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BACKGROUND INFORMATION AND IDEAS ON AVOCADO POLLINATION

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Avocado flowering, pollination and fertilization

Flowering. The avocado flower is bisexual and opens twice: it first opens in the female stage and at the second opening, usually on the following day, it functions as a male and pollen is released. The opening and the closing of the female stage flowers of a single tree (or cultivar), as well as that of the male stage flowers, occur simultaneously within each of the two flower stages, but at a different parts of the day. All the avocado cultivars are divided into two complementary flowering groups. 'Group A' cultivars which, in warm weather, bear open female stage flowers from the morning till noon time, and bear male stage flowers during the afternoon on the following day. 'Group B' cultivars, on the other hand, bear open female stage flowers in the afternoon and male stage flowers during the following morning. In most avocado cultivars there is a daily self-overlap phase of male and female flowering, which takes place for a period of 1 to 3 hours. Under cool weather conditions a delay of the male and the female openings may occur, this may result in a complete reversal as to the part of the day female and male flowers are open. At both male and female openings nectar is secreted, thus, insects that collect both nectar and pollen are the potential pollinators of the avocado.

Pollination. The avocado flowering behavior is a sophisticated mechanism that encourages cross-pollination, prevents self-pollination (within the flower) and offers the potential close-pollination (between neighboring flowers on the same tree, or within the cultivar). Cross-pollination occurs (during warm weather) between group B male-stage and group A female-stage flowers in the morning, and the opposite takes place in the afternoon. It may also take place between trees of the same flowering group, when there is an overlapping period between the male flowers of one and the female flowers of the other. The cross-pollination efficiency depends on the distance between the pollen donor tree and the pollinated tree, on the overlapping efficiency between the former male bloom and the latter female bloom, and on the pollinator mobility and density. Overlapping efficiency depends on the amount of female and pollen carrying male flowers that are opened simultaneously and on the length of the exposure period. In many cases, cross-pollination of a group A cultivar by a group B cultivar is more efficient than the opposite way, due to the efficient overlap between the group A female bloom and the group B male bloom, and the inefficient overlap of the opposite blooms. Close-pollination occurs during the daily self-overlap period of male and female-stage flowers within the same tree (or cultivar). During cool weather it may also happen when the afternoon bloom is delayed till the next morning and it overlaps with the normal morning bloom. Since during these flowering phases male and female flowers are at close proximity within the same inflorescence, the close-pollination efficiency may be very high. It depends on the self-overlapping period length and the percent of female flowers that are overlapping with the male flowers, and on the pollinator density. Most cultivars of the Mexican type and the Guatemalan type and their hybrids, present a daily efficient self-overlap of male and female flowers within the tree. Generally close-pollination is more efficient in the group A cultivars, and less so in the group B types. This is due to the more efficient self-overlapping of group A cultivars. Self-pollination occurs within the male-stage flower when its stamens release pollen, and this pollen reaches the stigma. This process does not necessarily demand pollinator in-

volvement, and may happen due to wind, or even spontaneously, due to gravity. Self-pollination of the male flower is a common phenomenon, which is more efficient in cultivars of male-stage flower of loosely closed inner stamens around the stigma.

Fertilization and fruit-set. Not enough is known about avocado fertilization and the fruit set process. Nevertheless, there is good evidence for several phenomena.

- The issue of the female reproductive apparatus viability is not clear. Some researchers have reported very low viability rates (in the range of a few percent of the flowers), while others achieved a fertilization success rate of 50%. However, the male fertility appears to be high in most cultivars: most flowers produce plenty of viable pollen, and it appears that most pollen grains are capable of supporting fertilization. It takes only one pollen grain to accomplish fertilization, and the other grains support it.
- In some cultivars, such as 'Hass', 'Ettinger' and 'Reed', it was demonstrated that one pollen grain has a very low probability to fertilize the female-stage flower, and twenty pollen grains or more per stigma are needed to achieve a high probability of fertilization.
- A higher likelihood of fertilization by out-cross pollen, compared to self pollen, was demonstrated in many cultivars. Moreover, it appears that pollen of certain cultivars is more potent than the pollen of others, since it results in a higher fertilization rate.
- Conflicting results were reported regarding the fertilization of avocado flower during the male stage. Under Mediterranean-type weather conditions, where mostly Mexican and Guatemalan cultivars are grown, the inability of the male-stage flower to achieve fertilization was clearly demonstrated. However, in Florida, with the local West-Indian cultivars, a very efficient male flower fertilization was found.
- Selective fruit drop of selfed-fruitlets has been observed in some cultivars. As a result, the percent of cross-pollinated fruits was found to increase during fruit growth and maturation. In most cases the resulting yield decreased with increase in distance from the pollen source. The available data may support the assumption that the selective self-fruit drop is more evident under stress conditions, and may be minimized, or disappear altogether, in more mild and humid environments.

Honey bees as avocado pollinators

Attractiveness of avocado flowers to the honey bees. Honey bees visit both female and male-stage avocado flowers. Usually they collect nectar from the two flower stages and pollen from the male stage. However, they sometimes collect only the male-flowers' pollen and will not visit the female ones. It is rare that they do not collect pollen, and actively brush it off from their bodies. Nevertheless, the avocado bloom attractiveness to the honey bees is low, in comparison to the flowers of numerous species that are in bloom at the same time and place, like the citrus spp and species of the Mint, Daisy and Mustard families (Labiatae, Fabaceae and Brassicaceae, respectively). Therefore, in many case honey bee foragers from hives, which were placed in the orchard for pollination purposes, abandon the avocado flowers and collect pollen and nectar from competing bloom. Thus, it is quite evident that the avocado flowers are not as well adapted to supply the honey bees' needs, when compared to the flowers of competing species.

How pollination is affected by the honey bee visit to the avocado flower. Honey bees that collect nectar, or nectar with pollen, create an efficient contact with the male-flower stamens and the female-flower stigma, by the same areas of their bodies. These body zones were found to carry large amounts of avocado pollen, on bees that were visiting male flowers during pollen release.

Efficiency of avocado pollen transfer through the honey bee hive. Some observations and experiments have demonstrated a very low and inefficient rate of avocado pollen transfer through the hive by body contact among the honey bees.

Transitions between male and female flowers and close-pollination efficiency. Honey bees that collect nectar, or nectar with pollen, were observed moving freely among neighboring, self-overlapping male and female avocado flowers. Therefore, close-pollination efficiency may be high, and depends mainly on honey bee density (Table 1). Since no avocado pollen transfer through the hive is occurring, however, close-pollination is accomplished only directly, between neighboring male and female flowers, and therefore depends on the efficiency of the daily self-overlap period between the two flower stages. On hot days in 'Nabal' the self-overlap period disappears, and close-pollination does not occur.

Table 1. Close-pollination efficiency.

Measurements made in Israel on 'Hass' trees (4 - 6 m high)		
Bees per tree	10	50
% of pollinated flowers, out of the daily female flower population	8	31
% of pollinated flowers, at the end of the daily female bloom	17	58
No. of pollen grains per pollinated stigma	4	5

Mobility between the trees and cross-pollination efficiency. Most honey bees collect nectar and pollen within a limited area of 1 to 3 trees. Therefore, they may perform cross-pollination only between neighboring trees that carry opposite-stage flowers and are at a distance of not more than two rows. A small percentage of the foraging honey bees (2 - 4%), however, move farther between rows and fields, and may carry avocado pollen for hundreds of meters away from its source. These are the scout bees, which, for the sake of information gathering, move among different locations and flowering species throughout the food collecting flight. The efficiency of cross-pollination between neighboring trees is not much lower than that of the close-pollination, but it drops dramatically with increasing distance from the pollen source (Table 2).

Table 2. Cross-pollination efficiency using 'Hass' medium-size trees with 'Ettinger' as the pollen source in Israel.

Bees per tree	10		50	
Distance between the pollen source and the pollinated tree (rows)	1	4	1	4
% of cross-pollinated flowers	6.5	1.5	27	8.5
No. of pollen grains per pollinated stigma	2.9	2.1	4.1	2.6

Does pollination limit avocado productivity?

One may assume that, in the case of the avocado, pollination can not play a role as a limiting factor to yield. A medium size mature avocado tree produces about 1 million flowers during a 30 - 60 day flowering season, which is approximately 10,000 to 40,000 new female flowers per day. Out of this, a total of only 400 to 600 flowers need to be successfully pollinated and fertilized to produce a fair crop. This can be accomplished by 2 - 3 honey bees in 1 day, during only 1 hr of the male and female flowers' self-overlap, who devote only half of their visits to the female flowers. However, in the field one can observe a measurable initial fruit set only after activity of 5 - 10 honey bees per tree during the whole female blooming period. At least one week of this level of visitation is needed to achieve a fair crop, and much more is needed for a good one. This paradox could be explained by the need for more than 20 pol-

len grains per stigma for an efficient fertilization, and the low average number of pollen grains that is deposited on the stigma by the bee during a visit. It may also stem from the heavy selective initial-fruit drop, where mostly the cross-pollinated fruits remain on the tree, and the inability of the honey bees to perform as efficient cross-pollinators.

To summarize, pollination may be a limiting factor for avocado productivity where one, or two, of the following conditions exist:

1. The pollinators' activity, which in most cases is the honey bee, is low, due to a low level of available pollinator population, or to the presence of more attractive competing bloom.
2. Cross-pollination efficiency is low, because of the low mobility of the pollinator insect, as in the case of the honey bee, and due to a relatively large distance from the pollen donor. In most avocado growing environments this is the case with regard to many cultivars, fields and seasons, if not in most of them.
3. In places where an efficient self-fertilization within the male-stage flower takes place, and self-pollination may be efficiently carried out by wind and gravity, pollination can not be a limiting factor to yield. However, in cultivars where the male flower inner stamens are tightly closed around the stigma, self-pollination may require the involvement of pollinating insect. In this case the need for a efficient pollinator is similar to that of the female flower.

What can be done to improve pollination?

I believe that a lot can be done, and that the consequences would justify the actions.

Introduce honey bee hives to the orchard and keep them there throughout the blooming season. Do not assume that 1 hive per acre is enough. To achieve good pollination you need at least 5 - 10 honey bees per medium tree, and more is much better. Check your trees twice a week during the blooming time! If bee density on the blooming trees is lower than 5 - 10, you should add more hives. Only rarely is 1 hive per acre sufficient, and in many cases 4 strong hives per acre is required!

Add pollen donor trees to the orchard. Most avocado cultivars need cross pollination to achieve their yield potential. Cross-pollination is efficiently performed only between adjacent trees, and not farther than two rows away from the pollen donor trees (about 12 m). Therefore, the minimum density of the pollen donor trees should be set to every 4^{th} row. Not all cultivars may serve as efficient pollen donors. Consult your extension adviser, and find out what pollen donor cultivars you should use, according to the orchard cultivar composition.

Keep the orchard open. Direct sunlight should reach the lower branches of each tree. This would enable the lower branches to carry more bloom, encourage a higher honey bee density in the orchard and would increase cross-pollination.

Alternative insect pollinators should be considered. In Israel a local species of bumblebee (*Bombus terrestris*) has been studied as avocado pollinator. In cases of low honey bee activity, and also in places with a distant pollen donor trees (more than 12 m), bumblebees were found to enhance yield significantly. In Mexico about 8 local species of stingless bees (Apidae, Meliponinae) have been observed to visit extensively all avocado types' bloom, which appears to be more attractive for them than for the honey bees. These species, which apparently are the avocado original pollinators, should be checked for their potential superior pollination efficiency in avocado orchards, and primarily within Mexico.