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FACTORS AFFECTING AVOCADO FRUITFULNESS

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It has been said that there are just 3 requirements for a superior commercial avocado: heavy production, heavy production and heavy production. This is, of course, a gross over-simplification. In fact, it is 1 side of a 2-sided coin—the other side is consumer-satisfying fruit quality. Both fruitfulness and quality are essential. To argue about which is more important is as pointless as the old arguments of heredity vs. environment.

Nevertheless, it remains true that "If it (high productivity) is present, many other weaknesses may be tolerable. If it is absent, all other virtues may be futile" (8). There doubtless have been a lot more highly flavored avocados discarded because of poor set than there have been highly productive cultivars discarded because of poor flavor.

Climate

Region of Origin

This information tells us a good deal about the inherent climatic heredity of a plant species. The avocado apparently originated in the Torrid Zone tropics of Central America (7). It is thus basically tropical in adaptation. Some forms have evolved adaptation to somewhat more rigorous climates, but the hardiest of these are also less desirable horticulturally. The commercial avocado cannot be expected to bear well outside the warm climates to which nature has adapted it.

Less Tropical Climates

Much of the world's commercial avocado production is from regions with less tropical climates, such as California, Israel, South Africa, Chile, Australia, a good part of Mexico – even Central and Northern Florida if extensive commercial enterprises should develop there. There are, of course, all gradations in climate, *e.g.,* while the avocado enterprises of California and Israel are at about the same latitude, the winter-spring Israeli climate is warmer and avocado set averages higher (6).

Freezing injury may vary from killed flower buds through increasing vegetative injury to tree death. Exposed fruit stems are especially vulnerable, resulting in fruit drop even when there is little vegetative damage. Freeze injury, then, can reduce fruitfulness from slightly in the current year through severe loss that year (either of set fruit or flower buds) to general unfruitfulness for 2 or even more years. Heaters or wind machines may be good investments in cold area, although devastating freezes may only occur only once every 10-20 years.

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Young trees, especially during the first winter, are very cold sensitive and the bud union and scion base should be protected by a cardboard cone or soil mounding so that cultivar regrowth can take place in the event of freeze damage. The tops of young trees can be protected by all sorts of devices ranging from palm fronds and corn stalks to staked overhanging cloth. The practicality of such steps depends on the balance between labor and material costs on the one hand and the probable gain in fruitfulness in terms of frost hazard. Scion hardiness does not appear to be influenced by rootstock hardiness (14).

Chilling injury of flower performance is probably the major factor limiting fruitfulness in the avocado regions of California and similar climates. The available cultivars are not well adapted to temperatures prevailing during the blooming period. An average difference of even 1°C can have a pronounced effect on fruit set.

Precise critical temperatures are difficult to determine because of the long blooming period, uncertainty as to how long before flower-opening the temperature has significant effect and the influence of the size of the previous crop on fruit set. Set potential appears to decline below a mean day and night temperature of about 20°C. Since this is much higher than the California blooming time average, it is understandable why California avocados set mostly toward the latter (warmer) part of the spring blooming period. Similarly, delayed blooming, such as results from a cool, cloudy winter, is conducive to heavier set (3).

Minimizing chill injury is possible within strict limits. The warmest area available should be chosen in less tropical areas. This has often been done by the avocado pioneers who, through trial and error, found that only a very limited part of California, for example, is suited to commercial avocado production. Local topography and exposure can mean the difference between a successful and non-successful enterprise within the general zone of adaptability. Thus, avocados may set far better if protected from ocean breezes by a hill or a windbreak. Weather records should be studies carefully, if available, before a planting decision is made (12). Observations of native vegetation and of more tender "index" vegetation after a major freeze can be helpful. The judgments of nearby experienced growers or public experts can also be helpful.

Problems from Heat

Excess heat can also greatly reduce avocado set. Hot, drying winds during the blooming period can desiccate the tender stigmas or styles. The thick outer coat of avocado pollen should protect it from drying out (16). However, sharp environmental variations reduce pollen viability. A daily fluctuation of 20°C is not uncommon in California.

Excess heat can kill the embryo after setting has occurred, thus sharply reducing marketable fruit yield. Heat is especially harmful when it strikes suddenly. This can occur frequently in the California type of climate.

Finally, heat can reduce fruitfulness by injuring the tree. Considerable bearing surface can be lost to limb-burn. More generally, debilitating heat can reduce tree growth year after year. Under hot and dry (especially windy) conditions, avocado

leaves may be wilted even though the roots have adequate water.

Horticultural Races

There are 3 commercial avocado races, which may be best classified taxonomically as equally distinct botanical varieties: West Indian (Antillean), *Persea americana* var. *americana;* Guatemalan, *P. americana* var. *guatemalensis;* and Mexican, *P. americana* var. *drymifolia (7,* 11). These are listed in increasing order of average adaptability to cold.

The best-adapted races or racial hybrids must be used for maximum fruitfulness. West Indian lines survive and even grow well in parts of California, but set little or no fruit. Conversely, Mexican lines may set little or nothing in really tropical areas where West Indians do fine. The first consideration in planting avocados in a new region is fruitfulness and the basic requirement for fruitfulness is racial adaptation.

Cultivars

Within each race there are some differences in climatic or other environmental adaptation. For example, 'Hass' and 'Nabal' are both largely Guatemalan in racial origin. But, at least in Israel (6), 'Nabal' is unusually well adapted in lighter soils, while 'Hass' prefers somewhat heavier soils. Likewise, 'Nabal' tolerates more cold than another Guatemalan, 'Anaheim'. Among West Indians, 'Waldin' is hardier than 'Pollock'. Many similar examples could be given.

The choice of cultivar is most important to maximize avocado production. All other aspects of care can be excellent and yet, by wrong choice of cultivar, the return on investment can be cut in half or even wiped out. Advice from successful growers and public professionals can be invaluable and the sales experience of marketing organizations must also be considered.

There are few specific dangers to avoid. Do not slavishly follow the experience of your neighbor since your microclimate, soil or other factors may be sufficiently different that a different cultivar may bear better on your property. Moreover, while he may have made the correct choice(s) at the time that he was planting, there may now be improved, higher-yielding cultivars adapted to your area. Sometimes it may be best to plant an older cultivar since your neighbor may have 1 that was over-planted relative to its available market.

The topic of this paper points up another danger. It financial return is the only real consideration, do not be swayed by beauty of foliage or fruit or superlative flavor. But there is a counter-danger here. Over-emphasis on immediate cash returns at the expense of ultimate consumer quality-satisfaction will prove in the long run to hurt the industry—and each grower. We are again reminded that fruitfulness is only half of the picture.

Scion Mutants

Bud sports for increased fruitfulness and other commercial qualities are known in many fruit species. The avocado is no exception. Hence, it may not be enough to specify the cultivar; one needs the heaviest-setting mutant strain in that cultivar. Differences in productivity among 'Fuerte' mutants were recognized long ago (13). More recently, a number of apparently superior-producing strains have been identified in Israel (6).

Some of the most significant avocado data now being published are from Israel's Volcani Center by Dr. Avraham Ben-Ya'acov. In brief, he has showed that there are large differences in productivity among the strains of a cultivar, large differences in productivity attributable to rootstock differences and—especially significant—large scion strain-rootstock interactions (1).

These findings are based chiefly on their major cultivar, 'Fuerte', so they are of direct interest to regions like California where the very important 'Fuerte' is leaving a market-supply depression as it declines due to insufficient production. They have major implications for wherever the avocado is grown, for they demonstrate the essential nature of the tree, regardless of the particular cultivars and rootstocks used.

One 'Fuerte' strain yielded about twice as much as a second strain on the same rootstock source over the 5 years of records. The differences were statistically highly significant. Similar results were obtained with other strains and other rootstocks and also with a different cultivar ('Ettinger'). The presence of numerous avocado mutations affecting fruitfulness is beyond question.

Recommendations

One obvious meaning of the above findings is that propagation wood of any cultivar should be carefully selected from only the highest-producing trees. Furthermore, wood should be selected from the highest-bearing branches or even parts of branches since initially only part of a tree is likely to be mutant.

Good nurserymen are well-aware of this general principle, but applying it is not as easy as it may sound. A reasonable profit requires reasonable labor costs per tree, including the time spent in obtaining budwood and the percentage take of the grafts made. The heavier a branch portion is bearing, the less likely it is to have good graft-wood. So the propagator who finds a tree with heavy set and then locates a part of that tree (or even part of an otherwise heavy-setting branch) with good budwood may be selecting indirectly for genetically poor setting! The only solution seems to be to identify parts of trees with consistently superior setting, then remove the fruit thereon and cut back the remainder of the tree (or even that branch) to stimulate vigorous growth. Such growth will then probably be maintained by heavy budwood cutting, with fruit removal if needed.

Three problems intervene: 1) identifying superior fruiting over several years, given the numerous factors that influence avocado productivity, 2) the probability of root-stock effects (see below) and 3) the certainty of environmental effects. Where higher temperatures during the bloom period are conducive to higher fruit set, one learns of supposedly much heavier setting trees, or a tree, or a tree portion. On

visiting the grove, the environmental situation of trapped warmth is often evident at a glance. In other cases, one cannot determine if the high set is due to a favorable microclimate.

Considering the potential gain in fruitfulness, it seems that the avocado industry around the world would be wise to follow the Israeli lead in making a serious investment of effort toward superior strains. Highly worthwhile advances could be made just from cultivating the habit of specific watchfulness whenever one is in the grove. Superior-producing strains are unknown in most cultivars, but they are probably present - unrecognized.

Always, one must beware of the danger that in selecting attractive, superior budwood, one is thereby selecting less productive strains.

Rootstocks

For maximum fruitfulness, it is not enough to have the best strain of the best cultivar. You must have it grafted onto the best rootstock. One cannot expect as much production if, in a high-salinity situation, one uses a stock that passes on a lot of salts; or if, in a high-lime situation, one uses a stock susceptible to chlorosis; or even if, in a comparatively chilly winter climate, one uses a purely West Indian race stock (6, 8).

Apart from specific environmental tolerances, rootstock effects on the performance of the top are known. In California, cultivars have made up to twice as much growth on Guatemalan as compared with Mexican stocks and seem to have suffered less drought injury on Guatemalan. Analysis of the data available so far indicates that yield is more or less correlated with tree size. If so, mature tree yield per hectare would average about the same regardless of root-stock. Comparative yield figures are scanty, unfortunately.

Ben-Ya'acov's findings in Israel (1) have exposed the complexities of scion-stock relationships in avocados. Again, the data chiefly involve their leading cultivar, 'Fuerte'. In 1 grove, a specific 'Fuerte' strain over the 4 years of records yielded 3.5 times as much on stock *X* as compared with stock *Y.* This increase was not due merely to larger tree size; in fact, the heavier-yielding tree combination had a statistically significant smaller average trunk diameter.

We might conclude that rootstock *Y* is evidently not desirable for 'Fuerte'. But then, complexities begin to show up. In the same orchard but with a different 'Fuerte' strain as scion, trees on stock *Y* set even more than the first strain had set on stock *X* (1). (There is evidently a misprint in his Table 1: 'Glickson 9' should read 'Glickson 8').

Recommendations

Results like those above lead to the conclusion that it may not be very meaningful to speak of superior avocado cultivar strains or superior rootstock sources. Instead, we need to think in terms of superior scion-rootstock combinations.

For regions like California, Australia, South Africa and others where Phytophthora root rot is rampant, resistance to that disease is of such over-riding importance that expensive research on yield differences of specific combinations may be hard to justify. While we await stocks that will provide a commercial solution to the root rot problem,

hopefully we will be able to start applying the Israeli discoveries and also perhaps make suitable arrangements to obtain some their superior rootstock materials. Also, their discoveries encourage expansion of our so-far limited attempts to re-create genetically identical scion-rootstock combinations of very heavy-yielding trees.

The latter approach is even more promising for avocado regions that do not have an overwhelming concern such as root rot. The Israeli findings alert one to the sort of thing to watch for. Always, the complicating effects of environment must be borne in mind: microclimate and micro-soil differences make individual tree yields suspect and large scale tests essential.

Cultural Care

This interacts with the other factors that affect fruitfulness. For example, 1 rootstock might be better under sprinkler irrigation, a different rootstock superior under drip.

The level of care in itself obviously will greatly influence fruitfulness. The best of all possible climate-race-cultivar-strain-rootstock combinations may be disastrously unfruitful if grove-management practices are ill-chosen or ill-applied.

This multi-faceted subject is dealt with by other presentations in this Short Course.

Girdling

This is a management practice that is not a part of necessary or obvious care, but it can be performed for the specific purpose of increasing fruit set.

California Experience

Girdling of avocado branches has been tried off and on, mostly by private growers, for several decades in California. Results have often been promising but large-scale statistics have never been published and perhaps never been gathered. Apparently, the experiments have not been continued long enough to determine the important long-range effects.

I have now started a girdling test involving several hundred trees belonging to a commercial grower. They are chiefly of the 'Fuerte' cultivar, since shy bearing is the major problem with that fine fruit. About one-third of each tree is given about a 1-cm-girdle each year. Only 1 year's data have as yet been obtained. 'Fuerte' trees seldom set appreciable fruit until about their fifth year; girdled 3-year-old trees set a light crop, about 3.5 times the average quantity of the checks. Older trees averaged about 2.5 times as much on the girdled trees, but even their set was very light for tree size.

Israeli Experience

This is where by far the greatest amount of girdling has been carried out (15, 17) different cultivars have been treated and dramatic increases in fruit set have often been obtained. Nevertheless, results in Israel have not always been favorable (6) and some of the early enthusiasm (17) should be viewed with a bit of caution. Long-

range effects are not yet self-evident. Many and diverse girdling experiments are continuing in Israel. From the varied opinions and procedures, definitive answers should gradually emerge.

Recommendations

Growers and researchers in other countries, in the meantime, might begin trials under local conditions. Various tools can be used (18) to remove a band of bark around the stem right down to the wood. As much as two-thirds of the tree can be girdled each year for greater results, but less is safer to tree health. A narrow width of band removal is also safer—1 cm is adequate and even the width of a saw cut may be effective. Recommendations have been given for the best month to girdle and this may vary with cultivar (17), but Israeli conclusions are not yet unanimous. In my first year's experience with 'Fuerte', maximum response resulted from girdling in November and again as flowering began in February, with less response from girdling in the intervening months.

Use enough trees to obtain statistically valid data, including enough randomized check (untreated) trees for a sound comparison. Continue the experiment for several years—there may be cumulative effects. Keep careful yield records. Fruit weight or volume is better than fruit counts, since average weight is commonly lower when more fruits set. Do not be misled by much heavier set on girdled branches than on the rest of the tree—the non-girdled portion may have reduced set because of the girdling, so only whole-tree comparisons are valid.

Bees

Nearly every avocado fruit that is set required a visit to that (female-stage) flower by a pollinating insect. In California, Israel and probably other similar climates, by far the most important pollinator is the honey bee. I understand that other insects are much more important than the bee in more tropical areas. The bee, as the only one with which I am familiar, and perhaps as the only one that readily lends itself to human manipulation, will occupy the balance of this discussion.

Bees can fly about 2 km from the hive and so are nearly ubiquitous in southern California areas. Therefore, it is exceedingly difficult to demonstrate unequivocal benefits to a grove from the placing of bee hives in that grove. A grower may add hives and get actually less subsequent set than he had the previous year: his total bee population may be decreased, due to fewer neighboring hives, or increased competition from other bloom, there may well be other factors limiting his crop that year (3).

Recommendations

I believe that placing additional bee hives in the grove may be the easiest way for the grower to increase the fruitfulness of avocado trees. Increased bee populations mean increased working of the flowers and thus increased chance for either self-pollination or cross-pollination—both of which are commonly difficult to achieve in avocado groves (see below). The inherent difficulties in demonstrating even major benefits suggest that such benefits could well be present, though unrecognized.

A minimum placement might be 2 hives per hectare. Up to 8 hives per hectare have been recommended in Israel (6). Some hive grouping is desirable for convenience, but pollination benefits are probably greater if the groups are not more than a couple of hundred meters apart. To minimize bee diversion to competing bloom, wait until the avocado trees have started blooming before bringing the hives in. Place the hives within the grove if possible or at least away from alternative sources of bloom, such as citrus.

Cross-pollination

The unique behavior of the avocado flower (8) means that, in nature, the flowers are nearly always cross-pollinated. Self-pollination requires unusual flower behavior or a specific bee (or other insect) inter-flower movement during brief periods of overlap or rather lengthy pollen carryover on the bee's body (16). (See the following article by Gazit on pollination and fruit set of avocado.) That 1 or more of these situations occurs with some frequency is shown by the good set often obtained on an isolated avocado tree or solid planting of 1 cultivar.

Nevertheless, it must now be regarded as an established fact that avocado trees set more fruit when there are flowers of a different avocado variety (cultivar) nearby (4). Statistical analyses in Israel (6) and California (2, 4, 5, 9, 10) have repeatedly shown major yield increases when there is provision for cross-pollination. More tropical regions may well have even greater increases since one of the circumstances thought to permit self-pollination is unusual flower function resulting from chilly blooming weather. Magnitude of increase is sometimes several-fold. In the largest experiment involving 'Fuerte' and 'Topa Topa' the increase averaged 40% over the 5 years that data were gathered. There are drawbacks and problems (2).

Recommendations

Benefits are greatest when the mutually cross-pollinating cultivars are of opposite A and B sex-stage flower type (8). The 2 cultivars should have their branches close together and preferably overlapping. This can be achieved by having a small branch of one cultivar grafted into the second major cultivar or by adjoining rows in the grove. When 2 rows of 1 cultivar are alternated with 2 rows of the other, grove transportation rows and other gaps should be within rather than between cultivars. See the section on Girdling for suggestions concerning check trees, sufficient tree numbers and years of results and yield records.

An avocado grower anywhere who does not have provision for cross-pollination is probably suffering significant reduction in fruitfulness below the potential of his trees.

Summary

A number of factors influence avocado fruit set. Climate is important in terms of frost injury to trees or flowers, flower chilling injury and excess heat. Select the site

carefully. The 3 horticultural races have important differences in climatic adaptation.

Cultivar selection is of major importance for maximum fruitfulness within each race. Strain selection may be critical within each cultivar—budwood should be chosen with utmost care. Rootstocks differ in adaptation and may be involved with strain differences in complex and significant yield interactions.

Good grove management is of obvious importance. One specific measure to increase fruit set is limb girdling: remove a strip of bark 1 cm or less in width, involving half or so of the tree each year. Determining local benefits of girdling requires randomization of enough check and treated trees, with several years' results. Moving hives of bees into the grove may also increase the set; minimize competition from other kinds of flowers by time and location of hive placement.

Cross-pollination is likely to increase commercial avocado set significantly. Intermix the A and B flowering types. Maximum benefits occur when the mutual cross-pollinizers have interlacing branches.

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