Chapter 5

HARVEST-AID TREATMENTS: PRODUCTS AND APPLICATION TIMING

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INTRODUCTION

Harvest aids are applied to facilitate leaf removal or enhance boll opening prior to mechanical harvest. Harvest-aid chemicals hasten harvest of a mature crop and reduce potential pre-harvest loss of yield or fiber quality. When cotton is properly defoliated, trash content is reduced and less cleaning of the lint is required at the gin, minimizing fiber damage and maintaining quality. Improper choice of harvest-aid materials can result in poor preparation for harvest and may lead to reductions in yield and quality. Ideally, the harvest-aid material chosen should defoliate the entire plant and open all mature bolls with minimal drying or desiccation (unless a desiccant is being applied for stripper harvest).

"Harvest aid" is a general term used to describe chemicals applied to terminate cotton growth, open bolls, defoliate, or desiccate the cotton plant. Defoliants are applied to remove leaves from the cotton plant and enhance the formation of an abscission layer at the base of the leaf petiole, resulting in leaf drop. For maximum leaf drop, defoliants require healthy, active leaves that are not drought-stressed. Warm temperatures generally enhance activity.

Contact-type or herbicidal defoliants slowly injure the leaf. The "wound response" causes ethylene to be produced, eventually leading to leaf drop. A similar response often is observed with other types of stress, such as drought, disease, insect injury, or mechanical damage. Hormonal or plant growth regulator (PGR) materials directly enhance ethylene production, which again leads to leaf abscission. Both types of harvest aids can cause leaf drop without injury to the leaf, thus avoiding "leaf sticking."

Desiccants are harsher treatments than defoliants. Desiccants dry the plant by causing the cells to rupture and lose cellular contents and water due to leakage. These chemicals lead to rapid moisture loss, resulting in leaf and stem desiccation.

Boll openers affect natural plant processes associated with boll opening but do not increase the rate of boll or fiber maturation. Defoliants can be tank-mixed with boll openers to provide improved overall harvest-aid performance. See Chapter 2 for a detailed description of how various harvest-aid treatments promote cotton harvest efficiency.

PREPARING COTTON FOR HARVEST-AID APPLICATION

Preparing cotton for harvest should be considered an important part of the overall production management system. In-season cultural practices have a significant impact on defoliation success, because the condition of the cotton plant dictates its response to harvest-aid treatments. Plants are defoliated more easily when cultural practices followed throughout the season are designed to promote well-fruited plants that mature evenly and early. These practices include establishment of healthy, uniform stands; adequate but not excessive moisture; proper fertilization; and well-timed insect, disease, and weed management. Proper management of the plant canopy with plant growth regulators is beneficial in many cases.

Generally speaking, defoliation is more easily accomplished when the plants have stopped both vegetative and reproductive growth (reached "cutout"). The ideal situation for harvest would be for the plant to reach maturity and, at the same time, exhaust available nutrients, especially nitrogen.

For maximum harvest-aid activity, it is important to follow appropriate pest management strategies for optimum cotton production. Diseases and insects can hurt cotton growth and lead to reduced boll load, which not only lowers overall yield potential, but also makes defoliation more difficult and costly. Effective weed management also is important for successful harvest preparation. Weeds, insects, and diseases cause reduced boll load and loss in yield potential. Weeds also directly influence the effectiveness of harvest-aid treatment by interfering with application and preventing thorough coverage of the cotton plant. Most harvest-aid products require complete coverage of the cotton foliage for maximum activity.

Proper irrigation management also can enhance effectiveness of harvest-aid treatments. Performance generally is best when soil moisture is relatively low at the time of harvest-aid application but sufficient to maintain plants without visible moisture stress. Plants severely moisture-stressed, with tough, leathery leaves, are difficult to defoliate. High moisture levels from excessive irrigation, on the other hand, contribute to rank cotton with dense foliage and delayed maturity that also reduce harvest-aid efficacy.

A detailed discussion of the impact of crop condition on cotton defoliation is presented in Chapter 4.

DEFOLIATION TIMING

Harvesting cotton as early as possible increases the likelihood of more ideal weather conditions and higher lint quality during the first part of the harvest season. It is important to apply harvest aids early enough to take advantage of the benefits of early harvest, while avoiding application so early that it decreases yield and quality of the cotton.

Timing of harvest-aid applications is not exact. There is a relationship between maturation of later-developing bolls and degradation of the earlier bolls that already are open. The correct decision is a compromise between these two factors. Timing of harvest-aid application varies with the area of the country, harvest-aid materials used, type of harvest, and individual preferences.

When harvest aids first were introduced, they were applied according to historical harvest dates; however, factors such as weather, heat unit accumulation, and cotton varieties made this technique largely undependable. Currently, timing is determined by a combination of techniques, each of which further confirms and verifies the others. These techniques are Percent Open Bolls, Cut Boll Technique, and Nodes Above Cracked Boll (NACB). These techniques will be discussed individually and, later, together as they relate to each other.

Percent Open Bolls was one of the earliest techniques developed; it was used extensively prior to the introduction of hormonal boll openers. Decisions for timing of defoliation were made by counting the total number of bolls on the plant that would contribute to harvest and calculating the percentage of these bolls that were open. The primary problem with this technique when used alone is that it does not allow for differences in boll development throughout the plant. If there is a gap in the fruiting pattern, some harvestable bolls may not be allowed to mature. Recommendations vary, but, for timing of defoliants, 65 to 90 percent of bolls should be open; for timing of desiccants in stripper cotton, 80 percent or more of bolls should be open. This technique should not be used alone, but rather in support of the other techniques described below.

The Cut Boll Technique is used to determine the maturity of the seed inside the boll. This technique has been used extensively since development of hormonal defoliants and boll openers. Cutting a mature green boll is roughly equivalent to cutting a one-inch diameter, wet cotton rope, and the knife must be sharp to obtain usable results. Be careful with this technique: Immature green bolls are sliced easily and lack of resistance may cause an accident! Mature green bolls are difficult to slice; when sliced, the seed inside the mature boll will have a dark seedcoat and a fully developed pale green embryo inside. Seeds that are not yet mature will have a light-colored seedcoat and will contain a gelatin-like substance.

The Cut Boll Technique is straightforward, but the difficulty in making harvest-aid timing decisions involves determining the approximate nodal position of the uppermost harvestable bolls. If the cotton clearly has "cut out," the topmost full-sized boll typically is regarded as the uppermost harvestable boll. Usually there is a visible size difference between this and the smaller bolls near the top of the plant. Missing fruit often make it somewhat more difficult to identify the average nodal position of the uppermost harvestable boll, but, once this boll (or nodal position) has been identified, it should be monitored and harvest-aid applications made when it attains the maturity criteria noted above.

Nodes Above Cracked Boll (NACB) is a relatively new technique that uses the principles of plant monitoring to determine the proper time for harvest-aid application. This technique can use average heat unit accumulations to determine whether the plant is ready for harvest-aid application or approximately how long it will be until the plant is ready. Square initiation, flowering, and boll development proceed up the main stem in an orderly manner during the life of the cotton plant. At first-position fruiting sites, the difference in age for each node is approximately three days, or 55 heat units. This relationship occurs in theory throughout boll development in the plant. As the end of the season approaches and daily heat unit accumulation declines, allowance will need to be made for the three-day rule. The difference between nodes may be four – even five – days as the season end nears and cooler temperatures are present.

The NACB technique was developed from data generated in a Cotton Foundation-supported project (Kerby *et al.*, 1992). Field tests were conducted in California in 1989-1991 and in Oklahoma, Texas, and Mississippi in 1990 and 1991. The tests were set up with the following comparisons:

Plot A. On the day of defoliation, all FB1 (first fruiting branch) bolls were harvested from the fruiting branch with a cracked boll (NACB = 0) and the next eight nodes above this cracked boll. In some locations, only six nodes above the cracked boll could be harvested. Bolls were mechanically opened and allowed to dry. Lint was pooled from each position and ginned. Average lint per boll and fiber quality were determined for each respective position.

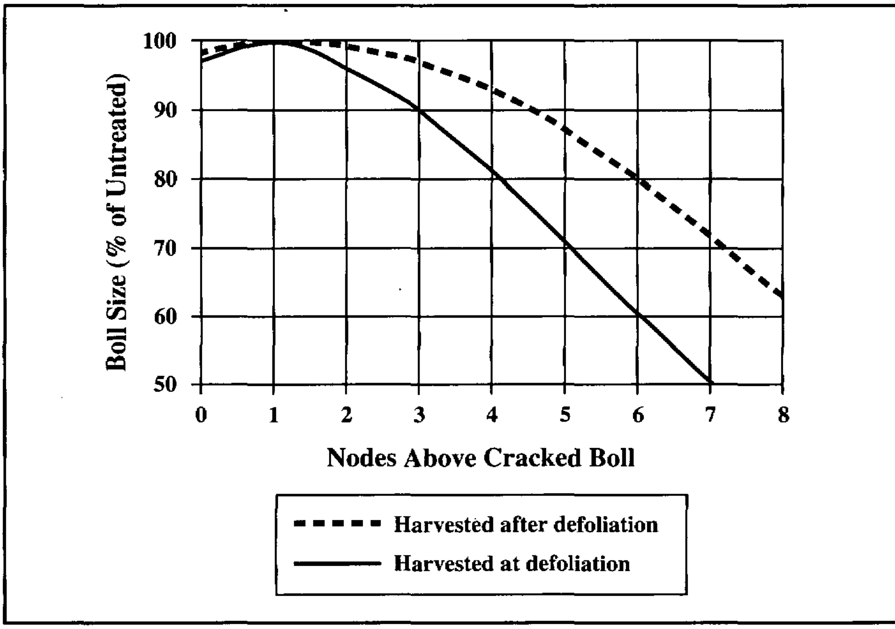
Plot B. On the day of defoliation, the fruiting branch with an FB1 cracked boll was tagged, and the plot was defoliated with 1.0 pound a.i. per acre of Prep™ tank-mixed with 2.0 pounds per acre of Folex® or Def®. When the effects of the harvest aid were fully expressed, the plots were harvested by position as related to NACB at the time of defoliation. Lint was pooled from each position and ginned, and fiber measurements were made as described in plot A.

Plot C. Plants were tagged as in plot B, but the plot did not receive any harvest-aid treatment. These plants were allowed to develop, and, late in the season when all the harvestable bolls were open, the plants were harvested by position according to where the cracked boll was located when the other plots were marked. Again, lint was pooled by position and ginned, and fiber measurements were made.

These treatments were made earlier than normal to ensure enough node positions above the FB1 cracked boll to the top of the plant. In the less-determinate picker varieties, the number of positions above cracked boll usually equaled eight, but in the more-determinate stripper varieties of cotton, it was difficult to obtain an adequate sample size for more than six nodes above the cracked boll. At each test location, 200 to 300 plants were tagged for each treatment. In each test, the number of bolls for each position averaged between 50 and 150, providing sufficient sample size to make weight and fiber determinations. Standard HVI (High-Volume Instrumentation) fiber analysis was performed by the Textile Research Center at Lubbock, Texas.

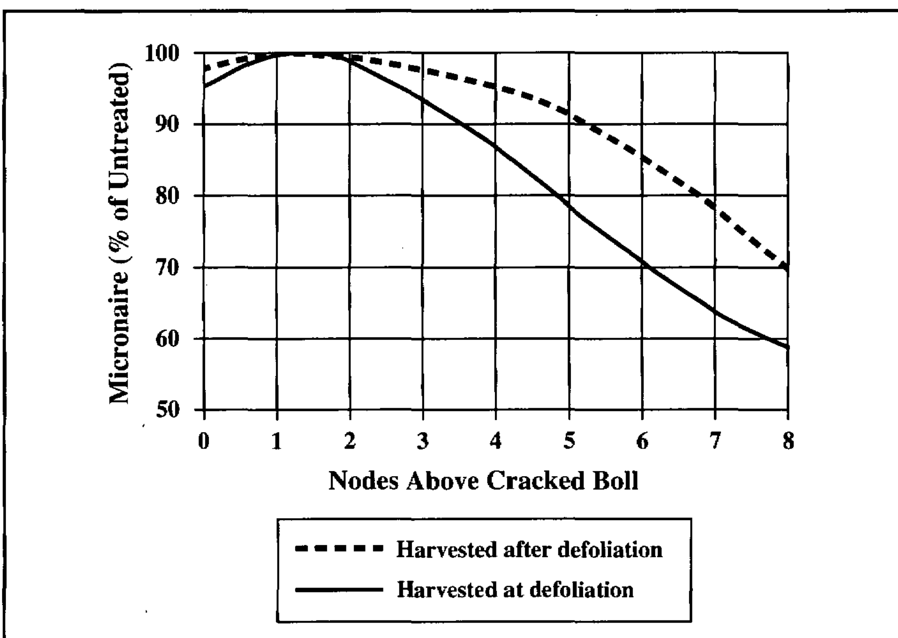
Boll Size – The difference in boll size between plots that were harvested on the day of defoliation and those that had been treated with a harvest aid is illustrated in Figure 1. The difference between the lines shows the amount of boll growth that took place after the plants were defoliated. This differential begins at the 2 NACB position and increases as NACB increases. At 4 NACB, bolls that were harvested after defoliation were 12 percent larger than those harvested immediately prior to defoliation and approximately 7 percent smaller than those allowed to remain on the plant until late in the season. Once boll size begins to be affected by increasing NACB, the relationship is nearly linear. Boll size decreased an average of 6.7 percent for each NACB greater than 2.8 at the time of defoliation. This relationship was true across all locations of the study. These data demonstrate that cotton bolls continue to gain weight after a defoliation treatment. Under a more harsh treatment, such as a high rate of desiccant, this increase in size would not be expected.

Micronaire – Evaluation of the data indicated that the only fiber property affected by early defoliation was micronaire. Differences in micronaire between bolls harvested at the time of defoliation and those harvested after defoliation began between 2 and 3 NACB and progressed in a nearly linear relationship (Figure 2). Micronaire decreased an average of 5.9 percent for each increase in NACB above 2.6. The rate that increasing NACB decreased micronaire differed



Source: Kerby *et al.*, 1992.

Figure 1. Effect of defoliation on boll size.



Source: Kerby *et al.*, 1992.

Figure 2. Effect of defoliation on micronaire.

by state, with the least effect in California and Oklahoma, and the greatest effect in Texas and Mississippi.

Fruiting Patterns – For these data to be accurately used, the number of fruiting branches and contribution of each position must be noted. Data have been developed in Mississippi (Jenkins *et al.*, 1990) and in California (Kerby *et al.*, 1987) to determine fruiting patterns of cotton. These data show that, as node number at the top of the plant increases, the percentage contribution of each position decreases dramatically. Programs have been developed to calculate potential yield and micronaire loss using data for fruiting-site contribution under specific conditions. When these data were summarized, it was determined that defoliation of cotton at NACB of less than or equal to 4 results in a yield loss of less than one percent with no reduction in fiber quality. Defoliating at an NACB of greater than 4 may allow more immature fibers to be harvested, decreasing micronaire. In many cotton production regions, producers may need to lower micronaire values to avoid high micronaire discounts. Under these conditions, defoliation at 5 or 6 NACB might be desirable.

As producers approach the time of defoliation, many factors other than plant growth stage will influence harvest-aid decisions. A producer may desire to apply harvest aids to a field in order to allow harvesting machines to start earlier or to avoid almost certain late-season weather patterns. The NACB technique will allow producers to accurately evaluate how much loss in yield and quality they are willing to absorb in order to schedule equipment and take advantage of good harvesting conditions.

In the field, plants that have a first-position cracking boll need to be selected at random from different areas. Identify the fruiting branch with the cracked boll as zero, and count nodes up the plant until you come to the branch with the final first-position boll that realistically will be harvested. If the NACB is equal to 4, the crop can be terminated with no loss in yield or quality. If the NACB is equal to 5, the loss probably will be negligible. If the NACB is equal to 6, the crop will need 50 to 75 more heat units (55 heat units per node of growth) before harvest-aid application.

HARVEST-AID PRODUCTS

Successful cotton harvest largely is dependent on the use of harvest-aid chemicals. Although information is available on when to apply harvest aids, seasonal and crop conditions have variable effects on cotton response to harvest-aid treatments. Often it is advisable to delay harvest-aid choice until the crop is nearly ready for defoliation. While variety, soil type, and cultural practices are known, weather is not predictable. The final decision on harvest-aid choice should be made near the time of the initial application.

Good spray coverage is essential for maximum harvest-aid effectiveness, because most of these materials are not readily translocated within the plant. Some research indicates that cone-type spray nozzles provide better coverage of cotton foliage than flat-fan or floodjet tips. Nozzle type, spray pressure, and ground speed (and, thus, application volume) should be chosen in accordance with the product label specifications (see Chapter 6 for details on application technology).

It is not advisable to treat more acres than can be harvested in a reasonable amount of time. Applying harvest aids too far in advance can expose cotton to weather and insect damage if harvest is delayed by equipment failures or excessive rainfall. Delayed harvest can allow regrowth that may hamper harvest and require the application of additional harvest-aid treatments.

Many products are registered for use as cotton harvest aids. Following is a discussion of harvest-aid products to assist in selecting the most appropriate treatment to achieve the results desired.

BOLL OPENERS

Prep, Super Boll®, Boll'd (ethephon) – Ethephon is effective in accelerating the opening of mature cotton bolls. Though not labeled as defoliants, satisfactory defoliation may result from applications made under favorable weather conditions or at higher use rates. If additional use of a defoliant is anticipated, it should be tank-mixed with ethephon or not applied for at least four days after application of the boll opener. In cotton with a dense canopy, ethephon can be applied at the boll-opening rate with a low rate of defoliant to achieve both boll opening and leaf drop. To be effective, bolls must receive spray coverage.

Ethephon also may allow once-over harvest. Harvest should be delayed until 14 days after application to allow optimum boll opening. Some shedding of immature bolls and squares may occur after Prep/Super Boll/Boll'd application.

Do not mix ethephon with defoliants containing sodium chlorate, as this will cause formation of hypochlorous acids that, in turn, emit toxic chlorine fumes. Ethephon should not be applied if rainfall is expected within six hours.

ENHANCED ETHEPHONS

Finish® (ethephon + cyclanilide) – This prepackaged mixture of ethephon (the active ingredient in Prep/Super Boll/Boll'd) and an activity enhancer will provide more rapid boll opening, more complete defoliation, and better inhibition of terminal regrowth than ethephon alone. When applied at labeled rates, based on the field conditions encountered, Finish can provide both defoliation and boll opening. Finish also provides some regrowth suppression, but typically less than that obtained with the full labeled rate of Dropp. Finish may be tank-mixed with other harvest aids to assist in defoliation under cool conditions or when cotton is rank, or for desiccation of weeds. Certain environmental conditions, such as high temperatures or moisture stress, may lead to leaf stick or leaf burn when Finish is mixed with other harvest-aid materials. Do not mix Finish with sodium chlorate, as this will cause formation of hypochlorous acids that, in turn, emit toxic chlorine fumes. Finish requires a six-hour rain-free period for optimum activity.

CottonQuik® (ethephon + AMADS) – This prepackaged mixture provides enhanced activity (better defoliation and faster boll opening), compared to ethephon (Prep/Super Boll/Boll'd) alone. Low temperatures will slow activity and require higher application rates. CottonQuik has limited regrowth inhibition and may require mixing with other harvest-aid materials to achieve acceptable defoliation and regrowth control. Thorough spray coverage is required for optimum activity. Do not mix with chlorates. CottonQuik is corrosive and can cause deterioration of cotton, nylon, and leather clothing.

Typically, satisfactory defoliation is achieved within seven days. Adverse conditions, such as low temperatures or toughened plants, may require up to 14 days.

DEFOLIANTS

Folex, Def (tribufos) – Folex and Def are phosphate-based materials that have been the standard defoliants for many years. They are effective over a broad range of environmental conditions. These products do not inhibit terminal growth and may not be effective in removing new growth or preventing regrowth.

The lower labeled rates have performed well only under nearly ideal conditions (plant ready to defoliate and warm temperatures). The higher labeled rates provide the most consistent results. When combined with ethephon, the lower rates of Folex/Def perform well.

In regional evaluations, overall performance of a single application of Folex/Def was similar to that of both Dropp® and Harvade® (Anonymous, 1999). Percent defoliation for Folex/Def was higher than for Dropp at 7 days after treatment (DAT) but not at 14 DAT. This indicated a faster response time for the Folex/Def treatment. Desiccation from a single Folex/Def treatment was similar to that from Dropp and Harvade. Folex/Def alone did not improve boll opening when compared with the untreated check. Addition of Prep to the Folex/Def treatment improved defoliation and boll opening, and decreased terminal regrowth below that of Folex/Def alone, but increased basal regrowth.

Sodium Chlorate (sodium chlorate) (several brand names) – At normal use rates (2 to 4 pounds a.i. per acre), sodium chlorate often is not as effective as the phosphate-type defoliants. At higher rates (5 to 6 pounds a.i. per acre), sodium chlorate may act as a desiccant, sometimes causing leaves to "stick" to the plant. Sodium chlorate does not prevent regrowth. This product is used to a limited extent to desiccate cotton in preparation for stripper harvest. If harvest is delayed after desiccation, stalk deterioration can occur, resulting in excessive trash in the mechanically harvested cotton.

Dropp, FreeFall™ (thidiazuron) – Dropp and FreeFall provide excellent defoliation and relatively good control of regrowth under warm, humid conditions. This material is excellent for removal of new, juvenile leaves. Thidiazuron activity is reduced and slowed under cool temperatures (nighttime temperatures below 60 F, or 15 C). Under cool conditions, tank-mixing with phosphate defoliants, Harvade or ethephon enhance defoliation activity while maintaining adequate regrowth inhibition. Under warm or hot conditions, rate selection of materials in the mixture is important, because higher rates may cause leaf desiccation and "leaf stick." Rainfall within 24 hours of application may reduce the effectiveness of thidiazuron. Application to drought-stressed cotton may result in less-than-satisfactory defoliation. Thidiazuron provides the best regrowth suppression among the defoliants currently available.

In regional trials, a single application of Dropp resulted in less defoliation than Folex/Def at 7 DAT, but was the same by 14 DAT (Anonymous, 1999). This indicated a slower response time for the Dropp treatment when compared with Folex/Def. Desiccation with Dropp was the same as with Folex/Def; desiccation was lower than with Harvade at 7 DAT, but not at 14 DAT. Apparently, desiccation differences with Harvade and, to a lesser extent, Folex/Def were transient, with all treatments responding similarly by 14 DAT. Dropp did not affect boll opening when applied alone, compared with untreated cotton. However, addition of Prep to Dropp improved boll opening over that of using Dropp alone. In addition, terminal regrowth was lower with Dropp and Dropp + Prep than with any other treatments evaluated.

Ginstar® (thidiazuron + diuron) – This prepackaged mixture provides enhanced activity compared to Dropp. Ginstar provides excellent control of regrowth and performs well under a wider range of temperature and humidity conditions than Dropp. The product is effective in removal of juvenile leaves. Ginstar has more potential to cause desiccation and leaf stick than Dropp in the more humid Southeast and Midsouth regions. It has performed well as a defoliant in the Southwest and has been especially effective in the arid West.

Harvade (dimethipin) – Harvade generally provides defoliation equivalent to phosphate-type materials, but it is not a strong inhibitor of terminal regrowth. A crop oil concentrate should be mixed with this product. Drought-stressed plants are slow to react to Harvade. Harvade is effective for desiccation of several weed species but is not active on new cotton leaves formed just prior to harvest-aid applications. Harvade is less sensitive to low temperatures than other defoliants and performs better than other materials when average temperatures are below 70 F.

At 7 DAT, percent defoliation and percent desiccation were higher for Harvade than for Dropp but were similar to Folex/Def (Anonymous, 1999). By 14 DAT, all three single treatments were similar. However, Harvade was the only single treatment (without Prep) that increased percent open bolls at 7 and

14 DAT, compared with untreated cotton. Addition of Prep to the Harvade treatment improved boll opening beyond that of the single Harvade treatment at 7 and 14 DAT. Terminal regrowth with Harvade (with and without Prep) was similar to that obtained using Folex/Def, but was not as low as with Dropp. The combination of Harvade + Prep reduced terminal regrowth when compared with the single Harvade treatment, but neither was equal to Dropp, with or without Prep. Basal regrowth with Harvade alone was the same as untreated cotton and the same as with Folex/Def. Addition of Prep increased basal regrowth compared with Harvade alone.

DESICCANTS

Cyclone® Max, Gramoxone® Max (paraquat) – At 0.05 to 0.08 pound a.i. per acre in a tank mix with a defoliant, paraquat can aid in defoliation and in opening of mature bolls. At higher rates, however, paraquat may prevent opening of immature bolls. Regrowth can be a problem after this treatment.

At higher use rates, paraquat is used most extensively as a desiccant in preparing cotton for stripper harvesting. Desiccant treatments should be delayed until cotton is at least 80 percent open. Late afternoon or evening applications of paraquat tend to increase desiccation of plant tissues. If harvest is delayed after complete desiccation, stalk deterioration can occur, resulting in excessive trash in mechanically harvested cotton (Bonner and Robertson, 1995).

PRODUCTS WITH OTHER APPLICATIONS

Accelerate® (endothall) – Accelerate, when tank-mixed with sodium chlorate or phosphate-type defoliants, causes more rapid cotton leaf drop. This product applied alone will not provide satisfactory defoliation. Good coverage is essential for enhanced activity of defoliants.

Roundup® (glyphosate) – Roundup can be used as a pre-treatment, or it can be tank-mixed with certain harvest aids to achieve defoliation and boll opening, late-season weed control, and suppression of cotton regrowth in conventional (non-Roundup Ready®) cotton. In the Southeast and Midsouth, Roundup provides good inhibition of regrowth when mixed with defoliants or ethephon. In the Southwest, Roundup applied as a pre-conditioner at 30 to 50 percent open bolls and 7 to 10 days prior to defoliation provided excellent regrowth suppression with no significant reductions in yield or micronaire

(Landivar *et al.*, 1996). Later applications (less than seven days before application) or tank-mixing Roundup with other harvest aids (Supak, 1996) tended to be less effective in providing extended regrowth control. Pre-harvest applications of this product can result in good control of several weed species, especially perennials. Roundup should not be applied to cotton grown for seed, as reductions in germination and seed vigor may occur.

Quick Pick® (cacodylic acid) – This product is best used as a second treatment to aid in removal of more mature leaves. Quick Pick will cause desiccation of younger leaves, especially at higher temperatures. In the Southwest, cacodylic acid tank-mixed with paraquat enhanced desiccation and delayed formation of new leaves (regrowth). In the Far West, cacodylic acid often is used in combination with sodium chlorate in cleanup applications, to enhance desiccation of leaves remaining after defoliation.

COMMON MIXTURES AND SEQUENTIAL TREATMENTS

All harvest-aid materials have weaknesses that may contribute to an unsuccessful attempt at harvest preparation. These weaknesses often can be overcome by using combinations of two harvest aids together (Snipes and Cathey, 1992). Harsh environmental conditions also can contribute to poor performance, but, again, these conditions often can be overcome by proper selection of two materials used together (Snipes and Cathey, 1992).

A review of university recommendations and popular literature reveals many combinations and sequential mixtures used as harvest aids. The balance between defoliation and desiccation easily can be upset by weather conditions, by condition of the crop, and by adjuvants used in addition to harvest-aid mixes. The goal of harvest-aid application is to cause sufficient injury to the plant to upset hormonal balance at the abscission zone and to allow the plant to begin the abscission process sooner than it would have without application of the harvest aid. If the rate or type of chemical injury is too severe, the leaf may be killed before the abscission process begins, causing the leaf to desiccate and not fall off the plant. If the chemical application is too light, the plant will not get enough material into the leaves to cause the abscission layer to form throughout the plant.

Boll openers, defoliants, desiccants – Harvest aids are classified loosely into three categories: boll openers, defoliants, and desiccants. Many times, a high rate of defoliant under warm temperatures can cause desiccation, a high rate of boll openers can cause defoliation, and a low rate of desiccants also can result in defoliation. Add to this the desire to suppress regrowth and the type of harvest (stripper or picker), and the situation can become very confusing.

Most recommendations for use of harvest aids will include tank mixtures of compounds that complement each other; these tank mixes will be more dependable than trying to use varying rates of one chemical.

Some harvest aids are better mixers than others. Products containing ethephon (Prep, Super Boll, Boll'd) will contribute to boll opening and leaf shedding when mixed with defoliants. Products containing thidiazuron (Dropp, Ginstar, FreeFall) will provide defoliation with suppression of regrowth. Products containing paraquat (Cyclone Max, Gramoxone Max) are useful as defoliants at lower rates and as desiccants at higher rates. The phosphate defoliants (Folex, Def) are useful as mixers when conditions are too cool for use of thidiazuron defoliants. Dimethipin (Harvade) can be used under warm or cool conditions with crop oil for defoliation, as well as for desiccation of some weeds prior to harvest. Recently, pre-packs have been developed using ethephon plus cyclanilide (Finish) and ethephon plus aminomethanamide dihydrogen tetraoxosulfate (CottonQuik) to combine boll opening and defoliation.

Many combinations of the above products are used, but, in general, in the southern areas of the Cotton Belt with picker cotton, the most common tank mixtures include ethephon-based products plus thidiazuron. If the cotton is more mature and does not need the hormonal boll openers, dimethipin can be used in combination with thidiazuron. In the northern areas of the Cotton Belt, phosphate defoliants usually replace thidiazuron, because they are more effective under cooler conditions. Harvest-aid programs in most stripper areas use paraquat products to condition the crop for stripper harvest. This treatment may follow a defoliant or an ethephon + phosphate treatment, or it may be used as a single treatment at a lower rate, followed by a higher-rate sequential treatment to condition the crop for harvest.

ADDITIVES/ENHANCERS

Successful termination of cotton growth and development with chemicals is influenced by several factors, including condition of the crop, the environment, and the type of defoliant used. Conditions that favor optimum defoliation include vegetatively dormant and reproductively mature (cutout) plants with turgid leaves that are treated when temperature, humidity, and sunlight intensity are high. Temperature plays a particularly important role in the process. When night-time temperature falls below 60 F (15.6 C), most harvest-aid chemicals are adversely affected. Because producers are unable to control the environment, success of a harvest-aid program depends on some factors beyond their direct control.

Numerous compounds have been used as additives to increase plant response to defoliants under adverse conditions. Among these additives are various surfactant-type chemicals, senescence- or abscission-inducing products, and fertilizers. Additives are compounds that may improve the performance of defoliants and desiccants, but which do not directly contribute to leaf shedding, boll opening, or plant drying. Additives include activators, adjuvants, surfactants, stickers, spreaders, and wetting agents. Although these compounds are widely known to increase the activity of herbicides, limited information is available on adjuvants and defoliant activity, especially with respect to temperature.

The following discussion provides a brief narrative of the diversity of the compounds used as additives or enhancers and their ability to increase defoliant activity.

Paraquat (Cyclone Max, Gromoxone Max) – Addition of small quantities of paraquat to defoliant mixtures has been quite effective in increasing the removal of juvenile leaves from the terminals of plants (Kirby and Steltzer, 1968; Cornelius *et al.*, 1970). Although paraquat often is considered to be a contact herbicide, it typically does penetrate leaf surfaces and undergoes some movement within plant tissues. Recent data indicate that paraquat applied later in the day has a better performance rating (defoliation and desiccation) than when applied at earlier times in the day (Cothren *et al.*, 1999).

Gibberellic Acid (GA) – Although no data are available on the application of this growth hormone to defoliation-ready, field-grown cotton, interesting results have been observed in controlled-environment studies. Applications of GA to cotton plants consistently promoted leaf abscission; the effects were enhanced further with the addition of ethylene. It appears that this hormone reduces the abscission-retarding action of auxin (Morgan and Durham, 1975).

Ammonium Sulfate and Crop Oil Concentrate – The interactions of these two adjuvants were examined at different temperatures in a controlled-environment study using the defoliant thidiazuron (Snipes and Wills, 1994). At day/night temperatures of 86/70 F (30/21 C), the addition of Crop Oil Concentrate (COC) increased leaf drop by 20 percent, and ammonium sulfate increased leaf drop by 23 percent at five days after treatment, compared to the use of no adjuvant. When the two adjuvants were combined in this temperature regime, leaf drop increased 58 percent. In a temperature regime of 70/55 F (21/13 C), less than 10 percent leaf drop occurred in all treatments at 5 DAT. The researchers also determined the percent absorption of thidiazuron. COC produced the highest absorption rates (33 to 46 percent) compared to ammonium sulfate (18 to 19 percent) and the control (no adjuvant) (7 to 10 percent).

Cyclanilide and AMADS – Finish and CottonQuik are relatively new cotton harvest aids marketed by Aventis Group and Griffin LLC, respectively. The active ingredients in Finish are ethephon and cyclanilide; in CottonQuik, they are ethephon and AMADS. Cyclanilide and AMADS, when combined with ethephon, enhance boll opening, defoliation, and regrowth suppression. In some field trials, Finish treatments provided better defoliation than did applications of ethephon and of thidiazuron (Pedersen *et al.*, 1997), but, most commonly, both Finish and CottonQuik are used in tank mixes with defoliants.

Endothall – Endothall, also known as Accelerate, has been shown to enhance the activity of some standard defoliants. When endothall and Folex were tank-mixed, leaf drop decreased 25 percent in the first few days of defoliant activity (Sterret *et al.*, 1973). Observations in field studies in Texas showed an enhancement of endothall uptake involving preparations containing ammonium sulfate, and a significantly greater percentage of necrotic leaf surface area occurring when pelargonic acid was combined, compared to either product alone (Tarpley and Cothren, 1997).

HARVEST-AID PERFORMANCE

Preparing cotton for harvest can be a daunting task because of the wide variation in conditions from year to year, region to region, and even field to field. Defoliation often is described as more of an art than a science, and harvest-aid recipes abound throughout the Cotton Belt.

In an effort to add some science to cotton-harvest preparation, a group of cotton scientists organized a coordinated, uniform effort to study cotton harvest-aid treatments. This Cotton Defoliation Work Group evaluated a core set of treatments over five years at 15 locations across the Cotton Belt, with additional treatments applied on a regional basis. An overview of the five-year study is provided in Chapter 7, and a comprehensive summary of the overall project is presented in Anonymous, 1999. The following discussion is based on the findings of this project.

BELTWIDE

Folex/Def works well as a defoliant but provides poor regrowth control (Anonymous, 1999). A single application of Dropp or Harvade generally provided defoliation similar to that of Folex/Def, although Dropp was less effective under cooler conditions and Harvade was not consistent across locations or years. Addition of Prep to Folex/Def treatment improved overall performance (both boll opening and defoliation) but did not improve regrowth suppression.

Dropp generally was slower-acting than Folex/Def at 7 DAT, but defoliation was equal for the two treatments by 14 DAT. Dropp was the most effective product for controlling both basal and terminal regrowth. Cotton treated with Dropp exhibited 50 percent less regrowth than untreated cotton.

Prep significantly increased boll opening within two weeks of application. Harvade was the only non-ethephon treatment that increased boll opening. Defoliation with Harvade was less consistent, but with higher desiccation than observed with Dropp or Folex/Def. Harvade generally performed best in the Southeast and Midsouth locations.

None of the harvest aids evaluated had a negative impact on cotton quality. Fiber strength, length, and length uniformity were not affected. Harvest aids did, however, reduce trash content and reduced lint staining from green tissue.

An economic analysis of the benefits of harvest-aid treatments is presented in Chapter 8.

REGIONAL DIFFERENCES

SOUTHEAST

Combinations of Prep with Harvade, Folex/Def, or Dropp performed better than the defoliants applied alone and were comparable to the three-way mixture of Dropp + Folex/Def + Prep (Anonymous, 1999). Adding Prep to the mixture improved both defoliation and boll opening. Dropp provided superior regrowth suppression. Finish also provided good defoliation and boll opening but was inconsistent when applied alone. The addition of a defoliant product improved the overall performance of Finish. Quick Pick + Dropp provided good overall performance and defoliation. Desiccation was no greater than with other treatments. Prep alone did not provide adequate defoliation or satisfactory overall performance.

MIDSOUTH

Harvade and Folex/Def had similar defoliation ratings, while Dropp was less effective than the other defoliants when used alone (Anonymous, 1999). When Dropp was applied with Prep, however, it provided results similar to other products mixed with Prep. Combining Prep with defoliants increased both defoliation and boll opening. In Mississippi, overall harvest-aid performance was consistently better when combinations were used, especially when Prep was included, compared to single-product applications. Dropp + Folex/Def and Harvade + Dropp had results similar to the Folex/Def + Prep treatment.

SOUTHWEST

In the spindle-picker-harvested cotton areas mainly in South and south-central Texas, Dropp and Ginstar were more effective than Folex/Def or Harvade in defoliation (Anonymous, 1999). Tank-mixing Prep with any of the defoliants did not consistently improve overall performance, defoliation, or boll opening. The combination of Prep with Folex/Def or with Harvade tended to promote terminal and basal regrowth, while the Prep combination with Dropp and Ginstar provided some regrowth suppression.

The most consistent harvest aid at 7 DAT was Dropp at 0.2 pound per acre. All treatments containing Dropp or Folex/Def in tank mixes or Ginstar alone provided good to excellent overall performance.

In the stripper-harvested areas, located from north-central Texas to Oklahoma, Ginstar and Folex/Def generally were more effective than Dropp or Harvade in overall performance. Ginstar and the Folex/Def + Prep combinations were superior to all other treatments in Texas, while Harvade + Prep was equal to Folex/Def + Prep in Oklahoma. Adding Prep to Dropp, Harvade, or Folex/Def tended to improve defoliation. Defoliation with Ginstar typically was very effective, and tank-mixing Prep with Ginstar provided little or no improvement in leaf shedding. In stripper-harvested cotton, a desiccant treatment is often needed in addition to any other harvest-aid treatment and normally is applied after the initial harvest-aid application.

FAR WEST

In general, one-time application of either single harvest-aid products or mixtures did not perform as well as the standard western practice of second "cleanup" applications (Anonymous, 1999). Most treatments provide satisfactory boll opening, with Harvade and Prep combinations performing best. Dropp alone was less effective than Prep or Harvade for boll opening.

Defoliation of upland Acala™ varieties grown in the San Joaquin Valley of California is accomplished with two applications of harvest-aid materials. Standard practices include applications of Prep, combinations of chemical defoliants with Prep, or defoliants alone as first treatments applied at the recommended stage of maturity. This initial harvest-aid treatment is followed by a second application to assist in further defoliation and complete desiccation of remaining leaves. Although a single application would be desirable, the norm for this production region is two applications. Compared with other cotton-growing regions, higher rates of harvest-aid materials usually are required in the Far West.

A more detailed discussion of regional differences can be found in Chapter 9.

SUMMARY

Cotton harvest preparation begins with planting and continues until harvest. In-season cultural practices significantly affect defoliation success, because the condition of the plant dictates its response to harvest-aid treatments. Terminating the crop is easier when the cotton has a heavy boll load and has ceased vegetative and reproductive activity. Proper management of fertility, irrigation, and pests will result in a crop ready for harvest-aid treatment and ultimately will lead to more successful cotton harvest.

Defoliation timing can be determined by several techniques, but the most widely used include Percent Open Bolls, Cut Boll Technique, and Nodes Above Cracked Boll. Harvest-aid timing is a compromise between maturation of later-developing bolls and degradation of the earlier-developed bolls already open. Best timing for harvest-aid application is arrived at by using a combination of these techniques, rather than any one of the procedures alone.

Several products are available for use as cotton harvest aids. These products differ in type of activity (boll opener vs. defoliant vs. desiccant and herbicide vs. PGR) and, thus, the situations where they are used. Their effectiveness can be altered by overall condition of the cotton plant and weather. Harvest-aid choice should be delayed until near harvesttime so that all these factors can be included in the decision.

In regional trials, overall performance was good for a number of harvest-aid treatments. In general, mixtures outperformed single products; several mixtures are available that provide sufficient leaf drop with adequate boll-opening activity, sufficient regrowth suppression, and no loss in fiber quality.

Regional differences in product activity were related to the type of cotton grown (picker- vs. stripper-harvested) and prevailing climatic conditions. Consult local experts to assist in making the best choice for your situation.

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