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Eliminating Alternate Bearing of the ‘Hass’ Avocado

Continuing Project: Year 2 of 4

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Benefit to the Industry

This research addresses the objective of the California avocado industry to develop and implement research programs that lead to increased grower profitability.

Annual production data for the last 14 years clearly depict 2- to 3-year on-off cycles for the California industry (Brokaw Nursery Inc., 2002; California Avocado Commission, www.avocado.org). The alternate bearing index [ABI = (year 1 yield – year 2 yield) ÷ (year 1 yield + year 2 yield)] for our numerous research orchards ranges from 0.57 to 0.92 (Lovatt, 1997). By this calculation, every other year grower income is significantly reduced below the orchard’s potential. Lower yields (5,700 lbs./a) in the 1990’s (Arpaia, 1998) reduced ABI, but reduced yields are not an acceptable solution to alternate bearing. Moreover, it is only a matter of time before climatic conditions initiate alternate bearing in avocado growing areas entraining trees again in on-off cycles. Alternate bearing is initiated by climatic conditions (freeze damage, high temperatures, drought) causing flower or fruit abscission which result in an off-crop year that is followed 1, 2 or 3 years later by an on-crop year, depending on how long it takes for the trees to recover. Conversely, climatic conditions that are optimal for flowering and fruit set such that crop thinning fails to take place result in an on-crop that is followed by an off-crop. Once initiated, alternate bearing becomes entrained through the effect of crop load on endogenous tree factors that ultimately impact floral intensity (Salazar-García et al., 1998). Thus, there is a recurring need for a corrective strategy that does not reduce yield, but the mechanism and the underlying physiological basis by which yield one year affects yield the next year remain unknown for avocado. The cultural practice of harvesting late to increase fruit dry matter and oil content exacerbates alternate bearing (Whiley, 1994); whereas early harvest (not possible in many areas or years if fruit due not meet legal maturity) or fruit removal by pruning or chemical or hand fruit thinning in an on-crop year reduce the severity of alternate bearing, they all reduce yield. The proposed research will define the mechanism by which alternate bearing becomes entrained in ‘Hass’ avocado and identify the physiology underlying the mechanism and devise and test strategies to eliminate alternate bearing.

Salazar-García et al. (1998) and Salazar-Garcia and Lovatt (2000) demonstrated that avocado trees carrying a heavy on crop produced vegetative shoots at the expense of floral shoots (inflorescences). Conversely, trees carrying a light off crop produced floral shoots at the expense of vegetative shoots. Crop load had no effect on the number of flowers per inflorescence. Reciprocity between floral vs. vegetative shoot development for on-crop vs. off-crop trees suggests that endogenous plant hormones might be playing a more important role in alternate bearing in ‘Hass’ avocado than resource (e.g., carbohydrate, N or other nutrient) availability, which would have resulted in a reduction in both vegetative and floral shoot development for trees carrying an on-crop. In a current study on nutrient partitioning in ‘Hass’ avocado (Rosecrance and Lovatt, unpublished), off-crop trees (low set in spring 2001 and remaining fruit removed in July 2001) produced significantly more reproductive structures and set more fruit for the 2002 return bloom (an average of 1.33 kg dry wt./tree per month March through June 2002) than trees that were not defruited in July 2001, which averaged only 0.08 kg dry wt./tree per month over the same period. Surprisingly, the presence of only a few fruit (2 kg, ~10 fruit) was sufficient to reduce the 2002 return bloom, indicating that the effect of fruit was not limited to the shoot on which they set.

Four questions need to be answered to solve the problem of alternate bearing of the ‘Hass’ avocado. (1) For on-crop trees, is reduced return bloom due to inhibition of vegetative shoot production and thus a lack of “wood” to bear next spring’s inflorescences? (2) Or, alternatively is reduced return bloom for on-crop trees due to inhibition of inflorescence development on an <u>adequate number of vegetative shoots</u>? (3) Are fruit the source of hormones or other compound(s) responsible for inhibition of vegetative or floral shoot development, whichever the case proves to be? (4) Does resource availability (carbohydrate, N and other nutrient reserves) play a role in alternate bearing in the ‘Hass’ avocado? Preliminary results suggest that it is the inhibition of vegetative shoot growth in spring-summer when trees are carrying a heavy on-crop that results in reduced flowering the following spring (Paz-Vega, 1997). Supplying a double dose of N in mid-April (anthesis, fruit set and initiation of the spring vegetative flush) significantly reduced alternate bearing for the 4 years of the study presumably by increasing vegetative shoot growth (Lovatt, 2001). However, export of compounds from the developing fruit that inhibit the transition of vegetative shoot apices to floral meristems cannot be ruled out (Paz-Vega, 1997). Moreover, evidence is accumulating in the literature that high nitrogen fertilization stimulates cytokinin production by roots. Jaime Salvo, a Ph.D. student in my lab., demonstrated that this is occurs for the ‘Hass’ avocado. This may be the reason why a double dose of N in mid-April contributes to reducing alternate bearing. Thus, in this investigation of alternate bearing, we will analyze the content of C, N and other nutrients in branches of on- and off-crop trees and in the roots of on- and off-crop trees and evaluate the effect of crop load not only on shoot development but also root development. The proposed research also relates to the following priority: “The role of endogenous and exogenous plant growth regulators in avocado and the evaluation of commercial growth regulators on flowering, fruit set, fruit size, yield and vegetative growth.” This research will also provide data sought under the priority related to canopy management, i.e., innovative techniques to increase production.

The proposed research supports the industry objectives, expectations and visions of increasing grower profitability. In orchards exhibiting alternate bearing, yield is reduced below the potential of the orchard and grower income is significantly reduced. The PI has successfully reduced the impact of alternate bearing in pistachio and is working towards eliminating alternate bearing in ‘Pixie’ mandarin. Similarities in the physiology underlying the mechanisms of entrainment are emerging. Furthermore, our approach to identifying the physiology underlying the mechanism of entrainment has proven valid in the two systems and is easily adaptable to the ‘Hass’ avocado. The results of this research will significantly increase yield and grower profitability. In addition, the results will identify treatments that can be used to increase floral intensity in other situations or annually. It is clear that yield is related to inflorescence number (Salazar-Garcia et al., 1998).

In addition, this project will save time in developing the use of exogenous foliar applications of PGRs to increase yield by identifying the specific PGR and phenological stage at which the PGR should be applied to eliminate alternate bearing. It will likely also utilize the results we have obtained in our previous CAC-funded research on N fertilization which demonstrated that supplying a double dose of N in mid-April (anthesis, fruit set and initiation of the spring vegetative flush) significantly reduced alternate bearing for the 4 years of the study.

Objectives

(1) To determine for on-crop trees if reduced return bloom is due to inhibition of vegetative shoot production and thus a lack of "wood" to bear next spring's inflorescences. (2) To determine if reduced return bloom for on-crop trees is due to inhibition of inflorescence development on an <u>adequate number of vegetative shoots.</u> (3) To determine if fruit are the source of hormones or other compound(s) responsible for inhibition of vegetative or floral shoot development, whichever the case proves to be. (4) To determine if resource availability (carbohydrate, N and other nutrient reserves) plays a role in alternate bearing in the 'Hass' avocado.

Experimental Plan and Design

Year 1 – To determine whether reduced flowering in spring for on-crop trees is due to a reduced number of vegetative shoots, on which to bear the inflorescences the following spring or to straightforward inhibition of inflorescence development on an adequate number of vegetative branches, we will conduct the following experiments. The experiments will be conducted in a commercial orchard exhibiting strong alternate bearing starting with a heavy on-year bloom. For 10 branches on each of 10 on-crop and 10 off-crop trees in the same orchard we will quantify the amount of shoot growth on each branch monthly starting in mid-April and the amount of floral and vegetative shoot growth during next spring bloom. Using a separate set of 20 on-crop trees, each month starting in April we will remove fruit from 10 branches of 10 on-crop trees (the remaining 10 on-crop trees will not have fruit removed) and quantify vegetative shoot production in response to fruit removal vs. no fruit removed and vegetative and floral shoot production during spring bloom the following year to determine the window when fruit is inhibiting either vegetative shoot growth or floral shoot development. In preparation for year 2, fruit will be removed from a set of 60 trees bearing light crops early in fruit set to create on-crop trees. This strategy has proven very successful in creating on-crop and off-crop trees in our nutrient uptake study in Moorpark, Calif. Trees from which fruit were removed flowered profusely compared to trees from which fruit was not removed, even if trees carried few fruit.

Year 2 – The experiment conducted in year 1 will be repeated on one set of trees to confirm the results of year 1 on shoot growth, return bloom and yield and repeated on another set of trees that will be destructively sampled monthly during the period(s) identified in year 1 as the time at which the fruit are exerting their effect on vegetative shoot growth and/or floral initiation. Buds will be collected from branches without fruit from off-crop trees,

branches with fruit from on-crop trees and from branches on a second set of on-crop trees that are defruited during the period(s) identified in year 1 as the time at which the fruit are exerting their effect on vegetative shoot growth and/or floral initiation. An aliquot of each branch itself will be analyzed to determine the concentration of C, N and other nutrients in on- versus off-crop branches. Root samples will be collected concurrently, the number of new root tips per kg soil quantified and the concentration of C, N and other nutrients in roots from on- and off-crop trees determined. Buds and root tip samples will also be analyzed for differences in PGR content. We are able to quantify changes in the auxin indoleacetic acid (IAA), the cytokinins zeatin riboside (ZR) and isopentyladenosine (IPA), gibberellin as GA_3, and abscisic acid (ABA). It is anticipated that the presence of fruit results in the accumulation of abscisic acid and/or the loss of the cytokinins zeatin riboside and isopentenyladenosine. In preliminary experiments, buds from shoots bearing fruit had higher concentrations of ABA than buds from shoots without fruit. Buds on shoots bearing fruit did not produce inflorescences, whereas buds from fruitless shoots flowered. Analysis of the PGR content of buds combined with the quantitative data on vegetative and floral shoot growth will enable us to determine exactly when and how the fruit are exerting their effect on return bloom. Developing fruit will be analyzed to determine if they export abscisic acid and other inhibitors by PGR analysis and by testing the ability of the fruit exudate to cause inhibition of vegetative shoot growth or floral shoot development. The results of this research also will allow us to determine if the effect of crop load on resource availability impacts root growth, thereby, reducing cytokinin synthesis and shoot growth and the resource availability in the branches necessary to support shoot growth.

Year 3 – The window during which fruit are exerting their negative effect will be confirmed by removing fruit from 20 on-crop trees just prior to this window and leaving fruit on 20 trees. Vegetative shoot growth, if appropriate, return bloom and yield will be quantified. Buds will be collected from both sets of trees and analyzed microscopically to assess floral shoot development and for PGRs to confirm the effects of the treatments. In addition, 20 trees with fruit will be treated with the appropriate PGRs (most likely cytokinins) with and without nitrogen just prior to and during the window identified in year 2. Buds will be collected and analyzed microscopically and for PGRs to confirm the effects of the PGR treatments. Vegetative shoot growth, if appropriate, return bloom and yield will be quantified. Specific treatments will be based on the results obtained in years 1 and 2.

Year 4 – The treatments used to eliminate alternate bearing in year 3 will be used on the on-crop trees in year 4 to confirm their effectiveness.

All data will be statistically analyzed by analysis of variance using SAS at $P \leq 0.05$.

Summary

In 2002-2003, trees were selected for the experiment based on the number of fruit on each tree and assigned to a treatment. Within the two groups (high on-crop trees or low off-crop trees), treatments were assigned in a randomized complete block design. Mature fruit were harvested in May 2003 and the crop loads were compared to the assigned treatments. As anticipated trees with little to no 2003 crop had the highest yield of mature fruit (61-68 kg/tree) ($P \leq 0.0001$). Trees with a good 2003 set fell into two groups: trees that yielded ~20 to 27 kg mature fruit/tree and those that yielded ~11 to 18 kg mature fruit/tree. The 2003 spring crop was removed from a set of 10 trees in June. At that time the crop weighed an average of 1.5 kg/tree.

Results collected during spring bloom 2004 clearly demonstrate the repressive effect of even a modest crop (37 kg) per tree on inflorescence development (Table 1). The data were obtained for four branches 24 mm in diameter and 94 cm long on each of five trees per treatment. It can be seen that the effect of the crop is a whole tree effect with regard to branches. The presence or absence of fruit on branches on on-crop trees was without effect compared to branches without fruit on trees with off-year crops. The presence of the crop also prevented the development of apical buds (reported as inactive buds), independent of the presence or absence of fruit on the branch, compared to branches without fruit on off-crop trees (Table 1). In addition, the results confirmed the predominance of indeterminate inflorescences in the 'Hass' bloom in California. Removal of all fruit (mature and setting fruit) in June from trees setting a heavy on crop (the previous year's crop averaged only 9 kg/tree for the trees in this treatment) resulted in a significant increase in inflorescence production and decrease in the number of inactive buds compared to both on-crop and off-crop trees (Table 1). The significantly greater number of inflorescences on trees with fruit removed in June is likely due to the fact that these trees had an off-crop (9 kg/tree) the previous year, whereas the off-crop trees had an on crop (70 kg/tree) the previous year. This difference is consistent with a possible role for resource availability in alternate bearing of 'Hass' avocado.

Additional experiments were conducted to determine whether the effect of the on-crop was a whole tree effect at the level of small shoots (8.4 mm in diameter and 11.6 cm in length) or an effect localized to shoots subtending fruit only. Five shoots of the size given above with and without fruit were tagged on each of five on-crop trees in June. The presence of fruit reduced the production of inflorescences and increased the proportion of inactive apical buds in spring 2004 compared to shoots without fruit (Table 2). Vegetative shoots produced in spring 2003 contributed little reproductive growth to the 2004 bloom compared to shoots that developed in summer-fall 2003. The majority of inflorescences produced in spring 2004 were borne on shoots in the 2003 summer-fall vegetative flush. To confirm the importance of the summer-fall flush to return bloom, fall shoots or both summer and fall shoots were removed from 5 off-crop trees, respectively. These trees produced no inflorescences during spring bloom 2004.

The results strongly suggest that fruit exert their influence on flowering by reducing the amount of summer-fall flush produced, thereby reducing the number of inflorescences produced the following spring. However, at this time the possibility that fruit also inhibit the transition of the vegetative shoot apex to a floral apex cannot be ruled out. To distinguish these two possibilities the following research is being done. Fruit are being removed from each of two trees each month, starting on 15 June and continuing through 15 January. Trees with on crops produce little to no summer flush until the trees were stripped of developing fruit in June, July or August. The September fruit removal was done at the time this report was written. In addition, we are collecting buds from the data trees for microscopic determination of the transition from vegetative to reproductive growth.

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Table 1. Effect of crop load on spring 2004 growth.

Treatment	Branch	Yield 2004	Inflorescence		Vegetative shoot	Inactive buds
			Indeterminate	Determinate		
		Kg/tree	----------------------------- % -----------------------------			
On-crop trees	+ fruit	36.82 a	15.71 b	0.70	61.47 a	22.11 a
	– fruit		15.79 b	0.00	61.80 a	22.41 a
Off-crop trees	– fruit	1.95 b	29.77 b	0.00	64.97 a	5.26 b
Fruit removed in June	– fruit	2.68 b	71.14 a	0.44	23.58 b	4.92 b

Table 2. Effect of crop load on total spring 2004 growth borne on spring and summer-fall 2003 shoots.

Treatment	Inflorescence		Vegetative shoot	Inactive buds
	Indeterminate	Determinate		
	--------------------------------- % ---------------------------------			
Total shoots				
+ fruit	25.00	1.39	53.29	24.30
– fruit	64.20	0.00	32.33	3.46
Spring shoots				
+ fruit	4.17	1.39	16.67	8.33
– fruit	18.00	0.00	4.00	0.80
Summer-fall shoots				
+ fruit	20.83	0.00	32.62	15.97
– fruit	46.20	0.00	28.33	2.66