensively cultivated, fully alternate-bearing oil olive grove (cv. Barnea) may fluctuate between 22 and 3 t fruit or between 4.4 and 0.6 t oil/ha in successive on- and off-years, respectively (Lavee 2006).

While environmental factors, such as temperature or water and nutrient availability, directly affect vegetative growth and the performance of most reproductive processes (induction, evocation, differentiation, bloom, fruit set, and fruit growth and ripening), endogenous determinants, namely the balances of carbohydrate, mineral nutrients, and hormones, are significantly involved in biennial bearing (Monselise and Goldschmidt 1982; Troncoso *et al*. 2010). Lavee (2006) has recently suggested a general scheme of alternate bearing in olive, taking into account the above endogenous processes and their interactions with environmental factors (e.g. temperature) during subsequent on- and off-years. According to this scheme, fruit production in olive is mainly dependent on the vegetative growth of the previous growing season. On the other hand, the degree of vegetative growth in any particular season is a function of the amount of fruit present on the tree during that season. Thus, the balance between the amount of developing fruit and vegetative growth in any given growing season will affect and control the potential fruit production for the following season.

Physiologically, biennial bearing in olive is thought to be due to the inhibition of floral bud induction and differentiation by growth substances that are produced and excreted by the developing seeds (Lavee 1989, 2006; Baktir *et al*. 2004). In addition, the metabolic effort required by a heavily yielding tree

10.1071/CP09090 1836-0947/09/121124

that is furnishing oil production during the late season might come at the expense of resources available for the subsequent reproductive process (Monselise and Goldschmidt 1982; Cuevas *et al*. 1994; Troncoso *et al*. 2010).

Attempts to interrupt the reproductive cycle of olive trees at early stages of floral development (Lavee 1989; Fernandez-Escobar *et al*. 1992) or during bloom (Lavee *et al*. 1999) have been either too risky or inefficient in lessening alternate bearing. On the other hand, chemical fruit thinning, which was first examined decades ago (Hartmann 1952; Lavee and Spiegel 1958; Lavee and Spiegel-Roy 1967), is quite commonly practiced, mainly to obtain large fruits in table olives (Martin *et al*. 1980; Krueger *et al*. 2004). The fruit thinning is generally carried out by post-bloom application of naphthalenacetic acid (NAA), which is absorbed by the leaves and fruit and translocated to the fruit pedicels and young developing embryos. Within 2 weeks of application, an abscission zone is formed, causing some fruit to drop (Krueger *et al*. 2004). The common practice in table olives is to apply 100 mg/L of NAA 10 days after full bloom, and to add 10 mg/L per day until 20 days after full bloom (Lavee and Spiegel 1958; Lavee and Spiegel-Roy 1967; Krueger *et al*. 2004).

Despite the long-established use of chemical thinning in table olives, there is little information on the potential use of NAA to reduce biennial bearing, with respect to oil olive cultivars. Solving the problem is of particular importance for the olive oil sector, occupying a 10-fold larger area than that of table olives, to guarantee an uninterrupted yearly supply of raw material for the oil industry. The objectives of the present study were therefore: (*a*) to test the ability of the common NAA fruit-thinning practice in table olives to reduce alternate bearing in oil olive cultivars (Picual and Barnea); (*b*) to examine the effects of NAA application in a broad range of concentrations on parameters of fruit and oil yield in oil olives in the year of application and in the following year, and (*c*) to identify an NAA treatment that would significantly reduce the tendency of Barnea to develop alternate bearing under heavily producing, intensive growing conditions.

Materials and methods

Two experiments were conducted between 2004 and 2007. The first tested the effect of the table olive-thinning methodology on the oil-olive cvv. Picual and Barnea, while the second focussed on examining the effects of a much broader range of NAA concentrations on the yield parameters of cv. Barnea.

Experimental site

The experiments were conducted in large commercial olive orchards located in an arid area near Kibbutz Revivim (34°87′N; 15°07′E; ~300 m a.s.l.) in the Negev highland desert of Israel. The yearly mean precipitation is <100 mm between November and February and it is unpredictable. The orchards are drip-irrigated throughout the year to reach a total of 900 mm. A detailed description of the environmental conditions and the practices used in these orchards is provided by Dag *et al*. (2008). Fertilisers are supplied continuously through the irrigation water at 200, 30, and 300 kg/ha.year of N,P, and K, respectively.

The first experiment was conducted in an orchard of Picual and Barnea, planted in 1995 at spacings of 7 by 3.5 m (407 trees/ha, Picual) and 7 by 5 m (286 trees/ha, Barnea), in which a uniform plot (~1 ha) of each variety was selected. According to yield data collected before the experiment, the first experimental year (2004) was expected to be an on-year.

The orchard for the second experiment, based mostly on cv. Barnea trees, was planted in 2000 at 7 by 4 m spacing. The selected plot (2 ha) was characterised by strong fluctuations in yield: in 2004, the average fruit yield was 22.8 t/ha, whereas in 2005, the plot was not harvested due to an absolute off-year. Therefore, the following year (2006) was expected to be a highly productive on-year.

NAA application

In all experiments, NAA was applied 10 days after full bloom during the afternoon, using Alphatop (Milchan Bros., Ltd, Israel) 20% (w/v) NAA, at a spray volume of 4 L/tree. The adjuvant BB5 (alkyl phenoxy polyetheylene ethanol, produced by C.T.Z. Israel) was added at 0.45 mL/L. In the first experiment, NAA was applied at 100 and 120 mg/L on 29 April 2004, and again to the same trees on 30 April (Barnea) and 8 May (Picual) 2006. In the second experiment, NAA was applied on 30 April 2006, at concentrations of 0, 40, 80, 120, 160, 240, and 320 mg/L.

Measurements

The fruit was harvested in the autumn, each treatment in accordance with the appropriate average maturity level (3–4), determined according to the international standard index for olive ripeness (IOOC 1984). All trees of each treatment were harvested on one day. All fruits were harvested from individual trees onto nets using mechanical combs, gathered, and weighed. A sample of 100 fruits was taken from each tree for a determination of average fruit weight, and to calculate the number of fruits per tree. The oil content of the fruit was determined by chemical extraction according to Avidan *et al*. (1999).

Experimental design and statistical analyses

The experimental design was random blocks, one row each block, with untreated neighbouring rows as a buffer. In each block (4 in the first experiment and 6 in the second), uniform trees were labelled (with at least 2 untreated buffer trees between them) and were assigned randomly to the treatments. In the first experiment, each block included 4 measured trees per treatment (16 trees in total), and in the second, 1 tree per treatment (6 trees in total). Data were analysed by 1-way ANOVA using JMP 5.0.1 software (SAS Institute, Cary, NC, USA). Differences between treatments were determined by Tukey-Kramer HSD test. Statistical analyses were conducted mostly at a significance level of $P < 0.05$.

Results

Experiment 1

In the first set of experiments, NAA application at a concentration similar to or slightly higher than that practiced with table olives did not result in any significant reduction in the on-year yield (2004) of either Picual (Table 1) or Barnea (data not shown). Nevertheless, in the subsequent off-year (2005), the Picual trees responded to the NAA treatment of the previous year by an almost

Table 1. Effect of 100 or 120 mg/L of NAA applied 10 days after full bloom in the spring of the expected on-year (2004) on the fruit yield of oil olive cv. Picual in that same year and in the following off-year

Values are means of 4 replicates ± s.e.

NAA application	Fruit yield (kg/tree) 2004	2005
Control	67.9 ± 1.5	11.9 ± 3.6
100 mg/L	64.3 ± 3.6	19.3 ± 2.8
120 mg/L	57.3 ± 2.5	22.7 ± 6.6
P-value	0.1028	0.2942

2-fold increase in fruit yield compared to the control trees. Barnea, on the other hand, produced extremely low yields in the off-year (2005), although a slight increase was nevertheless observed in the NAA-treated trees (data not shown).

In the second stage of this experiment (second treatment of the same trees), cv. Picual displayed no apparent trend towards biennial bearing. Fruit yield as well as oil yield were quite similar in both years, and were not significantly affected by the NAA treatments (Table 2). The number of fruits, however, did exhibit indications of biennial bearing, but the reduction in fruit number was almost completely compensated for by an increase in fruit size. This phenomenon also occurred in NAA-treated trees in the on-year. Barnea, in contrast, demonstrated unambiguous biennial responses of all yield parameters. NAA applications significantly reduced the number of fruit in the concurrent on-year (by ~26%), and doubled the number of fruit in the subsequent off-year, compared with control trees. Similar to Picual, the increase in fruit size in NAA-treated trees in the on-year compensated for the reduction in fruit number, so that fruit and oil yields did not differ significantly from the controls. On the other hand, in the off-year, the generally larger (2-fold) fruit size turned a small absolute increase in fruit number into a notable relative rise in fruit and oil yield, compared with the on-year (Table 2); the relative oil yield increased from ~0.5 in 2006, to ~1 g/fruit in 2007.

Experiment 2

The broad NAA concentration range tested in the second experiment in Barnea trees did not have noticeable effects on the current vegetative growth up to 240 mg/L (data not shown). Nonetheless, at the highest NAA concentration (320 mg/L), the on-year spring vegetative growth was slightly impaired, leading to some loss of apical dominance, which resulted in auxiliary sprouting a few weeks later. On the other hand, the wide NAA concentration range had an obvious effect on reproductive processes: due to the different numbers of fruit in accordance with the severity of the treatments, the time of harvest differed considerably. In the on-year (2006), the fruit harvest period lasted 10 weeks, starting on 25 October in the trees that had received the highest NAA concentration (320 mg/L), through 22 November (240 and 160 mg/L), 19 December (80 and 120 mg/L), and ending on 4 January 2007 with the control trees and trees treated with 40 mg/L NAA. In the subsequent off-year, however, all trees were harvested earlier, and fruit harvest lasted only 2 weeks (23 Oct.–5 Nov. 2007).

The most pronounced effect of NAA was on fruit load in the on-year (2006): the reduction in fruit number was significant and proportional to NAA concentration (Fig. 1). Thus, the number of harvested fruits per tree declined from an average of 40 000 in untreated trees to less than 15000 in trees treated with 320 mg/L NAA. On the other hand, the number of fruits harvested in the following off-year (2007) was fairly small in all treatments, only partially compensating for the decrease in fruit number induced by the NAA treatments in the previous on-year. While the control trees carried ~2000 fruits per tree in the off-year, trees that were treated with 240 mg/L NAA had 6600 fruits, and those treated with the highest NAA concentration, 320 mg/L, diverged slightly, producing more than 10 000 fruits per tree in the off-year. Consequently, the calculated average biennial (2006–07) number of fruits per tree steadily declined from 20 500 for fully alternate-bearing control trees to 12 000 per tree for the highest NAA concentration.

The decline in fruit numbers in the above experiment was compensated for by a significant increase in fruit size in the on-year. In the range 10 000–50 000 fruits/individual tree, a negative logarithmic relationship was evident between fruit size and fruit number (Fig. 2). In the off-year (2007), however, the fruit size was unaffected by the number of fruits per tree, even when the latter increased from 2000 to 7000. The fruit weight was somewhat reduced in that year only when the fruit number exceeded 10 000

Table 2. Effect of NAA application 10 days after full bloom in the spring of the expected on-year (2006) on yield parameters of 2 oil olive cultivars, Picual and Barnea, in the same year and in the following off-year

Values are means of 4 replicates. Within a column, values followed by the same letter are not significantly different by Tukey's HSD

NAA application	Fruit no./tree (×1000) 2006	2007	Fruit size (g) 2006	2007	Fruit yield (kg/tree) 2006	2007	Oil yield (kg/tree) 2006	2007
				Picual				
Control	20.7a	9.7	3.6c	6.8	70.2	59.3	13.1	9.8
100 mg/L	15.7b	8.8	4.2b	6.5	64.0	53.2	12.0	9.3
120 mg/L	12.9c	10.9	4.7a	6.0	58.1	61.8	10.6	10.7
P-value	0.019	0.071	0.038	0.066	0.068	0.113	0.062	0.093
				Barnea				
Control	40.1a	2.6c	2.3b	5.5	87.4	14.0b	19.0	2.5b
100 mg/L	28.5b	5.6b	3.0a	5.4	83.0	28.9a	17.3	5.2a
120 mg/L	29.5b	5.2a	2.9a	5.9	85.2	29.4a	18.2	5.2a
P-value	0.008	0.007	0.041	0.085	0.153	0.009	0.078	0.007

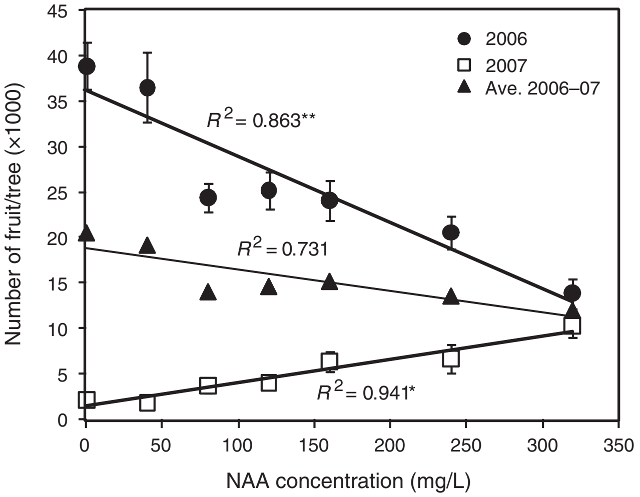

Fig. 1. Effect of NAA application 10 days after full bloom in an on-year (2006) on the number of fruits on oil olive cv. Barnea trees in the same year and in the following off-year (2007), and on the 2-year average. Values are means of 6 replicates ± s.e.; *, **, significance of R^2 at $P < 0.05$, $P < 0.01$, respectively.

per tree (Fig. 2). Interestingly, the pit fresh weight was stable in 2006 at 0.55 g, regardless the effects of the NAA treatments on the fruit size. Thus, the pulp/pit ratio increased in 2006 from 2.6 to 6.7 in accordance with the increase in fruit size and the decline in fruit load from 50 000 to 10 000 fruit/tree. In the subsequent year, pit fresh weight was higher, at the stable level of 0.81 g. The pulp/pit ratio was 5.25 throughout NAA treatments.

The 'trade-off' between fruit load and fruit size had a significant effect on fruit yield. Any level of reduction in fruit number (% thinning) was accompanied by a much smaller reduction in relative fruit yield. Even at the heaviest fruit thinning—38% of the control fruit, a substantial relative fruit yield was obtained—62% of the on-year control. A similar analysis showed that the corresponding off-year yields harmonised with those of the on-year. Thus, fruit thinning to the range of 35–65% of fruit number in an on-year appeared to slightly increase the average biennial yield (Table 3). Nevertheless, in practice, NAA applications, excluding the highest level tested, failed to break the alternate-bearing character of the trees used in this experiment. Only the most extreme NAA treatment was successful, bringing both on- and off-year yields close enough to the quite stable average biennial fruit yield (Table 3).

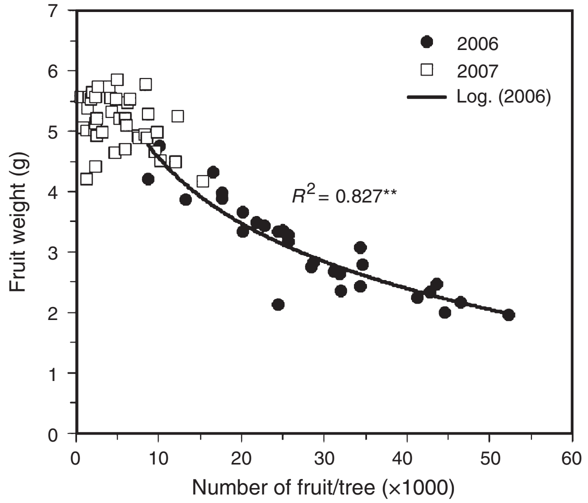

Fig. 2. Effect of on-year thinning on the yield parameters of Barnea oil olive trees (2006–07), demonstrating the 'trade-off' between fruit size and number of fruits per individual tree in the on-year and following off-year. ** Significance of R^2 at $P < 0.01$.

The oil yields correlated well with the fruit yields. The relative oil content was quite uniform, ~19.3% in both years, when fruit was harvested at the same maturation level, with no significant effect of NAA treatment on relative oil contents. Thus, the absolute oil content was strongly correlated with fruit size (Fig. 3*a*) and, due to the relationship between fruit number and size, the overall oil production was related to fruit number through a saturation function (Fig. 3*b*). Below 15 000 fruits per tree, the oil yield increased steeply; as the number of fruit increased, the increase in oil yield gradually declined. The fluctuations in oil yield between on- and off-years were very large, ranging from 18 to 2 kg/tree, respectively (Fig. 4). The NAA applications reduced oil yield in the on-year, but this decrease was fully compensated for by the corresponding oil yield in the subsequent year. Interestingly, the average 2-year oil yield in all treatments was around 10 kg/tree, close to the breaking point of the saturation curve, which occurred at ~15 000 fruits per tree (Fig. 3*b*). The application of 320 mg/L NAA, the highest concentration used in this study, was far more effective than the other concentrations, bringing the oil yield closer to the compensation point for both years (Fig. 4).

Discussion

Post-bloom NAA application is commercially practiced in table olive orchards to increase fruit size (Lavee and Spiegel 1958; Martin *et al.* 1980; Krueger *et al.* 2004), an important quality parameter in that industry. Although also intended to reduce biennial bearing of table olives (Martin *et al.* 1980), information about the efficiency of NAA application in this regard is scarce. The problem of alternate bearing is fundamental to the olive-oil

Table 3. Effect of NAA concentration, applied 10 days after full bloom in the spring of the expected on-year (2006), on fruit yields of cv. Barnea in that same year and in the following off-year

Values are means of 6 replicates ± s.e. The calculated 2- year average is also presented. Within a column, values followed by the same letter are not significantly different at $P < 0.05$ by Tukey-Kramer multiple comparisons test

NAA conc. (mg/L)	Fruit yield (kg/tree) 2006	2007	2-year ave.
0	91.7 ± 4.74a	11.4 ± 1.21c	51.6
40	89.4 ± 4.12a	9.5 ± 2.97c	49.5
80	78.4 ± 2.57b	20.2 ± 5.33bc	49.3
120	79.0 ± 7.02ab	21.5 ± 3.87b	50.3
160	80.2 ± 4.57ab	32.3 ± 5.30ab	56.3
240	72.8 ± 5.02bc	35.2 ± 8.45ab	54.0
320	57.3 ± 5.88c	47.8 ± 3.92a	52.6
P-value	0.031	0.017	0.061

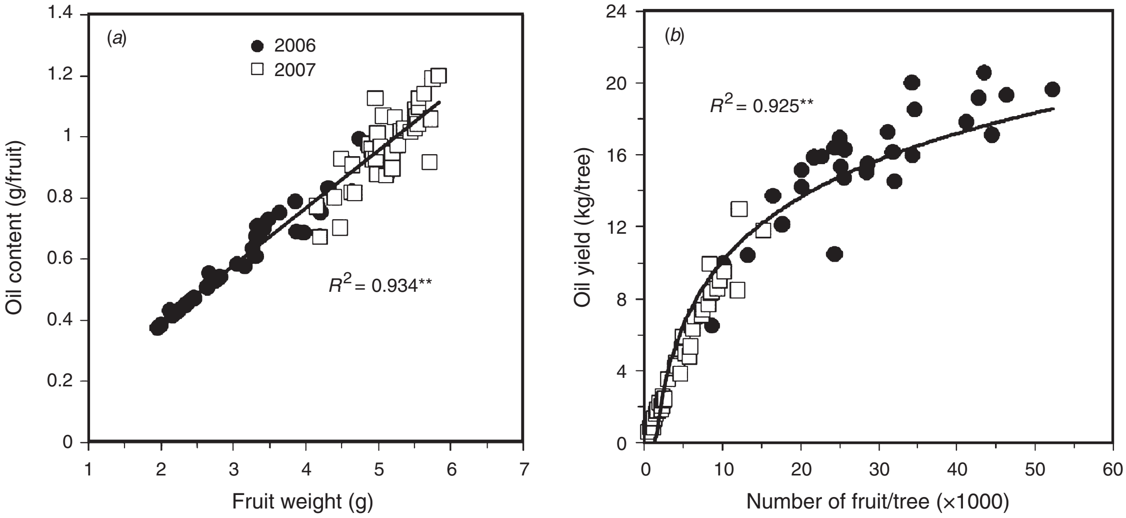

Fig. 3. Relationship between oil production and yield parameters of individual Barnea trees as affected by thinning treatments in the on-year (2006): (*a*) oil content *v.* fruit size; (*b*) oil yield *v.* number of fruits per tree. ** Significance of R^2 at $P < 0.01$.

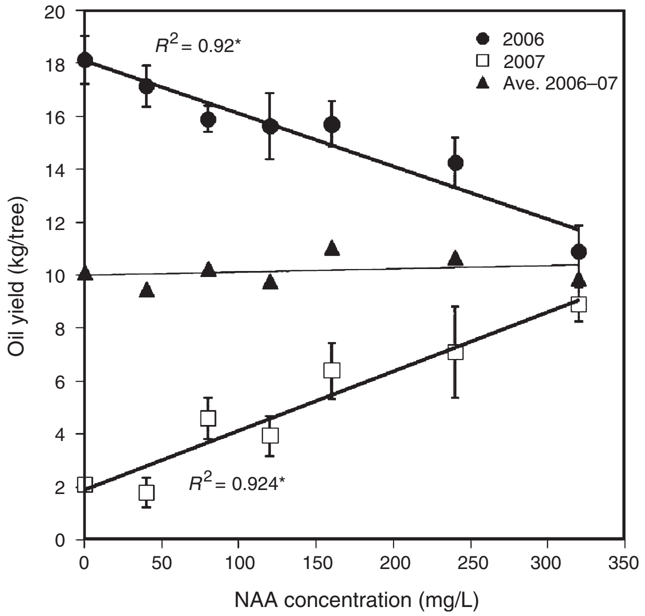

Fig. 4. Effect of NAA application 10 days after full bloom in an on-year (2006) on the oil yield of oil olive Barnea trees in the same year and in the following off-year (2007), and on the 2-year average oil yield. Values are means of 6 replicates ± s.e.; * significance of R^2 at $P < 0.05$.

industry, particularly in heavily producing intensive orchards (Lavee 2006).

In the first biennial cycle (2004–05), the commonly used range of NAA application (100 or 120 mg/L, 10 days after full bloom in the on-year) was tested on two oil olive cultivars, Picual and Barnea. NAA treatment resulted in an insignificant reduction in on-year yields and a pronounced trend towards increasing yields in the subsequent off-year, apparently having no effect on the biennial pattern (Table 1). However, the figures for total fruit yield in both years are likely to have masked any possible effects of NAA treatment on fruit number and consequent fruit size in each year. Since fruit number in an on-year is a determinant of alternate bearing (Monselise and Goldschmidt 1982; Lavee 2006), it is likely that the common NAA practice in the on-year not only affects fruit size due to thinning, but also results in an increase in return fruit number in the subsequent off-year. These assumptions were further investigated in the 2006–07 experiments.

The second cycle in this experiment (2006–07) confirmed that any reduction in fruit number, within or between years, was counterbalanced by an increase in fruit size (Table 2). Nevertheless, the recommended range of NAA concentrations for enlarging fruit size in table olives appeared to be inefficient at reducing alternate bearing, at least for cv. Barnea. Interestingly, one main difference between Picual and Barnea was fruit number in the on-year (20 000 and 40 000, respectively). In both cultivars, the fruit number dropped in the off-year; however, the greater the fruit load in an on-year, the smaller it was in an off-year. Thus, Picual experimental trees could produce more consistent fruit and oil yields during a 2-year cycle. Barnea behaved differently: it retained a clear biennial pattern even though the NAA treatments had reduced the fruit load to ~30 000/tree (Table 2). Nevertheless, the NAA treatments did induce some increase in the number of return fruit in cv. Barnea in the off-year, suggesting that a further reduction of fruit load in the on-year might generate even more fruit in the subsequent year and alleviate alternate bearing. That approach was examined by using a wider range of NAA concentrations on cv. Barnea in 2006–07.

Increasing NAA concentration reduced fruit number proportionally, down to less than 20 000 per tree with the 320 mg/L treatment (Fig. 1). Eventually, the time to harvest was shortened, confirming the negative relationship between fruit load and fruit maturation (Barone *et al.* 1994). The fruit number, or more precisely, the number of developing seeds on a tree, is the primary determinant of fruiting potential for the following year (Monselise and Goldschmidt 1982; Lavee 2006). This is assumed to be due to growth substances excreted by the developing fruit, which regulate concurrent vegetative development and also act as signals to initiate the metabolic activity that controls the reproductive process for the following year (Stutte and Martin 1986; Cuevas *et al*. 1994; Baktir *et al*. 2004; Lavee 2006). Thus, the extent to which the reduction in fruit number or the earlier harvest is responsible for the increase in fruit number in the subsequent year can be argued. Nevertheless, the latter remained relatively small, below 10 000 fruits per tree (Fig. 1), and the expectation of a proportional increase that would reflect the reduction in the number of fruit in the former year remained unfulfilled. Phytotoxicity of high NAA concentrations has been previously observed in table olives (Manzanillo) (Barranco and Krueger 1990). In the present study, only the highest NAA concentration (320 mg/L) impaired the normal spring vegetative growth, which was later replaced by new auxiliary growth. It may be speculated that this secondary growth was responsible for the exclusive return fruiting in this treatment. As mentioned by Lavee (2006), summer vegetative growth may often mature in the same year and be induced to bloom and carry fruit in the following year.

The second yield parameter, fruit size, generally compensated for the reduction in fruit load. Thus, the total fruit yield was less affected by the fruit-thinning treatments in the on-year (Table 2), even at a NAA concentration as high as 240 mg/L (Table 3). This may be the explanation for the lack of response by the vegetative growth to the reduction in the number of fruit: the overall demand by the developing fruit did not change; hence, the availability of supply for vegetative growth did not increase. It is worth noting the tendency of cv. Barnea fruit size to converge at around 2 g above a certain fruit load (Fig. 2). This is probably due to the early maturation of the endocarp (pit hardening) and the weaker sensitivity it has to fruit load, in contrast to the pulp. While the endocarp size remained quite constant (0.55 g) at any level of fruit load, the further growth demands of the mesocarp (with the energetically expensive oil biosynthesis there) yielded a remarkable increase in the pulp/pit ratio, from 2.6 to 6.7, in respect to the reduction in fruit load. The delay in fruit maturation and the low pulp/pit ratio both indicate that the high fruit loads characterising on-years strongly challenge the yielding capacity of Barnea trees. In contrast, in the off-year, there was no detectable 'trade-off' between fruit number and fruit size, indicating that the fruit-bearing potential of the trees was far greater than the actual yield, and that the maximum fruit size of cv. Barnea was, in accordance with its genetic potential, up to 6 g (Fig. 2).

An indication of the desirable yearly yield level may be found in the calculated average fruit yield of the 2 years, which converged to ~52 kg/tree, independent of the applied NAA concentration (Table 3), possibly expressing the potential yearly yield of consistently bearing olive trees under our conditions. Among all NAA treatments, only the highest concentration, which caused the most severe fruit thinning, came close to inducing relatively constant yields in both years (Table 3).

Oil yield closely followed that of the fruit (Fig. 3*b*). This is in agreement with previous findings that in olives, the relative oil content in the mesocarp at full fruit maturity reaches a uniform level, based on the genetic–environmental conditions, regardless of fruit size and tree load (Lavee and Wodner 2004). Hence, the absolute oil content was strongly correlated with fruit size (Fig. 3*a*), as previously reported (Lavee and Wodner 2004). The results of the present study indicate that the potential oil yield of Barnea trees under similar conditions for two years is close to 20 kg/tree (Figs 3*b*, 4). Thus, a consistent yearly yield of 8–12 kg oil/tree seems realistic, if fruit thinning is applied in an on-year. In addition, a consistent intermediate yearly yield provides an earlier harvest (compared with on-year), which is an advantage where frosts or heavy rains might damage the fruit or the oil quality.

In conclusion, cv. Barnea trees can be forced to bear consistent fruit or oil yields if the fruit number is reduced to less than 20 000 per tree in an on-year. At this planting density, this level of fruit load probably allows the optimum balance required by the olive tree between development of the current crop, vegetative growth, and processes that launch the subsequent reproductive cycle. It remains unclear whether fruit thinning would be required every 2 years, or if once broken, the alternate yielding habit fades away, until re-induced by external factors. Furthermore, the practical application of severe fruit thinning requires serious economic considerations due to the risks involved. These risks stem from the fact that environmental factors are a strong determinant of fruit yield in olives, which can often establish a new cycle of alternate bearing (Lavee 2006) or damage the yield of a given year. Possible differences in oil quality between on- and off-years, which are currently under examination, may also be of concern.

Acknowledgments

We thank Yulia Subbotin, Moshe Aharon, and Isaac Tzipori for their technical assistance. We also thank Izhar Tugendhaft and Nimrod Priel from 'Negev Oil' for assisting in the field activities, and Shlomo Glidai and 'Milchan Bros., Ltd' for providing the chemicals and technical assistance.

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Manuscript received 16 March 2009, accepted 10 August 2009