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2023–2024 Florida Citrus Production Guide: Plant Growth Regulators[1]

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Plant growth regulators (PGRs) are a tool used to manipulate vegetative and reproductive growth, flowering, and fruit growth and development. PGRs have been successfully used in agriculture for decades to amend plant growth characteristics to maximize yield and thus grower profit. Foliar-applied PGRs are routinely used in various fruit crops for flower and fruit thinning; improving fruit set, growth, and development; controlling vegetative growth; and reducing fruit drop. Citrus is no exception to the use of PGRs, which can provide significant economic advantages to citrus growers when used appropriately. According to the Florida state legislature, PGRs are defined as "any substance or mixture of substances intended, through physiological action, for accelerating or retarding the rate of growth or maturation or for otherwise altering the behavior of ornamental or crop plants or the produce thereof, but not including substances intended as plant nutrients, trace elements, nutritional chemicals, plant inoculants, or soil amendments."

Most PGRs are plant hormones, naturally occurring plant compounds. A plant hormone is a chemical signal produced in one part of the plant and then transported through vascular bundles to another part, where it triggers a response. Hormones regulate plant responses to various biotic and abiotic stimuli. PGRs are synthetic analogues of naturally occurring plant hormones (PGRs and hormones are used interchangeably throughout this document). There are five classic groups of PGRs: auxins, gibberellins, cytokinins, abscisic acid, and ethylene (Table 1).

In addition to the five classic PGRs, other groups of biochemicals are now also recognized as PGRs. They include jasmonates, salicylic acid, strigolactones, and brassinosteroids. Each group of PGRs has unique attributes and is involved in a number of different physiological processes.

It is very important to keep in mind that PGRs do not work in isolation. Plant response and efficacy of materials often depend on several factors, such as the concentrations of the materials, levels of other plant hormones, plant health, nutritional and water status, time of year, and climate. For example, the influence of gibberellins on citrus flowering, fruit set, seedlessness, color development, and preharvest fruit drop varies with many of these factors.

Auxins

Auxins were among the first plant hormones identified. Auxins are known to be involved in plant-cell elongation, apical dominance, inhibition of lateral bud growth, promotion of rooting, suppression of abscission, inhibition of flowering, and seed dormancy. A well-known auxin is indoleacetic acid (IAA), which is produced in actively growing shoot tips and developing fruit.

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Synthetic auxin analogs like 2, 4-dichlorophenoxyacetic acid (2, 4-D) and naphthalene acetic acid (NAA) are extensively used in fruit crop production. 2, 4-D is commonly used in agriculture as an herbicide. It is also used to control preharvest fruit drop and to increase fruit size, particularly in oranges, grapefruit, mandarin, and mandarin hybrids. The efficiency of 2, 4-D in reducing preharvest fruit drop increases when used with oil sprays. The timing of 2, 4-D application to reduce preharvest fruit drop should be carefully assessed to minimize undesirable effects on flowering and harvest timing.

NAA is used to inhibit the undesirable growth of suckers on tree trunks. As discussed earlier, NAA can inhibit lateral branching; therefore, its application to trunks keeps lateral buds in a dormant state. NAA can also promote fruit abscission and can therefore be used to thin excessive fruit and increase the size of the remaining fruit. Environmental conditions can greatly influence uptake and activity of NAA. High temperatures and delayed drying of spray solution due to high humidity both contribute to greater thinning action. Best results are likely to occur when applied between 75°F and 85°F. Because uptake continues for several hours after the spray dries, heavy rain within six hours of application may significantly reduce NAA action.

Gibberellins

Gibberellins, abbreviated as GA for Gibberellic Acid, have many effects on plants but primarily stimulate elongation growth. Spraying a plant with GA will usually cause the plant to grow larger than normal. GA also influences plant developmental processes like seed germination, dormancy, flowering, fruit set, and leaf and fruit senescence.

In citrus, GA is often used to delay fruit senescence. GA delays changes in rind color, and application will result in fruit with green rinds and delayed coloring. This will have a negative effect when selling fruit early in the season for the fresh-fruit market. However, this effect is desirable for late-harvested fruit because it results in fruit that are paler in color than the deeper-colored fruit from untreated trees. GA also affects flowering in citrus. GA application can reduce the number of flowers and therefore fruit yield. It is important to carefully assess timing of GA applications to avoid yield losses. Depending on the application time, GA can reduce preharvest fruit drop and improve fruit set in some citrus varieties.

Cytokinins

Cytokinins derived their name from cytokinesis (cell division) because of their role in stimulating plant cells to divide. In addition to being involved in cell division, cytokinins were shown to have important effects on many physiological and developmental processes, including activity of apical meristems, shoot growth, inhibition of apical dominance, leaf growth, breaking of bud dormancy, and xylem and phloem development. Cytokinins also play an important role in the interaction of plants with both biotic and abiotic factors, including plant pathogens, drought and salinity, and mineral nutrition.

Abscisic Acid

Despite its name, abscisic acid (ABA) does not initiate abscission (drop). ABA is synthesized in the chloroplast of the leaves, especially when plants are under stress, and diffuses in all directions through the vascular bundles. ABA promotes dormancy, inhibits bud growth, and promotes senescence. It also plays a major role in abiotic stress tolerance. During water stress, ABA levels increase in leaves, which leads to the closing of stomata, thereby reducing water loss due to transpiration. ABA is costly to synthesize; therefore, its use in agriculture is limited.

Ethylene

Ethylene, a gaseous hormone, is well known for its role in promoting fruit ripening. In addition, it plays a major role in leaf, flower, and fruit abscission. Ethylene also affects cell growth, shape, expansion, and differentiation. Plants under biotic or abiotic stresses produce high levels of ethylene, which triggers an array of responses. For example, when leaves are damaged or infected with pathogens, high levels of ethylene are produced to promote abscission of those leaves. In citrus, ethylene is commonly used in postharvest to degreen oranges, tangerines, lemons, and grapefruit, making them more attractive to consumers. Ethylene treatment of mature but poorly colored fruit enhances the peel color and increases the marketability of fruit.

New Classes of Plant Hormones

Brassinosteroids

Brassinosteroids (BR) play a pivotal role in a wide range of developmental processes in plants, such as cell division, cell differentiation, cell expansion, germination, leaf abscission, and stress response. Because of their involvement in many different physiological processes, application of BRs might be of interest in crop production. Successful use of BR in agriculture depends on the production of cost-effective, stable synthetic analogs of BR.

Strigolactones

This group of plant hormones is known for inhibiting shoot growth and branching and stimulating root-hair growth. Strigolactones also promote a symbiotic interaction with mycorrhizal fungi and facilitate phosphate uptake from the soil.

Jasmonates

This group of plant hormones is involved in plant defense responses. Herbivory, wounding, and pathogen attacks trigger the production of these hormones, which results in the regulation of plant-defense-related genes to fight the infection.

Salicylic Acid

Salicylic acid (SA) plays a role in plant growth and development processes, photosynthesis, and transpiration. SA is well known for mediating plants' defense response against pathogens. Their role in increasing plant resistance to pathogens is inducing the production of pathogenesis-related proteins. It is involved in the systemic acquired resistance (SAR) response, in which a pathogenic attack on one part of the plant induces resistance in the affected area as well as in other parts of the plant.

General Consideration for Use of PGRs in Citrus Groves in Florida

Because PGRs function by directly influencing plant metabolism, plant response can vary considerably, depending on the variety and plant stress level. Therefore, it is recommended that growers become familiar with PGR effects before application. Preliminary trials in a small field plot should be conducted before using on a large acreage of trees. Most PGRs work best when used with an adjuvant (surfactant, sticker, or spreader). PGRs are regulated as pesticides and therefore, label instructions need to be followed. *The label is the law*. Table 2 summarizes some of the PGRs that are known to be effective in Florida citrus production.

Things to consider when applying PGRs are:

- Concentration of active ingredient
- Spray volume
- Method of application
- Time of day
- Season
- Compatibility with other chemicals in the tank mix
- Type of adjuvant
- Weather condition (humid, dry, sunny, cloudy, windy)
- Tree health (canopy density)

Use of PGRs for Huanglongbing-Affected Trees

Trees affected by huanglongbing (HLB) often suffer from extensive preharvest fruit drop. Considering the ability of PGRs such as 2, 4-D and GA to reduce preharvest fruit drop, PGRs were considered good candidates to mitigate the extensive fruit drop associated with HLB. However, results from field trials with HLB-affected trees suggest that single applications of 2, 4-D and GA are not effective in reducing fruit drop. Nonetheless, recent findings suggest that 2, 4D along with GA (a combination application) can reduce fruit drop significantly in HLB-affected sweet oranges when applied in the October–December period.

Recently, a multiyear field trial with multiple GA applications in fall (September–January) at 20 g a.i. along with surfactant has shown improvement in yields of HLB-affected trees, a reduction in preharvest fruit drop, and an improvement in canopy density. In light of this current study and previous field trials, it is recommended that multiple GA applications in fall can be beneficial for HLB-affected sweet orange trees. For early sweet orange varieties, such as Hamlin, the sprays should start in August and end by November. GA application is likely to keep fruit green. Therefore, an interval of at least two months should separate last application and harvest.

If excessive flowering, prolonged flowering, or off-season flowering is identified as a problem in HLB-affected trees, GA applications in the fall (September–January) can be made at 10–20 g a.i., 100–120 gallons per acre without negatively affecting yield. Fall GA applications reduce flowering in the following season. However, GA can also cause delay in color break of the existing crop; therefore, for early-season varieties of sweet orange, mandarins, and grapefruit, applying GA after the fruit is harvested would be ideal. GA applications in 'Valencia' during fall may improve fruit size of the existing crop as well as next season's crop due to reduced flowering. Do not apply GA later than January, because late applications can suppress flowering significantly, resulting in low yields.

Table 1. Major plant growth regulator classes, associated function(s), and practical uses in agriculture.

Class	Associated Function(s)	Practical Uses
Auxins	Shoot elongation	Fruitlet thinning; increased rooting and flower formation; sprout inhibitor
Gibberellins	Stimulate cell division and elongation	Increase shoot length, fruit size, and fruit set
Cytokinins	Stimulate cell division	Prolong storage life of flowers and vegetables and stimulate bud initiation and root growth
Ethylene	Ripening, abscission, and senescence	Induces ripening and loosens fruit
Abscisic acid	Seed maturation, dormancy	Regulates plant stress
Jasmonates	Plant defense	Wound response
Salicylic acid	Systemic Acquired Resistance (SAR)	Defense against pathogenic invaders
Brassinosteroids	Developmental processes	Regulate germination and other developmental processes
Strigolactones	Suppress branching and promote rhizosphere interaction	Suppress branching, promote secondary growth, and promote root hair growth

Table 2. Plant growth regulator sprays—Florida citrus. Growth regulators may cause serious problems if misused. Excessive rates, improper timing, and fluctuating environmental conditions can result in phytotoxicity, crop loss, or erratic results. Under certain environmental conditions, 2, 4-D may drift onto susceptible crops in surrounding areas. Observe wind speed restrictions and follow all label directions and precautions.

Variety	Response	Time of Application	Growth Regulator and Formulation	Product Rate or Volume per Acre
Orange, Temple, and Grapefruit	Preharvest fruit drop	November–December. Do not apply during periods of leaf flush.	2, 4-D Dichlorophenoxyacetic acid (Citrus Fix, Isopropyl ester of 2,4-D 3.36 lb/gal)	3.2 oz
Navel orange	Reduction of summer-fall drop	6–8 weeks after bloom or August–September for fall drop. Do not make late application when fruit is to be harvested early. Do not apply during periods of leaf flush.	2, 4-D Dichlorophenoxyacetic acid (Citrus Fix, Isopropyl ester of 2,4-D 3.36 lb/gal)	2.4 oz
Grapefruit	Delay of rind aging process and peel color development at maturity; combine with 2, 4-D for fruit drop control.	August–November. Late sprays can result in re-greening.	Gibberellic acid, GA_3 (ProGibb 4%, ProGibb 40%, ProGibb LV Plus)[2]	16–48 gram a.i.[3]
Tangerine hybrids				20–40 gram a.i.
Navel oranges				16–48 gram a.i.
All round orange				20–60 gram a.i.
Navel oranges Ambersweet orange Sweet orange	Improvement of fruit set and yield; can result in small size and leaf drop.	December–late January	Gibberellic acid, GA_3 (ProGibb 4%, ProGibb 40%, ProGibb LV Plus)[2]	15–25 gram a.i.
Tangerines Mandarins Grapefruit		Full bloom		8–30 gram a.i.
Processing oranges (late varieties)	To increase juice extraction yield	Color break	Gibberellic acid, GA_3 (ProGibb 4%, ProGibb 40%, ProGibb LV Plus)[2]	20 gram a.i.
Processing oranges (Early varieties) Late varieties	To improve vegetative growth and reduce fruit drop[4]	August–November (repeated application 30–45 days apart) September–December (repeated application, 30–45 days apart)	Gibberellic acid, GA_3 (ProGibb LV Plus)	20 gram a.i.

[1] Rates are based on application of 500 gal per acre to mature trees. The effects of applications at lower volumes (concentrate sprays) are unknown.
[2] Do not use in spray solutions above pH 8.
[3] Active ingredient; follow the label for variety-specific rates and conversion to fluid ounce per acre.
[4] November–December application of GA is likely to reduce return bloom in spring. If low flowering has been an issue, avoid application in this period.