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REASONS FOR LOW YIELDS OF AVOCADOS

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The first thing that must be said is that often we can only guess at the reason for poor avocado fruit-set. Avocado production in California is subject to a number of environmental influences. These interact in ways that are complex and imperfectly understood. Hence, it may not be possible to choose among the different factors that could bring about low yields and point at one as *the* culprit in a particular case.

Moreover, it is far from certain that we have as yet identified all of the factors that are responsible for poor setting. The more I learn about the avocado, the more I realize how little we really know.

The remainder of this article lists some of the factors that influence avocado fruit yields in this state. Where possible, suggestions are given for ameliorating the situation.

I. *Climate.* To those of us who are transplanted mid-Westerners, the avocado regions of California seem like a tropical paradise. But actually this climate has been described as "seratropical," meaning a more temperate climate than the *subtropical* weather characteristic of Florida, for example. Whatever term may be used, the important point is that in California the avocado is growing in a more severe climate than that in which it presumably originated (3).

The "nature of the beast" — the available avocado genes — make it best adapted to a more tropical region. Hence, the avocado grows more rapidly in such regions than it does in California. More important, it bears heavier crops in such regions. This explains why—barring hurricanes — average avocado fruit yield is nearly twice as great in Florida as it is in California (4).

The major climatic factor affecting avocado yields in this state appears to be temperature during the blooming period. A difference of even a degree or two can have a major effect on fruit set (8). Ordinarily, the higher the temperature mean, the more favorable the set prognosis. This explains why most of our set is usually toward the end of the blooming period. But a real heat wave, especially when accompanied by a low humidity, is not conducive to fruit-setting.

In cool weather, the Fuerte flower may simply fail to open in the female stage. This makes fruit set impossible.

The critical period is obviously that in which the trees are actually blooming. So it is not safe to generalize and say that a mild winter means a good avocado set — although even this shows a surprisingly good correlation.

An example of the complications that arise is provided by the winter of 1964-65. This was marked by much more late rain than is usual, followed by an unusually heavy avocado set (the state average was some 6500 pounds per bearing acre (9). Growers expressed to me the opinion that the heavy set was a result of improved tree condition which in turn was a result of the exceptional rains leaching salts out of the root zone. And this doubtless played an important part: trees with leaf tip-burn are manifestly not in the best condition to set and mature fruit. But avocado trees in apparently superb condition too often fail to set properly.

Another reason for the good set in the spring of 1965 was the poor crop the preceding crop year — only about 2200 pounds per bearing acre. But the season of 1955-56 saw an average per acre yield equally low, yet the 1956-57 crop was the poorest in recent history, at just 1600 pounds per acre (8).

The chief reason for the excellent set in the spring of 1965 was in all probability the warm weather prevalent during enough of the blooming season. Nevertheless, the mean high temperature during the earlier part of the usual season of avocado bloom was actually below normal (because of overcast and rainy conditions). University of California at Riverside records show that March, 1965 had 1.23 inches of rain — well above average. Then April that year had 4.63 inches — which is much more than the combined rainfall totals for the preceding six Aprils on which I checked the records.

What apparently happened was that the cool, wet weather delayed much of the bloom to unusually late in the season, until temperatures above normal for avocado bloom were in fact experienced. So set was heavy.

Now temperatures during the avocado blooming season are of course determined by other factors than rain or cloudiness. Also, the avocado has an unusually long season of bloom, so that average conditions during that span may be less important than just a period of days (or even hours) when conditions are optimum for fruit-set. Thus qualification is piled upon complication. The even heavier crop set in the spring of 1966 followed a March and April both with below-average precipitation. And the 1967 rainfall pattern for these two months was much like that of 1965 — yet avocado set is poor.

Only rarely can we positively identify the determinants of relative avocado yields. And then I wonder if we aren't usually kidding ourselves, or at least over-simplifying.

Obviously, we cannot do much about California's climate, whether long-range or seasonal. (Wind machines and pot heaters are for a different purpose, and of dubious benefit at the relatively high temperatures where fruit-set is being determined).

But we can choose among the diverse California climates, by choosing the specific region in which we will grow avocados. Choice of variety is here of central importance. The statement "Fuertes don't do well in this region" is in large part another way of saying "In this region, the weather is usually too cool during the Fuerte blooming season for its female flower structure to function properly, or at least too cool to facilitate the transfer of pollen to receptive pistils."

This situation is of course not limited to the Fuerte. It is an unfortunate fact that a poor spring for Fuerte set is usually a poor spring for the set of other varieties also, including the later-blooming Hass. Stan Shepard of Carpinteria recently stated (private communication) that he had noted no benefit to Rincon set of cross-pollination — but he had observed major effects of shelter from the cool ocean breezes.

So the topographical difference of even a half-mile may make the difference between success and failure of an avocado enterprise.

A shelterbelt on the seaward side may have equally dramatic yield benefits, by increasing the grove temperature through reduction in air movement. (As another illustration of climatic complications, I recall a young avocado grove that experienced a freeze some years back. A series of windbreaks extended part way across the grove. Frost damage was severe in the lee of the windbreak trees, but beyond them, where air movement was not impeded, there was very little damage.)

Hence, anyone planning to enter the business of avocado growing should first investigate carefully. Such factors as water availability and soil type are of obvious importance. So is climate.

In a new area, temperature records will be necessary. In a long-established avocado area, the experience of local growers is most helpful. In *any* area, the guidance of the Farm Advisor will be invaluable.

II. *Variety.* This determinant of avocado yields has connections with the climatic factor already discussed. First, the best source of counsel is the county Farm Advisor, as he interprets the recommendation of the California Avocado Society's Variety Committee in light of local conditions.

Second, varietal adaptation is largely a matter of climatic adaptation.

There are a couple of pitfalls here. The prospective grower may be too influenced by the experience of some other grower. The latter may have done well with a variety that would not be a good choice for our new man: there may be unrecognized differences between their two locations, or the established grower may be reasonably successful but still not have made the best varietal choice for himself.

Another possible pitfall is making one's choice of variety on the basis of other factors than money-bringing tonnage. A good grower derives satisfaction from growing a very high quality fruit, such as Nabal or Edranol. But neither variety bears consistently enough to be the basis of a profitable venture. Perhaps a special temptation is present for the grower who is trying to help the industry by developing new varieties — especially if he has named a variety after his wife or daughter!

To the grower with a well-developed esthetic sense, attractiveness of foliage or fruit may contribute, if subconsciously, to the decision concerning varieties. There are few ornamentals in Southern California that I consider as beautiful as a lush Nabal or Leucadia or even Bacon avocado tree. And such considerations are valid in the case of the small grower who is more concerned with decorative landscaping than with maximum returns.

But the commercial grower must of course reject sentiment for realism, and make financial return his essential aim.

Yet another varietal pitfall is partly the converse of the above. This is the danger of making immediate (rather than long-range) returns the major consideration. Unless ultimate consumer satisfaction is the real concern, growers will make a few pennies extra in the short run at the cost of many dollars in the long run. A variety that is inferior in such quality features as flavor, fibre, seed size, keeping ability, etc., will hurt the industry. The problem of course is that such a variety may bring in more money than a good variety does. This may be made possible by its heavy crop, especially if it matures in the fall season of minimum avocado availability.

The higher the price that an inferior variety brings, the greater is its harmfulness — for the more likely the consumer is to feel "taken." When Mayos bring 35 cents per pound, something needs to be done.

Hopefully, avocado breeding will soon provide us with better fall varieties. In the meantime, and for all seasons of the year, the best guide is the C.A.S. Variety Committee.

III. *Strain.* It is not always enough to select a particular variety — there may be different strains of the same variety. This is known among tree fruits generally. One example is the redder skins on which the American apple industry is now based in good part.

Among avocado varieties, the Fuerte is notorious for its tendency to "sport"; that is, to change its nature by genetic mutation. Such sports may affect the tree, or the fruit, or both. Most are inferior and useless. But Fuerte sporting has produced strains (7) that are superior in yielding ability. (The fruits themselves appear to be identical.)

Good nurserymen have long known this, and have selected their buds accordingly. General grower knowledge is important in order to encourage and the taking of buds from the best-setting trees, rather than from the trees that are most readily available.

I have not observed any strain differences in the Hass, Bacon, or Zutano varieties. But the erratic variation in avocado yields from other causes makes it difficult to perceive real and significant strain differences. In all avocado varieties, propagating materials should be taken from trees that are not only free from any indication of sunblotch (preferably indexed) but that are also of proven high yielding ability.

The problem of course is to know whether the superior yield of a particular tree is due to its genes (strain differences) or its environment.

Environmental differences are of two kinds. First, the location may give it a superior climate. We have perhaps all observed individual Fuerte trees, near the south or west wall of a house (or in some other spot where heat is trapped), that regularly set far more fruits than nearby Fuertes; the reason is increased temperature during the blooming period, as discussed earlier.

A second environmental difference pertains to the soil. As there are microclimates, there are also innumerable differences within a small area in such soil factors as depth, structure, and constituents. But even when the local soil is actually the determinant of unusually good avocado fruit-set, it is exceedingly difficult to determine just what is so advantageous about that particular soil. And *even* if the favorable soil characteristic can be identified, inducing it on a commercial scale may not be economically practical.

There are also two kinds of genetic influences that can bring about superior yields. First, it may be the rootstock. Rootstocks are known to have different kinds of physical or physiological (biochemical) effects on tree-fruit scions, any one of which may have a major yield consequence.

To illustrate again the complications that arise for avocado fruit-set, consider one way that rootstock differences may effect yield differences: by altering the time of scion bloom. For example, one Topa Topa seedling may cause the Fuerte grafted on it to flower a week or two later than Fuerte grafted on a different Topa seedling. The former might thereby still be blooming when the weather becomes warm enough to permit a good set, while the latter, with the same soil and climate, could have a crop failure.

But a late bloom is not always advantageous. In occasional years, the rootstock that induced later Fuerte blooming might thereby have delayed bloom from a period favorable to fruit-set, into a period too hot and dry for good avocado setting. Still more qualifications may be necessary. In a particular year, one avocado variety may set better with a rootstock that induces earlier blooming, while a second variety may set better with a rootstock that delays its bloom. And the particular soil or microclimate may just reverse these average reactions.

So we see again how qualification is piled upon complication.

The second genetic factor determining the yield of an avocado variety is, then, strain differences within it. Such are known in the Fuerte and may well be present in all varieties if we look carefully enough.

To identify real and commercially profitable avocado mutant-sports is quite difficult for the reasons that have been discussed. These may be reviewed as follows.

Variety A may average better fruit crops than variety B. But this may be true only of strain B of variety B — its strain A may be of superior average yield. But this may apply only to rootstock A — on stock B, strain B may usually be better. But this may be true only in soil A — in soil B, rootstock B may instead be inferior on the average. But this relationship in turn may be true only with a seasonal climate A — in years that have climate B, soil B may make strain B superior . . . and so the complicating interactions pile up.

Actually, the true situation may be much more complicated yet. We have assumed only two contrasted possibilities, A and B, for each of the factors — there may be many. Also, there doubtless are many additional factors at work in an avocado grove. For example, soil A may be superior to soil B at fertilizer level A — with the reverse true at fertilizer level B; but this may be true only at irrigation level A, whereas level B reverses things once more . . .

We have so much to learn about avocado culture.

The practical grower can hope only to arrive at a "best-guess" average for his own conditions. His weapons are the experiences of others; Farm Advisor recommendations; and especially his own experimentation and keen observations.

In trying to decide between the genetic and the environmental possible causes of exceptional good set on individual trees, it should be noted that genetic attempts to develop whole groves of trees bearing exceptionally well have largely failed. That is, when buds were taken from such exceptional trees and even when the rootstock was (with difficulty) propagated, thus producing new trees genetically identical in all respects to the parent one, the new trees still showed mediocre and variable yields. This indicates that the original exceptional set was a result of the environment — although a complicated gene-environment interaction cannot be ruled out.

I am reasonably certain that mutant strains for superior yields are present, unrecognized, in our avocado groves. More careful observations and large-scale testing are needed to isolate such strains. This sort of effort should pay good returns in grower profits.

IV. *Culture.* This refers to all of the grove-care or management practices. Beyond choice of location, variety and planting distance, the kind, amount, and frequency of fertilization are involved. So are the amount and frequency of irrigation. The kind (quality) of water is very important, but is usually beyond the control of the grower. Pruning and eventual thinning practices enter in. Pest and disease control may be necessary.

All of these aim at producing the tree that will set the most fruit— while making possible harvesting at reasonable cost.

This does not necessarily mean the tree that looks "healthiest." For example, Dr. T. W. Embleton and his co-workers at UCR have shown that there is an optimum leaf nitrogen content for maximum avocado yields; additional nitrogen applications may produce more luxuriant foliage, but fruit production declined to even less than that obtained at quite deficient nitrogen levels (6).

Cultural factors are not in my field of specialization and will not be further discussed here. The grower's best sources of information are the Farm Advisors and the pertinent Extension Service bulletins, of the University of California.

V. *Bees.* The evidence from our caging experiments indicates the following. Practically every avocado fruit set means that a honey bee transferred pollen to that flower, from some other flower. One possible exception refers to the need for a pollinating agent, such as the bee: very rarely, gravity or wind may act to transfer the pollen to a receptive pistil. We do not know that this actually occurs, but our experimental results indicate that it is at least so rare that it can be ignored by the practical avocado grower.

Another exception is more plausible. Other large flying insects than the honey bee doubtless can effect pollination. In some avocado regions of the world, the honey bee is practically unknown, and other pollinating insects have been observed working the flowers. Wild bees of various kinds probably pollinate occasional avocado flowers in California. They are of very limited use to us, first because of their small numbers in avocado groves, and secondly because they do not lend themselves to human manipulation.

Still other insects may be involved. One grower reported that he had very poor avocado set until one spring when he hung a number of steer hides to cure in the grove. The hides attracted large numbers of flies, the flies were observed working the avocado flowers — and the grove set its first good avocado crop. Whether or not this was just a coincidence is not known. It has never been proven that a fly can pollinate an avocado; testing this is one of the projects that we hope to carry out soon.

Even if such pollination proves possible, it may not be practicable for the commercial grower. Flies, also, do not readily lend themselves to human manipulation, although experts in the field might be able to help us solve that problem. Personally, I would prefer to have bees rather than "filthy" flies in my grove.

But flies do have certain potential advantages. Some people are allergic to bee venom — fatalities occasionally result from bee stings. Also, the respective reproductive patterns means that it is much easier to develop resistance to such insecticides as DDT in the fly than in the honey bee. In fact, most fly populations in contact with humans have developed such resistance on their own, by the natural selection of favorable genetic mutations. Man can expedite the development of this resistance in the honey bee, but it requires time and expense. I do not know of any breeding work now in progress along this line, although such will probably have to be done if honey production is to have much of a future.

In summary, then, while there are potentially other pollination methods, at the present time the California avocado industry is dependent upon the honey bee.

Does this sometimes represent a bottleneck for our avocado production? I think that it does.

Now, theoretically, since a thousand fruits or less on a tree make a good crop, only a thousand bee visits to individual flowers should be necessary. But most flowers on an avocado tree are doomed to abscission — the tree can mature fruits from a maximum of about 1/10th of 1% of the flowers when bloom is heavy.

Also, most bee visits fail to effect pollination. In the first place, the visit must occur during the first opening of the flower, when it is in the female stage (pistil-receptive); the following day that flower will open a second time, shedding pollen and secreting most of its nectar — but a bee visit at this male stage is too late to pollinate that flower.

Second, there must be the transfer of viable pollen, to the receptive pistil stigma. This process is unusually difficult in the case of the avocado, because of the flower behavior alluded above. Since all of the open flowers on a given tree (or even of a given variety, in the same general climate) are likely to be in the same stage (whether male or female), where can the bee visiting a female-stage flower have gotten pollen with which to fertilize it?

One possibility is storing it on his body from a male-stage visit to a different flower earlier. We do not know that this ever happens in the case of the avocado.

Another possibility is cross-pollination *(see* below). Relatively few California trees are close enough to a suitable pollinator for this to occur on a commercial scale.

So we must depend primarily upon self-pollination. This may mean pollen from the same flower, or from another flower on that tree, or from a different tree of the same variety. A different flower is somewhat more likely to be able to provide pollen. For it can have a different exposure on the same tree, or a different microclimate on a different tree, and so be a little out of step in the daily male-female synchronized opening pattern.

It is fortunate that the maximum flight period for bees is usually about 11 a.m. to 2:30 p.m. — during the period when the male and female stages of avocado flowers are most likely to overlap.

In any case, the greater the bee population, the better the chances for self-pollination. For the higher the ratio of working bees to pollen available, the greater the likelihood that bees will force open pollen sacs that are not quite dehisced in the crucial female stage, and so obtain the pollen necessary for fruit set. Moreover, the greater the bee density, the more likely the bees are to travel from flower to flower, and so to make the best of such inter-flower overlap in male and female stages as may be present; this is probably the chief source of avocado set in California.

One can, however, postulate just the reverse: that higher bee density means more rapid pollen gathering, so that none is left to overlap with subsequent female stage. We simply do not know if this at times occurs.

It is nearly impossible to prove an association between bee population and avocado fruit set. The honey bee may fly miles from its hive. Hence, in groves of moderate size, one grove may add hives of bees and still have a lower bee density than a second grove with no hives stationed on it, but with a number of hives on nearby properties.

Also, actual bee counts are tricky because of variation in bee number with day-to-day and even hour-to-hour changes in temperature, because of bee number fluctuation with fluctuation in availability of other bee pasture, and because the long avocado blooming season makes it difficult to determine just when the crop set — and so what working-bee density was associated with that set.

Moreover, the avocado's notoriously erratic bearing behavior due to other causes (both known and unknown) makes it hard to show a correlation between the density of bees and the amount of set when such is the case.

A grower may add no bees to his grove one year and get a fair set. Next year he may add hives of bees — and get a poorer avocado crop. There are at least three possible explanations. First, that bee-pollination was the limiting factor neither year; the crop was less the second year because of adverse weather or other environmental factors. Second, that the bee-population was the limiting factor both years; he actually had fewer bees working his grove the second year because of considerably fewer neighboring hives, or because competing bee pastures lured too many of his bees elsewhere, or for similar reasons. Third, that the bee population was the limiting factor only the first year—and extra hives then would have given him a good crop; the second year, some adverse environmental factor made a good set impossible regardless of bee number.

Again we see the complications faced by the student of avocado bearing performance.

My studies of avocado flower behavior in conjunction with my observations on bees in various groves, convinces me that the average California avocado grower would have better crops if he had more honey bees. The very unfeasibility of proving it strengthens my belief — for this explains why, even though it is the logical conclusion, it has never been demonstrated.

How many hives should a grower reasonably add? If any member of his family is allergic to bee venom, obviously none. Otherwise, a minimum rule-of-thumb figure for some other bee-pollinated crops is one hive per acre. (Since it is not at present to prove that bees are of benefit to avocado set, it is manifestly clear that no recommendation specific for the avocado is possible). For almonds, two or three good hives per acre are preferable. It is best to have the groups of hives no more than 1/4 mile apart — 1/10 mile is better.

In cool weather especially, a hive with twice the number of bees will do more than twice the amount of flower-working. So strong hives are a great advantage.

To prevent the bees from being largely diverted to other pasture than your avocados, do the following when practical:

TABLE 1. Total number of Fuerte fruits for crop seasons 1961-62 to 1966-67, based on annual tree averages for different cross-pollination treatments.

Graft	*Fruit Number*
Check (*no* graft)	674
MacArthur	585[1]
Rincon	720
"B" seedling[2]	708
"A" Seedling[2]	835
Stewart	863
Wilhorne	899
Yama	953
Nowels	1023
Topa Topa	1058
Mayo	1061
Jalna	1222

[1] *The fact that Fuertes with MacArhur grafts have averaged actually less than the check Fuertes is presumably due to a combinaton of two things: chance variation, plus the fact that the grafting would remove a small part of the Fuerte bearing surface (and subsequent set on the MacArthur grafts would not be included in the Fuerte total).*

[2] *The Fuerte flower is of "B" opening pattern; hence "A"-type varieties were selected for grafting for cross-pollination. But an error was made in the case of one seedling that proved to be of "B" type.*

1) Place the hives (or have them placed by the beekeeper) after the avocados begin blooming, so that the bees will "get the avocado habit" right away.

2) Place the hives in the avocado grove if possible; at least try to avoid a location such that the bees will have to fly past citrus (or other attractive pasture) to get to the avocados.

3) Control other bloom, such as by mowing mustard that is beginning to flower.

It is fortunate that insecticides rarely need to be applied in avocado groves. At least avoid the use of such insecticides during the blooming season.

In most avocado areas, commercial apiarists are available for short-term rental of bee hives.

VI. *Cross-pollination.* We know that avocados set more fruit when two (or more) varieties are close enough together for cross-pollination to occur. This is a consequence of its remarkable flower behavior, so that any given tree (or even entire variety) functions as a male during part of the day, and as a female during a different part of that day.

Varieties that are female in the morning are termed Type "A"; this includes the Anaheim, Dickinson, Duke, Hass, Jalna, MacArthur, Mayo, Mexicola, Nowels, Rincon, Topa Topa, and Yama varieties. Type "B" varieties are female in the afternoon. Included here are Bacon, Edranol, Elsie, Fuerte, Irving, Nabal, Wright, and Zutano.

Interplanting an A and a B variety, provided that their blooming season overlaps adequately, thus provides maximum opportunity for cross-pollination. We have thereby obtained yield increases up to 150%, in individual years with 50% increases frequent.

That these increases were in fact due to cross-pollination rather than to some other environmental factor is conclusively shown by my results from grafting branches of different varieties into Fuerte trees. Such a setup rules out possible yield-increasing factors other than cross-pollination.

The grafting was carried out in the spring of 1960, at the O. K. Anderson grove in Pauma Valley. Table 1 summarizes the results for the 6 crop seasons since. The very first spring following the grafting, Fuerte set on all trees that had appreciable graft bloom averaged 48% greater than on the check Fuerte trees; this increase was statistically very highly significant ($P = < 0.001$).

As Table 1 shows, grafts of the MacArthur and Rincon varieties had no appreciable benefit. Neither did a seedling of "B" flowering type— which is reasonable.

With the other seven named varieties, the Fuerte set increase ranged from 29% to 81%. Jalna is indicated to be the best pollinator of Fuerte; but Topa has been more widely tested elsewhere and may be at least as good generally. It is unfortunate that the Hass variety was not included in this comparative test.

For further details, including recommended procedures, see the recent literature (1, 2, 4, 5). The basic requirements include sufficient of each of the following: treated trees; check trees; overlap or at least close proximity of the two varieties; yield records; number of years for the test; maintenance, especially pruning as needed.

SUMMARY

Low avocado yields in California are partly a result of climatic factors over which we have no control. But yields can be increased in the following ways:

1) Select the best variety.

2) Select the best strain of that variety.

3) Use the best cultural methods.

4) Bring in more bees during the blooming period.

5) Provide for cross-pollination.

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