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Use of Plant Growth Regulators to Increase Fruit Set, Fruit Size and Yield and to Manipulate Vegetative and Floral Shoot Growth

Continuing Project: Year 2 of 4

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Benefit to the Industry

This research addresses the research priority: "The role of endogenous and exogenous growth regulators in avocado and the evaluation of commercial growth regulators on flowering, fruit set, fruit size, yield and vegetative growth."

The results of this project will provide both practical and basic information to guide the avocado industry in the use of commercial plant growth regulators (PGRs) to: (1) prevent flower abscission; (2) to reduce fruit abscission during fruit set, June drop and preharvest drop for late hanging fruit; (3) to increase fruit size; and (4) to regulate growth of vegetative shoots and indeterminate floral shoots.

It has long been the goal of growers and researchers alike to be able to manipulate the vegetative and reproductive growth of crop plants. Avocado growers and researchers are no exception. At the present time, plant growth regulators are perhaps the most powerful tools available for achieving this goal. However, in the specific case of avocado production, the use of PGRs remains underdeveloped despite the enormous potential that PGRs offer for maximizing yield, optimizing fruit size and quality, and increasing net dollar return to the grower. In contrast, for a wide variety of tree crops, there are many examples of the successful use of PGRs to solve production problems. PGRs have been used successfully as foliar sprays to increase flowering, synchronize bloom, or change the time of flowering to avoid adverse climatic conditions or to shift harvest to a time when the market is more economically favorable. Foliar-applied PGRs are routinely used to improve fruit set, reduce June drop or to prevent pre-harvest drop to increase yield. PGRs sprays are applied to increase fruit size directly by stimulating cell division or to increase fruit size indirectly by decreasing fruit number through the application of PGRs that reduce the number of flowers formed or promote flower or fruit abscission. PGRs have been used as both pre- and post-harvest treatments to hasten or slow the ripening process, color development, and maturation of specific fruit tissues to improve the quality of the product sold in the market. More recently, success has been achieved using PGRs to even out alternate bearing and increase cumulative yield for multiple alternate bearing cycles. The emerging use of PGRs to overcome the adverse effects of abiotic stresses is increasingly successful. Surprisingly, these successes have been achieved with a modest number of commercial PGRs that are members of one of the five classic groups of plant growth regulators: auxins, cytokinins, gibberellins, abscisic acid and ethylene. Hence, the tools we need are already available.

If PGRs can be used successfully to solve production problems in other tree crops, they can be used to solve these same problems in avocado production.

Limited research has been conducted on the use of foliar-applied plant growth regulators in avocado production. This is especially true in California. The research will provide much needed information on the best PGR and time of application for increasing fruit set and/or size and how these treatments affect the growth of indeterminate floral and vegetative shoots. This research will provide the first information for whole trees on the effects of foliar-applied 6-benzyladenine and prohexadione-Ca on fruit set, fruit size, yield, growth of vegetative shoots and indeterminate floral shoots, and on return bloom the following spring. If treatments are successful, we will have the first efficacy data needed for adding avocado to commercial PGR labels.

Objectives

The objectives are to screen four PGRs, 6-benzyladenine, GA_3, prohexadione-Ca, and CPPU, for their ability to increase fruit set, fruit size and yield without reducing quality or return bloom and to learn their effect on growth of vegetative and indeterminate floral shoots.

Accel (Valent BioSciences$_{TM}$ Corp.) contains the cytokinin 6-benzyladenine (1.8%) plus $GA_{4,7}$ (0.18%). Cytokinins stimulate cell division, increase sink activity to improve the ability of fruit to compete for resources (Bower and Cutting, 1988), prevent leaf abscission and aging, and maintain leaves as sources of photosynthetic carbon, nitrogen and other nutrients and endogenous PGRs. This may be important during flowering and fruit set, both of which rely on resources provided by mature leaves. High levels of cytokinin during early fruit development are critical for obtaining large size fruit (Cutting, 1993; Cowan et al., 1997). Accel is registered in California for use on apples, necessitating only efficacy data to add avocado to the label.

ProGibb (Valent BioSciences$_{TM}$ Corp.,) contains 4% GA_3, which is known to stimulate cell enlargement. GAs are important in the early stages of fruit development and fruit set. Work by Salazar-Garcia and Lovatt (2000) demonstrated that GA_3 increases fruit set and size when applied in March. Other application times need to be tested with these goals in mind to complement our GA_3 research testing the use of GA_3 to even out alternate bearing and increase cumulative yield. With sufficient efficacy data, some of which must be collected in California, avocado could be added to the ProGibb label and used in commercial avocado production in California.

Apogee (BASF) contains 27% prohexadione calcium, a new GA biosynthesis inhibitor. Test results on apple show that prohexadione calcium at 125 mg ai/L inhibits vegetative shoot growth for approximately 4 weeks. We are using prohexadione-Ca to inhibit the growth of the vegetative shoot of indeterminate inflorescences to reduce the competition that exists between setting fruit and the developing flush. Previous work using Paclobutrazol to inhibit vegetative shoot growth during the fruit set period was successful in increasing total yield and total number of fruit of export size (Kremer-Köhne and Köhne, 1998). Prohexadione-Ca offers a safe alternative to Paclobutrazol.

CPPU **(Valent BioSciences$_{TM}$ Corp.), N-2-chloro-4-pyridinyl-N-phenylurea, is a powerful cytokinin. There is currently a section 3 for its experimental use in California.**

Experimental Plan and Design

We are testing the efficacy of 6-benzyladenine, GA_3, prohexadione-Ca and CPPU in the following treatments: (1) GA_3 (25 mg ai/L) applied at S-8, cauliflower stage; (2) prohexadione-Ca (125 mg ai/L) applied at S-8 (cauliflower stage) and at S-11 (anthesis); (3) 6-benzyladenine (25 mg ai/L) applied at S-11, anthesis; (4) CPPU (15 mg ai/L) in July just prior to the period of exponential fruit growth; (5) GA_3 (25 mg ai/L) applied in mid-July [prior to S-2 (transition from vegetative to reproductive growth)] followed by prohexadione-Ca (125 mg ai/L) 30 days later (mid-August); and (6) control trees receiving no PGRs. Yield (kg/tree), fruit size distribution (pack out) and fruit quality of 100 randomly selected fruit, including seed size and germination, fruit length to width ratio, and vascularization, discoloration and decay are determined at harvest. Leaves are collected in September for nutrient analysis (Albion Laboratories). The experimental design is randomized complete block with 20 individual tree replicates per treatment. There are buffer trees between treated trees and buffer rows between treated rows. The research is being conducted in a commercial orchard owned by the Irvine Company. This orchard is maintained by regular pruning.

Summary

The harvest for year 1 of this project was scheduled for July 2002. The trees were harvested in March, 1 day after my visit to the orchard to check tree phenology and 1 day before my SRA's visit to the orchard to apply treatments! The treatments had no significant effect on the length of vegetative shoots or the vegetative shoot of indeterminate inflorescences by the end of June.

The harvest for year 2 was in July 2003. GA_3 significantly increased shoot elongation 30 days after treatment but significantly reduced total yield per tree and the kg and number of fruit in all size categories except sizes $\geq$ 40 compared to the control (Tables 1 and 2). Thus, GA_3 significantly reduced the pack out of fruit of size 60+48+40. This result is consistent with the findings of Lauren Garner (personal communication) that despite early and rapid vegetative shoot development in response to GA_3, GA_3 actually slows leaf maturation and keeps a higher percentage of leaves of indeterminate inflorescences as sinks rather than sources for a longer period of time. Consistent with the findings of Lauren Garner (personal communication),
prohexadione-Ca inhibited the growth of the vegetative shoot apex of indeterminate inflorescences, but not the growth of vegetative shoots. Prohexadione-Ca decreased the kg and number of fruit in all size categories from 84 through 60 but had no effect on fruit of sizes 48 or 40. Thus, prohexadione-Ca had no significant effect on total yield or the pack out of fruit of sizes 60+48+40. Prohexadione-Ca increased the kg and number of fruit of sizes > 40. 6-Benzyladenine significantly reduced the kg and number of fruit of sizes 70 and 60, had no effect on fruit of size 48 and 40, and significantly increased the kg and number of fruit of sizes > 40 such the pack out of 60+48+40 was equal to that of the control but with more fruit of size > 40. 6-Benzyladenine had no significant effect on total yield per tree. Neither CPPU nor GA_3 followed by prohexadione-Ca had a significant effect on total yield. Both treatments reduced the kg and number of fruit of sizes 70 and 60.

The PGR treatments had no significant effect on the length of time it took for fruit to ripen (Table 3). Prohexadione-Ca applied at the cauliflower stage of inflorescence development and again at anthesis resulted in fruit that were significantly longer than fruit from the untreated control trees ($P \leq 0.05$). No other PGR treatment significantly affected fruit length. All PGR treatments, except CPPU, significantly increased the diameter of the fruit compared to control fruit ($P \leq 0.01$). All PGR treatments significantly increased the diameter of the seed compared to the seed of fruit from untreated control trees ($P \leq 0.01$). However, since the PGR treatments increased fruit diameter, the increase in seed diameter did not result in a loss in flesh width (Table 3). The PGR treatments had no significant effect on internal fruit quality (Table 4).

Harvest for year 3 was in April 2004. GA_3 significantly increased total yield in terms of both kg and number of fruit per tree by significantly increasing both kg and number of fruit of size 70, 60 and 48 (Tables 5 and 6). The packout of fruit of 60+40+48 was significantly greater than the control as both kg and number of fruit per tree. No other PGR treatment had any effect on yield or packout as kg or number of fruit per tree compared to the control (Tables 5and 6). No PGR affected the days to ripen, seed size or internal fruit quality (Tables 7 and 8).

Harvest for year 4 will be in April 2005.

Key Points from the Research Thus Far

The results with GA_3 are consistent with those we obtained in Carpinteria. GA_3 only increases fruit size and packout of larger sized fruit (60+48+40) in an on crop year. No PGR treatment had a negative effect on fruit quality.

Harvest for year 3 will be in July 2004.

Literature Cited

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Table 1. Effect of PGR treatments applied each spring on total kg fruit and kg fruit of packing carton sizes 84, 70, 60, 48, 40, and greater than 40 per tree of 'Hass' avocado trees harvested in 2003.

		Packing carton size							
PGR treatment	Total	84	70	84+70	60	48	40	60+48+40	>40
	kg fruit/tree								
GA_3	17.59 b[z]	0.32 b	1.38 b	1.69 b	2.31 b	6.53	5.57 c	14.41 b	1.49 b
Apogee	37.54 a	0.61 b	2.47 b	3.08 b	4.60 b	14.44	11.48 ab	30.51 ab	3.95 a
Accel	39.06 a	1.01 ab	2.94 b	3.95 b	5.22 b	13.89	12.23 a	31.34 a	3.77 a
CPPU	29.46 ab	1.12 ab	2.87 b	4.00 b	4.43 b	11.37	7.22 bc	23.01 ab	2.45 ab
GA_3 and Apogee	40.07 a	1.15 ab	3.12 b	4.27 b	5.60 b	16.40	11.09 ab	33.09 a	2.71 ab
Control	46.61 a	1.82 a	6.50 a	8.33 a	10.06 a	19.43	7.19 bc	36.69 a	1.59 b
LSD	18.74	0.93	2.75	3.50	4.16	9.34	4.86	16.15	1.98
P-value	0.05	0.04	0.01	0.01	0.01	0.12	0.03	0.08	0.07

[z] Values in a vertical column followed by different letters are significantly different at specified *P* levels by LSD Test.

Table 2. Effect of PGR treatments applied in spring on total number of fruit and number fruit of packing carton sizes 84, 70, 60, 48, 40, and greater than 40 per tree of 'Hass' avocado trees harvested in 2003.

		Packing carton size							
PGR treatment	Total	84	70	84+70	60	48	40	60+48+40	>40
	no. fruit/tree								
GA_3	73 c[z]	3 b	9 b	12 b	12 b	27	19 c	58 b	4 b
Apogee	154 abc	5 b	16 b	21 b	24 b	60	39 ab	122 ab	11 a
Accel	164 ab	9 ab	19 b	28 b	27 b	58	41 a	126 a	11 a
CPPU	129 bc	10 ab	18 b	28 b	23 b	47	24 bc	94 ab	7 ab
GA_3 and Apogee	172 ab	10 ab	20 b	30 b	29 b	68	37 ab	134 a	8 ab
Control	218 a	16 a	42 a	57 a	52 a	81	24 bc	156 a	5 b
LSD	85	8	18	24	21	39	16	68	6
P-value	0.03	0.04	0.01	0.01	0.01	0.12	0.03	0.08	0.07

[z]Values in a vertical column followed by different letters are significantly different at specified *P* levels by LSD Test.

Table 3. Effect of PGR treatments applied in spring on days to ripen and fruit quality of 'Hass' avocado trees harvested in 2003.

PGR treatment	Days to ripen	Fruit length	Fruit diameter	Seed diameter	Flesh width[z]
		-- *mm*	--	--	--
-					
GA_3	11	104 ab[y]	69 a	38 a	15.5
Prohexadione-Ca	11	107 a	68 ab	37 a	15.0
6-Benzyladenine	11	104 ab	67 ab	36 a	15.5
CPPU	12	101 b	66 bc	36 a	14.5
GA_3 and Prohexadione-Ca	12	100 b	68 ab	36 a	16.0
Control	11	101 b	64 c	33 b	15.0
LSD	1	5	3	3	1.5
P-value	0.73	0.05	0.01	0.01	0.67

[z] Width of the fruit flesh from the peel to the seed.

[y]Values in a vertical column followed by different letters are significantly different at specified *P* levels by LSD Test.

Table 4. Effect of PGR treatments applied in spring on internal fruit quality[z] of 'Hass' avocado trees harvested in 2003.

PGR treatment	Flesh quality: Vascularization	Flesh quality: Discoloration	Flesh quality: Decay	Seed germination
	---------- *Visual evaluation (0-4)* ----------			
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GA_3	0.8	0.3	0.4	0.2
Prohexadione-Ca	0.7	0.4	0.3	0.1
6-Benzyladenine	0.6	0.4	0.3	0.2
CPPU	0.9	0.5	0.3	0.1
GA_3 and Prohexadione-Ca	0.6	0.5	0.2	0.1
Control	0.5	0.2	0.2	0.2
LSD	0.4	0.4	0.3	0.2
P-value	0.34	0.47	0.84	0.63

[z]When ripe, internal fruit quality was evaluated for abnormalities and discoloration. Vascularization (presence of vascular bundles and associated fibers) of the flesh was also determined. The internal fruit quality parameters were visually rated on a scale from 0 (normal) to 4 (high incidence of abnormalities, discoloration, or vascularization).

Table 5. Effect of PGR treatments applied in spring on total kg fruit and kg fruit of packing carton sizes 84, 70, 60, 48, 40, and greater than 40 per tree of 'Hass' avocado trees harvested in 2004.

PGR treatment	Total	Packing carton size 84	70	84+70	60	48	40	60+48+40	>40
	kg fruit/tree								
GA_3	41.79 a[z]	1.87 a	8.96 a	10.83 a	15.40 a	13.11 a	2.33	30.84 a	0.12
Prohexadione-Ca	23.13 bc	0.47 bc	3.63 b	4.10 b	7.24 b	9.03 ab	2.72	18.99 bc	0.04
6-Benzyladenine	22.34 bc	0.36 c	2.99 b	3.35 b	5.81 b	10.31 ab	2.79	18.91 bc	0.08
CPPU	30.57 b	1.66 ab	5.43 ab	7.09 ab	8.77 b	11.94 a	2.58	23.29 ab	0.20
GA_3 and Prohexadione-Ca	16.72 c	0.60 bc	2.78 b	3.38 b	5.25 b	6.40 b	1.59	13.24 c	0.10
Control	21.13 bc	1.09 abc	4.68 b	5.77 b	7.11 b	6.94 b	1.26	15.31 bc	0.05
LSD	10.34	1.25	3.55	4.63	4.88	4.57	1.36	8.47	0.21
P-value	<0.0001	0.07	0.01	0.01	0.001	0.02	0.15	0.001	0.72

[z] Values in a vertical column followed by different letters are significantly different at specified *P* levels by LSD Test.

Table 6. Effect of PGR treatments applied in spring on total number of fruit and number fruit of packing carton sizes 84, 70, 60, 48, 40, and greater than 40 per tree of 'Hass' avocado trees harvested in 2004.

		Packing carton size							
PGR treatment	Total	84	70	84+70	60	48	40	60+48+40	>40
	no. fruit/tree								
GA_3	215 a[z]	16 a	57 a	73 a	79 a	54 a	8	141 a	0
Prohexadione-Ca	111 bc	4 bc	23 b	27 b	37 b	37 ab	9	84 bc	0
6-Benzyladenine	104 bc	3 c	19 b	22 b	30 b	43 ab	9	82 bc	0
CPPU	153 b	14 ab	35 ab	49 ab	45 b	50 a	9	103 ab	1
GA_3 and Prohexadione-Ca	82 c	5 bc	18 b	23 b	27 b	27 b	5	59 c	0
Control	109 bc	9 abc	30 b	39 b	36 b	29 b	4	69 bc	0
LSD	56	11	23	32	25	19	5	39	1
P-value	<0.0001	0.07	0.01	0.01	0.001	0.02	0.15	0.001	0.72

[z] Values in a vertical column followed by different letters are significantly different at specified *P* levels by LSD Test.

Table 7. Effect of PGR treatments applied in spring on days to ripen and fruit quality of 'Hass' avocado trees harvested in 2004.

PGR treatment	Days to ripen	Fruit length	Fruit diameter	Seed diameter	Flesh width[z]
		-- *mm* --			
-					
GA_3	14	93	67	38	28.8
Prohexadione-Ca	14	95	68	39	29.2
6-Benzyladenine	14	96	67	39	28.0
CPPU	14	97	68	40	28.5
GA_3 and Prohexadione-Ca	14	96	68	39	28.8
Control	14	95	68	38	29.9
LSD	1	5	3	2	2.0
P-value	0.30	0.70	0.93	0.73	0.48

[z] Width of the fruit flesh from the peel to the seed.

[y] Values in a vertical column followed by different letters are significantly different at specified *P* levels by LSD Test.

Table 8. Effect of PGR treatments applied in spring on internal fruit quality[z] of 'Hass' avocado trees harvested in 2004.

PGR treatment	Flesh quality			Seed germination
	Vascularization	Discoloration	Decay	
	-- *Visual evaluation (0-4)* --			
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GA_3	0.3	0.08	0.20	0.03
Prohexadione-Ca	0.4	0.03	0.03	0.00
6-Benzyladenine	0.5	0.05	0.18	0.00
CPPU	0.2	0.03	0.03	0.00
GA_3 and Prohexadione-Ca	0.6	0.27	0.08	0.00
Control	0.3	0.05	0.05	0.05
LSD	0.3	0.13	0.22	0.07
P-value	0.31	0.27	0.50	0.53

[z] When ripe, internal fruit quality was evaluated for abnormalities and discoloration. Vascularization (presence of vascular bundles and associated fibers) of the flesh was also determined. The internal fruit quality parameters were visually rated on a scale from 0 (normal) to 4 (high incidence of abnormalities, discoloration, or vascularization).