Chapter 3

INFLUENCE OF ENVIRONMENT ON COTTON DEFOLIATION AND BOLL OPENING

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INTRODUCTION

The results obtained from chemical defoliation of cotton are among the least predictable of the operations a farmer may perform (Cathey and Hacsklaylo, 1971). Factors influencing the response include weather conditions, spray coverage, and the absorption and translocation of harvest-aid chemicals, all of which are influenced by the environment. Weather conditions are perhaps the most important factors affecting efficiency of defoliation (McCarty, 1995).

For these reasons, cotton defoliation is considered as much an art as it is a science (McCarty, 1995). The variability in response to harvest aids may be related to different environmental factors that condition the crop during the growing season, especially to weather conditions during and after harvest-aid application. The objectives of this chapter are to summarize knowledge about environmental effects on harvest-aid performance, with emphasis on defoliation and boll opening of upland cotton, and to provide perspectives from different regions of the U.S. Cotton Belt.

GROWING SEASON CONDITIONS

Environmental conditions during the growing season determine crop condition at time of harvest-aid application. These include effects of water stress on the thickness and composition of the leaf cuticle and effects of moisture supply, nitrogen nutrition, and fruit set on vegetative growth and senescence. In general, mature and senescent plants are more responsive to harvest aids, especially if they were not severely moisture-stressed during the growing season.

MOISTURE EFFECTS ON THE LEAF CUTICLE

The thickness and composition of the leaf cuticle are influenced by moisture supply and atmospheric humidity during the growing season. In humid cotton-growing environments, leaf cuticles tend to be thinner and more easily penetrated by harvest aids than those on cotton grown in arid environments (Roberts *et al.*, 1996). In contrast, high seasonal temperatures often are accompanied by low humidity, which contributes to the development of thick, brittle leaf cuticles, even with irrigation.

In nonirrigated conditions, leaves become toughened under prolonged drought (Cathey, 1986). Conditions that cause cotton leaves to be wilted, tough, or leathery tend to delay absorption of harvest-aid materials. In a comparison of well-watered and drought-stressed cotton in Arkansas (Oosterhuis *et al.*, 1991), water deficit increased leaf cuticle thickness by 33 percent and altered cuticle wax composition by increasing its molecular weight. These effects increased the hydrophobic quality of leaf surfaces and decreased penetration of defoliants in aqueous solution. After 24 hours, uptake of ^{14}C-dimethipin was reduced by 34 percent in leaves of drought-stressed plants relative to those from well-watered plants; consequently, defoliation was reduced. Use of a crop oil adjuvant may be advisable to promote uptake under these conditions (AgrEvo USA Co., 1997).

NITROGEN NUTRITION EFFECTS

Nitrogen nutrition during the season influences the vegetative growth and maturity of cotton and, therefore, the extent of natural senescence at the time of defoliation. High nitrogen concentrations in plant tissue delay abscission zone formation in both leaf petioles and sutures in the boll walls, which in turn delays boll opening (Hake *et al.*, 1990). In cotton with excessive N, upper canopy leaves shade bolls, thus maintaining a cooler environment and slowing their maturation.

By contrast, late-season N deficiency promotes senescence and accelerates abscission. A heavy boll load also forces the plant into cutout and senescence by using most available carbohydrates for boll maturation rather than for vegetative or root growth (Hake *et al.*, 1996).

TEMPERATURES FOR BOLL MATURATION

To a large extent, temperatures determine the length of the boll maturation period (time from flowering to boll opening). Later-set bolls normally encounter cooler temperatures and, consequently, require a longer period to mature (Cathey *et al.*, 1982). Counting degree-days from flowering until maturity of the last effective boll population has been proposed as a defoliation timing procedure (Pearson, 1985; Bourland *et al.*, 1997). Cotton grown in Arkansas requires about 850 growing degree-days (base 60 F, or 15.6 C) from flowering to boll opening (Bourland *et al.*, 1997). Of the 850 degree-days in the boll period, the last 75 to 100 are not associated with weight gain but with drying and boll opening processes (Supak, 1991; Kerby, 1988). This information can be used to calculate the minimum heat-unit requirement for boll maturation and subsequent defoliation timing. Bourland *et al.* (1997) suggest that defoliation with fewer than 850 degree-days may be advisable along the northern edge of the U.S. Cotton Belt and in other areas when forecasts of adverse weather may indicate a need to harvest early. However, premature crop termination may reduce lint yields. In a two-year study of defoliation timing, Stringer *et al.* (1989) found that yields and micronaire values were reduced with crop termination earlier than 750 or 850 degree-days after cutout. The yield reduction averaged 14 percent for each 100 degree-day increment of earlier termination, but the reduction was not consistent between the two years of that study.

ENVIRONMENTAL CONDITIONS DURING HARVEST-AID APPLICATION

Prevailing weather at time of application is a major factor limiting defoliation efficiency (Cathey, 1986). Weather factors that most influence harvest-aid performance are temperature, sunlight, relative humidity, drought stress, and the occurrence of rainfall shortly after application.

TEMPERATURE AND SUNLIGHT

High temperatures and intense sunlight are desirable for chemical defoliation. High temperature and solar radiation at the time of application render the waxy layer of the leaf more pliable and speed movement of harvest-aid chemicals through the cuticle (Roberts *et al.*, 1996).

The rate of chemical activity within the leaf also is temperature-dependent. Applications of contact-type herbicidal defoliants during periods of high temperatures can result in damage to the leaf tissue, thereby limiting absorption of the defoliant. If the leaf dies before the abscission layer is activated, then desiccation rather than defoliation may occur (Hake *et al.*, 1990).

Minimum temperatures for activity of various harvest aids have been determined (Table 1). In general, desiccants remain active at lower temperatures than defoliants, and contact-type defoliants remain active at lower temperatures than materials with hormonal activity (Hake *et al.*, 1996). For instance, thidiazuron and ethephon are more sensitive to low temperatures than other harvest aids (Supak, 1995). Paraquat activity is influenced to some extent by sunlight as well as by temperature, as low light intensity immediately after application slows paraquat activity, resulting in more translocation of paraquat within the plant. Biles and Cothren (1996) showed that late afternoon application of paraquat resulted in more plant desiccation than did morning or midday application.

Table 1. Minimum temperatures (T_{min}) for optimum performance of selected harvest aids..

Harvest-Aid Material	T_{min} (Degrees F)	T_{min} (Degrees C)
Sodium chlorate	50	10
Paraquat	<55[1]	<13[1]
Tribufos	55-60	13-16
Dimethipin	55	13
Ethephon	60	16
Thidiazuron	65	18

Source: Hake *et al.*, 1996.
[1]Activity slows but performance is maintained below this temperature.

Night temperatures above 60 F (15.6 C) are considered particularly important at defoliation time (Cathey, 1986). Night temperatures below 60 F (15.6 C) for three or four nights before or after a defoliant application result in slower metabolic activity of the cotton plant and subsequent slower defoliation. For example, defoliation with dimethipin may be reduced if night temperatures fall below 60 F (15.6 C) for three to four nights before or after application (Uniroyal Chemical Co., 1997). The use of thidiazuron alone can result in less than desirable defoliation when night temperatures fall below 60 F (15.6 C) (AgrEvo USA Co., 1997). However, activity of these defoliants generally is improved under cool conditions if they are tank-mixed with other harvest aids, such as ethephon (Gwathmey and Hayes, 1997).

The temperature sensitivity of ethephon can be compensated for to some extent by increasing rates under cooler conditions. Recommended rates of ethephon vary from 1 pound a.i. per acre, at temperatures above 80 F (27 C), to 2 pounds a.i. per acre at cooler temperatures that are above 64 F (15.6 C) (Rhône-Poulenc Ag Co., 1997b).

RELATIVE HUMIDITY

High atmospheric humidity at application is desirable for several reasons. Harvest-aid chemicals remain in an available state for a longer period on the leaf surface when humidity is high, facilitating uptake (Cathey, 1986). High humidity before application results in spongy cuticles that are more easily penetrated by harvest-aid materials (Hake *et al.*, 1996). High humidity also contributes to maintenance of water content in the leaf, which aids in chemical movement into the leaf (McCarty, 1995). Satisfactory defoliation with thidiazuron depends on high humidity and high moisture content in cotton leaves (AgrEvo USA Co., 1997).

By contrast, low humidity during application decreases uptake due to rapid drying of spray droplets on the leaf surface. Adjuvants (crop oils and some surfactants) may compensate to some extent by enhancing penetration of the leaf cuticle, thus increasing efficacy of defoliants such as dimethipin or thidiazuron (Hake *et al.*, 1990; Snipes and Wills, 1994; Supak, 1995).

Although high humidity is desirable, cloudy weather reduces response to defoliants for reasons not fully understood (Cathey, 1986). Cloudy weather often is accompanied by cooler temperatures and lower rates of photosynthetic activity in the leaf, which may account for some of the observed reduction in response.

CROP WATER STRESS

Crop water stress at the time of defoliation tends to reduce response to harvest aids, as leaves have become toughened and have lower metabolic activity (Cathey, 1986). Drought stress reduces defoliation by dimethipin (Uniroyal Chemical Co., 1997). Conditions that cause cotton leaves to be wilted, tough, or leathery tend to delay absorption of harvest-aid materials. The use of adjuvants and contact defoliants may be advisable under these conditions (Rhône-Poulenc Ag Co., 1997a).

In arid environments, irrigation termination is synchronized with crop termination in order to shift hormonal balance of the plant towards senescence (Roberts *et al.*, 1996). Increasing plant water stress tends to hasten boll opening (Hake *et al.*, 1996), but sufficient moisture must remain for defoliants to activate the abscission layer of the leaf petiole.

PRECIPITATION SHORTLY AFTER APPLICATION

Harvest aids differ in time required after application to reach a rain-safe condition. Thidiazuron, formulated as a wettable powder, is susceptible to being washed off by rains within 24 hours because of slow absorption by the plant, which can result in reduced defoliation activity. The addition of a crop oil concentrate increases the rate of thidiazuron absorption and reduces this effect (Elsner and Taylor, 1978). Rainfall within six hours after application reduces defoliation by dimethipin (Uniroyal Chemical Co., 1997). By contrast, once tribufos has dried on the leaf surface, subsequent rain or dew does not adversely affect activity. Application of tribufos is not recommended when heavy rainfall is expected within one hour (Rhône-Poulenc Ag Co., 1997a). If rain occurs as ethephon-treated bolls are beginning to open, "hard locking" of the bolls can occur and cause significant yield losses (Supak, 1991).

ENVIRONMENTAL CONDITIONS AFTER APPLICATION

Response to harvest-aid chemicals after application most frequently is limited by temperatures that govern the rates of chemical and physiological activity. For satisfactory response, night temperatures above 60 F (15.6 C) are required for three to five days after application of most defoliants (Cathey, 1986).

HEAT UNIT ACCUMULATION EFFECTS

Harvest aids that depend on physiological processes in the plant, such as ethephon or thidiazuron, typically require temperatures above 60 F (15.6 C) for optimal activity. As an example, the boll opening response to ethephon is highly correlated with degree-day accumulation after treatment (DDAT base 60 F, or 15.6 C). Under Tennessee field conditions, ethephon required more than seven days and from 52 to 108 DDAT to significantly increase the boll opening of Deltapine® 50 cotton (Gwathmey and Hayes, 1996).

A three-year study in Tennessee showed that interactions between ethephon and defoliants occurred under cool conditions that provided only 24 to 47 DDAT to first harvest (Gwathmey and Hayes, 1997). Ethephon enhanced defoliation more with thidiazuron than with tribufos but did not increase boll opening with dimethipin under these conditions. Overall, the boll-opening effects of ethephon and defoliant mixtures tended to be more variable under cool conditions than under the more optimal temperature regimes.

Another hormonal type of harvest aid is Finish®, a mixture of a cyclanilide and ethephon. The cyclanilide acts as an auxin transport-inhibitor and is synergistic with ethephon (Pederson *et al.*, 1997). In the north Delta region of the U.S. Cotton Belt, Finish was a slightly less effective defoliant at 14 days after treatment (DAT) under cool conditions than a mixture of tribufos and ethephon, but had similar defoliation activity under warmer conditions (Hayes *et al.*, 1996). Equivalent rates of ethephon applied as Finish (pre-mix) or tribufos + ethephon (tank mixture) produced similar boll opening by 14 DAT under both cool and warm conditions. However, Legé *et al.* (1997) found that Finish defoliated more effectively than a tribufos and ethephon mixture by seven DAT under cool, wet conditions in the Southeastern Coastal Plains.

Q_{10} OF BIOLOGICAL ACTIVITY

The factor by which a reaction rate changes with each 10 C (18 F) increase in temperature is called the Q_{10} (Salisbury and Ross, 1992). Plant response to contact-type defoliants doubles for each 10-degree Celsius rise between 15 C and 35 C (59 F and 95 F) (Cathey, 1986; Lane *et al.*, 1954). Under cool conditions, contact materials may not wound the plant sufficiently to result in defoliation (Roberts *et al.*, 1996).

Cool temperatures after application (daily maximum of 18 C to 24 C, or 64 F to 75 F) require twice the rate of ethephon for boll opening as warmer temperatures (daily maximum of 29 C to 35 C, or 84 F to 95 F). Leaf shedding also proceeds twice as fast at an air temperature of 35 C (95 F) as at 25 C (77 F) (Hake *et al.*, 1990).

FREEZING CONDITIONS

The greatest threats to cotton harvest are weather-related, especially a premature freeze of green bolls that interferes with boll opening (Crawford, 1985). If the freeze is prolonged, cells in the abscission layers between carpel walls in the bolls are killed, preventing boll opening. Fiber development also is impaired by chilling injury at temperatures between 0 C and 10 C (32 F and 50 F) (Hake and Kerby, 1996).

A freeze will kill leaf tissue, but its effects on defoliation depend on the extent of leaf senescence. Observations on the High Plains indicate that, if a senescent crop has been conditioned by one or more (nonfreezing) cold fronts, bolls usually will open and leaves will shed after a freeze. However, if freezing temperatures occur prior to senescence, leaves may not shed, because the abscission layer in the leaf petiole is killed before activation of the abscission layer.

UNIFORM HARVEST-AID EVALUATION

A five-year (1992-96) harvest-aid study was conducted at 16 locations throughout the U.S. Cotton Belt, using a uniform experimental design and protocol (Anonymous, 1999). U.S. test environments were located in the Southeast, Midsouth, Southwest (picker and stripper cotton sites), and Far West. Seven "core" treatments were applied in all environments at 55 percent (± 5 percent) open bolls. These treatments consisted of three defoliants (tribufos, dimethipin, and thidiazuron) applied with and without ethephon, and an untreated check. Treatments were applied and harvest-aid response data were collected from each plot as described in the research report of the Cotton Defoliation Work Group, "Uniform Harvest Aid Performance and Fiber Quality Evaluation" (Anonymous, 1999).

At each site, weather data were obtained from the nearest National Weather Service Cooperative Station or from a nearby automated weather station. To characterize the range of weather conditions over the years and locations of testing, these data were partitioned by quartiles (Table 2). Favorable weather conditions generally prevailed, but a wide range of weather conditions was recorded before and after treatment, and at the time of treatment application, in the 80 test environments.

Weather – One objective of this study was to relate performance of harvest aids to weather variables. Relationships between weather and response variables (defoliation, desiccation, boll opening, and regrowth) were determined from simple linear regression and corresponding harvest-aid responses by univariate analysis of variance (Logan and Gwathmey, 1998). Defoliation and boll opening responses to harvest aids were evaluated as differences from untreated check plots in each environment.

Unpublished results from these analyses indicate that weather conditions before and after treatment generally affected defoliation and boll opening more than weather conditions at the time of application. Relative to untreated cotton, defoliation responses to all harvest aids improved with higher minimum temperatures from planting to application. However, in environments

Table 2. Distributions of weather data by univariate analysis of weather variables recorded before, during, and after treatment application in the Uniform Harvest-Aid Evaluation conducted for five years at 16 locations.

Weather Variable (units)	Min.	Q1[1]	Median	Q4[2]	Max.
From planting to treatment:					
Mean maximum temperature (F)	82	86	88	90	93
Mean minimum temperature (F)	56	65	67	68	72
Heat (DD60 F)	1886	2142	2332	2550	2958
Rain (in)	0.48	11.45	15.39	20.47	45.02
At the time of treatment:					
Cloud cover (%)	0	0	10	38	100
Air temperature (F)	56	77	83	87	98
Relative humidity (%)	15	44	55	70	92
Wind speed (mph)	0	3	4	7	10
Rain during 7 days prior (in)	0	0	0.10	0.53	2.56
Rain during 7 days after (in)	0	0	0.11	0.81	8.50
From treatment to 14 days after treatment:					
Mean maximum temperature (F)	72	78	83	89	99
Mean minimum temperature (F)	42	52	57	64	76
Heat units (DD60 F)	0	85	148	226	399
Rain (in)	0	0.02	0.71	2.49	15.52

Source: Logan and Gwathmey, 1998.
[1]Q1= upper threshold for 1st quartile.
[2]Q4= lower threshold for 4th quartile.

that experienced low (Q1) maximum and minimum temperatures from planting to treatment application, the percent of open bolls was greater at 14 days after treatment with ethephon-defoliant mixtures than in the untreated check plots. These differences diminished at higher (Q4) maximum and minimum temperatures. This result indicates either that, relative to the untreated check, ethephon increased boll opening more under cooler seasonal conditions than in warmer environments, or, possibly, that the rate of boll opening in mature, untreated cotton was greater under higher temperature regimes, and applications of ethephon (additional ethylene) failed to increase that rate significantly. Data in Table 2 suggest that the cooler environments had average minimum temperatures of 65 F (18 C), with maximum temperatures averaging 86 F (30 C) from planting to treatment. In the warmer test environments, minimum temperatures averaged 68 F (20 C) and maximum temperatures averaged 90 F (32 C) from planting to treatment.

High relative humidity at the time of application improved defoliation response to thidiazuron at seven days after treatment, with or without ethephon, relative to the check. Higher maximum and minimum temperatures after application also improved defoliation response to thidiazuron, relative to the check, in a manner consistent with the temperature sensitivity of the active ingredient. However, boll-opening response to mixtures of defoliants with ethephon was smaller than that of untreated cotton in environments with high maximum temperatures after application. This finding suggests that boll opening is affected more by ethephon in cooler environments (but above the critical minimum of 60 F, or 15.6 C) than in warmer environments where heat unit accumulation is more influential (Logan and Gwathmey, 1998).

REGIONAL PERSPECTIVES

SOUTHEAST

Most areas in the Southeastern region have a wide selection of harvest-aid products that can be used with comparable efficacy and cost. Various tank mixtures of ethephon and a defoliant of any type have resulted in good performance. Therefore, the primary obstacle to harvest-aid performance is the interaction between application timing and the weather conditions just prior to, during, and after harvest-aid application.

The harvest-aid challenges for the northern tier of states in the Southeastern region are slightly different from those in the southern tier. The northern areas typically use early-maturing varieties, which usually are ready for termination with harvest-aids between late August and late October. Cool temperatures begin to complicate harvest-aid performance as early as mid-September. By the first part of October, product performance and cost-effectiveness associated with their use are hindered severely by falling temperatures. Rain is more likely in October, making the timing of harvest-aid application and subsequent harvest difficult to manage.

Full-season varieties commonly are grown in the southern portion of the Southeastern region, and harvest-aid applications typically are made between late August and late November. Rainfall and cool temperatures begin to influence harvest-aid product performance adversely by mid-October; by November, frequent rainfall is the more common cause of poor harvest-aid performance.

Some areas of the Southeast have problems managing application of harvest aids around the harvest schedule of other crops, especially peanuts. Because the profit margin for peanuts typically is higher than that for cotton, producers may elect to apply harvest aids too early, at the risk of incurring some yield and quality loss from premature termination. Or, they may delay harvest-aid applications until after peanut harvest and risk yield and quality losses from weathering of open bolls.

Other areas of the region are typified by many small fields, making it difficult to coordinate harvest-aid application and subsequent harvest dates. These areas also have limited harvesting capacity; many fields that are defoliated correctly cannot be harvested on time because of equipment limitations and weather factors. Conversely, defoliation of other fields is delayed beyond the optimum when producers realize that harvest is proceeding slower than expected.

The Southeast frequently experiences difficulty in harvest-aid application and harvesting because of late-season tropical storms and hurricanes. Producers usually are advised to delay harvest-aid applications until after an impending storm moves through their area. Yield losses from high winds and rainfall associated with these storms are less severe if the leaves are left intact, rather than defoliated prior to the storm.

Southeastern producers may elect to manage harvest-aid programs to spread the risk of yield and quality losses related to weather factors, as well as the associated performance deterioration of harvest-aid materials, as the season progresses. Two ways to manage this risk are to use varieties with different relative maturities and to vary planting dates to help coordinate harvest-aid application and harvest dates.

MIDSOUTH

The challenge in the Midsouth region is to use harvest-aid chemicals to achieve an optimal compromise between the risks of terminating the crop too early and the risks of harvesting the crop too late. In most years, the weather in early fall provides higher temperatures and more optimum conditions for harvest-aid activity than later in the fall. These optimum, drier conditions for harvesting and module building also help preserve fiber quality. In years and in fields where early crop maturity is attained, this compromise is relatively easy to achieve, because harvest aids normally can be applied with little risk of yield or quality loss with a timely harvest. A mature crop and prolonged periods of warm, sunny weather offer the producer the widest possible range of harvest-aid options, as conditions favor their activity.

When the crop is later-maturing, however, it becomes more probable that weather conditions for harvest-aid activity and for harvest operations will deteriorate as the fall season progresses. Under these conditions, a satisfactory compromise between early termination and late weather problems becomes more difficult to achieve. As night temperatures fall below 60 F (15.6 C), most harvest-aid chemicals become less effective, or higher rates are needed. Temperature sensitivity of chemicals with hormonal activity, such as ethephon, becomes more apparent. More time is needed after application for these materials to condition the crop for harvest, prolonging crop exposure to weather-related losses as rains become more frequent in late fall. The temptation exists to use an inexpensive desiccant such as sodium chlorate as a salvage treatment under these conditions, or simply to wait for a killing frost in the northern tier of the Midsouth region. A killing frost desiccates leaves that remain on the plant, which may be ground into "pepper trash" that mixes with lint during spindle picking. Although this approach may appear to be economical, it often results in additional lint cleaner costs at the gin and in leaf grade discounts upon classing of the lint.

Premature application of harvest aids, in an attempt to advance the harvest schedule to avoid later weather-related problems, also can result in price discounts. Ethephon-based harvest aids can cause green bolls to open while they still contain immature fibers with low micronaire. This practice also can reduce lint yield. Crop monitoring software can help producers avoid these problems by predicting when the crop will be adequately mature to apply harvest aids safely, based on heat unit (DD60) accumulation after cutout (Oosterhuis *et al.*, 1996). Defoliation is recommended by the COTMAN program when 850 DD60s accumulate after cutout (five nodes above white flower) or after the last effective boll population has been produced, whichever occurs first. This allows producers to establish an approximate schedule for defoliation and harvest of various fields based on historical records of heat unit accumulation for their location.

The ideal harvest-aid scenario is one in which the crop is early, uniformly mature, and senescing naturally because of heavy boll load and nitrogen depletion. The leaf cuticle has not thickened because of drought stress during the season. The weather is warm, sunny, and humid on the day of harvest-aid application; no rain falls after application, and night temperatures remain above 60 F (15.6 C).

SOUTHWEST

The Southwest region, comprising Texas, Oklahoma, and a portion of New Mexico, extends from the subtropical Rio Grande Valley, characterized by warm days and nights and an extended growing season, to the semiarid High Plains, which has a much shorter growing season with generally warm days but cooler nights. Heat unit accumulation throughout the growing season ranges from less than 2000 DD60s in the northern portion of the Texas High Plains and Oklahoma to more than 2800 DD60s in the Rio Grande Valley. Rainfall varies from less than 10 inches (250 mm) in the El Paso area to greater than 40 inches (1 m) along the upper Gulf Coast of Texas.

These location or climatic differences have major impacts on the efficacy of certain harvest-aid products. For example, thidiazuron (Dropp®) often is the defoliant of choice in South Texas, but it rarely is used as a stand-alone defoliant from central Texas northward. Also, except under ample irrigation, ethephon or defoliant + ethephon combinations rarely are used in South and central Texas. Because of the warm temperatures at the time treatments are applied, leaf removal allows the sun to warm maturing bolls sufficiently to stimulate ethylene production and accelerate boll opening. In contrast, studies have confirmed that defoliant + ethephon combinations improve both defoliation and boll opening in the cooler regions of Texas and Oklahoma.

Presently, more than 70 percent of the cotton produced in the Southwest is stripper harvested (Evans, 2000). The primary requirements for stripper harvesting are that all harvestable bolls are open and that all extraneous materials (burs, leaves, stems) that may be collected and mixed with the seed cotton during the harvesting operation are desiccated. As a result, the potential for heating during field storage is reduced, which leads to more efficient ginning and cleaning of stripped cotton. Ideally, defoliants or combinations of defoliants and boll openers are used prior to desiccation to remove most leaves and enhance boll opening. Typically, defoliants or defoliant + boll opener mixtures are applied approximately five to 10 days before the crop is treated with a desiccant. Although desirable, such sequential treatments may not be economically practical if crop yield potentials are limited by drought or other factors.

Most picker cotton in the Southwest is grown in areas with higher rainfall or adequate irrigation to ensure higher, more consistent yields. In the Southwest, crops generally are prepared for picking with a single application of a defoliant or boll opener + defoliant combination. Sequential applications of a defoliant followed by a defoliant or combination defoliant + boll opener may be warranted when tall, rank plants with dense foliage are present. Under conditions where the crop is mature and senescent, and especially if the yield potential is limited, growers may elect to pick cotton without prior chemical defoliation.

Regrowth often is a serious problem, primarily in the warmer southern and central sections of the Southwest. Some harvest aids provide temporary suppression of new leaf development (e.g., thidiazuron), whereas plants rapidly refoliate after defoliation, desiccation, and boll opening that may be induced by others (e.g., ethephon, paraquat). Research by Landivar *et al.* (1996) has shown that applications of Roundup® at approximately 50 percent open bolls (or 7 to 10 days before a defoliant or other harvest aid is applied) resulted in extended regrowth suppression, enhanced defoliation efficiency, and no significant reductions in yield or micronaire. Tank-mixing glyphosate with the defoliant can reduce application costs, but regrowth suppression with such treatments has been somewhat erratic in central Texas (Supak, 1996). Although Roundup can be effective in inhibiting regrowth, it should not be applied pre-harvest to either conventional or Roundup Ready® cotton that is being grown for seed, as reductions in seed germination or vigor, may occur; pre-harvest application of Roundup to cotton grown for seed, or application prior to boll maturation, does not conform to Roundup Ultra® label restrictions (Monsanto Co., 1997).

Timing of harvest-aid applications is a key consideration. Delayed crop termination and harvest can result in costly yield and fiber-quality reductions due to field losses and weathering. Conversely, premature crop termination also can reduce yields and quality. Occasionally, crops deliberately are terminated prematurely to stop fiber development and minimize the risk of high micronaire fiber (Sheperd, 1994), to condition crops that have not attained maturity for a hard freeze (mainly on the Plains of Texas and in Oklahoma) or to escape other adverse weather events (e.g., hurricanes along the Gulf Coast).

FAR WEST

The Far West region includes the states of Arizona and California, and portions of New Mexico. Although characterized as an arid to semiarid region, distinct environmental differences in the major production areas of each state affect defoliation and harvest practices. Most upland cotton in Arizona is grown in the "low desert" elevations, which have an arid climate, while most of California has a Mediterranean climatic regime. California's acreage is dominated by plantings in the southern San Joaquin Valley. Other areas of importance are the desert valleys of southern California and, more recently, the Sacramento Valley of northern California.

Cotton production in this region is characterized by a hot, dry growing season; irrigation is the most common denominator. Climatic conditions in the Far West provide some advantage in preparing the crop for defoliation, as the moisture and nitrogen supplied to the crop can be terminated with the last irrigation of the season. Excessive moisture and nitrogen, however, coupled with physiological traits of heat-stress tolerance, thicker leaf cuticles, and tolerance to *Verticillium* wilt, can produce cotton plants that are difficult to defoliate. These factors contribute to the need for higher rates of defoliants and secondary applications to achieve satisfactory results.

The low desert areas of both Arizona and California often experience a monsoon period with elevated humidity during late July and extending through August. After this humid period, weather conditions during September and early October usually are ideal for defoliation, as daily high temperatures can be above 80 F (27 C) well into late October.

The San Joaquin Valley tends to be cooler than the desert production areas. Even though November weather can be clear and sunny, heat unit accumulation drops sharply from cooler night- and daytime temperatures. The average heat unit (DD60) accumulation in the San Joaquin Valley for the 30-day period between September 20 and October 20 is approximately 10 units per day (average for 30-day period from 1995 to 1998). The average heat unit accumulation for the following 30 days, from October 21 to November 21, was less than three heat units per day for the same four-year period. Therefore, crop termination and planning for defoliation prior to the onset of cool weather and harvest during this "open harvest" window is an important management goal.

Improvements in picking efficiency and in the "earliness management" of Acala™ cottons led to a dramatic increase in once-over harvesting in the San Joaquin Valley during the 1980s. The practice of once-over harvest depends on the use of ethephon to open all bolls. The temperature sensitivity of ethephon provides Western producers with an additional incentive to manage for early maturity, to increase the likelihood that the activity of ethephon will benefit from warm weather conditions.

Harvest of the Far West crop is performed with spindle-type harvesters, and seed cotton is stored in modules; therefore, timely defoliation plays an important pre-harvest role in assuring lint quality. In California's San Joaquin Valley, harvest usually begins by early October. Normal weather patterns will allow for dry harvest conditions through mid-November. After mid-November the chances of harvest delays from rain and foggy conditions increase greatly. Moisture in seed cotton on the standing crop is increased by heavy dew or fog, reducing the number of effective harvest hours per day and increasing the risks of weather damage to exposed seed cotton and of moisture-related damage in modules. By contrast, the desert valleys of southern California and Arizona normally have an extended harvest period because of dry weather during the late fall months.

Cotton acreage in the San Joaquin Valley is required by law to be disked to fully incorporate the plant residue by late December. This practice is part of the mandatory planting and crop destruction dates established to maintain a 90-day host-free period for pink bollworm control. Early termination of the southern California and Arizona acreage also has shown benefits from reduced insect pressure the following season. Therefore, timely pre-harvest preparation will continue to be a management practice that ensures both quality of the harvested crop and benefits of lower pest pressure, while providing management options in preparing for the next season's crops.

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