Effect of Foliar-applied Plant Bioregulators on "June Fruit Drop", Yield and Fruit Size of 'Hass' Avocado

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Abstract

Research was conducted to evaluate the effectiveness of foliar-applied plant bioregulators (PBRs) to reduce "June fruit drop" and increase yield and fruit size of 'Hass' avocado under rainfed conditions in Nayarit, México. Treatments were applied approximately 1 month before the expected start of June fruit drop in 10 ± 1 L aqueous solutions per tree to achieve full canopy coverage. The surfactant Silwet L-77® at 1 mg·L^{-1} was added to all treatments, including the control. In Year 1, the following treatments were applied in June, when fruit were about 5 to 7 cm long: (T-1) 25 mg·L^{-1} 2,4-D (66 mg·L^{-1} Citrus Fix®), (T-2) 45 mg·L^{-1} aminoethoxyvinylglycine (300 mg·L^{-1} Retain®), (T-3) 0.45 mg·L^{-1} 6-benzyladenine (25 mg·L^{-1} Accel®), and (T-4) control (surfactant only). For Year 2, treatments were modified and applied when fruit were 3-4 cm long (20 May) or 5 to 7 cm long (15 June): (T-1) 10 mg·L^{-1} 2,4-D (26.3 mg·L^{-1} Citrus Fix®) in May and June, (T-2) 12.5 mg·L^{-1} 2,4-D (23.9 mg·L^{-1} Citrus fix®) in May and June, (T-3) 20 mg·L^{-1} 2,4-D (52.6 mg·L^{-1} Citrus Fix®) in June, (T-4) 22.5 mg·L^{-1} aminoethoxyvinylglycine (150 mg·L^{-1} Retain®) in May and June, and (T-5) 45 mg·L^{-1} aminoethoxyvinylglycine (300 mg·L^{-1} Retain®) in June, (T-6) control (surfactant only). A randomized block design with 10 single-tree replications was used. Intensity of June fruit drop in control trees was 47% to 66%. A reduction of 19.4% to 17.3%, in the intensity of June drop was achieved by tree canopy sprays in June of 20 mg·L^{-1} 2,4-D (52.6 mg·L^{-1} Citrus Fix®) or 45 mg·L^{-1} aminoethoxyvinylglycine (300 mg·L^{-1} Retain®), respectively. In addition, these treatments increased by 17% to 18% the kg of large size fruit (170 to >266 g per fruit) per tree. These results will be of great economic benefit to the avocado grower.

INTRODUCTION

Avocado yield is highly variable due to alternate bearing (production of a heavy "on" year crop followed by a light "off" year crop). Climatic differences in the various avocado-growing regions contribute to uneven bearing. For example, in Michoacán, Mexico, yield of 'Hass' avocado oscillates from 4 to 10.5 metric tons/ha (ASEEAM, 1998), although there are some orchards with sustained yields of 15 metric tons/ha (Aguilera-Montañez and Salazar-García, 1996). In the state of Nayarit, Mexico, a mature well-managed 'Hass' avocado orchard commonly yields more than 25 metric tons/ha (Salazar-García and Lazcano-Ferrat, 2003). For the 'Hass' avocado in California, average yield is only 6.9 metric tons/ha; with the coastal avocado growing area averaging higher annual yields than the southern inland region.

In Nayarit, the 'Hass' avocado is cultivated under rainfed conditions with a rainy season from June to September. Bloom occurs in the winter (January-February) and harvest is carried out nine months later. Generally, no mature fruit are present on the trees at the time of bloom. The 'Hass' avocado flowers prolifically, producing 1 to 2 million flowers each winter-spring. However, low initial fruit set and the additional loss of fruit due to "June drop" reduce potential yield.

"June drop" is a problem of economical importance in every avocado growing region and in Nayarit more than 40 % of potential yield may be lost by this cause. The so called June drop occurs in July, about a month after the beginning of rains and coincides with the initiation of the period of rapid fruit growth and the first major root flush at the time of high temperatures. It has been postulated that fruit drop is a consequence of a strong competition for carbohydrates, water and/or plant hormones. Competition for carbohydrates commonly occurs when each inflorescence sets three or more fruit.

Plant bioregulators (PBRs) like GA_3, 2,4-D or 6-benzyladenine are typically used in the production of several fruit tree crops to increase fruit retention during the fruit set and June drop periods. For avocado such research has been quite limited. Accel® (Abbott laboratories) contains the cytokinin 6-benzyladenine plus $GA_{4,7}$. Cytokinins stimulate cell division, increase sink activity to improve the ability of fruit to compete for resources (Bower and Cutting, 1988) and applied to the canopy may reduce fruit drop and increase fruit size by maintaining cell division throughout fruit development. Research performed in South Africa provided strong evidence that low cytokinin concentration in developing fruit is a factor contributing to the small fruit size problem of 'Hass' avocado (Cowan et al., 1997). Lovatt (2004) mentioned that canopy sprays to 'Hass' avocado of 25 $mg{\cdot}L^{-1}$ of 6-benzyladenine (as Accel) applied when inflorescences were at anthesis significantly reduced the weight and number of fruit of sizes 70 (135-177 g) and 60 (135-177 g), had no effect on fruit of sizes 48 (213-269 g) and 40 (270-325 g), and significantly increased the kg and number of fruit of sizes >40 (>325 g), such that the pack out of 60+48+40 was equal to that of the control but with more fruit of size >40. The 6-benzyladenine had no significant effect on total yield per tree.

Blumenfield and Gazit (1974) found low levels of auxins, gibberellins and cytokinins in avocado fruit that abscised, compared to normal fruit. Seed production of auxins and gibberellins decreased at the time of abscission while the fruit levels of abscisic acid and ethylene increased. 2,4-D has been related to avocado fruit growth and stimulates both cell division and cell expansion and has shown the potential to increase fruit size (Gazit and Blumenfield 1972). Citrus Fix® (AMVAC Chemical Corp.) contains the auxin 2,4-D and applied as foliar sprays can be used for pre-harvest fruit drop control of Navel, Valencia, grapefruit, lemons, tangelos and other citrus hybrids, as well as to increase fruit size in these citrus and mandarins (Chao, 2005). So far no information is available for avocados. Retain® (Abbott laboratories) is an ethylene biosynthetic pathway inhibitor (aminoethoxyvinylglycine) that, when applied before June drop, may decrease fruit drop and increase yields of several fruit species. No information was available for avocado; however, foliar sprays of 200 $mg{\cdot}L^{-1}$ Retain to Asiatic pear (*Pyrus pyrifolia*) decreased fruit drop (Abbot, 2000). Information on the use of PBR's to improve avocado productivity in Mexico is limited. Thus, the present research was undertaken to quantify the effect of foliar-applied plant bioregulators on the reduction of "June fruit drop" as well as their capacity to increase yield and fruit size of 'Hass' avocado under rainfed conditions.

MATERIALS AND METHODS

Research was conducted during 2001 (Year 1) and 2004 (Year 2) crop cycles in two 16-year-old commercial 'Hass' avocado orchards in the state of Nayarit, Mexico. The 'Alberto' orchard was located in Venustiano Carranza (21º 32' N, 104º 59' W; 900 m above sea level (asl); 1,300 mm annual rain; 21 ºC annual average temp.). The 'Bernabé' orchard was situated in Xalisco (21º 26 ' N, 104º 55' W; 1,100 m asl; 1,185 mm annual rain; 21.7 ºC annual average temp).

Treatments

For Year 1, 20 avocado trees in their "on" crop cycle were selected at each of the Alberto and Bernabé orchards. For Year 2 a total of 60 trees with similar characteristics were chosen at the Alberto orchard. In both orchards trees were grafted on local "criollo" sexual (seedling-raised) rootstocks, spaced at 8 x 8 m and cultivated under rainfed conditions.

PBRs considered in this study were: Accel® (6-benzyladenine 1.8 % plus $GA_{4,7}$ 0.18 %, Abbott Laboratories, North Chicago, IL, USA), Alco/Citrus Fix® (2,4-D 38 %, AMVAC Chemical Corp., Los Angeles, CA, U.S.A.), Retain® (aminoethoxyvinylglycine 15 %, Abbott laboratories, North Chicago, IL, USA.).

In Year 1, fruit growth was quantified in the Alberto and Bernabé orchards and treatments were applied on 3 June when fruit were about 5 to 7 cm long: (T-1) 25 mg·L^{-1} 2,4-D (66 mg·L^{-1} Citrus Fix®), (T-2) 45 mg·L^{-1} aminoethoxyvinylglycine (300 mg·L^{-1} Retain®), (T-3) 0.45 mg·L^{-1} 6-benzyladenine (25 mg·L^{-1} Accel®), and (T-4) control (surfactant only).

For Year 2, treatments were modified and applied only in the Alberto orchard when fruit were 3-4 cm long (20 May) or 5-7 cm long (15 June) and were: (T-1) 10 mg·L^{-1} 2,4-D (26.3 mg·L^{-1} Citrus Fix®) in May and June, (T-2) 12.5 mg·L^{-1} 2,4-D (23.9 mg·L^{-1} Citrus fix®) in May and June, (T-3) 20 mg·L^{-1} 2,4-D (52.6 mg·L^{-1} Citrus Fix®) in June, (T-4) 22.5 mg·L^{-1} aminoethoxyvinylglycine (150 mg·L^{-1} Retain®) in May and June, and (T-5) 45 mg·L^{-1} aminoethoxyvinylglycine (300 mg·L^{-1} Retain®) in June, (T-6) control (surfactant only).

Treatments were applied between 7:00 and 9:00 A.M., approximately 1 month before the expected start of June drop, with a backpack motorized sprayer (Efco Model IS-2026, Reggio Emilia-Italy). To assure full canopy coverage 10 ± 1 L of aqueous solution (pH 5.5) per tree was used. The surfactant Silwet L-77® (Loveland Industries INC., Greeley, CO, USA) at 1 mg·L^{-1} was added to all treatments, including the control.

Fruit Drop and Yield

The intensity of June fruit drop was assessed on four branches 1 m in length and 6 to 10 cm in diameter evenly distributed around each experimental tree. The number of fruit present on each selected branch was recorded at the time of treatment (May or June) as well as in September, after the end of the June drop period.

Total yield per tree and the proportion of fruit of various sizes were determined at harvest in both Year 1 (13 Nov. 2001) and Year 2 (12 Nov. 2004) for all replicates. 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: marble (<135 g), second (135-169 g), first (170-210 g), extra (211-265 g) and super extra (>266 g).

Statistical Analyses

The experiments had a randomized complete block design. In Year 1, a randomized block design with five single-tree replications per orchard was used. For year 2 the same experimental design was used but with 10 single-tree replications. 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 and is reported at P = 0.05.

RESULTS

Intensity of June Fruit Drop

In Year 1 intensity of June fruit drop was not significantly affected by PBRs applied in either the Alberto and Bernabé 'Hass' avocado orchards (Table 1). June drop ranged from 33.1% to 54.1% with the lower values for the treatment with 25 mg·L^{-1} 2,4-D applied on 3 June.

For Year 2 the control trees had the greatest amount of June fruit drop (66 %) and all treatments with 2,4-D or aminoethoxyvinylglycine significantly reduced the intensity of fruit drop (Table 2). The effect of two applications of 2,4-D at 10 or 12.5 mg·L^{-1} in May and June was not different (49.5 and 47.9 %, respectively).

Effect of PBRs on Yield and Fruit Size

Total yield per tree was not significantly affected by any PBR treatment in either year of the study and fluctuated from 81.6 to 108.4 kg/tree in Year 1 and from 148.9 to 179.7 kg/tree in Year 2 (Tables 3 and 4).

Treatments with PBRs increased fruit size by decreasing the production of fruit of sizes marble and second. In Year 1, a single application in June of 2,4-D, aminoethoxyvinylglycine, or 6-benzyladenine decreased the production of fruit of sizes marble plus second to a value ranging from 42.3 to 55.6 kg/tree compared to 81.9 kg/tree produced by the control (Table 3).

For Year 2, the application of any treatment based on 2,4-D or aminoethoxyvinylglycine increased the production of large size fruit (≥ first). This effect was reflected in the increased production of fruit of the combined pool of first+extra+superextra which ranged from 108 to 120 kg/tree compared to 73 kg/tree for the control (Table 4). Control trees had the greatest production of smaller size fruit (marble+second), which reached 75.9 kg/tree.

DISCUSSION

In Year 1, percentage of fruit drop in June was lower for treatments of 2,4-D or aminoethoxyvinylglycine applied on 3 June. Based on these results, a second year of research testing more treatments was undertaken. Results of Year 2 showed that all PBRs evaluated reduced the intensity of June fruit drop by 16.5% to 19.4% compared to control trees. The economic benefit over the cost of product plus application expenses identified two treatments as the most profitable: i) 20 $mg \cdot L^{-1}$ 2,4-D (52.6 $mg \cdot L^{-1}$ Citrus Fix®) in June, or ii) 45 $mg \cdot L^{-1}$ aminoethoxyvinylglycine (300 $mg \cdot L^{-1}$ Retain®) in June.

Under rainfed conditions of Nayarit soil available moisture in a mature 'Hass' avocado orchards may decrease up to 50% to 60% in the top-soil (50-cm depth). Water-deficit stress imposed on avocado trees in this condition makes it reasonable to expect a decrease in growth promoting substances (i.e. auxins, cytokinins, gibberellins) and a concomitant increase in growth inhibiting substances (i.e. abscisic acid and ethylene) as was found by Blumenfield and Gazit (1974) in abscising avocado fruit. The reduction of June fruit drop by means of tree canopy sprays of 2,4-D or aminoethoxyvinylglycine could logically be attributed to their capacity to increase the levels of auxins in the avocado fruit and decrease the levels of ethylene, respectively. Positive effects of 2,4-D in controlling fruit drop are common for several citrus cultivars (Coggins, 1981; Chao, 2005). However, the present research constitutes the first report for avocados.

In the present study, the reduction in the intensity of June fruit drop did not significantly increase yield. However, yields were relatively high for orchards under rainfed conditions, 81.6 to 179.7 kg/tree (spaced at 8 x 8 m).

Based on total yield per tree, in Year 1, 78.1% of the fruit produced by control trees were of smaller sizes (marble+second; <135-169 g per fruit). In contrast, the proportion of smaller fruit was only 51.3%, 44.1%, and 53.8% for 2,4-D, aminoethoxyvinylglycine and 6-benzyladenine, respectively.

In Year 2, control trees produced only 49% of total yield as the combined pool of first+extra+superextra. In contrast, trees receiving the best treatments for reducing June fruit drop, 20 $mg \cdot L^{-1}$ 2,4-D in June, or 45 $mg \cdot L^{-1}$ aminoethoxyvinylglycine in June, produced 66.3% and 67.1% of their fruit in these larger size categories, respectively. Similar results were found in California by Lovatt (2004), where 'Hass' avocado trees treated with 6-benzyladenine produced fewer small size fruit and a greater number of large size fruit of packing cartoon sizes 60+48+40 and > 40 (178->325 g/fruit).

In the present research we have documented that the intensity of June fruit drop in untreated 'Hass' avocado trees cultivated under rainfed conditions was 47% to 66%. And that a reduction in the intensity of June drop can be achieved with foliar applications of 2,4-D or aminoethoxyvinylglycine in June. In addition, these treatments significant increased fruit size. This result will be of great economic benefit to the Nayarit avocado grower.

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Tables

Table 1. Effect of several foliar-applied PBRs on the intensity of June fruit drop of 'Hass' avocado. Average of the Alberto and Bernabé orchards. Year 1 experiment.

Treatments (applied on 3 June 2001)	N[1]	Fruit drop[2] (%)
25 $mg \cdot L^{-1}$ 2,4-D (as Citrus Fix)	7.2	33.1 a[3]
45 $mg \cdot L^{-1}$ aminoethoxyvinylglycine (as Retain)	14.7	43.2 a
0.45 $mg \cdot L^{-1}$ 6-benzyladenine (as Accel)	12.4	54.1 a
Control (surfactant only)	15.9	47.0 a
Pr>F		0.0998

[1] Average number of fruit per branch present at the time of treatment.
[2] Evaluation performed on 3 Sep. 2001.
[3] Means comparison in columns by Duncan, P = 0.05.

Table 2. Effect of foliar-applied 2,4-D and aminoethoxyvinylglycine (AVG) on the intensity of June fruit drop in the Alberto 'Hass' avocado orchard. Year 2 experiment.

Treatments	N[1]	Fruit drop[2] (%)
10 mg·L^{-1} 2,4-D (as Citrus Fix) on 20 May and 15 Jun.	22.0	49.5 b[3]
12.5 mg·L^{-1} 2,4-D (as Citrus Fix) on 20 May and 15 Jun.	14.9	47.9 b
20 mg·L^{-1} 2,4-D (as Citrus Fix) on 15 Jun.	18.1	46.6 b
22.5 mg·L^{-1} AVG (as Retain) on 20 May and 15 Jun.	19.4	48.0 b
45 mg·L^{-1} AVG (as Retain) on 15 Jun.	22.2	48.7 b
Control (surfactant only)	20.3	66.0 a
Pr>F		0.0001

[1] Average number of fruit per branch at the date of treatment.
[2] Evaluation performed on 9 Sep. 2004.
[3] Means comparison in columns by Duncan, P = 0.05.

Table 3. Effect of several foliar-applied PBRs on total fruit yield and fruit size of 'Hass' avocado. Average of the Alberto and Bernabé orchards. Year 1 experiment harvested on 13 Nov. 2001.

Treatments (applied on Jun.)	Total. (kg/tree)	Yield according to fruit size (kg/tree)						
		Marble (M) (<135 g)	Second (S) (135-169 g)	First (F) (170-210 g)	Extra (E) (211-265 g)	S. Extra (SE) (>266 g)	M+S (<135-169 g)	F+E+SE (170->266 g)
25 mg·L^{-1} 2,4-D (as Citrus Fix)	108.4 a[1]	26.6 b	29.0 a	29.1 a	21.2 a	2.5 a	55.6 b	52.8 a
45 mg·L^{-1} aminoethoxyvinylglycine (as Retain)	96.0 a	18.7 b	23.6 a	24.6 a	22.6 a	6.5 a	42.3 b	53.7 a
0.45 mg·L^{-1} 6-benzyladenine (as Accel)	81.6 a	11.4 c	32.5 a	25.7 a	10.5 a	1.5 a	43.9 b	37.7 a
Control (surfactant only)	104.9 a	45.6 a	36.3 a	11.8 a	7.6 a	3.6 a	81.9 a	23.0 a
Pr>F	0.0945	0.0011	0.3562	0.0760	0.2439	0.1525	0.0002	0.0626

[1] Means comparison in columns by Duncan, *P* = 0.05.

Table 4. Effect of foliar-applied 2,4-D and aminoethoxyvinylglycine (AVG) on total fruit yield and fruit size of 'Hass' avocado in the Alberto orchard. Year 2 experiment harvested on 12 Nov. 2004.

Treatments	Total (kg/tree)	Yield according to fruit size (kg/tree)						
		Marble (M) (<135 g)	Second (S) (135-169 g)	First (F) (170-210 g)	Extra (E) (211-265 g)	S. Extra (SE) (>266 g)	M+S (<135-169 g)	F+E+SE (170->266 g)
10 mg·L^{-1} 2,4-D (as Citrus Fix) on 20 May and 15 Jun.	174.5 a[1]	14.9 b	44.3 a	63.2 a	33.4 a	18.7 a	59.2 b	115.3 a
12.5 mg·L^{-1} 2,4-D (as Citrus Fix) on 20 May and 15 Jun.	179.7 a	17.6 b	42.1 a	67.4 a	32.7 a	19.9 a	59.7 b	120.0 a
20 mg·L^{-1} 2,4-D (as Citrus Fix) on 15 Jun.	174.5 a	18.1 b	40.8 a	65.5 a	31.0 a	19.1 a	58.9 b	115.6 a
22.5 mg·L^{-1} AVG (as Retain) on 20 May and 15 Jun.	170.9 a	16.6 b	46.3 a	59.3 a	30.4 a	18.3 a	62.9 ab	108.0 a
45 mg·L^{-1} AVG (as Retain) on 15 Jun.	161.4 a	14.6 b	38.6 a	60.8 a	31.6 a	15.8 a	53.2 b	108.2 a
Control (surfactant only)	148.9 a	27.6 a	48.3 a	36.9 b	26.6 a	9.5 b	75.9 a	73.0 b
Pr>F	0.0749	0.0158	0.3920	0.0001	0.7568	0.0159	0.0436	0.0001

[1] Means comparison in columns by Duncan, *P* = 0.05.