FLOWERING AND FRUIT SET OF CITRUS

A. H. Krezdorn

The purpose of this discussion is to review basic information available on flowering and fruit set of citrus and on production practices that can be manipulated to influence either or both to the advantage of the grower. Flowering and fruiting are part of the sexual or reproductive cycle leading to seed production. Thus, a knowledge of flowering, flower structure and the hormonal stimuli associated with the sexual events leading to seed production, pollination, pollen tube growth, sexual fertilization and subsequent seed development forms the basis for manipulating production practices to enhance flowering and fruit set. In addition, it should be recognized that flowering, fruit set and subsequent fruit development depend on an adequate complement of healthy, functioning leaves and it is, therefore, vital that production practices be directed to this end.

FLOWERING

Time of Flowering

In Florida and other subtropical regions orange, grapefruit and mandarin characteristically have a single, intense flowering period of about 2 to 4 weeks of open bloom following the winter (low temperature-induced) dormancy period. Flowering starts just prior to but occurs mostly concurrent with the spring growth flush of leaves. This is most often in March. Out-of-season bloom (off-bloom) is occasionally produced in June or August following severe drouth-induced dormancy. Lemons and limes also have their primary bloom in the spring but produce small intermittent bloom throughout the year. Kumquat has a pronounced winter dormancy in the subtropics and does not produce flowers or spring leaf flush until May.

Bloom occurs with the onset of rains following drouth-induced dormancy in the tropics. There is often a main flowering period with the onset of rain following a pronounced dry season and a small flowering period following the end of the rainy season when there are intermittent short periods of drouth and rain.

Flower Formation

Flower Bud Induction. Buds (growing points in the axils of leaves) are initially vegetative. Some ultimately change or differentiate into floral or fruit buds. It has been determined that flower induction (the time period during which biochemical factors induce a change from a vegetative to a floral bud) normally occurs during the winter dormant period.

Flower Bud Differentiation. The anatomical changes that take place when vegetative growing points convert to floral ones do not occur until shortly before flowering. Deciduous fruit trees, on the other hand, differentiate their flower buds during the previous summer and they are readily recognizable by their shape and size.

Citrus flower buds can not be visibly recognized by shape and size. Recently, however, scientists in California were able to predict the presence of flowering shoots with 90% accuracy. Shoots that flowered had smaller leaves, fewer nodes, fewer thorns and more branching.

Factors Affecting Flower Formation

Juvenility. Seedling oranges and grapefruit require 8-15 years to flower. The protracted period of non-flowering in orange and grapefruit seedlings is called juvenility and it is apparently hormonally controlled. Buds taken from the flowering portion of the tree produce flowers within 3 or 4 years when budded on a seedling rootstock but the lower, older portion of the seedling tree remains juvenile for life. Thus, a seedling tree cut back to primary framework branches produces a juvenile canopy once again.

The juvenile period for mandarins is only 5 years. Lemon seedlings require only 2-3 years to fruit and Key limes 1 to 2 years. This kind of juvenility differs from the non-flowering period of standard nursery trees budded with buds from old-line, fruiting trees in that the latter is due to excessive vegetative vigor and is not persistent.

Fruit. It is well established that shoots with fruits do not flower the following year. Thus, heavy crops are often followed by lighter ones and a degree of alternate bearing develops. Some mandarin types, Murcott in particular, bear so heavily that there are virtually no flowers the following year. This can be overcome by pruning back a portion of the fruiting shoots either during bloom or the early fruiting stage during the heavy crop year. This reduces the fruit load and stimulates production of many new non-flowering shoots that flower the next year. Thinning or removing part of the fruit in the spring also alleviates alternate bearing. Holding crops of grapefruit and oranges on the tree long after first legal maturity is reached will moderately reduce the subsequent crop. Spot picking or removing about 50% of the crop early will largely alleviate the effects of late harvest.

Shade. Citrus will tolerate considerable shade and still flower and fruit; however, best flowering occurs when leaves are fully exposed to the sun. Thus, pruning (topping and hedging) as practiced in Florida is vital to consistent, adequate flower production.

Tree Vigor. Excessive vegetative vigor, from whatever cause, will reduce flowering. It is unlikely excessive vigor will result from fertilization or irrigation programs; however, excessive fertilizer and water might slightly delay fruiting of young trees.

Pruning is the practice that commonly results in greatly reduced flowering on portions of the tree. It has been common practice to hedge trees on 4 sides, pruning 2 sides one year, the other 2 sides the next and then skipping a year. Flowering and fruiting is sparse the season following hedging of a given side because of the excessively heavy pruning. There is no published research to precisely establish the best frequency of pruning for the various varieties. My observations lead me to believe annual but very light pruning is best; however, pruning in alternate years may be satisfactory. With closer spacings being used in new plantings, pruning and its influence on vigor and light will become an increasingly important factor.

Leaf Loss. Leaves produce the tree's food or energy source and excessive leaf loss will reduce flowering. The primary reasons for leaf loss are freeze injury, mites and greasy spot. Loss of leaves can reduce flowers the following spring to the point of crop reduction. Leaf loss in early winter is worse than a similar loss in late winter because flower induction will already have taken place in the latter case. There are not adequate data to determine how much leaf loss due to freezes can be tolerated. Some growers in chronic cold areas feel a 25% leaf loss in mid to late winter will reduce the crop little if any. This is the coarsest of estimates, however.

Greasy spot disease can cause devastating leaf loss and reduced flowering and fruiting. Good greasy spot control is vital to maximum flowering and fruiting. There appears to be a general consensus that spring mite damage to leaves is not significantly harmful. Loss of leaves in the fall from mite damage can, however, be harmful.

Gibberellic Acid (GA). Gibberellic acid applied to leaves shortly before bloom will usually reduce the number of flowers formed. Australian scientists have suggested its use to reduce the bloom and thereby the crop, in heavy crop years, as a means of reducing alternate bearing. GA has not worked well in this respect. This widely reported effect of GA does, however, demonstrate the hormonal nature of flowering.

Girdling. Girdling healthy trees in the early fall will usually increase flowering on healthy, non-juvenile trees. It will not overcome seedling juvenility. However, there appears to be no place for this procedure in the Florida production program and there are dangers involved.

THE FLOWER AND INFLORESCENCE

The citrus flower is perfect; i.e., it has both female and male sex organs in the same flower. Many species of plants have the sex organs in different flowers on the same tree or even on different trees (Fig. 1).

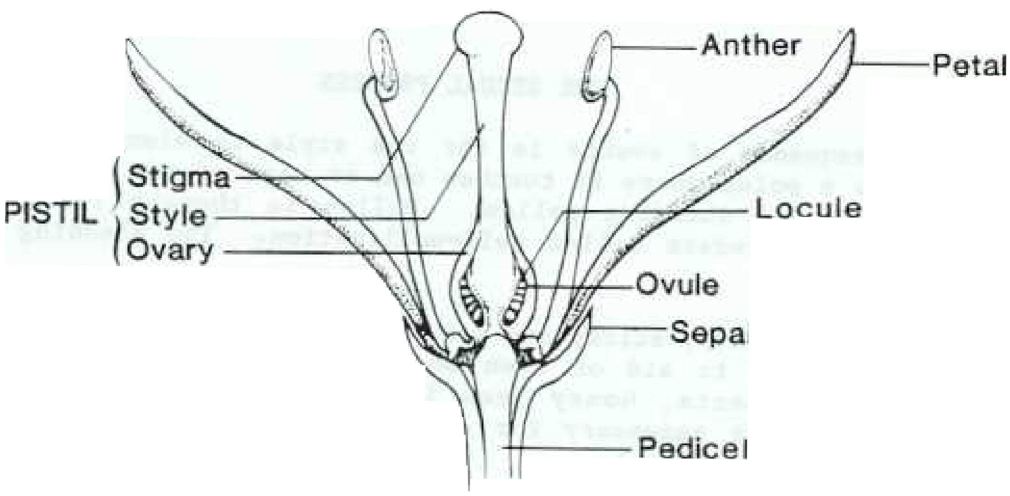

Fig. 1. Diagrammatic portrayal of open citrus flower.

There is a single female sex organ (pistil) in the center of each flower. It consists of a bulbous ovary which is attached to the receptacle (broadened apex of the flower stem or pedicel). A slender, stalk-like style arises from the apex of the ovary and the broadened apex of the style is the stigmatic knob and surface. A viscous material (stigmatic fluid) is exuded from the stigmatic surface as the flower matures. The pistil appears simple (consisting of 1 pistil) but it consists of 10-12 fused simple pistils as evidenced by the 10-12 cavities (locules) in the ovary and the 10-12 passages (stylar canals) extending from the respective ovarian cavities through the style and to the stigmatic knob. There are ovules, which become the seeds, attached to the interior walls of the ovarian locules. The ovule consists of an embryo sac surrounded by tissues known as integuments which at maturity become the seed coat. Inside the embryo sac are an egg cell, 2 polar nuclei and some other cells called antipodals and synergids respectively. There is a layer of tissue between the embryo sac and integuments called the nucellus. Cells from the nucellus can grow into the embryo sac and form nucellar (vegetative) embryos. There is a disc-like nectary that produces nectar at the base of the ovary. The nectar, which attracts bees, is converted into honey.

Just outside the base of the ovary and attached to the receptacle are several series or whorls of male sex organs (stamens). Each stamen consists of a stalk-like filament bearing an anther at its top. The anthers produce many thousands of heavy, sticky, bright yellow pollen grains. Exterior to the stamens are white petals (some species have purple tinged white petals) and exterior to the petals are the green sepals (collectively the calyx), fused into a cup-like structure and like the other flower parts, attached to the receptacle.

Citrus produces both single flowers and groups of flowers (inflorescences) and both can occur either in the axils of mature leaves of previous growth flushes (bouquet bloom) or interspersed in the axils of immature leaves of the new growth (leafy bloom). Moreover, the leafy bloom varies from short vegetative shoots of 1 or 2 leaves to strong shoots with a number of leaves. The inflorescence itself is more or less a corymb or determinate inflorescence meaning the uppermost flower is the most mature.

THE SEXUAL PROCESS

The usual sequence of events is for the style to elongate and extend the stigmatic knob to a point where it touches one or more of the anthers just as the latter are opening and shedding pollen. Pollen is thereby transferred to the stigma by contact, a process called self-pollination. The shedding of pollen is called anthesis.

Citrus pollen is heavy, sticky and not wind-blown; however, the shaking of the flower by wind appears to aid or even be necessary in causing the anthers and stigma to touch. Insects, honey bees in particular, aid in bringing about self-pollination and are necessary for cross-pollination (the transfer of pollen from flowers of another variety).

The pollen on the stigmatic surface is caught in the sticky stigmatic fluid where it germinates or grows. Each germinating grain extends a pollen tube through the style, into the ovary and ultimately into the ovule where it discharges 2 sperm (male) nuclei (Fig. 2).

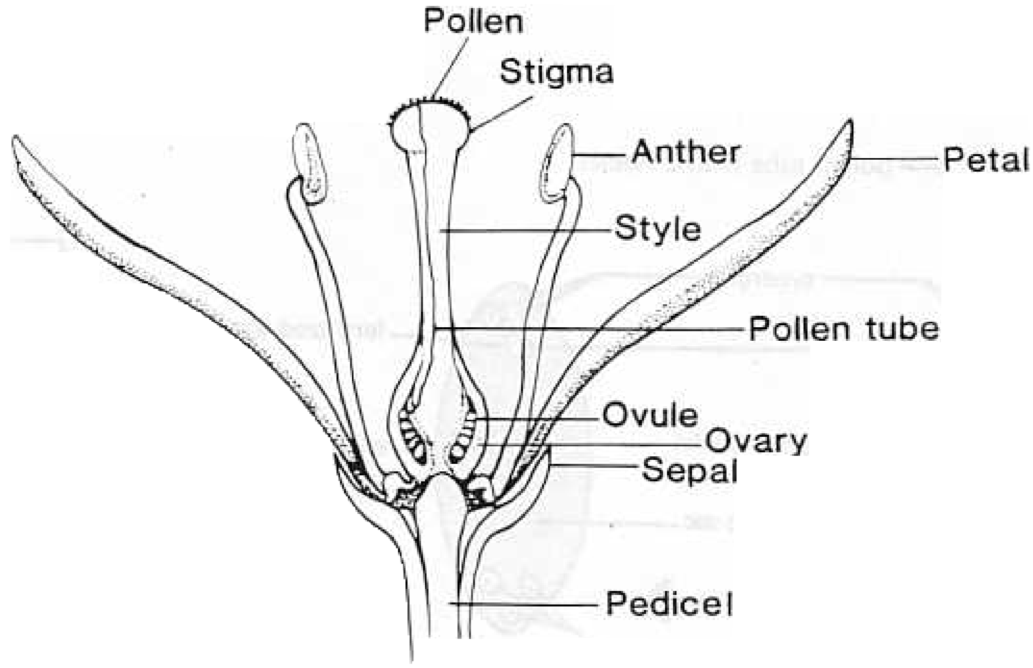

Fig. 2. Pollination and pollen tube growth.

One of the sperm nuclei fuses with the egg cell in the embryo sac of the ovule to form the zygote. The zygote develops by cell division and differentiation into the sexual embryo. The other sperm cell fuses with the 2 endosperm or polar nuclei, also in the embryo sac, and develops into the endosperm, a material used to nourish the developing embryo (Fig. 3).

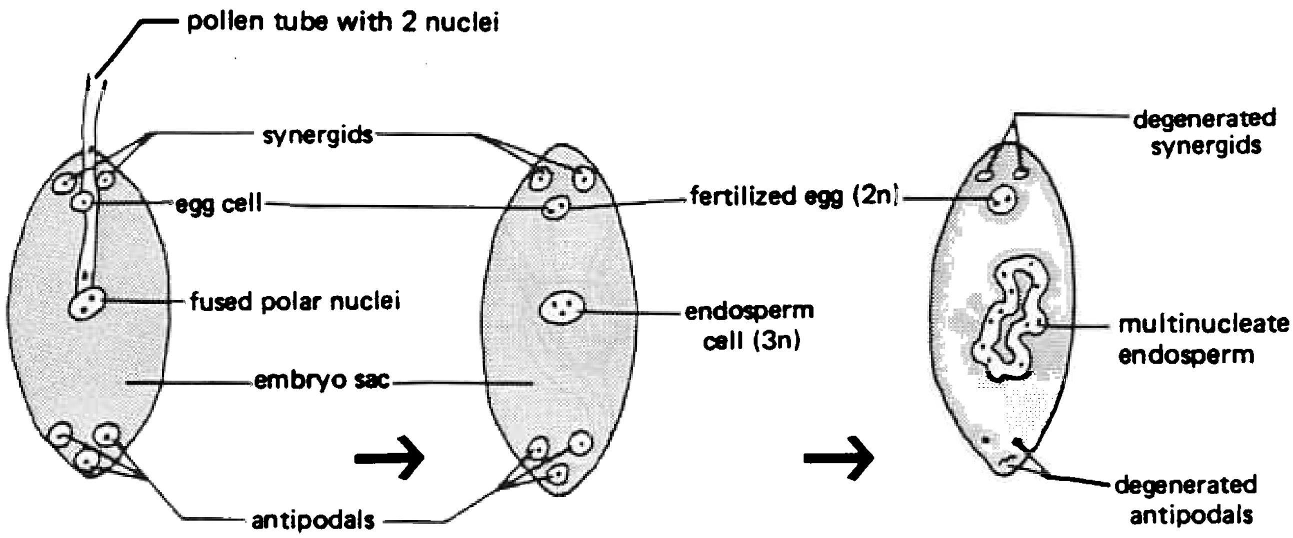

Fig. 3. Fertilization and endosperm development within the embryo sac.

Fusion of the sperm cells with the female egg and polar nuclei cells respectively, is called double fertilization, as opposed to single fertilization in animals. The ovules subsequently develop into seeds.

Each step, pollination, pollen tube growth, sexual fertilization and subsequent seed development appear to furnish or stimulate the production of growth regulators that prevent ovary or fruit drop; however, sexual fertilization and subsequent seed development appear to play the most vital roles in fruit set and fruit enlargement. Thus, the sexual process appears vital to fruit production; however, this is not always true. The exception is termed parthenocarpy, or production of fruit without the stimulus of sexual fertilization. Such fruit are, therefore, seedless. In citrus there are a number of varieties, such as Redblush grapefruit, that are strongly parthenocarpic. The hormonal stimulus that results in development of seedless fruit is not well understood. Apparently there is sufficient production of growth regulators in the ovarian tissues to prevent abscission and bring about fruit development. There are varying degrees or strengths of parthenocarpy. Moreover, some varieties require at least the stimulation of pollen tube growth or even sexual fertilization and subsequent seed abortion in order to fruit. In cases of weak parthenocarpy satisfactory fruiting is highly dependent on preventing physiological stress such as inadequate moisture.

FRUIT SETTING

General

Fruit set is defined in various ways. Here, fruit is considered as set when it has developed to the point that it can be expected to remain on the tree until maturity unless caused to drop by severe physiological stress or mechanical or pest injury. This takes the fruit through what is commonly called June drop, which may actually occur in late May.

Many unopened flowers shed during the bloom period. Then pistils of many opened flowers shed soon after petal fall; however, many enlarged ovaries that appear healthy remain. Still later, many of these small fruit turn yellow and fall prior to the June drop. Finally, there is the June drop. The first waves of fruit abcission are due to problems associated with both the sexual process and to competition among fruit. Later fruit drop is almost entirely due to competition. Flowers arising directly on growth flushes of the previous season set little fruit and flowers on weak, leafy bloom also have a heavy abscission rate. The strong, new leafy shoots with several leaves set the most fruit. Thus, good tree vigor is vital. Research in California with seedless navel oranges indicates the great majority of fruit that sets come from the last part of the bloom after the new leaves attain full size. This is not true in Florida, at least with some varieties, where an appreciable quantity of fruit sets on leafy bloom throughout the flowering period, even though heavier set occurs in the latter part.

These observations are explained at least in part by work in Florida with radioactively labeled carbon in citrus leaves. The labeled carbon was used to trace the movement of carbon-containing leaf photosynthates or food. Little or no radioactively labeled food moved to the developing fruitlets when pollen was excluded from a seedy variety; however, food did move into these young fruit as soon as the new leaves obtained full size and some of this fruit set parthenocarpically. On the other hand, there was a strong movement of labeled food materials into the fruitlets when the pistils were pollinated before leaves were full size. Similarly, labeled food material moved into fruitlets following applications of GA to the stigmas of pistils. Thus, one theory is that growth regulators (hormones) resulting from the sexual process cause leaf photosynthates or food to move into the fruitlets and delay or prevent abscission. The number of flowers produced is usually so great that only a small fraction of the fruit must be set to produce a maximum crop. Even so, there are conditions under which even trees with extremely heavy bloom set little or no fruit.

Sexual Incompatibility

General. The pollen of some varieties is incompatible with the pistils, even though the ovules of the flower are fertile; i.e., the pollen is incapable of bringing about sexual fertilization even though both male and female components are functional. This is called sexual self-incompatibility where the pollen and ovules of the same variety are involved and cross-incompatibility where pollen of one variety is incapable of bringing about fertilization of another.

Incompatibility in citrus is due to slow pollen tube growth, apparently caused by inhibitors in the style. This results in abscission of the style before the pollen tube can enter the ovary and discharge its sperm nuclei into the embryo sac. Sexual fertilization is thereby precluded and fruit set of non-parthenocarpic varieties is nil to very little. When flowers of self-incompatible Orlando tangelo and pummelos were opened well before the flower would normally open and self-pollinated by hand their self-incompatibility was overcome. It is not known whether this was due to the very short style or to absence of chemical inhibition in the style.

Most self-incompatible citrus varieties are only weakly parthenocarpic. Lack of sexual fertilization results in varying degrees of unfruitfulness. 'Page' is self-incompatible but highly parthenocarpic so it produces large quantities of seedless fruit when self-pollinated and seedy fruit when cross-pollinated.

Sexually Incompatible Varieties. All pummelos are sexually self-incompatible. Many mandarin x grapefruit hybrids, such as 'Orlando', 'Minneola', 'Robinson', 'Osceola', 'Nova', 'Sunburst' and 'Clementine' (a hybrid of unknown origin) are self-incompatible. 'Orlando' and 'Minneola' are cross-incompatible. Not all mandarin x grapefruit hybrids are self-incompatible. 'Murcott' and 'Temple', mandarin hybrids of unknown origin, are self-compatible. There is no sexual compatibility among commercial sweet orange, grapefruit and true mandarin varieties.

Cross-Pollination. One means of overcoming self-incompatibility is cross-pollination with a compatible pollen. This is the most common corrective measure used in Florida; however, this results in seedy fruit. The variety used as a pollen source is the pollenizer and the honey bee, which carries the pollen between the 2 varieties, is the pollinator or vector. A good pollenizer for a self-incompatible variety should have the following characteristics:

1. Sexually cross-compatible
2. Overlapping bloom period
3. Produce large amounts of pollen
4. Produce flowers every year
5. Produce commercially marketable fruit
6. Be as cold tolerant as the main variety

At times one must accept a less than perfect pollenizer variety; however, the limiting factors (1,2 and 4 above) can't be compromised. Suggested pollenizer varieties for important commercial Florida varieties are given in Table 1.

1. Pollenizer varieties for important self-incompatible citrus varieties.

Pollenizer Variety	Main Variety: Minneola	Nova	Orlando	Robinson	Sunburst
Minneola[1,2]	U	U	U	U	U
	?	U	S	S	S
Orlando	U	S	U	S	S
Robinson[3]	U	U	S	U	U
Sunburst	S	S	S	S	U
Temple[2,4]	S	S	S	S	S
Murcott[1,2,5]	U	U	U	U	U

S = Satisfactory; U = unsatisfactory ? = unknown

[1]Tends to alternate bearing

susceptible

[3]Produces too little pollen unless used as the main variety

[4]Much more sensitive to freeze damage than the other varieties

[5]Bloom does not overlap any of the other varieties

<u>Note</u>: No sweet orange or grapefruit variety is considered a satisfactory pollenizer, even though some seedy varieties of oranges are slightly effective.

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Plan A    P O O O O P O O O O P

          P O O O O P O O O O P

          P O O O O P O O O O P

          P O O O O P O O O O P


Plan B    O O O O O O

          O P O O P O

          O O O O O O

          O P O O P O

          O O O O O O


Plan C    P O O P O O P

          P O O P O O P

          P O O P O O P

            O O P O O P
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Fig. 4. Pollenizer planting plans.
P = pollenizer; O = the primary or main variety
Plan A and B are usually satisfactory for trees with space on 4 sides and less satisfactory for tight hedgerows. Plan C is suggested for hedgerows but it requires more pollenizer trees.

It is noteworthy that 'Robinson' produces very little pollen. 'Robinson' works satisfactorily with 'Orlando' if most of the trees are 'Robinson' and a few are 'Orlando'. Under this situation both fruit well. However, 'Robinson' does not produce sufficient pollen to effectively cross-pollinate a large number of 'Orlando'. Also, 'Orlando' is such an excellent pollenizer that alternating rows of 'Robinson' and 'Orlando' may result in excessive fruit setting of 'Robinson' and subsequent limb breakage. 'Temple' requires scab control. Thus, it should be planted in pollenizer rows, instead of using individual trees interspersed with the main variety in order to facilitate spraying. 'Minneola' is not a satisfactory pollenizer, even though it is cross-compatible with some self-incompatible varieties because it tends to lower flower production in some years.

Two basic plans are used when trees are maintained as individuals, i.e., pruned on 4 sides (Fig. 4). Plan A uses 20% pollenizers and Plan B about 11%. This takes into account the habit of bees to work back and forth between about 2 rows. These plans may not work as well where trees are hedgerowed because bees tend to limit flights up and down the hedgerows instead of crossing over 2 adjacent rows. The best solution to this problem is not known but Plan C (Fig. 4) should suffice.

Gibberellic Acid. GA sprays at 10 ppm concentrations applied from full bloom to two-thirds petal fall have effectively set and produced commercial size crops of seedless 'Robinson', 'Nova', 'Orlando' and 'Minneola' in Florida. GA will probably work on all of the self-incompatible mandarin hybrids but published research is lacking for varieties other than those mentioned.

There are some undesirable side effects. Fruits induced by GA are reduced in size and development of orange peel color is slightly delayed. 'Robinson' is inherently so small it can't usually tolerate the size reduction. GA is, however, usually satisfactory when used on 'Minneola', 'Orlando' and 'Nova'. The color delay can usually be tolerated. Exceeding the recommended dosage or concentration of GA will result in severe leaf drop.

Girdling. A single, deep knife cut made around the trunk of the tree from full bloom to two-thirds petal fall has been used effectively to produce seedless crops of 'Orlando', 'Minneola', 'Robinson' and 'Nova'. In one experiment trees were girdled 8 years with excellent results and no deleterious effects. Girdling would probably be effective on other self-incompatible mandarin hybrids but trials are lacking. Girdling is only effective on fully-foliated, vigorous trees. Trees with 25 to 50% leaf loss due to a freeze do not respond favorably to girdling. The use of girdling is a moot point, however, because the characteristics of the existing labor force preclude its use, even though it was once used effectively on several thousand acres of trees.

Strongly Parthenocarpic Selections. Nothing has been done in Florida to search for strongly parthenocarpic selections of self-incompatible varieties. In Morocco, however, strongly parthenocarpic strains of self-incompatible Clementine have been found and propagated. It is not known whether strongly parthenocarpic mutants of self-incompatible varieties grown in Florida could be found but growers and nurserymen should be on the alert for them because this would result in seedless fruit.

Rootstocks. Excellent crops of seedless 'Orlando' fruit have been consistently produced on the few commercial blocks with sweet lime rootstocks in Florida. A rootstock trial using 'Orlando' as the scion variety and a wide range of rootstocks also demonstrated that trees on sweet lime rootstock set large crops of fruit without cross-pollination while rootstocks such as 'Cleopatra' mandarin and sweet orange set and produced very little fruit. Rusk citrange produced heavy crops on small trees and other rootstocks varied in the yields induced. The ability of sweet lime to induce or enhance parthenocarpic fruit set is apparently related to its deep, widespread root system and therefore its ability to reduce or avoid water stress. Little use has been made of rootstocks to enhance parthenocarpic fruiting but the possibility exists and needs to be explored further.

NAVEL ORANGES

Navel oranges have almost completely sterile pollen and ovules. Thus, seed induction is not a solution to low fruit set as in the case of self-incompatible varieties. Cross-pollination by hand is, however, partially successful and work from South Africa indicates pollen of certain citrus varieties is more effective than others even though very few seeds are induced. Thus, appropriate cross-pollination apparently induces stimulative parthenocarpy through pollination and pollen tube growth; however, cross-pollination via bees was ineffective. This is partly because only nectar gathering bees visit navel flowers, due to lack of viable pollen, and they are reportedly less effective as cross pollinators. Moreover, it is doubtful that bees would carry sufficient pollen to have the same stimulative effect as the massive amounts of pollen that were transferred by hand pollination. GA is not effective in inducing fruit set when entire trees are sprayed, even through it is effective when individual flowers are treated by hand, for reasons not known. Actually, the largest problem with navels is not fruit set but summer and summer-fall drop. This subject is covered in another part of this course.

STANDARD VARIETIES

Fruit setting is not a limiting problem with standard orange, grapefruit and mandarin varieties if trees are healthy and well cared for. The factors most important in fruit set are moisture and nutritional stress. It is particularly important to have adequate nitrogen and moisture during the fruit set period and to avoid minor element deficiencies. Magnesium deficiencies once caused reduced fruit set but Mg deficiency is rarely seen. In general, it is rare to see a mineral deficient tree in Florida. If anything, excessive fertilizer is used.

The development and proper use of irrigation in the last several decades has undoubtedly done much to increase fruit set. There are still many unirrigated groves and a portion of those irrigated are provided insufficient water. Thus, irrigation is the production practice that could most likely result in large increases of fruit set through better use. Rootstock plays an important role in fruit setting but fruit set is only one factor involved in selecting a rootstock.

The Division of Plant Industry has budwood sources of standard varieties, such as 'Valencia', that yield far better than others. There are no data to show this is a matter of fruit set; however, improved fruit set is most likely involved because all flower adequately and trees are essentially the same size. Thus, it is extremely important to use the best yielding selections of whatever variety is being planted.

Fruit set of standard varieties is not affected directly by disease in Florida. However, fruit set of 'Key' lime, a minor variety, is virtually reduced to nil by lime anthracnose (*Gloeosporium limmeticola*) that attacks only flowers of this variety. Common anthracnose (*Colleotot*r*ichum gloesporides*) causes a blossom blight of sweet orange in the hot, wet tropics that greatly reduces fruit set and yield unless trees are sprayed during bloom with proper fungicides. It is not a problem in Florida. Of course, trees seriously weakened by cold injury or disease will produce a great preponderance of bouquet and weak leafy bloom that will set fruit poorly.

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