Citus Production Guide: Plant Growth Regulators[1]

Tripti Vashisth, Chris Oswalt, Mongi Zekri, Fernando Alferez, and Jamie D. Burrow[2]

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 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. The 2017 Florida Statutes define PGRs "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" (The Florida Legislature 2017).

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 analogs of naturally occurring plant hormones (PGRs and hormones mean the same throughout this document). There are five classic groups of PGRs: auxins, cytokinins, gibberellins, abscisic acid, and ethylene (Table 1).

Recently, a few new groups of PGRs have been recognized. 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. Moreover, it is very important to keep in mind that hormones or PGRs do not work in isolation. Their response and efficacy often depend on several factors, such as their concentrations, levels of other plant hormones, plant health, nutritional and water status, time of year, and climate. For example, gibberellins' influence on citrus flowering, fruit set, seedlessness, color development, and pre-harvest fruit drop varies with those factors listed above.

Auxins

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

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2. Tripti Vashisth, assistant professor, Horticultural Sciences Department, UF/IFAS Citrus Research and Education Center; Chris Oswalt, Extension agent III, UF/IFAS Extension Polk County; Mongi Zekri, Extension agent IV, UF/IFAS Extension Hendry County; Fernando Alferez, assistant professor, Horticultural Sciences Department, UF/IFAS Southwest Florida Research and Education Center; and Jamie D. Burrow, Extension program manager, UF/IFAS Citrus REC; UF/IFAS Extension, Gainesville, FL 32611.

Synthetic auxin analogs like 2, 4-dichlorophenoxyacetic acid (2, 4-D) and naphthaleneacetic acid (NAA) are extensively used in fruit crops. 2, 4-D is commonly used in agriculture as an herbicide. 2, 4-D is also used to control pre-harvest fruit drop, increase fruit size (oranges, grapefruit, mandarin, and mandarin hybrids), and control leaf and fruit drop. The efficiency of 2, 4-D in reducing pre-harvest fruit drop increases when used with oil sprays. The timing of 2, 4-D application to reduce pre-harvest fruit drop should be carefully assessed to minimize undesirable effects on flowering and harvest timing. However, 2, 4-D should not be applied too early in the season as it may lose its desirable effect.

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 dormant state. NAA can also promote abscission of fruit; therefore, it can be successfully used to thin excessive fruit set and increase size of the remaining fruit. Environmental conditions can greatly influence uptake and activity of NAA. Higher temperatures and delayed drying of spray solution both contribute to greater thinning action. Best results are likely to occur when applied between 75°F and 85°F. Since 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, make up the second group of plant hormones. GA has many effects on plants, but it primarily stimulates elongation growth. Spraying a plant with GA will usually cause the plant to grow vegetatively larger than normal. GA also influences various plant developmental processes, such as seed germination, dormancy, flowering, fruit set, and leaf and fruit senescence.

GA is used in citrus to delay fruit senescence. GA delays changes in rind color; therefore, its application will result in fruit with green rinds and delayed coloring, which will have a negative effect on marketing fruit early in the season for the fresh fruit market. While this effect is desirable for late-harvested fruit, it results in fruit that are paler in color than the deeper-colored fruit from untreated trees. GA can also affect the flowering in citrus; therefore, GA application can reduce the number of flowers and eventually fruit yield. Application close to flowering season can reduce the number of flowers; therefore, timing of GA applications should be carefully assessed. Depending on application timing, GA can reduce pre-harvest fruit drop and improve fruit set in some citrus varieties.

Cytokinins

Cytokinins were named because of their role in stimulating plant cells to divide. In addition to being highly involved in cell division, cytokinins have been 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. ABA plays a major role in abiotic stress. During water stress, ABA levels increase in leaves and make guard cells close, reducing transpiration (water loss). 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 to promoting fruit ripening, ethylene 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 that trigger an array of responses. For example, when leaves are damaged or infected, high levels of ethylene are produced to promote abscission of those leaves. Ethylene is commonly used in de-greening oranges, tangerines, lemons, and grapefruit that remain green after ripening, making them more attractive to consumers. An 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 phenomena in plants, such as cell division, cell differentiation, cell expansion, germination, leaf abscission, and stress response. Based on the involvement of BR in a number of physiological processes, their application might be of interest in horticultural crops. Successful use of BR in agriculture depends on the production of cost-effective and 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 highly involved in plant defense response. Herbivory, wounding, or pathogen attacks trigger the production of these hormones, which result in the regulation of plant defense-related genes to fight the infection.

Salicylic Acid

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

Use of PGRs for Huanglongbing-Affected Trees

Huanglongbing (HLB)-affected trees often incur severe problems with pre-harvest fruit drop. Due to the ability of certain PGRs such as 2, 4-D and GA to reduce pre-harvest fruit drop, they were considered as good candidates to mitigate HLB-associated pre-harvest fruit drop. However, extensive field trials by Albrigo and Stover (2015) suggest PGRs are inconsistent in reducing HLB-associated pre-harvest fruit drop. Therefore, it is not suggested to use PGRs to alleviate HLB-associated pre-harvest fruit drop.

General Consideration for Use of PGRs in Citrus Groves in Florida

Since PGRs function by directly influencing plant metabolism, plant response can vary considerably depending on the variety and plant stress level. Therefore, it is highly recommended that growers become familiar with PGRs and their effects before application, and should test them on small plots before treating significant acreage. Most PGRs work best when used with an adjuvant (surfactant, sticker, or spreader). PGRs are regulated as pesticides; therefore, the label should be followed. *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
- Volume of spray
- Method of application
- Time of the day for application
- Season
- Compatibility with other chemicals in the tank mix
- Type of adjuvant
- Weather condition (humid, dry, sunny, cloudy, windy)
- Tree health (canopy density)
- Plant stress

References

Albrigo, L. G. and E. W. Stover. 2015. "Effect of plant growth regulators and fungicides on huanglongbing-related preharvest fruit drop of citrus." *HortTechnology* 25(6): 785–790.

The Florida Legislature. 2017. "§487.021." *The 2017 Florida Statutes*. Accessed on January 3, 2018. http://leg.state.fl.us/STATUTES/index.cfm?App_mode=Display_Statute&Search_String=&URL=0400-0499/0487/Sections/0487.021.html

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; increase 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.

CAUTION: Growth regulators may cause serious problems if misused. Excessive rates, improper timing, and fluctuating environmental conditions can result in phytotoxicity, crop loss, and/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 per Acre[1]
Orange, Temple, and Grapefruit	Pre-harvest fruit drop	November–December. Do not apply during periods of leaf flush.	Citrus Fix 2, 4-D Dichlorophenoxyacetic acid (Isopropyl ester 3.38 lbs/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.	Citrus Fix 2, 4-D Dichlorophenoxyacetic acid (Isopropyl ester 3.38 lbs/gal)	2.4 oz
Tangerine and Murcott	Fruit thinning; activity is temperature-dependent. Severe over-thinning may result from applications made to trees of low vigor and/or under stress conditions	Mid-May.	Naphthaleneacetic acid, NAA (Fruit Fix 800 g/gal liquid amine formulation)	2–5 pts Use lower rates on Murcott.
Seedless Grapefruit	Delay of rind aging process and peel color development at maturity; combine with 2, 4-D for fruit drop control	November–January.	Gibberellic acid, GA_3 (Pro-Gibb 4% liquid concentrate)[2]	20 oz
Tangelos	Improvement of fruit set; can result in small size and leaf drop	Full bloom.	Gibberellic acid, GA_3 (Pro-Gibb 4% liquid concentrate)[2]	10–30 oz
Minneola Tangelo	Delay of stem-end rind deterioration	Early December.	Gibberellic acid, GA_3 (Pro-Gibb 4% liquid concentrate)[2]	20 oz

[1] Rates are based on application of 500 gals 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.