POLLINATION AND FRUIT SET: POLLINATION REQUIREMENT

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Considerable information has been developed on floral induction and the flowering process in *Citrus* in the papers which precede this one. Flower induction is a prerequisite to fruit production, so it is very important to have a clear understanding of the process. However, simply producing large numbers of flowers does not necessarily guarantee a subsequent large crop of fruit to harvest when they mature. There are many problems which can occur that disrupt the fruiting process, resulting in diminished crops which can threaten the profitability of citrus operations. To better understand the potential problems and how to deal with them, we must first study the citrus flower and the processes which cause the flower to develop into a fruit.

Most seed-producing plants (including *Citrus*) require a trip through the sexual process of pollination, fertilization and subsequent fruit set to produce a crop. Seeds are produced in this process, and in some crops, the seeds are the desired crop. In these crops, the sexual process is essential or there will be no crop to sell. Grains, peas, beans, peanuts, pecans and a host of other seed crops come to mind and sexual fertilization and subsequent seed development are clearly all-important. Some crops, including many fruit crops, may produce with or without seeds. Since seeds are generally regarded by the consumer as unnecessary or even undesirable, seedless fruits are in great demand. Bananas are an example of a desirable seedless fruit. It is difficult to even imagine eating a seedy banana. Many grape cultivars are also seedless and both 'Thompson' and 'Flame' are outstanding examples.

Citrus cultivars vary in the degree of seediness from almost totally seedless 'Tahiti' lime to the heavily-seeded (40-50 seeds/fruit) 'Duncan' grapefruit. While some cultivars are commercially seedless or are quite seedy at all times, others may have varying seed content due to conditions which occurred during the seed development period. In fact, there are several factors which can control the degree of seediness and fruit set in at least some of the commercial citrus cultivars and these will be investigated in this and subsequent papers in this publication.

The Citrus Flower

A citrus flower is usually botanically perfect (both male and female sex organs are in the same flower). The female portion of the flower is known collectively as the pistil and is comprised of the stigma, style and ovary (Fig. 1). During the sexual process, pollen is deposited on the sticky surface of the stigma, germinates and grows down the inside of the style into the ovary, into one of the locules where fertilization of the egg takes place, resulting in the formation of a seed.

The pistil is surrounded by a whorl of stamens (the male portion of the flower) which consists of long filaments with anthers at the top. The anthers are hollow and contain the pollen necessary for the process of sexual fertilization.

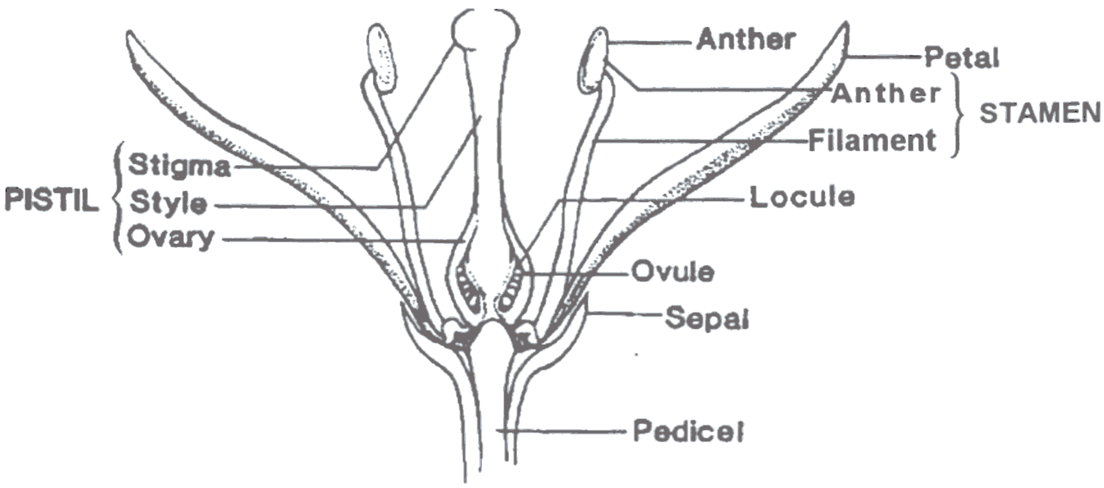

Figure 1. Diagrammatic portrayal of open citrus flower.

Exterior to the stamens and pistil are the petals (usually five) and then the sepals which are fused into a cup-like structure (the "calyx") and like the other flower parts, attached to the receptacle.

With the floral structure in mind we can proceed to the sexual process, fertilization and seed development.

The Sexual Process

In the normal self-pollination process, pollen shedding from the anthers comes in contact with the sticky surface of the stigma. (This process of pollen shedding is known as anthesis.) Citrus pollen is heavy and sticky and depends upon contact of flower parts or insects (usually bees) to effect pollination. The pollen sticks to the stigmatic surface where it germinates, sends a pollen tube down through the style and ultimately into the ovary below. Once inside the ovary, the pollen tube continues the journey to an ovule where two sperm nuclei are discharged. One of these nuclei fuses with an egg cell and a zygote is formed, later to become the sexual embryo. The other sperm cell combines with the two polar nuclei of the eight-celled embryo sac to form the triploid endosperm. This material will later be used in the seed to nurture the developing embryo.

In most seed-bearing plants, pollination, pollen tube growth, sexual fertilization and seed development are all essential to the development of the fruit. This is likely the result of growth regulators which are produced during the sexual process that prevent the developing fruitlet from dropping. In *Citrus*, the sexual process (or at least certain parts of it) are not absolutely essential to fruit production in all cultivars. Fruit production in the absence of stimuli from sexual reproduction is known as parthenocarpy.

Strongly parthenocarpic citrus cultivars tend to set large numbers of fruit without the necessity of the sexual process. Such fruit are, of course, quite seedless. The 'Redblush' grapefruit is a good example of a strongly parthenocarpic cultivar. Other cultivars vary in the degree of parthenocarpy from very strong to quite weak with many gradations in between. Cultivars which are normally quite seedy may, in fact, be strongly parthenocarpic but this is not revealed in nature because the sexual process and subsequent seed production prevails. Navel oranges are generally considered to be moderately parthenocarpic (though some would argue weakly parthenocarpic is more correct). Since the navel fruit are nearly completely seedless due to both degenerate ovules and a small amount of pollen, they are set tenuously and often drop during periods of environmental stress. Other cultivars, such as the 'Orlando' tangelo, are moderately parthenocarpic but have little seed production with self-pollination due to a sexual self-incompatibility. 'Orlando' trees can set modest crops of seedless fruit when planted in large blocks where cross-pollination from other compatible cultivars is not possible. However, productivity can be dramatically increased in mixed plantings of 'Orlando' with efficient pollenizer trees. While productivity increases, seediness also increases as a result of the sexual process present in the mixed plantings.

Clearly, citrus fruit production and the sexual processes which may or may not be essential are often fairly complex. We will investigate causes of poor fruit set morphologically and try to determine production practices to mitigate fruit set problems in the balance of this paper.

Morphological Problems Contributing to Fruit Set Problems

Cultivars which are strongly parthenocarpic need not be discussed here as they tend to set commercially acceptable crops of fruit regardless of "problems" which might otherwise affect the sexual process and subsequent fruit production. Cultivars producing seedy fruit also tend to not have fruit set problems and will likewise not be a topic for discussion here. However, the moderately to weakly parthenocarpic cultivars are of great concern as they are the ones whose productivity can perhaps be enhanced by certain horticultural practices.

Sterility. An obvious problem of the sexual process is sterility. The absence of female flower parts is perhaps the greatest cause of concern when it occurs. The absence of male flower parts, while inconvenient, can be mitigated by cross-pollination in many cultivars. An absence of functional ovules (as in navel oranges) can be a concern since cross-pollination is not likely to produce benefits since no seed can be produced. The number of chromosome sets (ploidy level) may also be a cause of sterility. ('Tahiti' lime, for example, is triploid and functionally sterile, but due to strong parthenocarpy, sets commercially acceptable crops of fruit.) In general, however, sterility problems in weakly parthenocarpic cultivars have been dropped from the selection process as undesirable traits so there is little need for further discussion here.

Incompatibility. Sexual incompatibility can be a cause of poor fruit set in certain types and cultivars of citrus. Pummelos and many of the tangerine X grapefruit hybrids are self-incompatible (and in some cultivars, cross-compatibility problems exist).

When an incompatibility exists, the pollen is not compatible with the pistil (even if the ovules are viable). In other words, the pollen is incapable of effecting sexual fertilization. The terms self-incompatibility and cross-incompatibility are used to describe the problem when it occurs respectively, within a single cultivar, or if different cultivars are involved.

Citrus incompatibility is due to slow growth of the pollen tube. This is apparently due to the presence of inhibitors (or lack of promoters) in the style. This delay in pollen tube growth means that most of the styles will abscise before the pollen tube can enter the ovary, effectively precluding sexual fertilization. Experimentally, this problem has been overcome by bud pollination before flowers open and by reducing the length of the style. While interesting, the practices are without value to the average citrus grower.

Overcoming Self-incompatibility Problems

There are several methods for dealing with problems of incompatibility. Foremost among these is cross-pollination. Application of growth regulators and girdling have also been shown effective. More subtly, but perhaps equally important, are a wide range of horticultural practices which affect tree vitality and the subsequent ability of the tree to carry a weakly parthenocarpic crop to maturity.

<u>Cross-pollination</u>. The most important method of overcoming self-incompatibility is the introduction of compatible pollen from trees nearby by interplanting and judicious use of bee pollination. Selection of the best possible pollenizer trees is essential to success. The ideal pollenizer cultivar should have all (or at least most) of the following characteristics:

a. sexually cross-compatible
b. bloom period must overlap with cultivar to be pollinated
c. produce large amounts of pollen
d. produce large crop of flowers every year
e. produce commercially marketable fruit
f. possess cold tolerance similar to target cultivar
g. possess similar horticultural needs as target cultivar

As in selecting a rootstock, no one pollenizer is likely to be perfect and some compromises may be necessary. Characteristics "a" and "b" cannot be compromised and "d" should not. There may be some room for compromise in the other characteristics, but each will result in a loss of pollenizer efficacy. Some pollenizers can be so effective that too many fruit are set on the target trees and the ratio of donor trees to target trees must be kept very low. Other pollenizers are less efficient due to low flower numbers or the amount of pollen produced, and the ratio must be increased. Some specific examples of some pollenizer considerations (among many which exist) can be found below:

- Since 'Robinson' produces very little pollen, it works well as a pollenizer for 'Orlando' if the majority of the trees are 'Robinson'. Also, 'Orlando' is a very effective pollenizer for 'Robinson' and the number of 'Orlandos' must be held down to prevent over-cropping and limb breakage of the 'Robinsons'.

- Since 'Minneola' often produces low flower numbers, it is not a satisfactory pollenizer even though it is cross-compatible with many self-incompatible cultivars. However, it may work satisfactorily if the ratio of 'Minneola' trees to target trees is increased.

- Some cultivars require special disease control considerations. Scab on 'Temple' and *Alternaria* on 'Minneola' come to mind as examples. Special spraying programs for these disease-susceptible cultivars would suggest that the trees be planted in pollenizer rows, instead of interspersing trees within the block.

Transportation of the pollen from the donor tree to the receptor tree is absolutely essential. Citrus pollen is quite heavy and sticky and will not get from one tree to another without assistance. Honeybees are the best pollinators available and one properly placed colony of bees per two acres is recommended for best results.

When devising a planting scheme to assure effective cross-pollination, it is clear that several variables may need to be dealt with. While each and every idiosyncrasy may not be worthy of consideration, several planting schemes have been devised over the years to deal with most of the common situations likely to be encountered. These are presented in graphical form in Figure 2.

Figure 2. **Pollenizer planting plans.**

PLAN A

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* O O O O * O O O O *
* O O O O * O O O O *
* O O O O * O O O O *
* O O O O * O O O O *
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PLAN B

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O O O O O O O O O O
* O O * O O * O O *
O O O O O O O O O O
* O O * O O * O O *
O O O O O O O O O O
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PLAN C

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* O O * O O *
* O O * O O *
* O O * O O *
* O O * O O *
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PLAN D

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* * O O O O * * O O O O * *
* * O O O O * * O O O O * *
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* = Pollenizer; O = the primary or main variety. Plans A and B are usually satisfactory for trees with space on four sides and less satisfactory for tight hedgerows. Plan C is suggested for hedgerows but it requires more pollenizer trees. Plan D is used by some growers to facilitate harvest of pollen cultivar.

Two basic plans are used when trees are maintained as individuals by pruning all four sides. (Plans discussed here are those portrayed in Fig. 2.) Plan A uses 20 percent pollenizers and Plan B uses about 16.6 percent. These plans take into account the habit of bees to work back and forth between about two rows. These plans will not work as well with hedgerow plantings because the bees will fly up and down the hedgerows instead of crossing over two adjacent rows. The best solution to this problem is likely to be the use of Plan C. However, this plan uses a very high percentage of pollenizer trees (33 percent). This is not a problem if fruit from the pollenizer trees has value similar to the variety being pollinated. Yet another alternative plan is available when harvest facilitation of the pollenizer cultivar is important. Plan D puts the pollenizers in blocks of four and picking tubs can be set in the middle of the trees.

Selecting the proper cultivar for use as a pollenizer is extremely important. Even the best planting plan will not work if the wrong pollenizer is selected. This is a fairly complicated process since there are several factors to consider. The available information has been compiled into Table 1. Using 'Robinson', for example, and selecting a good pollenizer, we would come up with

Table 1. **POLLINATION OF CITRUS HYBRIDS***

SOURCE: Dr. C. Jack Hearn, Retired, Plant Breeder, USDA Horticultural Field Station, Orlando, FL

	Hybrid to be Pollenized						
Pollenizer	Orlando	Sunburst	Page$_3$	Nova	Osceola	Robinson	Minneola
Robinson$_1$	G	F-G	N	N	P	P^a	
Nova	VG	VG	N	P^a		N	
Page	G		P^b	N	G	N	
Sunburst	G^a	P^a		G^a		G	VG
Osceola	G^a				P^a	P	
Orlando	P^a	VG	G	VG	VG	VG	N
Minneola	N	G^a					P^a
Lee$_2$	VG	G^a	G	G^a	VG	VG	
Fallglo$_2$		G					G^a
Temple$_2$	VG	VG	G	VG	G^a	VG	VG

*Adequate density and arrangement of pollenizers is required to ensure proper pollination.
*Adequate honeybee population required to move pollen from pollen source trees to the hybrid

Key – VG = very good; G = good; G^a = believed to be good, however limited data exist on this combination; F = fair; P = poor; P^a = poor as a self-pollinator; P^b = sometimes good, small fruit; N = not compatible. Areas left blank do not have sufficient data to state effectiveness as a pollenizer.

Limited pollen produced by Robinson.
2) Varieties do not require cross pollination
3) Page may bloom before other varieties.

'Orlando', 'Lee' and 'Temple' as possibilities. We would then need to consider other factors and remember that 'Temple' can be scabby and is not particularly cold-tolerant, that 'Lee' is not a cultivar with great market value and that the number of 'Orlando' trees must be kept low to avoid over-cropping the 'Robinsons'. While the process is not necessarily straightforward, armed with the table and other pertinent facts, an informed decision can be made.

Growth regulators. Gibberellic acid (GA) has been shown to be effective in increasing fruit set on many of the self-incompatible citrus hybrids in Florida. Sprays of GA at a concentration of 10 ppm applied between full bloom and two-thirds petal fall have effectively resulted in the set of commercial crops of seedless 'Orlando', 'Minneola', 'Nova' and 'Robinson'. No doubt the material would likewise be effective with other incompatible cultivars, but experimental data is lacking for Florida.

The application of GA is not without problems. Results may be spotty and more effective at some times than others. Fruit size may be small due to the absence of seeds, especially when large crops are set. Orange peel color may be slightly delayed, but this is a relatively minor problem.

Girdling. A single knife cut through the cambium into the wood around the tree trunk has been shown to effectively enhance the cropping of 'Orlando', 'Minneola', 'Robinson' and 'Nova'. Other incompatible cultivars have shown similar response in the field, but these were not replicated trials and experimental data are lacking. Girdling cuts should be made during the period between full bloom and two-thirds petal fall. This is a very labor-intensive practice and is not widely used at this time.

Horticultural Practices Impacting Fruit Set

Many production practices have an influence on fruit set. This is true whether one is dealing with a self-incompatibility problem or one of weak parthenocarpy. Both problems result in fruit which is not strongly held on the tree and is subject to drop under less than favorable conditions. Therefore, it is logical that anything a manager can do to minimize tree stress is likely to increase production. A partial list of stress considerations is listed below.

a. Soils - Good soils are instrumental to success. Good fertility and water-holding capability are very important. Navel oranges will benefit greatly from good soils since they are so sensitive to stress.
b Water - Optimum water relations enhance fruit set. Excesses and shortfalls are troublesome and should be avoided. Good management is essential.
c. Fertility - Adequate (but not excessive) levels of minerals are important. Frequent feeding through use of fertigation and/or foliar sprays may be effective. Post-bloom nutritional sprays appear to be helpful.
d. Carbohydrate reserve - A good supply of carbohydrates is helpful. Good nutrition and tree condition can build reserves. Stress and large crops deplete carbohydrates.
e. Pruning - Pruning can affect water relations and nutritional levels. Be sure to time properly so as not to cut future blossoms unless thinning is necessary.

f. Rootstock - Judicious rootstock selection for optimal adaptation to soil and growing conditions is extremely important in helping minimize stress.
g. Harvest date - Remove fruit as early as possible to allow trees time to recover for next crop. This is especially important when crop extends into next year's bloom period.

Conclusions

Pollination is important, but not always absolutely essential to produce some citrus crops. A good understanding of the flowering and fruiting processes, floral morphology and anatomy and the factors affecting fruit set and development are all very important. This paper and the others which comprise the proceedings of this short course should help greatly in making informed decisions regarding the management of citrus groves and hopefully increasing their fruit set and productivity.

Suggestions for Further Reading

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