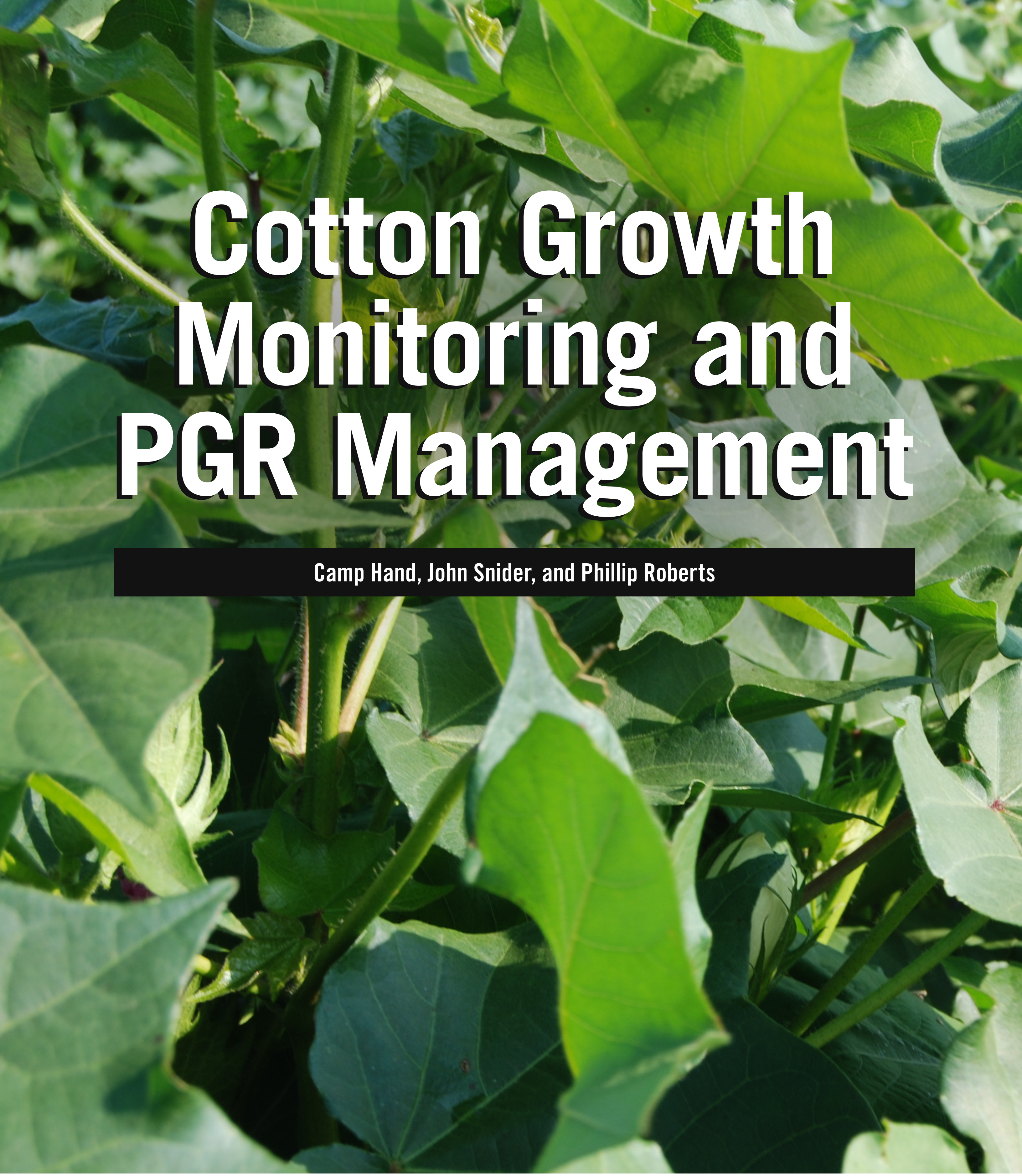

Cotton Growth Monitoring and PGR Management

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Upland cotton (*Gossypium hirsutum*) is a perennial, tropical plant that has been bred and adapted for annual crop production in temperate climates. Cotton develops on a predictable schedule, although stresses can have profound effects on growth rate and the timing of key developmental events.

Plant monitoring helps to determine if the plant is growing and fruiting normally. Cotton growth is influenced primarily by temperature and moisture, and plant development proceeds roughly according to a heat–unit model that uses 60 °F as the base temperature. In this model, heat units are referred to as DD–60s and are calculated based on an average daily temperature minus 60 °F. The formula is as follows:

$$\frac{Max\ °F + Min\ °F}{2} - 60\ °F = \text{DD–60s}$$

For example, a day with a maximum temperature of 90 °F and a minimum temperature of 72 °F produces 21 DD–60s:

$$\frac{90\ °F + 72\ °F}{2} - 60\ °F = \frac{162}{2} - 60\ °F = 81 - 60\ °F = 21\ \text{DD–60s}$$

Any temperature above 93 °F should be entered in the formula as 93 °F because growth likely does not increase at higher temperatures. Current and historical heat–unit accumulations for numerous locations across the state can be referenced at the University of Georgia Weather Network website.

Table 1 estimates development rate based on accumulated DD–60s. Because growth and development are dependent upon many factors in addition to temperature, these numbers are approximations only and have been adapted from Ritchie et al. (2004).

Table 1. Cotton development as influenced by DD–60s.

From planting to:	DD–60s	Days
Emergence	50	4 to 14
Pinhead square	550	35 to 45
First bloom	940	55 to 70
Peak bloom	1700	85 to 95
First open boll	2150	115 to 120
Harvest	2500 to 2700	140 to 160

Plant growth monitoring

Cotton growth monitoring should be initiated at the growth stage between eight and 10 leaves. Cotyledons are the pair of seed leaves first observed after emergence, and are attached to the main stem directly opposite from each other. The node at the point where the cotyledons are attached is counted as Node 0. As growth progresses, the cotyledons fall off, leaving two small scars opposite each other near the base of the plant (Figure 1A).

The first true leaf is Node 1 and should be visible within 7 to 10 days after emergence. Subsequent main–stem leaves will emerge in an alternating pattern in approximately 3–day intervals (longer if under cool or stressed conditions), or every 50 DD–60s. These leaves occur singly at each node. The area of stem between each leaf or

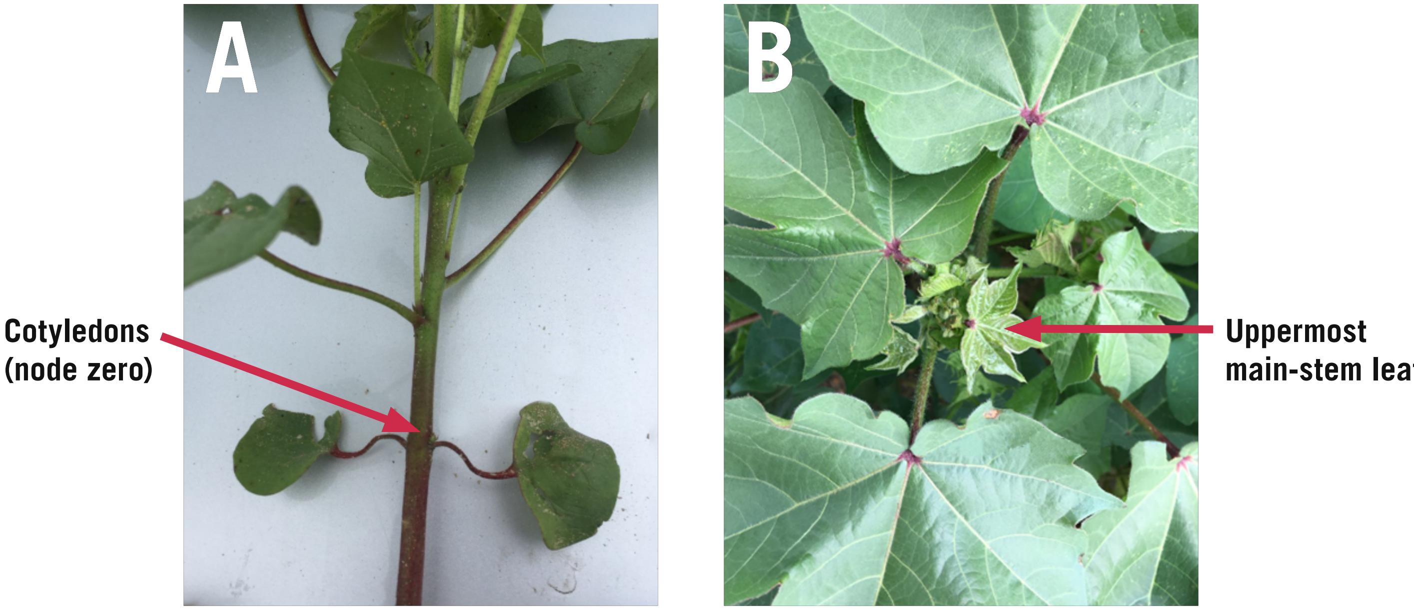

Figure 1. Young cotton cotyledons still present near the base of the plant (A), and the uppermost unfolded leaf node (B).

node is called the internode. Fruiting branches normally begin to develop at Node 5 to 7 from a tiny bud in the leaf axil or from the point at which the main–stem leaf is attached. Fruiting branches develop a fruiting bud or square with a subtending leaf at 6–day intervals in positions successively farther away from the main stem. A diagram of subtending leaves is shown in Figure 2. Squares are first visible approximately 5 weeks after planting (depending on environmental conditions), and the square opens as a white flower approximately 3 weeks later. The day after the white flower opens, the flower will turn pink, fall off, and the boll will begin to develop. The subtending leaf is the major source of photosynthate for boll development and accounts for more than 80% of the carbohydrate requirements of a developing boll (Ashley, 1972). Vegetative branches (usually two or three per plant) develop at nodes, at main–stem leaves below the first fruiting branch, and sometimes from the second bud adjacent to a fruiting branch if it is injured. Generally, vegetative branches tend to be larger at the ends of rows or next to skips within rows, which is what allows the cotton plant to compensate so well for gaps.

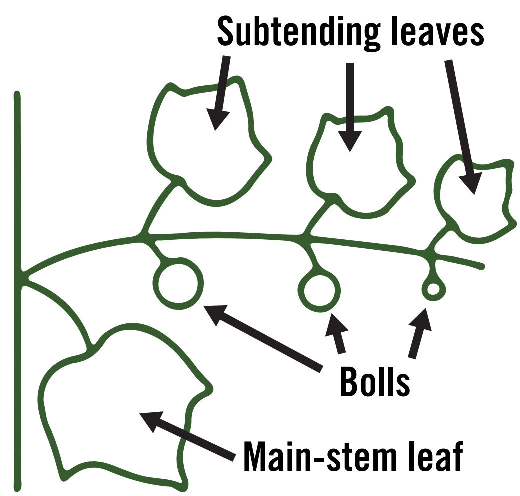

Figure 2. Example of subtending leaves and main–stem leaves on a cotton plant. Adapted from "Leaf physiology and management," by D. Oosterhuis, T. Kerby, and K. Hake, May 1990, *Cotton Physiology Today*, p. 1. (https://www.cotton.org/tech/physiology/cpt/plant-physiology/upload/CPT-May90-REPOP-144.pdf).

When counting nodes, it is important to distinguish where to start and stop. The starting point is the cotyledons, which is Node 0. Once the cotyledons fall off, it is important to feel near the base of the stem to find the opposite scars before beginning to count true nodes. True leaves may fall off as well, but the node still can be felt. Additionally, when nearing the top of the plant, only count to the uppermost unfolded main–stem leaf. If a leaf hasn't unfolded, it should not be counted in the total number. When counting nodes, it may be simpler to distinguish them when the leaves are removed from the plant. Figure 1 shows examples of young cotton cotyledons still present near the base of the cotton plant (A) and the uppermost unfolded leaf node (B) that would be included when counting nodes.

Cotton plants usually develop 21 to 23 nodes. However, aggressive full–season varieties may develop more than 25 nodes or main–stem leaves during long growing seasons with adequate moisture and/or moderate boll loads. Harvestable bolls develop starting with Nodes 5–7, and nodes up to 20–22 can develop fruiting branches. While 80% is a good goal for first–position square retention at early bloom, experience in Georgia and other long–season environments suggests that extremely high early–retention rates may limit yields by limiting vegetative growth and total fruiting sites. This is because plants with high retention rates tend to reach cutout earlier than plants with lower retention rates. Cutout usually occurs when fewer than five nodes or main–stem leaves remain above the uppermost white flower (nodes above white flower, or NAWF). Flowers present at cutout will produce the last effective boll population to contribute appreciably to yield. Boll retention in the top two to three nodes is usually very low since the plant is normally in cutout due to boll load, water, and/or nutrient stress.

Plant selection and sampling for monitoring purposes

Usually, 20 normal plants should be evaluated from each field on a weekly basis beginning at the eight– to 10–leaf stage. Avoid plants with damaged terminals, uneven spacings (select the dominant plant in hill–dropped cotton), and plants that are 20% taller or shorter than the field average. Table 2 displays height–to–node ratio values associated with different cotton growth stages. Height–to–node ratio can be calculated by measuring plant height and then dividing it by node number. This can assist in growth monitoring and also can inform decisions associated with management.

Table 2. Height-to-node ratios in cotton at different stages of growth.

	Vigor index (Height-to-node ratio)		
Crop stage	**Normal**	**Stressed**	**Vegetative**
Seedling cotton	0.5 to 0.75	—	—
Early squaring	0.75 to 1.2	0.7	> 1.3
Large square to first bloom	1.2 to 1.7	< 1.2	> 1.9
Early bloom	1.7 to 2.0	< 1.6	> 2.5
Early bloom + 2 weeks	2.0 to 2.2	< 1.8	> 2.5

In very general terms, an ideal plant would be 44 to 50 in. tall with 22 to 24 total nodes. An ideal height–to–node ratio would be between 1.8 to 1.9, with the first fruiting branch at node 6, 12 to 14 total fruiting branches, boll retention of 67% (eight to 10 first–position bolls), and cutout beginning at node 18 to 20. When monitoring indicates that the plant is stressed or growing abnormally, the cause should be determined and corrected as soon as possible. Timely analysis of the soil, petioles, and tissues can detect nutrient deficiencies or excesses. Drought stress can be relieved only by timely rain or irrigation, but stress also can result from herbicide injury, disease, nematode injury, soil compaction, and temperature extremes.

Plant growth regulators (PGR) containing mepiquat can be used to regulate excess vegetative growth, which is indicated by a high vigor index. If excessive vegetative growth is due to fruit loss, the cause of the fruit loss should be determined and corrected quickly, especially if related to insects. Other causes of fruit loss may include cloudy weather, heat or drought stress, heavy boll load, and cutout. Maximum yields can be obtained by optimizing growth conditions through proper management.

Plant growth regulator (PGR) management

The best growth regulator for cotton is good, early fruit set and boll retention, as this generally will deter excess vegetative growth. However, many factors can influence the ability of the cotton plant to balance vegetative and reproductive growth, including nitrogen levels, soil moisture, insect control, plant population, and crop management. As a management tool, growth regulators containing mepiquat are used specifically to reduce internode length, which in turn reduces overall plant height. Mepiquat is available in several formulations.

Mepiquat applications might be associated with a slight increase in early fruit retention, which contributes to an earlier maturing crop. Many studies evaluating PGR impacts on yield have shown little to no impact (Collins et al., 2017; Dodds et al., 2010; Johnson & Pettigrew, 2006; Samples et al., 2015). Yield advantages associated with PGR applications primarily are associated with earlier maturity and greater harvest efficiency (Biles & Cothren, 2001; Briggs, 1981). It's not easy to predict the conditions that likely would result in a positive response to mepiquat, except in problematic or irrigated fields that historically result in adversely tall plants. With the wide range of growth potential among our current modern varieties, before applying mepiquat it is important to understand the growth characteristics of each variety and how the environment influences its growth potential. Rainfall or irrigation typically dictates the likelihood of excessive growth more than most other factors. Field history and fertility also can provide insight on the likelihood of excessive growth.

Mepiquat formulations that include the hormone kinetin (Gin Out) or are formulated as a pentaborate salt (Pentia) as opposed to a chloride salt (all others) have resulted in similar responses to other mepiquat–containing PGR. A beltwide study indicated that treating cotton with mepiquat chloride (Pix), mepiquat chloride + kinetin (Mepex), or mepiquat pentaborate (Pentia) at matchhead square followed by another application 2 weeks later did not result in differences in the number of mainstem nodes, yield, or fiber quality (Dodds et al., 2010). Stance is a premix of mepiquat chloride and cyclanilide, and this product is used at lower rates compared to other mepiquat–containing products. Stance has similar impacts on crop growth and development to other mepiquat–containing products when used with appropriate timings and application rates. Stance was evaluated in the same beltwide study, and its use did not result in differences in the number of mainstem nodes, yield, or fiber quality compared to the other mepiquat–containing products (Dodds et al., 2010). Stance has the potential to have milder effects than other mepiquat–containing products because of the lower use rates, which could reduce the risks of stunting when hot or dry weather follows application.

Factors that must be considered for PGR application include: stage of plant growth, rate of plant growth, pest control, and anticipated plant growth (irrigation, drought, fertility). Because of the many variables, there are no hard and fast rules regarding the rate and timing of mepiquat. Fields vary in growth. Weather varies by year and location, so recommendations must be flexible. Here are some examples of how these factors can impact PGR management.

Stage of plant growth

It's important to apply PGR during the right stage of plant growth to get the maximum impact. Ideally, plant–growth regulation should occur when the plant is smaller rather than larger. This is because bigger plants may dilute the PGR that is applied. Collins et al. demonstrated this idea well (2017): When applied at early bloom, applications of mepiquat chloride at 6 and 12 oz per acre reduced plant height by 14% and 20%, respectively, at the end of the season when compared to nontreated plants in three out of four environments. Additionally, boll retention increased at both rates of mepiquat chloride compared to nontreated plants across all environments. Although boll retention was improved, there were no significant differences with respect to lint yield or fiber quality. In the same study, applications were made at cutout and had no impact on plant height or yield. Although labels suggest potential benefits from late–season applications of products containing mepiquat, this study demonstrates that they have little to no impact on cotton growth or yield at the rates applied in this study. Further research is being done on higher application rates of mepiquat products applied late in the season in Georgia. If more growth regulation is necessary in certain fields to control rank (i.e., tall and heavy vegetative) growth and improve boll retention, PGR applications should be made early in the season when they will have the biggest impact.

Rate of plant growth

As mentioned earlier, cotton growth and development are dictated primarily by temperature. Previous research has evaluated cotton growth in different temperature regimes and the impact of mepiquat chloride applications (6 oz/acre; Reddy et al., 1990). In this study, the optimum range for cotton growth was day temperatures of 95 °F and night temperatures of 77 °F. The plants were similar in height on the day of application, but 55 days after treatment the plants treated with mepiquat chloride were 12 in. shorter than nontreated plants, which equated to nearly three nodes. However, the response to mepiquat chloride under less ideal temperatures is of greater interest. When plants were treated with day temperatures of 68 °F and night temperatures of 50 °F, plants did not grow as fast as in ideal conditions, and a 10–in. reduction in cotton height was observed when plants were treated with mepiquat chloride. Additionally, the height of plants treated with mepiquat chloride remained constant for the duration of the experiment, which showed that PGR applications in less–than–ideal growing conditions can lead to stunting. Therefore, cotton should receive a PGR application only in ideal growing conditions when the plant is actively growing.

Pest management

PGR applications should be considered a part of a comprehensive pest–management program. For example, in fields where target spot (*Corynespora cassiicola*) historically has been an issue, PGR can reduce the severity of this disease by minimizing rank growth (Kemerait, 2021). Although fungicides may still be necessary to manage this pest, timely PGR applications can assist in management as well.

When considering PGR applications after certain herbicides or with later herbicide applications, take care to avoid herbicides that can increase the likelihood of stunting. One example is using Envoke (trifloxysulfuron–sodium) with mepiquat chloride. Previous research has indicated that applications of Envoke mixed with mepiquat chloride decreased plant height at harvest by 10% compared to applying Envoke alone (O'Berry et al., 2008). Although the same study showed that yield was not impacted, tank–mixing these products in some conditions could result in stunting and should be avoided.

The main insect pests that can cause flower or fruit loss—or abscission—in cotton include tarnished plant bugs and caterpillar pests. Research has indicated that regardless of the cause of fruit abscission, it's possible for strategic plant growth regulation to increase boll retention in other positions, thus compensating for the fruit loss (Cook & Kennedy, 2000). When square loss became economically large enough to justify additional inputs to avoid further losses, it was advantageous to use mepiquat chloride; doing so could increase the retention of second-position bolls and even result in increased yield in some cases.

Anticipated plant growth

When making decisions about PGR, one of the trickier factors is projecting plant growth, as there are a few factors that can contribute to it. The nitrogen application rate is one management input that can be used to estimate projected plant growth. In a study conducted in North Carolina, nitrogen rates ranging from 25 to 100 lb per acre were evaluated (York, 1983). Generally, plant height at the end of the season increased as nitrogen rate increased, regardless of mepiquat chloride treatment. This indicates that more aggressive PGR management might be necessary for higher fertility areas, or if the goal of fertilizing is higher yield.

Additional factors affecting anticipated crop growth include rainfall or irrigation prior to and following PGR applications. In irrigated conditions, there is less risk of stunting, so it is much easier to make PGR applications because water following the application isn't as big of a concern as in dryland production. In irrigated conditions, a common approach is to apply 16 oz/acre at first bloom and then a follow–up application at the same rate around 2 weeks later. The key in vigorous growing conditions with aggressive varieties is to make applications earlier, preferably when the plant is 12 to 16 in. tall. In dryland production, where active growth will slow down significantly during extremely dry conditions, an untimely PGR application could result in stunted plants and reduced yield potential. Producers must take greater care in dryland conditions. PGR applications generally should be considered at first bloom, with preferred rates being around 8 oz/acre (see Table 3). Follow–up applications may be necessary if aggressive growth persists.

Table 3. Growth regulators, usage rates, and conditions/restrictions affecting application.

Growth regulator	Broadcast rate/acre	REI**/PHI***	Remarks
mepiquat chloride* Pix 0.35 L, others	8–24 fl oz	12 hr/30 days	Do not use more than 48 fl oz per acre per year. Increased rates necessary for more vigorous growth conditions, and for applications made later in the season.
mepiquat pentaborate* Pentia 0.82 L, others	8–24 fl oz	12 hr/30 days	Do not use more than 48 fl oz per acre per year. Do not apply to cotton that is drought stressed. Do not plant another crop within 75 days of last treatment. Do not graze or feed cotton forage to livestock.
mepiquat chloride + kinetin* Gin Out 0.35 L, others	4–16 fl oz	12 hr/30 days	Do not use more than 48 fl oz per acre per year. Do not apply to cotton that is stressed. Do not plant another crop within 75 days of last treatment. Do not graze or feed cotton forage to livestock.
cyclanilide + mepiquat chloride Stance 0.92 L	2–4 fl oz	24 hr/30 days	Do not use more than 22 fl oz per acre per year. Allow a minimum of 7 days between applications. Increased rates may be necessary for more vigorous growth conditions.

* The sum of all mepiquat chloride–containing products must not exceed 0.132 lb active ingredient of mepiquat chloride per acre per season.

** Restricted entry interval; this is the amount of time following application of chemicals that workers must wait before entering a field.

*** Preharvest interval; this is the amount of time needed between application of chemicals and when the crop may be harvested.

Application timing

To determine when PGR applications are necessary, look at the nodes near the top of the plant once applications have been initiated. Of particular interest is the fourth internode, which is the length of the stem between the fourth and fifth nodes. This internode is the standard for PGR decisions because it is fully elongated, which means it is a good measure of the growth conditions and vigor of the cotton crop. PGR applications do not shrink internodes but do slow internode elongation if that internode is actively growing. Generally, if the fourth internode length is greater than 2 to 3 in., a PGR application may be necessary. A simpler way to evaluate this in the field is to determine if three or more fingers (whose combined width will be 2–3 in.) can fit in the fourth internode. Figure 3 shows an example where more than three fingers could fit in the fourth internode, indicating that a PGR application might be necessary.

Figure 3. Using the width of three fingers within the fourth internode of a cotton plant to determine whether a PGR application is necessary.

A common error is to delay application past the point where the product can provide its maximum benefit. Some varieties may not require aggressive use of mepiquat, while some may require multiple applications at higher rates depending on the environment. Because every situation is different, it is important for growers to closely monitor plant growth in each of their fields and apply mepiquat accordingly.

Summary

Optimal growth control should result in plant height that is efficient for harvest while avoiding excessively tall plants that may obstruct spray applications or exhibit lodging (i.e., displacement), delayed maturity, or loss of critical fruit. Plants should be tall enough to support adequate fruiting sites for optimal yields while achieving full canopy closure. Any plant growth regulation strategy should attempt to slow terminal growth enough so that the increasingly developing boll load will restrain vigorous vegetative growth, with terminal growth ceasing at an optimal plant height. Plant growth regulation strategies that are too weak (late applications, low rates) may result in excessively tall plants in fields with a history of rank growth or in vigorous cultivars, whereas strategies that are too aggressive (early/multiple applications, high rates) may result in insufficient plant height or fruiting site production for maximizing yield. Therefore, these decisions need to be made on a case–by–case basis.

Varieties may differ in response to PGR applications. Continuous research is being conducted on newer cotton varieties to evaluate PGR response and to categorize these varieties by PGR management regime. Recommendations for PGR management by variety can be found on the UGA Cotton webpage. PGR decisions are complex, and your UGA county Extension agents and specialists can help with those decisions. If you have questions on PGR management or any other aspect of cotton production, contact your local UGA county Extension agent and they will find the answers you need.

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