California Avocado Society 1964 Yearbook 48: 78-85

Avocado Yields Increased By Interplanting Different Varieties

B. O. Bergh
Associate Specialist, University of California, Riverside

M. J. Garber
Associate Biometrician, University of California, Riverside

ABSTRACT

Statistically significant increases in fruit set, associated with the interplanting of two or more varieties, were observed in avocado groves throughout southern California. Specifically, there was an apparently beneficial effect from proximate trees of Topa Topa, Hass, and Zutano on Fuerte set; of Rockwood on Zutano set; of MacArthur on Edranol set; and of Hass, Zutano, and Rincon on MacArthur set. The most plausible explanation for most of these yield increases is cross-pollination,

Popenoe (8) once stated that "an acre of land will yield a larger amount of food when planted to avocados than it will in any other tree crop known." This may be true in more tropical areas; but in California, for the 17 harvesting seasons from 1945-46 to 1961-62, average annual yield per bearing acre was only 3,700 pounds (9). In Florida in 1957, the last normal crop year before the 1958 freeze, average yield was a little over 6,000 pounds per acre (4). This is a reasonable long term mean yield for the major Florida varieties, as calculated by approximation from the data given by Ruehle (11). Evidently, apart from major climatic catastrophes, avocado yields have been appreciably higher in Florida than in California. In fact, low yields are a recognized and serious drawback to avocado production in California (1, 5).

MATERIALS AND METHODS

With the aid of avocado producers and farm advisors in the various avocado-growing counties of Southern California, proximal plantings of two (or more) different varieties were located. Those groves which seemed to offer possibilities of a statistically reliable comparison were selected for yield studies (2). That is, there had to be a sufficient number of comparable treated and check trees. The comparison made was, in each case, between trees of a given variety adjacent to those of a different variety ("treated"), and trees of the former variety that were in the same grove but farther removed from the other variety (or varieties).

In most cases, yields were determined simply by counting the fruits on the trees concerned. Accumulative hand counters were used to minimize human error. Usually one person did all of the counting in each grove, to prevent confounding from inter-human variability. This was not practiced during the earlier years of the project, but tree

The authors wish to express their appreciation for the assistance given by County Farm Advisors C. D. Gustafson (San Diego), C, C. Delphey (Ventura), and G. E. Goodall (Santa Barbara), and by the various growers in whose orchards the observations were made.

by tree counting was carried out in a direction transverse to that of treatments; thus, the individual counters each counted the same proportion of trees proximal and distal to the trees of the second variety.

Even when only one person did the counting, the same transverse order was followed whenever it was considered practicable. Thereby the effects of proximity to another variety were less likely to be confounded with such factors as visibility (which varies with time of day, cloudiness, etc.), fluctuations in the alertness of the counter, and probably others. This sort of precaution is desirable especially since the avocado fruits were in every case green; with large trees it becomes impossible to make completely accurate counts by any practical method short of actual fruit harvest. It was usually not feasible to wait for fruit harvest for two reasons. First, most of the data involve groves in which spot picking, according to size, spreads the harvest over several months. Second, with numerous trees, large-scale picking by crews makes the keeping of individual tree records at best hazardous; in one case where we attempted this, an error by a picker resulted in the loss of all the data.

Therefore, the data are based largely on fruit counts made on the trees shortly before harvest. In regions subject to severe fall winds, with the accompanying danger of fruit being blown off, the counts were made before the season of anticipated wind. A number of check counts showed that two counts of the same tree would not differ greatly, usually by less than about 5%. In any case, such error would contribute to a larger experimental error term, which would introduce a note of due caution in our analysis and interpretation.

RESULTS

In the J. M. Best grove in Pauma Valley, San Diego County, Fuerte trees had been interplanted with Topa Topa trees for windbreak purposes at every tenth Fuerte column. A preliminary report was made on the 1957-58 season Fuerte set in this grove (2). A detailed statistical analysis of results from several subsequent years will be published elsewhere (Bergh and Garber, in press). For the 1963-64 season—set in the spring of 1963, counted in the fall of 1963, and harvested in the winter of 1964—column averages of fruits set were exceptionally variable (Fig, 1); the check trees averaged 74.7 fruits compared with 205.8 for the Fuerte that adjoined the Topa Topas, a yield increase of 175%. Over the seven consecutive years in which fruit counts were made, there was a highly significant ($P=<0.001$) increase in fruit set next to Topa Topas for each season ending in an even number; the three odd-year seasons ranged from no appreciable difference to a highly significant set decrease on the Fuerte trees adjoining Topa Topas. Over-all, proximity to Topa Topa trees was associated with an increase in fruit set of about 40%. In the Griswold grove near Fallbrook in San Diego County, two rows of the Hass variety were flanked on both sides by solid blocks of Fuerte trees. Fruit counts were made (Table 1) in the first Fuerte row on either side and also in the third Fuerte row on either side, over three seasons. Only the first 11 trees in each row were considered uniform enough to justify analysis, since beyond this section the trees were growing on a ridge with shallow, variable soil. The over-all average was 75.3 fruits for checks and 113.0 for the treated trees next to a Hass row; hence, there was a 50% larger set on the Fuerte trees adjoining this second variety. For the three years combined, the difference is significant at the 0.01 probability level.

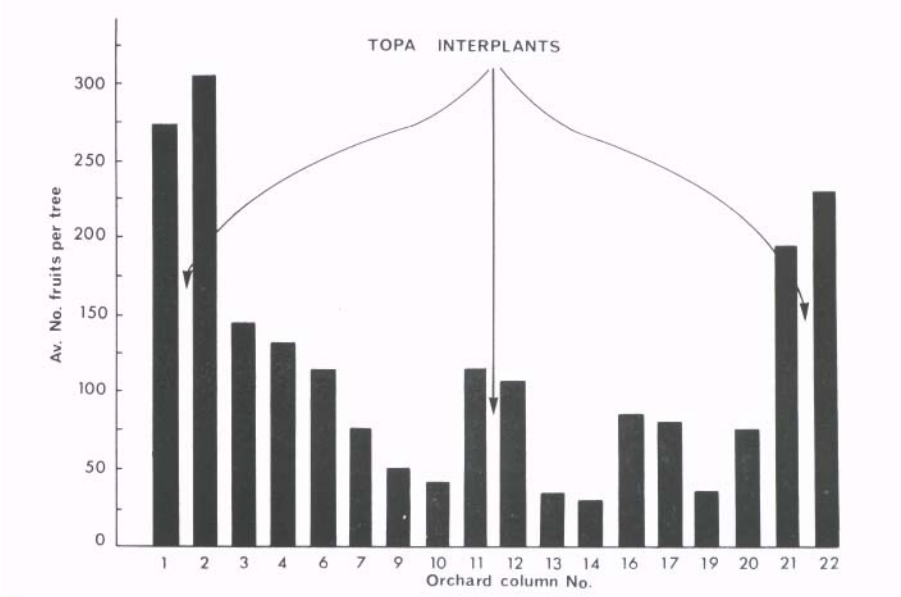

Figure 1. Fuerte set in relation to Topa Topa interplants, 1963-64. (J. M. Best grove). Heavy pruning reduced the fruit set on rows 9 to 14 especially.

Table 1. Fuerte set in relation to Hass interplants, in mean number of fruits per tree (Griswold grove).

Season	Check #1	Adjoining Hass # 1	Adjoining Hass #2	Check #2
1958-59	71.3	113.9	107.5	69.4
1959-60	140.1	188.5	183.6	121.8
1960-61	30.5	63.5	21.0	18.7

In the Beck grove, also near Fallbrook. Calif., yield estimates in boxes per tree had been made by the owner for other purposes and were available from the first set in 1951-52 until 1957-58. In one section of the grove, solid blocks of Fuerte and of Hass adjoin each other. Fruit set was therefore analyzed for 29 trees in each of the first four Fuerte rows beginning with the row next to Hass. Combining the six years of data, the average yields were respectively 1.46, 1.27, 1.25, and 1.31 boxes. Hence, Fuertes next to Hass averaged 14% more fruit than the check trees. The difference is significant at the 0.025 probability level. Each year since 1954, the Fuerte row adjoining Hass trees had the highest set of the four rows analyzed. In 1958-59, by which time larger tree size had resulted in a larger proportion of the Hass-Fuerte pairs interlacing, actual fruit counts of the first and third Fuerte rows gave respective means of 105.3 and 81.8 fruits. This is a 29% difference. But the usual high variability of individual avocado tree yields makes the difference not significant statistically; the range was 3 to 246 fruits per tree for checks, and 0 to 311 for the treated trees.

Fruit counts were made on two other Fuerte groves in San Diego County, in 1958-59, In the Coover grove in Pauma Valley, a Topa Topa windbreak is growing along one side of the Fuerte grove. In a block of 15 trees per row, the Fuerte row adjoining the Topa

Topas averaged 137.4 fruits per tree, compared with 130.9 fruits per tree as the mean of the next three Fuerte rows.

In the Martin grove near Fallbrook, Fuerte trees that have branch contact with trees of the Zutano variety averaged 127.0 fruits as compared with 89.0 fruits as the mean of Fuerte trees lacking contact with a second variety. The difference is 43%. It is not statistically significant; the total number of trees involved was only 35, with 19 check trees ranging from 8 to 255 fruits and 16 treated trees ranging from 9 to 318 fruits per tree.

In the Montgomery grove near San Dimas, Los Angeles County, a row of Rockwood trees was planted down the middle of a predominantly Zutano variety grove. So two treated Zutano rows, one on either side of the Rockwood rows, were compared with two check Zutano rows, four rows distant from the Rockwoods and one in either direction. On one side of the Rockwoods the rows were 11 trees long; on the other side they were 36 trees long. The summary in Table 2 shows that the results were reversed between the 2 years counted. In both years, the difference was significant at the 0.05 level.

Table 2. Zutano set in relation to Rockwood interplants (Montgomery grove).

Season	Check #1	Adjoining Rockwood #1	Adjoining Rockwood #2	Check #2
1959-60	108.4	130.7	125.9	110.9
1960-61	123.6	88.6	85.7	113.8

At the Mason grove north of Camarillo in Ventura County, the varieties Edranol and MacArthur are generally planted alternately; but the row on either side of the control driveway is solid Edranol. Tree spacing distance was only 10 feet, and very few Edranol trees do not have branches that reach to within a few feet of MacArthur branches. The arbitrary classification was into "heavy contact" versus "no contact;" the latter category includes all Edranol trees that do not have branches closer than about 2 feet from MacArthur branches. There were a few such trees scattered through the grove, although most of them were in the two driveway rows. From a total of 75 trees, the results as summarized in Table 3 show small and reversed differences in 1959-60. In 1958-59, the Edranol trees that had MacArthur contacts averaged in the two sections respectively 42% and 30% more fruits; analysis of variance gives a mean difference F value just larger than the 0.10 probability level.

Table 3. Edranol set in relation to MacArthur interplants (Mason grove).

Season	Grove section	Checks	Contact
1958-59	East	47.4	67.3
	West	58.6	76.2
1959-60	East	41.5	48.2
	West	56.6	52.7

In the Cavaletto grove just north of Santa Barbara, MacArthur trees had originally been planted with a spacing distance of 30 feet by 18 feet. Top-working of usually every other tree to the Fuerte, Hass, Zutano, or Rincon varieties has resulted in varying degrees of MacArthur contact with other varieties of varying age. Number of fruits set per tree was recorded for two years from a total of 106 MacArthur trees; other trees were omitted because of Verticillium wilt injury. The data are summarized in Table 4.

Table 4. MacArthur set in relation to interplants of other varieties (Cavaletto grove).

		Fuerte	contact	Zutano	contact	Hass	contact	Rincon	contact
	a/	b/	c/						
Year	Check	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy
1958-59	189.2	177.0	183.1	192.9	259.2	198.9	266.7	258.7	259.4
1959-60	165.6	75.0	152.5	222.7	212.9	66.7	237.5	163.3	203.2

a/ — more than 10 feet of separation between the nearest branches of MacArthur and the second variety.
b/ — 0 to 10 feet separation.
c/ = overlap of branches.

Inter-varietal contact was arbitrarily classified into three degrees, as indicated. The fruit yield averages are quite erratic, partly because of generally far too few trees in each class: one class had only two trees, two classes had only three. But on the average, MacArthur yield increased with degree of inter-varietal contact. Trees with less than 10 feet spacing from a tree of another variety, yielded more over the two years than the contrasted checks to a highly significant degree. More detailed comparisons are weakened statistically by low tree numbers and high error variance. For the two years combined, heavy Hass contact resulted in greater MacArthur yields than light Hass contact to a degree that approximates the 5%level of probability. Since this difference results in part from the abnormally low yields associated with light Hass contact in 1959-60, the significance is suspect. But in 1958-59, MacArthur trees with heavy Zutano contact outyielded those with light contact to a degree that is statistically highly significant. If the light-contact results are disregarded as biologically intermediate and direct comparison is made between the check MacArthurs and those having heavy contact with trees of other varieties, the 1958-59 data show that Zutano, Hass, and Rincón contact in each case is associated with a significantly increased fruit set; for Hass the difference is highly significant.

DISCUSSION

The data from the various groves observed show that trees of a given variety frequently set more fruit when located proximate to a second variety than when located farther removed from the other variety. But statistically significant exceptions were encountered. The consistent alternation of effects over seven seasons in the J. M. Best grove seems explainable on the basis that the much heavier set on the adjoining trees each preceding year, gave the check trees a temporary advantage that more than compensated for their location disadvantage with respect to Topa Topa trees.

This explanation may also fit the statistically significant, seasonal reversal of Zutano set

in relation to Rockwood trees in the Montgomery grove. Likewise it may account for the disparate seasonal results with Edranols on the Mason property. It may similarly explain the failure of the Coover Fuertes to set appreciably more fruit on trees next to Topa Topas, in the single year that fruit counts were made. Data from the various groves show clearly that a single year's observations can be quite misleading. In fact, in another season, a worker in the Coover grove was impressed by what he thought appeared to be much heavier fruit set proximate to the Topa Topas.

Ordinarily, however, actual fruit counts are necessary to demonstrate even major average differences; the Martin and the Beck 1958-59 ranges are typical of the individual tree data, and illustrate the unusual variability of avocado fruit set per tree. This great variability also makes it necessary to have an unusually large number of tree replications in order to make real differences statistically significant, as illustrated by both the Beck and the Martin results.

Far too few trees per class were available for analysis in the Cavaletto grove. By lumping both years, all four interplanted varieties, and both categories of contact, proximity of another variety was shown to increase MacArthur set to a highly significant degree. But this comparison involves two sources of weakness. In the first place, the classification division point at 10 feet of separation is a purely arbitrary interruption of continuously variable distance. Hence the comparison probably involves a diluting of the effects of real overlap between two varieties with the intermediate situation of up to 10 feet of separation; the statistical analysis was made of the combined "contact" data because the greater number of observations was found to more than compensate in terms of statistical significance for the assumed dilution of treatment effect. A second diluting factor is suggested by the results from Fuerte contact in Table 3. For both years and for both degrees of contact, MacArthurs adjoining Fuertes averaged actually less fruit than the check trees. It seems probable that cross-pollination is the major factor producing greater set on trees proximal to those of another variety in the various groves studied. The Fuerte variety is not recommended for planting in Santa Barbara County, because of its poor fruit set under conditions of cool weather during the blooming period (6). The Hass and the Rincon, on the other hand, are the two varieties favored for this area (10), because of their consistently good crops; and the Zutano bears well in nearly all avocado regions (7). The reason for poor Fuerte set in coastal areas like that of the Cavaletto grove is not known, but might he related to abnormal behavior of the male gametophyte, or both gametophytes, at low temperatures. At least, there would appear to be valid biological justification for regarding contact with Fuerte trees as more properly conferring "check" rather than "treated" status. If this is done, re-analysis shows that MacArthur trees less than 10 feet from a second variety set respectively 15% and 24% more fruits in the two seasons of counts; MacArthur trees with branches overlapping those of a second variety set respectively 38% and 42% more fruits.

In the Mason grove, an unusually close planting distance has resulted in extreme tree crowding. Moreover, the MacArthur trees proved more vigorous than the Edranols, and the latter are severely restricted in development in the main body of the grove. It is only the check Edranols along the driveway that have made reasonably normal growth. Under the circumstances, a subjective evaluation would be that if the check trees with their greater bearing surface yielded no more than the treated trees on the average,

then the treatment—contact with trees of the MacArthur variety—must have had a beneficial effect on fruit set. Since the treated trees actually outyielded the checks in 1958-59 to such a degree that the probability is just one in ten of such a difference being due to the errors of random sampling, a major increase in Edranol set due to MacArthur proximity is strongly indicated. Moreover, the comparison involves an arbitrary division point at about 2 feet of branch separation; check trees must also have benefited from MacArthur proximity under these conditions.

The Best grove analysis likewise lacked a biologically sound distinction between check and treated trees. The Fuerte row next to Hass was regarded as the treated, but over most of the years of observation, the trees were too small to make branch contact. This is presumably why the mean difference, although statistically significant, was only 14%. Even in the final year of analysis, many of the trees in the treated row would have been considered check trees according to the criterion used in other groves. Such weaknesses of the experimental setup were present in most groves, and presumably did much to reduce the calculated effects of treatment differences.

There are a number of possible reasons for the increased fruit set on trees next to those of a different variety: some unknown soil biochemical benefit; more efficient utilization by two varieties of moisture or nutrients; wind reduction by interplants that are more closely spaced or taller; or, less crowding due to slower growth of the interplants. The first two suggested reasons are as yet without experimental support among avocados; certainly yield increases of a magnitude reported in this paper seem most unlikely from such factors. Reduced crowding and wind control are largely antithetical; each may have been of some benefit in individual groves, but the major cause of the often strikingly increased set must be sought elsewhere. That cause is probably cross-pollination—contrary to the prevalent belief in California (3, 5).

Failure to demonstrate significant beneficial effects of interplanting in some instances was presumably due to the presence of too few replication trees, or to the great variability of avocado tree yields, or to the heavier set the preceding season on the trees adjacent to the interplants; for some varieties in at least some years, proximity of a second variety may confer no yield advantage.

LITERATURE CITED

1. Bergh, B. O. 1961. Breeding avocados at C.R.C. Calif. Avocado Soc. Yearbook 45: 67-74.
2. Bergh, Bob, and Don Gustafson. 1958. Fuerte fruit set as influenced by cross-pollination. Calif. Avocado Soc. Yearbook 42: 64-66.
3. Chandler, W. H. 1958. Evergreen orchards. 2nd. ed. Lea and Febiger, Philadelphia. 535 p.
4. Florida State Marketing Bureau. 1961, and earlier years. Annual Agricultural Statistical Summary.
5. Hodgson, R. W. 1947. The California avocado industry. Calif. Agr. Ext. Serv. Circ. 43, 93 p.
6. Hodgson, R. W., and S. H. Cameron. 1936. Temperature in relation to the alternate

bearing behavior of the Fuerte avocado variety. Proc. Amer. Soc. Hort. Sci. 33: 55-60.

7. Johnston, J. C. 1959. Avocado varieties for California. Calif. Agr. Ext. Serv. Leaflet 106, p.p.
8. Popenoe, Wilson. Manual of tropical and subtropical fruits. Macmillan Co., New York. 474 p.
9. Rock, R. C., and R. G. Platt. 1962. Economic trends in the California avocado industry. Calif. Agr. Ext. Serv. un-numbered mimeograph. 11 p.
10. Rounds, M.B., Chairman Calif. Avocado Soc. Variety Comm. 1957. Report. Calif. Avocado Soc. Yearbook 41: 15-16.
11. Ruehle, G. D. 1963. The Florida avocado industry. Florida Agr. Ext. Serv. Bull. 60. 100 p.