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Use of GA_3 to Manipulate Flowering and Yield of 'Hass' Avocado

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Abstract. Avocado trees (*Persea americana* Mill.) bearing a heavy crop produce a light "off" bloom the next spring. This results in a light crop and a subsequent intense "on" bloom the year after. The objective of the study was to quantify the effects of GA_3 canopy sprays applied to 'Hass' avocado trees during the months preceding an "off" or "on" bloom on inflorescence and vegetative shoot number and yield. The experiment was initiated approximately seven months before an anticipated "off" bloom in an attempt to increase flowering intensity and yield. GA_3 (25 or 100 $mg \cdot L^{-1}$) was applied to separate sets of trees in September (early stage of inflorescence initiation), November (early stage of inflorescence development), January (initial development of the perianth of terminal flowers), March (cauliflower stage of inflorescence development; only 25 $mg \cdot L^{-1}$), or monthly from September through January (only 25 $mg \cdot L^{-1}$). Control trees did not receive any treatment. GA_3 (100 $mg \cdot L^{-1}$) applied in September reduced inflorescence number in both years, but not yield. GA_3 (25 or 100 $mg \cdot L^{-1}$) applied in November before the "on" bloom reduced inflorescence number with a concomitant increase in vegetative shoot number and 47% yield reduction compared to control trees. This treatment might provide avocado growers with a tool to break the alternate bearing cycle by reducing yield in an expected "on" crop year to achieve a higher yield the following year. GA_3 (25 $mg \cdot L^{-1}$) applied in November or January stimulated early development of the vegetative shoot of indeterminate inflorescences. January and March applications did not affect the number of flowering or vegetative shoots produced either year. GA_3 (25 $mg \cdot L^{-1}$) applied in March at the start of an "off" bloom increased 2-fold the production of commercially valuable fruit (213 to 269 g per fruit) compared to the control.

Inflorescence initiation of 'Hass' avocado in Southern California begins in July to August; anthesis occurs in March to April (Salazar-García et al., 1998). Fruit can be harvested 11 months after flowering (February the following year) (Lovatt, 1990). Mature fruit of 'Hass' avocado are frequently "stored" on the tree for harvest anytime through August. Excessive fruit load or late harvest contributes to alternate bearing, in which trees (orchards) bear a high yield ("on" crop year) followed by a bloom of low intensity ("off" bloom) and the resulting low yield ("off" crop year) (Monselise and Goldschmidt, 1982).

In 'Hass' avocado, spring-flush shoots borne on indeterminate inflorescences that set fruit do not flush in summer or fall, nor do they produce inflorescences the following spring (Salazar-García et al., 1998). Indeterminate inflorescences can account for 90% of the total inflorescences produced during spring bloom (Salazar-García and Lovatt, 1998). Thus, when trees are carrying an "on" crop, the number of shoots that bear inflorescences is reduced significantly. This results in an "off" bloom that sets an "off" crop with a concomitant increase in both summer and fall vegetative shoot flushes, potential flowering points for the next year. Thus, the cycle of alternate bearing is perpetuated.

Indeterminate inflorescences of 'Hass' avocado have low fruit set potential (0.05%) (Salazar-García and Lovatt, 1998). It has been proposed that competition for water, nutrients, and photosynthate occurs between the apical vegetative shoot, which normally develops during the period of anthesis and fruit set, and setting fruit of indeterminate avocado inflorescences (Bower and Cutting, 1992; Cutting and Bower, 1990; Whiley, 1990; Zilkah et al., 1987).

Our recent research provided evidence that GA_3 alters inflorescence phenology and morphology in predictable ways (Salazar-García and Lovatt, 1998). GA_3 applied in November, before inflorescence buds have initiated a full complement of secondary inflorescence axes, reduces flowering intensity due to the production of partially formed inflorescences, each bearing fewer flowers, but accelerated inflorescence and vegetative shoot development. The results suggest the possibility of using a November application of GA_3 preceding an "on" bloom to even out alternate bearing by reducing the formation of secondary axes of inflorescence buds. Later GA_3 applications (December or January) did not affect inflorescence or flower number, but hastened the development of the vegetative shoot at the apex of indeterminate inflorescences. Due to advanced development caused by the application of GA_3, leaves become sources of photoassimilates at fruit set, rather than competing sinks (Blanke and Lovatt, 1998). Thus, both early and late foliar GA_3 applications provide possible strategies for manipulating avocado productivity.

The present research was undertaken to quantify the effects of two GA_3 concentrations applied at five different times to 'Hass' avocado trees before an "off" or "on" bloom on the production of inflorescences versus vegetative shoots by apical buds, as well as inflorescence morphology and phenology. In addition, fruit set, yield and fruit quality parameters were determined. The objective was to identify a treatment strategy using GA_3 to increase cumulative yield in an alternate bearing 'Hass' avocado orchard.

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Materials and Methods

Tree selection. This experiment used 10-year-old 'Hass' avocado trees on a Duke 7 clonal rootstock in a 5-ha commercial orchard, planted at 4.9 × 6.0 m spacing (340 trees/ha), in Corona, Calif. (34° N latitude). One hundred and eighty trees bearing an "on" crop were selected for uniform high fruit load, health, and vigor in August 1994. The trees were harvested 11 months later in July (Yield = 58.9 ± 6.5 kg/tree, n = 180).

GA_3 treatments. For the fist year of this experiment, treatments were applied from September 1994 through March 1995 before an "off" bloom. Treatment effects were quantified for the "off" bloom (March to April 1995) and the resulting crop harvested the following year in May 1996. During the second year (1995), GA_3 treatments were repeated on the same trees from September 1995 through March 1996 before the "on" bloom. Treatments were evaluated for their effect on the "on" bloom (March to April 1996) and the resulting crop harvested the following year in June 1997.

GA_3, prepared from Progibb (4% GA_3 Abbott Laboratories, North Chicago, Ill.) plus 1 $mL\cdot L^{-1}$ Triton X-100 (Sigma Chemicals, St. Louis, Mo.) in water (pH 5.5), was applied to the canopy at the rate of 8 ± 1 L of solution per tree to provide full canopy coverage to the point of runoff. A total of nine treatments were tested that consisted of two GA_3 concentrations (25 or 100 $mg\cdot L^{-1}$ GA_3) applied once to separate sets of 20 trees each on 15 Sept. 1994 and 1995 (treatments 1 and 2), November 1994 and 1995 (treatments 3 and 4), or January 1995 and 1996 (treatments 5 and 6). Two additional treatments were evaluated: a monthly spray of 25 $mg\cdot L^{-1}$ GA_3 from September 1994 and 1995 through January 1995 and 1996, respectively (treatment 7) and a one time application of 25 $mg\cdot L^{-1}$ GA_3 in March 1995 and 1996 (treatment 8). The control (treatment 9) consisted of 20 untreated trees. To determine the stage of inflorescence bud development at each treatment date, two apical buds of summer shoots from 10 out of the 20 control trees were collected. Buds were fixed in FAA (5 formalin : 5 acetic acid : 90 ethanol, by volume), dehydrated, infiltrated, embedded, sectioned, and stained as described by Salazar-García et al. (1998).

Time of flowering. Time of flowering was recorded as the elapsed time from the application of the first treatment (15 Sept. 1994 and 1995) to the presence of 50 inflorescences per tree with all their flowers at anthesis.

Type of growth produced by apical buds. Five branches 1 m in length and 6 to 10 cm in diameter were selected evenly around each of 10 trees per treatment. At the end of the flowering period, the number of inflorescences (including determinate and indeterminate), vegetative shoots, and inactive apical buds on each branch were recorded.

Precocious shoot development of indeterminate inflorescences. In year two (1995–96), the effect of GA_3 at 25 $mg\cdot L^{-1}$, a lower concentration than previously tested (50 and 100 $mg\cdot L^{-1}$ GA_3) by Salazar-Garciá and Lovatt (1998), on the rate of vegetative shoot development relative to the development of flowers of indeterminate inflorescences was determined for control trees and trees that received a GA_3 spray in November 1995 (treatment 3) or January 1996 (treatment 5) before the "on" bloom. The total number of leaves, total leaf area, and the length of the oldest leaf were recorded for five indeterminate inflorescences at the stage of open flowers (anthesis) for each of the 20 trees per treatment.

Fruit set and yield. Five additional branches 1 m in length and 6 to 10 cm in diameter were selected evenly around each of 10 (year 1994–95) or 20 (year 1995–96) trees per treatment. After the June drop period (23 Aug. each year), all fruit present on each of the selected branches were counted and the type of inflorescence (determinate or indeterminate) on which each fruit was set was identified. Total yield per tree and the proportion of fruit of various sizes were determined at harvest (16 May 1996 and 30 June 1997) for all 20 replications. The weight of 100 randomly selected individual fruit per tree was used to calculate packout per tree. The following fruit sizes (g per fruit) were used: size 84 (99–134 g), size 70 (135 to 177 g), size 60 (178 to 212 g), size 48 (213 to 269 g), and size 40 (270 to 325 g). Alternate bearing index (ABI) for the experiment was calculated using the equation: ABI (%) = (difference between yield of year 1 and year 2)/(sum of yields of year 1 and year 2) × 100.

Statistical analysis. The experiment had a randomized complete-block design. Data were collected from 20 single-tree replications per treatment unless stated otherwise above. Before statistical analysis, data were tested for normality, and a paramet-

Table 1. Stage of apical bud development of 'Hass' avocado trees at the time of GA_3 application.

Sampling date	Bud stage[z]	Bud status[z]	
		Macroscopic	Microscopic
15 Sept.	3	Buds were closed and pointed with senescent bud scales.	Primary axis meristem was convex and four secondary axis inflorescence meristems had been initiated.
15 Nov.	4	Bud scales were separated due to the fact that inflorescence bracts had expanded on all sides of the bud.	The primary axis inflorescence meristem was flat and there were 10 secondary axis inflorescence meristems present.
15 Jan.	5	Buds were swollen and the scales had separated further than in Stage 4.	The oldest (basal) secondary axes had elongated and had developed tertiary axis meristems, initial development of perianth of terminal flowers of the secondary and tertiary axes could be seen.
15 Mar.	8	Obvious elongation of secondary axes (cauliflower stage), the tertiary axes were still covered by subtending bracts, but small closed flowers could be seen.	All floral parts were present, meiosis had occurred in the anther locules as evidenced by the presence of microspores, and the integuments were forming on the ovule.

[z]Based on the scale developed by Salazar-García et al. (1998).

Table 2. Effect of GA_3 applied the months (September to January) before an "off" and "on" bloom (March to April) years on the type of growth produced by apical buds of 'Hass' avocado trees.

		Shoots observed/ tree (no.)		Type of growth (% total shoots)[z]			
				Inflorescences		Vegetative shoot	
Application date	GA_3 concn ($mg \cdot L^{-1}$)	Off (1995)	On (1996)	Off (1995)	On (1996)	Off (1995)	On (1996)
Control	0	88	105	13.3 abc[y]	45.7 a	71.9 a	38.3 c
15 Sept.	25	82	85	10.9 bcd	23.6 ab	65.2 a	49.4 abc
	100	63	85	2.6 d	15.3 bc	79.0 a	53.0 ab
15 Nov.	25	69	80	28.5 a	12.1 bc	58.9 a	54.4 ab
	100	81	85	11.6 cd	8.0 c	77.1 a	60.2 a
15 Jan.	25	76	85	19.8 ab	27.6 ab	68.1 a	44.1 bc
	100	82	105	7.1 bcd	37.3 a	69.0 a	39.1 c
Monthly	25	85	100	4.4 d	11.7 bc	70.5 a	60.9 a

[z]Means were obtained from 10 tree replications and five branches/tree. Statistical analysis were done on data transformed by arcsin{(sqrt(%)}.
[y]Mean separation in columns by Duncan's multiple range test, $P = 0.05$.

ric or nonparametric test was performed in consequence. Data expressed as percentages were transformed by arcsin of the square root of the observation (Steel and Torrie, 1980) and then a normal analysis of variance was performed. Means comparison were performed using Duncan's multiple range test (parametric test) or Dunn's test (non parametric test) and is reported at $P = 0.05$.

Results

Stage of apical bud inflorescence development at the time of GA_3 treatment. The predominant stage of inflorescence bud development at the time of GA_3 treatment was determined by using the scale developed by Salazar-García et al. (1998). The scale is based on the macroscopic and corresponding microscopic characteristics of the bud. Buds collected on the date a specific treatment was applied in each year of the study were at a similar stage of development in both years (Table 1). By the first spray date (15 Sept.), apical buds were closed and pointed with senescent bud scales, which corresponded to an early stage of inflorescence bud initiation (Salazar-García et al., 1998). The sprays on 15 Nov. and 15 Jan. were made at more advanced stages of inflorescence bud development but before budbreak. By the last spray date (15 Mar.) apical inflorescences were at the cauliflower stage.

Effect of GA_3 on date of flowering. Application of GA_3 had no effect on the date of flowering (number of days from 15 Sept. to the presence of 50 inflorescences at anthesis per tree) relative to the control in either year of the study.

Effect of GA_3 on the type of growth produced by apical buds. For the untreated control trees, 13% of total shoots produced were inflorescences in the "off" bloom during the year of heavy fruit load, compared to 46% in the "on" bloom during the year of light fruit load (Table 2). Production of inflorescences was affected by both the time and concentration of GA_3 treatments as well as by fruit load. GA_3 (25 $mg \cdot L^{-1}$) applied in November before an "off" bloom increased the percentage of inflorescences relative to all other treatments but not the control and those treated in January (Table 2). GA_3 applied at 100 $mg \cdot L^{-1}$ in September or at 25 $mg \cdot L^{-1}$ monthly from September to January before the "off" bloom significantly reduced inflorescence production relative to the control. GA_3 applications made before the "on" bloom at 100 $mg \cdot L^{-1}$ in September or November or at 25 $mg \cdot L^{-1}$ in November or monthly from September to January significantly decreased the percentage of inflorescences compared to the control (Table 2).

Conversely, a greater percentage of vegetative shoots was produced during spring of the "off" bloom (72 % of total shoots for the control) than during the "on" bloom (38 % for the control) (Table 2). Application of GA_3 before the "on" bloom at 100 $mg \cdot L^{-1}$ in September or November and at 25 $mg \cdot L^{-1}$ in November or monthly from September to January significantly increased the percentage of vegetative shoots produced with a concomitant decrease in the percentage of inflorescences produced.

Presence of inactive apical buds in control trees was ≈15% in both years. GA_3 application did not significantly affect the percentage of inactive buds in either year compared to the control (data not shown).

In both years, indeterminate inflorescences were predominant. GA_3 (100 $mg \cdot L^{-1}$) applied in September or monthly at 25 $mg \cdot L^{-1}$ from September to January before the "off" bloom resulted in fewer indeterminate inflorescences (Table 3). For the "on" bloom year, the highest production of indeterminate inflorescences was in control trees (42 % of the total shoots). All applications of GA_3 made before the "on" bloom significantly reduced the percentage of indeterminate inflorescences, with the exception of the January treatments. No GA_3 treatment affected the percentage of determinate inflorescences in either year (data not shown).

Precocious shoot development of indeterminate inflo-

Table 3. Effect of GA_3 applied to 'Hass' avocado in the months (September to January) before an "off" and "on" bloom (March to April) years on the production of indeterminate inflorescences.

		Indeterminate inflorescence (% of total shoots[z])	
Application date	GA_3 concn ($mg \cdot L^{-1}$)	Off (1995)	On (1996)
Control	0	13.3 abc[y]	42.2 a
15 Sept.	25	10.9 bcd	19.8 bc
	100	2.6 d	14.1 cd
15 Nov.	25	28.0 a	12.0 cd
	100	11.6 cd	7.8 d
15 Jan.	25	19.8 ab	27.4 abc
	100	7.1 bcd	34.2 ab
Monthly	25	4.4 d	11.3 cd

[z]Means were obtained from 10 tree replications and five branches/tree. Statistical analysis were done on data transformed by arcsin{sqrt(%)}.
[y]Mean separation in columns by Duncan's multiple range test, $P = 0.05$.

Table 4. Effect of a prebloom (November or January) application of GA_3 at 25 $mg \cdot L^{-1}$ at two stages of inflorescence bud development on the development of the vegetative shoot of indeterminate inflorescences of 'Hass' avocado trees[z].

Application date and bud development stage[y]	Leaves/ inflorescence (no.)	Total leaf area (cm^2)	Length of oldest leaf (cm)
Control	6.5 c[x]	8.2 c	1.9 c
15 Nov. (Stage 4)	7.4 b	17.3 b	3.7 b
15 Jan. (Stage 5)	8.7 a	37.5 a	5.5 a

[z]Each mean was obtained on 9 Apr. 1996 of the "on" bloom year from five inflorescences at anthesis per tree and 20 tree replications.
[y]Average microscopic stage of bud development (Salazar-García et al., 1998): Stage 4 = flat primary axis meristem with 10 secondary axis inflorescence meristems; Stage 5 = elongation of oldest secondary axes in which tertiary axis meristems are present. Initial development of perianth of terminal flowers of secondary and tertiary axes.
[x]Mean separation in columns by Duncan's multiple range test, $P = 0.05$.

Table 5. Effect of GA_3 applied in the months (September to March) before an "off" and "on" bloom (March to April) on fruit set by 'Hass' avocado trees. Evaluations were done on 23 Aug. 1995 and 1996.

Application date	GA_3 concn ($mg \cdot L^{-1}$)	Fruit/1-m-long branch[z] (no.) Off (1995)	On (1996)
Control	0	0.04 b[y]	1.69 a
15 Sept.	25	0.07 b	1.11 ab
	100	0.00 b	0.86 ab
15 Nov.	25	0.48 a	0.43 b
	100	0.02 b	0.43 ab
15 Jan.	25	0.31 ab	0.46 ab
	100	0.04 b	0.71 ab
Monthly	25	0.00 b	0.66 ab
15 Mar.	25	0.12 b	1.03 ab

[z]Each mean was obtained from five 1-m long branches/tree for 10 and 20 tree replications in "off" and "on" bloom years, respectively.
[y]Mean separation in columns by Duncan's multiple range test ("off" bloom year) and Dunn's test ("on" bloom year), $P = 0.05$.

RESCENCES. When evaluated at anthesis, GA_3 (25 $mg \cdot L^{-1}$) applied on 15 Nov. 1995 or 15 Jan. 1996 before an "on" bloom increased the rate of development (number of leaves/inflorescence, leaf area, leaf length) of the vegetative shoot of indeterminate inflorescences (Table 4). This response was greater when GA_3 was applied at Stage 5 of bud development (January 1996) than when apical buds were at Stage 4 (November 1995).

FRUIT SET AND YIELD. GA_3 at 25 $mg \cdot L^{-1}$ applied in November 1994 before the "off" bloom increased the number of fruit set (avg. = 0.5 fruit/branch) compared to the control and all other GA_3 treatments except 25 $mg \cdot L^{-1}$ GA_3 applied in January (0.3 fruit/branch) (Table 5). Fruit set (no./branch) for the control was higher for the "on" bloom than for the "off" bloom (Table 5). GA_3 (25 $mg \cdot L^{-1}$) applied in November 1995 before the "on" bloom significantly reduced fruit set compared to the control; other GA_3 treatments did not affect fruit set that year.

The first year GA_3 treatments were made before the "off" bloom, thus the yield data was for an expected "off" crop year (Table 6). Control trees had an average yield of 18 kg/tree. Most of the GA_3 applications did not affect kg fruit/tree, compared to control, but did affect the size of the fruit harvested. The November 1994 prebloom GA_3 (25 $mg \cdot L^{-1}$) application increased yield 2-fold in fruit of commercial size 70 (fruit weighing 135 to 177 g) which is not of economic importance. The March 1995 GA_3 (25 $mg \cdot L^{-1}$) application increased 1-fold the production of commercially valuable fruit of size 48 (213 to 269 g) compared to the control.

The second year GA_3 treatments were made before an anticipated "on" bloom; yield data corresponded to an "on" crop year (Table 6). Control trees yielded 80 kg fruit/tree. Except for the November 1995 prebloom GA_3 (25 $mg \cdot L^{-1}$) treatment, which significantly reduced yield (42 kg/tree), no treatment differed significantly from the control. GA_3 treatments did not significantly affect fruit size compared to the control.

During the first year of the experiment, fruit from the previous spring bloom were present on the trees. This provided the opportunity to evaluate the effect of GA_3 treatments on fruit retention and fruit size of the existing crop, an effect that is independent of altering bloom or inflorescence morphology. For the existing fruit, GA_3 at 25 $mg \cdot L^{-1}$ applied in September 1994 (10 months before harvest) increased the amount of size 40 fruit (270 to 325 g) relative to the control (6.2 vs. 2.7 kg/tree) (Table 7). In addition, GA_3 at 25 $mg \cdot L^{-1}$ applied in September increased the amount of size 48 fruit (213 to 269 g) relative to other GA_3 treatments, but had no effect on the quantity of small-sized fruit per tree (sizes 84 to 60).

EFFECT OF GA_3 ON ALTERNATE BEARING. GA_3 applications affected the 2-year cumulative yield, although none differed from the control. Treatments with GA_3 at 25 $mg \cdot L^{-1}$ had higher cumu-

Table 6. Effect of GA_3 applied in the months (September-March) before an "off" (1995) and "on" (1996) bloom (March-April) years on yield and fruit size of 'Hass' avocado trees.

Application date	GA_3 concn ($mg \cdot L^{-1}$)	Yield (kg/tree) Off	Yield On	Size 84 Off	Size 84 On	Size 70 Off	Size 70 On	Size 60 Off	Size 60 On	Size 48 Off	Size 48 On	Size 40 Off	Size 40 On
				Distribution of yield by size (kg/tree)									
Control	0	18 ab[z]	80 ab	0.3 b	8.1 abc	2.4 b	32.4 abc	8.8 ab	28.7 abc	5.3 b	10.2 abc	1.5 a	0.4 a
15 Sept.	25	14 ab	107 a	0.2 b	11.7 a	1.7 b	44.9 a	4.1 b	35.9 a	6.1 ab	13.4 a	2.1 a	0.3 a
	100	10 b	80 ab	0.2 b	6.6 abc	1.9 b	32.8 abc	3.8 b	29.0 abc	3.2 b	11.3 ab	0.6 a	0.1 a
15 Nov.	25	35 a	42 c	2.0 a	4.2 c	7.8 a	18.6 c	17.7 a	15.6 c	6.4 ab	3.8 c	0.9 a	0.1 a
	100	15 ab	71 bc	0.4 b	7.7 abc	2.5 b	29.1 abc	6.7 b	25.8 abc	3.3 b	8.4 abc	2.0 a	0.1 a
15 Jan.	25	27 ab	60 bc	0.9 ab	6.1 bc	3.2 b	26.9 bc	13.2 ab	20.9 bc	7.8 ab	6.3 bc	2.1 a	0.2 a
	100	17 ab	83 ab	0.3 b	10.3 ab	3.0 b	37.2 ab	7.2 ab	27.4 abc	5.6 ab	7.5 abc	0.8 a	0.4 a
Monthly	25	14 ab	65 bc	0.2 b	5.9 bc	2.0 b	26.6 bc	4.0 b	24.7 abc	5.8 ab	8.0 abc	1.8 a	0.2 a
15 Mar.	25	34 a	89 ab	0.4 b	6.1 bc	5.3 ab	39.3 ab	12.6 ab	33.6 ab	11.6 a	10.1 abc	3.7 a	0.2 a

[z]Mean separation in columns by Duncan's multiple range test, $P = 0.05$.

Table 7. Effect of GA_3 treatments applied to the existing fruit 5 to 10 months before harvest (18 July 1995).

Application date	GA_3 concn ($mg \cdot L^{-1}$)	Yield (kg/tree)	Distribution of yield by size (kg/tree) Size 84, 70, 60	48	40
Control	0	66.1 a[z]	40.8 a	22.4 abc	2.7 b
15 Sept.	25	73.1 a	37.6 a	29.0 a	6.2 a
	100	60.5 a	38.4 a	19.4 abc	2.5 b
15 Nov.	25	49.2 a	29.6 a	17.3 bc	2.0 b
	100	55.5 a	36.6 a	16.9 bc	1.9 b
15 Jan.	25	63.3 a	40.7 a	20.6 abc	1.7 b
	100	52.1 a	33.5 a	17.4 bc	1.1 b
Monthly	25	51.9 a	33.9 a	15.5 c	2.3 b
15 Mar.	25	63.2 a	32.3 a	27.2 ab	3.4 b

[z]Mean separation in columns by Duncan's multiple range test, $P = 0.05$.

lative yields when applied in September or March than in November or January (Table 8). The alternate bearing index was not affected by GA_3 treatments. Controls trees had an average cumulative yield of 98 kg/tree, with an ABI = 56.8% (Table 8).

Discussion

A higher production of vegetative shoots at the expense of inflorescence production was evident for control trees during the "off" bloom. The opposite occurred in the "on" bloom, resulting in greater production of inflorescences. This research attempted to use GA_3 to alter this relationship. GA_3 sprays applied at early stages of inflorescence bud development (Stages 3 and 4) stimulated the production of vegetative shoots at the expense of inflorescences. GA_3 treatments at more advanced stages of bud development (Stage 5 and later) had no effect on the production of inflorescences. Five monthly applications of GA_3 during the process of inflorescence bud development (September to January) were not able to fully inhibit flowering. In addition, there was no significant effect of GA_3 treatments on the date of anthesis.

In Southern California apical buds of 'Hass' avocado branches produce mainly indeterminate inflorescences; determinate inflorescences are borne in axillary buds. In a previous study of the effect of GA_3 sprays on avocado branches (Salazar-García and Lovatt, 1998), high GA_3 concentration (1000 $mg \cdot L^{-1}$) inhibited the growth of axillary buds along the shoot. However, when axillary bud break occurred, only determinate inflorescences were produced. Similarly, trunk injections of GA_3 to 33-month-old 'Hass' avocado trees inhibited axillary bud break (Salazar-García and Lovatt, 1999). In the present study, sprays with GA_3 up to 100 $mg \cdot L^{-1}$ to whole trees did not significantly inhibit production of axillary determinate inflorescences. No external flower abnormalities were observed in any GA_3 treatment and all flower parts (tepals, stamens, staminodes, and pistil) were present.

Precocious development of the vegetative shoot of indeterminate avocado inflorescences occurred in response to GA_3 at 50 to 1000 $mg \cdot L^{-1}$ sprayed onto branches (Salazar-García and Lovatt, 1998) or injected into the stem of young or mature trees (Salazar-García and Lovatt, 1999). In this study, similar results were achieved when whole trees were treated with only 25 mg GA_3/L. Thus, GA_3 application alters inflorescence phenology of 'Hass' avocado by hastening the development of the vegetative shoot of indeterminate inflorescences relative to the secondary axes and flowers of the same inflorescence or to untreated control inflorescences. Precocious development of the vegetative shoot might increase the potential of this type of inflorescence to set fruit if leaves are sources of photoassimilates at the time of fruit set and early fruit development rather than competing sinks, which has been postulated as a cause of low fruit set and yield in avocado (Bower and Cutting, 1992; Cutting and Bower, 1990; Whiley, 1990). Another important advantage of precocious shoot development and leaf expansion is the earlier protection of young developing fruit from sunburn. In the untreated control trees, vegetative shoot development did not occur until the fruit were larger, leaving them exposed to potential sunburn damage for a longer period.

Although no data are shown in this paper, a delay in color break and blackening of the avocado fruit was observed for late harvested fruit of GA_3-treated trees. The potential use of foliar GA_3 applications to extend the harvest season by delaying blackening of the avocado fruit could prove beneficial to commercial growers and deserves further investigation. Presence of vascular browning of the pulp was not affected by GA_3 treatments in any of the years evaluated.

Tree yield variation increased after the beginning of the experiment, making it difficult to detect significant differences among treatments. However, our field observations indicate that some treatments may deserve further research. GA_3 applied in September or November may have the potential to break the alternate bearing cycle by reducing production of inflorescences in an expected "on" bloom year to reduce yield that year to

Table 8. Effect of GA_3 applied in the months (September to March) before both the "off" and "on" bloom (March to April) years on 2-year cumulative yield and alternate bearing of 'Hass' avocado trees.

Application date	GA_3 concn ($mg \cdot L^{-1}$)	Cumulative yield (kg/tree)	ABI (%)[z]
Control	0	98 ab[y]	56.8 a
15 Sept.	25	121 a	76.0 a
	100	90 ab	68.1 a
15 Nov.	25	77 b	27.8 a
	100	86 b	65.0 a
15 Jan.	25	87 b	44.0 a
	100	100 ab	63.8 a
Monthly	25	79 b	66.4 a
15 Mar.	25	123 a	40.7 a

[z]Alternate bearing index = (Difference between yield of year 1 and year 2)/(Sum of yields of year 1 and year 2) × 100.
[y]Mean separation in columns by Duncan's multiple range test, $P = 0.05$.

achieve a higher yield during an expected "off" crop year. GA_3 spray at the cauliflower stage (March) appears to be a promising strategy to reduce alternate bearing. The March spray had no effect on the production of inflorescences; instead it caused precocious development of the vegetative shoot of indeterminate inflorescences (data not shown) and resulted in numerically higher fruit set and yield when applied either during an "off" or "on" bloom year, with no loss in the yield of larger size fruit. Our results support the hypothesis that, under California conditions, low fruit set in avocado may be caused, at least in part, by competition between the vegetative shoot of indeterminate inflorescence and setting fruit (Blanke and Lovatt, 1998). The physiological changes caused by GA_3-induced precocious leaf development and their effect(s) on fruit set and development remain to be determined.

The effects of GA_3 treatments (time of application and concentration) were different when made before an "off" versus "on" bloom year, despite the fact that the buds were on average at the same stage of development when the treatments were made in two separate years. Using GA_3 sprays during an "off" or "on" bloom year to increase yield or to even out alternate bearing will require careful attention to GA_3 concentration, stage of inflorescence development at the time of treatment, and tree fruit load.

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