Harvest Aid Materials and Practices for California Cotton

A Study Guide for Agricultural Consultants and Pest Control Advisers

REVISED EDITION

ROBERT B. HUTMACHER

RON N. VARGAS

STEVEN D. WRIGHT

BRUCE A. ROBERTS

UNIVERSITY OF CALIFORNIA • Agriculture and Natural Resources

Publication 4043 e

(Scan of Publication 4043. No content was updated from the 2003 printing.)

Harvest Aid Materials and Practices for California Cotton

A Study Guide for Agricultural Consultants and Pest Control Advisers

REVISED EDITION

ROBERT B. HUTMACHER
ASSOCIATE COOPERATIVE EXTENSION SPECIALIST, COTTON, UNIVERSITY OF CALIFORNIA SHAFTER RESEARCH AND EXTENSION CENTER, AND ASSOCIATE AGRONOMIST, DEPARTMENT OF AGRONOMY AND RANGE SCIENCE, UNIVERSITY OF CALIFORNIA, DAVIS

RON N. VARGAS
UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION FARM ADVISOR AND COUNTY DIRECTOR, MADERA COUNTY

STEVEN D. WRIGHT
UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION FARM ADVISOR, TULARE COUNTY

BRUCE A. ROBERTS
UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION FARM ADVISOR AND COUNTY DIRECTOR, KINGS COUNTY

UNIVERSITY OF CALIFORNIA • Agriculture and Natural Resources

Publication 4043e

(Scan of Publication 4043. No content was updated from the 2003 printing.)

WARNING ON THE USE OF CHEMICALS

Pesticides are poisonous. Always read and carefully follow all precautions and safety recommendations given on the container label. Store all chemicals in the original labeled containers in a locked cabinet or shed, away from food or feeds, and out of the reach of children, unauthorized persons, pets, and livestock.

Confine chemicals to the property being treated. Avoid drift onto neighboring properties, especially gardens containing fruits or vegetables ready to be picked.

Do not place containers containing pesticide in the trash nor pour pesticides down sink or toilet. Either use the pesticide according to the label or take unwanted pesticides to a Household Hazardous Waste Collection site. Contact your county agricultural commissioner for additional information on safe container disposal and for the location of the Hazardous Waste Collection site nearest you.

Dispose of empty containers by following label directions. Never reuse or burn the containers or dispose of them in such a manner that they may contaminate water supplies or natural waterways.

PRECAUTIONS FOR USING PESTICIDES

Pesticides are poisonous and must be used with caution. READ THE LABEL CAREFULLY BEFORE OPENING A PESTICIDE CONTAINER. Follow all label precautions and directions, including requirements for protective equipment. Use a pesticide only on crops specified on the label. Apply pesticides at the rates specified on the label or at lower rates if suggested in this publication. In California, all agricultural uses of pesticides must be reported. Contact your county agricultural commissioner for details. Laws, regulations, and information concerning pesticides change frequently, so be sure the publication you are using is up to date.

Legal Responsibility. The user is legally responsible for any damage due to misuse of pesticides. Responsibility extends to effects caused by drift, runoff, or residues.

Transportation. Do not ship or carry pesticides together with foods or feeds in a way that allows contamination of the edible items. Never transport pesticides in a closed passenger vehicle or in a closed cab.

Storage. Keep pesticides in original containers until used. Store them in a locked cabinet, building, or fenced area where they are not accessible to children, unauthorized persons, pets, or livestock. DO NOT store pesticides with foods, feeds, fertilizers, or other materials that may become contaminated by the pesticides.

Container Disposal. Dispose of empty containers carefully. Never reuse them. Make sure empty containers are not accessible to children or animals. Never dispose of containers where they may contaminate water supplies or natural waterways. Consult your county agricultural commissioner for correct procedures for handling and disposal of large quantities of empty containers.

Protection of Nonpest Animals and Plants. Many pesticides are toxic to useful or desirable animals, including honey bees, natural enemies, fish, domestic animals, and birds. Crops and other plants may also be damaged by misapplied pesticides. Take precautions to protect nonpest species from direct exposure to pesticides and from contamination due to drift, runoff, or residues. Certain rodenticides may pose a special hazard to animals that eat poisoned rodents.

Posting Treated Fields. For some materials, reentry intervals are established to protect field workers. Keep workers out of the field for the required time after application and, when required by regulations, post the treated areas with signs indicating the safe reentry date.

Harvest Intervals. Some materials or rates cannot be used in certain crops within a specific time before harvest. Follow pesticide label instructions and allow the required time between application and harvest.

Permit Requirements. Many pesticides require a permit from the county agricultural commissioner before possession or use. When such materials are recommended in this publication, they are marked with an asterisk (*).

Processed Crops. Some processors will not accept a crop treated with certain chemicals. If your crop is going to a processor, be sure to check with the processor before applying a pesticide.

Crop Injury. Certain chemicals may cause injury to crops (phytotoxicity) under certain conditions. Always consult the label for limitations. Before applying any pesticide, take into account the stage of plant development, the soil type and condition, the temperature, moisture, and wind direction. Injury may also result from the use of incompatible materials.

Personal Safety. Follow label directions carefully. Avoid splashing, spilling, leaks, spray drift, and contamination of clothing. NEVER eat, smoke, drink, or chew while using pesticides. Provide for emergency medical care IN ADVANCE as required by regulation.

PLANTS

PESTICIDE USE WARNING—READ THE LABEL

Pesticides are poisonous and must be used with caution. READ THE LABEL CAREFULLY BEFORE OPENING A CONTAINER. Precautions and directions MUST be followed exactly. Special protective equipment, as indicated on the label, must be used.

STORAGE. Keep all pesticides in original containers only. Store separately in a locked shed or area. Keep all pesticides out of the reach of children, unauthorized personnel, pets, and livestock. DO NOT STORE with foods, feeds, or fertilizers. Post warning signs on pesticide storage areas.

USE. The suggestions given in this publication are based upon best current information . Follow directions. Measure accurately to avoid residues exceeding established tolerances. Use exact amounts as indicated on the label, or use lesser amounts as suggested in this publication. Use a pesticide only on crops, plants, or animals shown on the label.

CONTAINER DISPOSAL and TRANSPORTATION. Consult your county agricultural commissioner for correct procedures for rinsing and disposing of empty containers. Do not transport pesticides in vehicles with foods, feeds, clothing, or other materials, and never in a closed cab with the vehicle driver.

RESPONSIBILITY. The grower is legally responsible for proper use of pesticides, including drift to other crops or properties, and for excessive residues. Pesticides should not be applied over streams, rivers, ponds, lakes, runoff irrigation, or other aquatic areas, except where specific use for that purpose is intended.

BENEFICIAL INSECTS. Many pesticides are highly toxic to honeybees and other beneficial insects. The farmer, the beekeeper, and the pest control industry should cooperate closely to keep losses of beneficial species to a minimum.

PROCESSED CROPS. Some processors will not accept a crop treated with certain chemicals. If your crop is going to a processor, be sure to check with the processor before making a pesticide application.

POSTING TREATED FIELDS. When worker safety re-entry intervals are established, be sure to keep workers out and post the treated areas with signs when required, indicating the safe re entry date.

PERMIT REQUIREMENTS. Many pesticides require a permit from the County agricultural commissioner before possession or use. When such compounds are recommended in this publication, they are marked with an asterisk (*)

PLANT INJURY. Certain chemicals may cause injury or give less than optimum pest control if used at the wrong stage of plant development, in certain soil types, when temperatures are too high or too low, when the wrong formulation is used, and when excessive rates or incompatible materials are used.

PERSONAL SAFETY. Follow label directions exactly. Avoid splashing, spilling, leaks, spray drift, or clothing contamination. DO NOT eat, smoke, drink, or chew while using pesticides. Provide for emergency medical care in advance.

For information about this and other publications, contact

University of California Agriculture and Natural Resources
Communication Services
1301 South 46th Street
Building 478 - MC 3580
Richmond, California 94604

Telephone 1-800-994-8849
E-mail: danrcs@ucdavis.edu
http://anrcatalog.ucdavis.edu

An electronic version of this publication is available on the ANR Communication Services Web site at http://anrcatalog.ucdavis.edu.

Publication 4043e

Previous printing 2003. Digitally re-issued 2010; no content was updated from the 2003 printing.

Contents

Foreword

This guide was prepared by personnel of the University of California Cooperative Extension (UCCE) as a source of review information for agricultural pest control advisers and others interested in reviewing information regarding harvest aid use in California cotton. It is not meant to be the only source of information on this topic, but rather a basic source of information on important considerations and topics for advisers to review. Due to the changing nature of crop production practices, dominant varieties, and available chemical materials, additional sources of information should be consulted to acquire and maintain an up-to-date knowledge of economical, safe, and effective harvest aid practices. Continuing education courses, crop production meetings, field experience, and additional reading materials are a necessary part of this education process.

This publication summarizes basic plant processes and responses that are important to leaf loss and harvest preparation; the impact of production practices on the efficacy of defoliants and desiccants; and basic guidelines for determining how best to use chemical materials to promote defoliation and desiccation. Data on factors influencing the efficacy of harvest aid treatments and their effect on the harvested crop are included in this discussion.

Acknowledgments

The authors acknowledge UCCE Farm Advisors Brian Marsh, Dan Munk, Doug Munier, Michael Rethwisch, and Herman Meister; UCCE Staff Research Associates Tomie Martin-Duvall and Mark Keeley; Principal Agricultural Technician Raul Delgado; UCCE Farm Advisor Emeritus Bill Weir; and Research Assistants Gerardo Banuelos and Joseph Padilla. The assistance of personnel of the UC West Side Research and Extension Center in conducting field research has been excellent and is appreciated. Encouragement in developing this guide and editorial assistance from Mary Louise Flint and Patricia Gouveia of the UC Integrated Pest Management Program was very helpful. Finally, we acknowledge the first edition of this study guide, which was entitled *Defoliation and other Harvest Aid Practices*, and its editors Kamal M. El-Zik and V. T. Walhood, for providing a basis for this revised edition.

Research work that evaluated the performance of harvest aid chemicals has been financially supported by the University of California; UCCE Madera County, Kings County, and Tulare County; University of California West Side Research and Extension Center; California Department of Pesticide Regulation; and California Crop Improvement Association. We also gratefully acknowledge the assistance of various chemical companies and their representatives for their advice and for making harvest aid materials available for field trials.

Harvest Aid Materials in California Cotton

Harvest aid chemicals are applied to cotton to increase the rate of leaf loss and desiccation, which allows timely initiation of harvesting operations. The primary goals of good harvest aid preparation are to

- stimulate boll opening and maturation (to the maximum degree possible with certain chemicals)
- facilitate more efficient mechanical harvesting at a time that corresponds to good weather conditions and the availability of harvest equipment
- achieve as close as possible to the maximum collection of harvestable crop
- preserve high fiber quality and provide maximum economic returns

There is an economic incentive in harvesting cotton crops as early as possible while avoiding yield or quality losses. In the typical weather in cotton production areas of California, there are more hours per day of favorable harvesting conditions during the generally warm, early days of the fall. Harvest aid materials are applied to cause leaves to shed earlier, more uniformly, and more completely than would otherwise occur under "normal" environmental conditions. A more timely and uniform defoliation with control of regrowth reduces trash levels and also reduces the incidence of staining problems in harvested cotton. Uniform defoliation and control of regrowth cut down on problems and delays with harvest, help avoid high moisture problems in the modules and in the gin, and preserve better fiber quality.

Of increasing importance to the cotton producer are potential impacts of crop termination and defoliation decisions on fiber quality. In light of the premiums and discounts for specific fiber quality parameters occurring with the introduction and wide acceptance of high volume instrumentation (HVI) testing, choosing the proper harvest aid chemicals and avoiding harvest-related problems can be of great importance in most production years. This is particularly true for Pima cotton, where difficulties with late-season termination, "sticking" leaves on plants, and staining and high module moisture content can be significantly more damaging to quality and price than in Upland cottons.

Determining what harvest aid chemicals to use and how much to spend on harvest preparation are not simple decisions, since factors such as late-season crop vigor, nitrogen status, and plant water status exert a large influence on success in cotton defoliation and harvest. Producers and consultants must determine the timing of applications of one or more harvest aid chemicals, which materials to apply, and at what rate. Weather conditions (principally air temperature) and crop growth stage and vigor have a large impact on the choice of harvest aid materials and application rates to assure good efficacy. The weather can also affect the relative utility of tank mixes and repeat applications, as can crop vigor and levels of water or nutrient stress. The maturity of the crop and desired schedule for harvest, based not only on weather but also on the availability of equipment, labor, and other field operations, also influence the timing of harvest aid applications.

Each year brings different environmental conditions, and each individual field may have vigor, variety, and maturity differences that impact the efficacy and cost of harvest aid materials as well as the choice of which materials and practices to use. The tradeoff between cutting costs and maintaining good quality is especially difficult at defoliation time, when much of the crop budget has been spent and there is a temptation to hold back on further expenses. Proper preparation of the crop, however, remains very important in achieving the best price for a good-quality crop.

In the cotton production cycle, defoliation and desiccation by application of harvest aid materials is the last operation in which management practices have a significant impact on profit. These final harvest aid management decisions include timing of applications; which harvest aid materials to use; consideration of the effects of crop vigor, boll load and distribution, and water and nutrient status on "readiness" and efficacy of harvest aids; and the likely impacts of weather conditions prevailing at and after the time of applications. These factors together strongly influence overall harvest efficiency, fiber quality, and lint value. High production costs and limited profit potential in cotton production dictate that growers do everything possible to properly prepare the crop for effective, reduced-cost defoliation that still protects lint quality and price.

ADVANTAGES OF USING HARVEST AIDS

Properly used, harvest aids:

- prepare crops for harvest in a more predictable, timely manner
- help straighten lodged plants for better drying and picking
- reduce the number of high-moisture-content green leaves, which otherwise would lower fiber grade
- can stimulate and enhance boll opening and increase yield and quality
- can reduce leaf trash and other impurities at harvest and in the gin
- improve the uniformity of boll opening and maturity required for mechanical harvest
- reduce the chances of fiber damage due to high water content in modules of harvested cotton
- reduce lint losses associated with excessive need for cleaners during ginning when cotton has higher trash content
- promote a more uniform preparation and condition of cotton that can improve the speed of ginning
- improve efficiency in use of labor and equipment for harvest
- allow harvest during more favorable weather conditions
- reduce the amount of time lint is exposed to late-season insect pests, under certain conditions
- allow more time to prepare the ground and equipment for the subsequent crop

Cotton Growth Patterns

WHY USE HARVEST AIDS?

If growers did not intervene to force an annual production cycle, cotton grown in relatively mild climates like California would likely be a perennial plant with a life span of several years or more. Winter temperatures in the San Joaquin Valley and even the Sacramento Valley are generally not cold enough to kill all parts of the plants if plants were left intact in the field. The taproot and lower stem would usually survive a mild freeze and start up new vegetative growth when temperatures moderated. Annual production cycles are more conducive to large-scale cotton production because of enhanced ability to control the timing and duration of fruit (boll) production; improved opportunities for mechanical harvesting; more-uniform fiber quality with a narrower fruiting period; and fewer problems with overwintering insect pests that can occur if plants are left in the field.

In an annual production system in California, it is difficult to depend on declining air temperatures or a freeze to initiate cotton defoliation, since the timing of weather changes is uncertain. In order to harvest large areas, make efficient use of equipment and labor, and avoid fiber and seed quality damage associated with exposure to rain and very cold weather, growers have adopted chemical harvest aids to improve control of the timing and degree of leaf loss. Harvest aid chemicals are seldom, if ever, applied at rates that kill cotton plants; in fact, most plants show regrowth of leaves several weeks or more after chemical applications. Harvest aids are applied to improve control of leaf loss and drying.

Without chemical harvest aid applications, in the late summer and early fall cotton begins to shed many leaves in the natural process of aging (senescence) as the crop matures, irrigations are terminated, and air temperatures cool. Leaves fall off (senesce) in response to changes in hormone levels (which are influenced by many factors); physical damage associated with aging; and status of nutrients and other chemical constituents. Some leaf loss can also occur in response to environmental stress (heat, pollution, cold, or nutrient deficiency) or biotic stress (disease or insect or mite damage). Unless weather conditions are very cold, however, the basically indeterminate growth habit of cotton means that as long as some water and nutrients remain available, the plants will put out at least some new leaves to replace those lost, resulting in a continuing production of new green leaves that interfere with harvest operations.

IMPACTS OF COTTON GROWTH HABIT AND CULTURE ON NEED FOR HARVEST AIDS

Cotton as grown in California production fields is an annual crop planted in the spring and harvested in the fall. After planting, seed germination through seedling emergence generally takes 5 to 14 days, depending on soil temperature and water status. The growing period required for cotton is fairly long, with a minimum of about 150 days from emergence to harvest for shorter-season Upland cotton varieties and a maximum of over 200 days for some longer-season Acala and Pima varieties. Most cotton varieties grown commercially have one dominant vegetative stem, which produces buds from which leaves, fruiting branches, and other vegetative branches are formed. The extent and duration of vegetative growth, the number and extension of fruiting branch development, and the tendency to produce secondary vegetative branches are influenced by varietal genetics, environmental conditions (temperature, day length, pest and disease pressure), and management practices that impact pest damage as well as nutrient and water availability.

During early vegetative growth, the cotton plant develops two cotyledons and 5 to 8 main stem nodes with leaves that develop and expand in size during this largely vegetative growth stage (see Fig. 1). Additional growing points (auxiliary buds) are present where each main stem leaf attaches to the stem, and additional fruiting and vegetative branches can occur at these sites if conditions are favorable. Some of these buds can differentiate to produce fruiting branches, and development of the first fruiting branch in commercial cotton varieties typically takes place at about the 5th to 8th node above the cotyledons. If good growing conditions persist, most nodes above that first fruiting branch can also produce fruiting branches.

Flowers on cotton plants are formed from buds that can develop in many positions on the plant, including main stem nodes, fruiting branches, and vegetative branches; however, most of the yield is produced on fruiting branches. If flower buds are retained and blooms are successfully pollinated, the fruit are made up of multiple seed contained within 4 or 5 compartments called "locules" or "locks" within the carpel wall, or boll. The fiber that is the primary product of interest in cotton production forms as specialized cells on the surface of the developing seed. Several fiber properties can be influenced by late-season management practices such as irrigation, nutrient status and fertilization, and harvest aid applications. Fiber length is largely determined within the first 20 to 24 days after pollination and can be affected by severe stress from lack of water or from high temperatures, but it is relatively insensitive to other environmental conditions (Mauney and Stewart 1986). Fiber length is usually not affected by harvest aid decisions. Fiber strength is determined over a longer time period, ranging from about 40 to over 55 days, and it can also be affected by severe environmental stresses as well as carbohydrate and nutrient limitations, especially lack of nitrogen or potassium (Hake, Hake, and Kerby 1996; Mauney and Stewart 1986). Fiber strength and fiber micronaire (a measure of fineness and maturity) in late-season bolls can be strongly influenced by late-season irrigation management and harvest aid decisions, and strength and micronaire measurements outside acceptable ranges can result in price reductions. For more information on the impact on micronaire of harvest aid timing decisions and other practices see Kerby and Bassett 1993; see also the section "Timing of Harvest Aid Applications" in this study guide.

Variety, plant density and shading, and pest damage to developing flower buds or fruit are just some of the factors that can influence which flower buds are retained and successfully produce mature fruit. Flower buds at all stages of development are referred to as

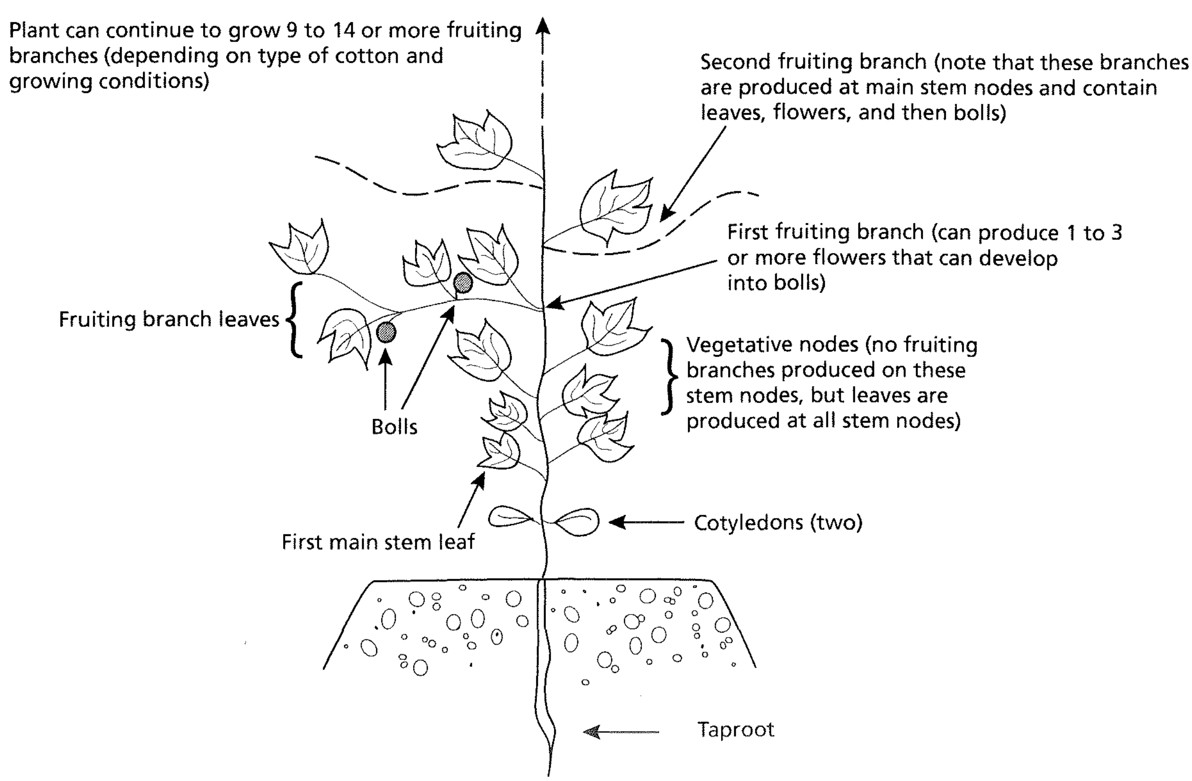


Figure 1. Generalized growth pattern and primary vegetative and reproductive parts of the cotton plant.

"squares," while the developing fruit (including the seed, developing fiber, and walls of the fruit) are called "bolls." The fiber and seed yields of the plant are impacted by many factors, including the duration of new growth, which is important in adding additional flowering/fruiting sites; the number of fruit retained despite losses associated with pest pressure; nutrition or carbohydrate limits; and the number of seed and fiber contained within each boll, which can be expressed as differences in boll size.

Since the cotton plant is grown for the reproductive part of the plant (fiber and seed), the relative balance between vegetative and reproductive growth is important in producing good yields on a plant of manageable size. Environmental conditions or any cultural practices that promote excess vegetative growth instead of reproductive growth and fruit retention can lead to plants that are more difficult and more costly to defoliate and prepare for harvest. Growth cannot be properly described as characterized by strictly defined vegetative and reproductive growth stages, as commercial cotton varieties have an indeterminate growth habit that can produce new vegetative and reproductive structures simultaneously as long as favorable growing conditions allow. The interaction between developing reproductive structures (bolls) and new vegetative structures (stems and leaves) and roots is complicated, but some generalizations can be made:

- Developing bolls (fruit) have a large need for carbohydrates and nutrients to complete development, and once plants are in a more reproductive growth pattern, bolls are effective competitors for these materials when compared with vegetative structures and roots.
- If fruit retention is moderate to high, the fruit outcompete the vegetative structures for nutrients and carbohydrates, and vegetative growth usually slows.
- If early- to mid-season fruit retention is low, there is less competition for carbohydrates and nutrients, typically promoting more vegetative growth and development of later-developing fruiting sites with a delay in fruit production and maturity.
- Management practices such as high nitrogen, excessive or too frequent irrigations, and very high planting densities can promote greater vegetative growth, reduce early fruit set, and delay fruit set and maturity, producing later harvests.
- Higher fruit losses can occur with conditions such as temporary anaerobic conditions after rains or irrigation, prolonged high air temperatures, or insect damage from lygus or other pests. Particularly if this occurs in the early season or midseason, significant fruit loss can result in more vigorous vegetative growth and later maturity.

Leaf Loss and Desiccation

Leaf loss, or leaf abscission, is a normal concluding process in the development of a cotton leaf, with the leaf dropping off the plant after formation of an abscission layer in the petiole. As a crop with subtropical to warm temperate zone origins, most growth does not occur at temperatures less than 60°F (15.5°C), and the most rapid vegetative development occurs when daytime peak temperatures exceed 80° to 90°F (26.5° to 30°C). Cotton leaves rapidly initiate and expand during these warm weather conditions. New leaves attain functional maturity in about 7 to 10 days and expand to maximum area within about 18 to 21 days after rapid expansion begins. Many new leaves can be formed at growing points on the main stem, vegetative branches, and sympodial (fruiting) branches.

As weather begins to cool markedly, with days lower than 80°F (26.5°C) and nights lower than 55°F (12.8°C), and as shorter photoperiod conditions develop in the fall in cotton production areas such as the San Joaquin Valley, cotton growth is severely decreased. Temperatures at or below freezing can damage leaf and stem tissue extensively, causing leaf loss within a relatively short time following freezing conditions of at least several hours' duration. Unless temperatures reach 20°F (–6.5°C) or lower, however, stem tissue and many of the growing points will not be severely damaged, and regrowth (growth of new leaves) can often be seen within a week or more after the freeze. Freezing conditions in the fall in California are not reliable enough in timing or severity to defoliate cotton, so it is essential to use harvest aid chemicals to ensure better timing and efficacy in preparing the crop for harvest.

The progression and rate of cotton plant development from early vegetative development, through initiation of flowering, to the maturation of seed and fiber is a complex interaction of metabolic processes. These processes are controlled or influenced by the variety's genetic "programming" and the complex interactive effects of various environmental conditions including light levels, nutrients, temperature, water availability, pollution levels, and applied chemicals. For definitions of terms used in this discussion of the final stages leading up to loss of leaf tissue, see the glossary at the back of this publication.

Research investigations over many years and on many species of plants have clarified many of the biochemical and metabolic changes that occur with progressive deterioration of plant parts with senescence, and how some of these processes are affected by the use of chemical harvest aids. Only general details of the processes will be described in this section. Interested readers can refer to excellent additional explanations listed in the references. Although many theories offer explanations of how specific environmental conditions and physiological interactions influence leaf senescence and abscission, some broad generalizations can be made regarding what occurs during senescence and abscission processes in plants such as cotton.

SENESCENCE

Most research has shown senescence of tissue to be a highly ordered sequence of processes, with certain types of metabolic changes and deterioration occurring before others, suggesting a genetically programmed sequence of events rather than a very rapid overall deterioration. To further complicate matters, it has also been shown that environmental stresses (pathogens, insect and mite pest damage, and stresses from deficient nutrients, water deficits, high or low temperature, or air pollution) can act as initiators of senescence, with considerable influence on the timing and growth stage at which senescence processes begin. A complex group of plant hormones are also involved in regulating plant morphology and the rate and timing of many growth and senescence processes.

General theories for the different phases of senescence have been elaborated in Nooden, Guiamet, and John 1997, and are described as

- an *initiation phase*, in which genetic influences on the timing of breakdown processes, combined environmental stresses, and other metabolic changes increase the levels of degradative enzymes and begin the functional problems in metabolic processes

- a *degeneration phase*, during which more major metabolic disruptions begin to occur
- a *senescence phase*, in which metabolic disruptions continue to become more severe and cell membrane integrity declines, eventually resulting in tissue death

The timing of leaf senescence tends to follow a pattern according to the growth habit and morphology of the plant. For example, plant species such as wheat, barley, and corn grow as determinate annuals: they flower only during a brief period of several days to a week or slightly more, mature the developing seed, and undergo a very rapid senescence that may result in the entire plant dying. Other plants such as most cotton, grow as indeterminate perennials: senescence processes are progressive, and under moderate environmental conditions not all parts of the plant die at the same time. It is important to note that plant species differ greatly in the degree to which senescent leaves abscise from the plant. Small grains, such as wheat or barley, do not generally form abscission zones and drop leaves, even with applications of defoliant or hormones. Some common dicot crop species, such as tomatoes, also do not generally drop many leaves in patterns such as that seen in cotton.

There are two dominant theories (see Cothren, Gwathmey, and Ames 2001) for major sequences of occurrences leading to senescence, the *nutrient diversion theory* and the *hormonal theory*. The nutrient diversion theory is based largely on the idea that as plants such as cotton transition from largely vegetative growth to reproductive growth, the need of developing fruit for various nutrients draws heavily on plant reserves and may often exceed the nutrient uptake ability of the plants. During this same period, research has shown that root nutrient uptake generally declines in cotton due to reductions in new root development and a decline in the function of older roots. The theory is based in part on observations that late in fruit development, certain physiological changes are commonly observed to occur as senescence proceeds. These changes include:

- reductions in leaf chlorophyll and ribonucleic acids important in protein synthesis
- changes in concentrations of hormones such as auxin (reduced) and ethylene (increased)
- solubilization of complex carbohydrates and certain proteins involved in photosynthesis, and subsequent translocation of these simpler transport forms as well as some inorganic ions to developing fruit and younger leaves
- translocation of nutrients such as nitrogen (N), phosphorus (P) and potassium (K) preferentially to developing fruit and younger leaves instead of to roots and older leaves

The hormonal theories explaining senescence involve complex interactions of at least five different classes of hormones (ethylene, abscisic acid, auxin, cytokinin, and gibberellin); and more-recent studies have also implicated additional classes of plant hormones. The general idea is that the balance of hormones at various stages of plant development become important, because some of these hormones influence processes promoting senescence, while others can inhibit senescence. The following is a very brief review of the potential role of the five major classes of hormones in senescence and abscission.

- **Abscisic acid (ABA).** Increases in abscisic acid concentrations occur during senescence and can be associated with changes in tissue chlorophyll content and other cellular constituents.
- **Auxin.** The concentration of auxin in leaf tissue decreases gradually from high levels in younger leaf tissue to much lower levels in senescing leaves. In younger leaves, high auxin levels are thought to inhibit ethylene synthesis, while in leaves far along in the senescence process, auxin may actually help induce additional ethylene synthesis.
- **Cytokinin.** Cytokinins have been implicated in delaying senescence through impacts on the promotion of nutrient mobilization and may positively influence sink strength for photoassimilate movement.
- **Ethylene.** Increases in tissue ethylene synthesis and concentrations have been shown to be associated with progressive degradation of ribonucleic acids and chlorophyll, and of the solubilization of some leaf proteins, all of which are factors that reduce the long-term viability of plant tissues. Ethylene has also been implicated as involved in promoting senescence through impacts on activation of specific enzymes.
- **Gibberellin.** As with auxin and cytokinin, there is evidence that higher gibberellin concentrations are associated with a delay in senescence.

A concept that in some ways bridges both theories suggests that the reduced flow of photosynthetically produced products to the roots is involved in the timing of senescence processes, since it leads to reduced root nutrient levels and reduced transport of the hormone cytokinin to the shoot (Cothren, Gwathmey, and Ames 2001). Cytokinin transport to the shoot has been shown to delay senescence. Evidence of direct impacts of specific leaf hormone levels on senescence and abscission comes from studies in which foliar applications of hormones such as auxin or cytokinin have significantly delayed senescence in treated leaves. However, experimental evidence also exists for an interactive involvement of multiple classes of hormones, so it is likely that in most plants, multiple hormones exert influence on the rate and timing of progression toward senescence. The specific responses to plant hormones can be impacted both by the concentration and form of each specific hormone as well as by the relative concentrations of different hormones in plant tissue. The interested reader is referred to Cothren, Gwathmey, and Ames (2001) for more detailed information and additional references.

ABSCISSION

Senescence processes lead up to the physical separation of leaves from the plant, or leaf abscission. Morgan 1984 offers a general model for the hormonal control theory of the involvement of hormones in leaf abscission processes. Three phases mentioned by Morgan include: a leaf maintenance phase, a shedding induction phase, and a leaf shedding phase. During the leaf maintenance phase, high levels of the hormone auxin are synthesized in the leaf, and this hormone as well as others are involved in holding down production of hydrolytic enzymes that are involved in abscission. In the leaf shed induction phase, concentrations and synthesis of the hormone ethylene increase and auxin concentrations decrease. Some of the reasons for reductions in auxin concentrations during this phase are the impacts of ethylene on auxin production and rate of breakdown. As stated previously in the discussion of senescence, additional hormonal factors and environmental factors are also thought to exert influences. The leaf shedding phase is characterized by increases in ethylene synthesis, concurrent reductions in auxin concentrations, chlorophyll degradation, and the formation of leaf abscission zones.

Near the end of leaf senescence in cotton, many metabolic and physical changes begin to occur in cells near the junction of the petiole and stem, leading up to the physical separation of the leaf petiole from the stem, or abscission. The site where the actual physical separation of the petiole from the stem will occur is called the abscission zone (Fig. 2). At such locations on the plant, there is an active synthesis of specific types of enzymes involved in breaking down structural cell wall components and some membranes (Cothren, Gwathmey, and Ames 2001; Walhood and Addicott 1968). The vascular (water and food-conducting) tissue between the stem and petiole remains functional through early periods of development of the abscission zone, continuing to allow water, nutrients, and carbohydrates to move between leaf and stem. At the abscission zone, hormones influence factors such as specialized cell division and cell structure to form a weakened area that can fracture at the time of leaf abscission, as well as a corky protective layer on the stem side of the scar (Walhood and Addicott 1968). In microscopic examinations, the abscission zone can be seen as a relatively narrow zone with cells that are smaller than those in surrounding tissue, with the abscission zone occurring as a narrow fracture where cell walls break down and a structurally weak area occurs where the petiole and leaf blade can separate from the main stem (see Fig. 2).

DESICCATION

The previous discussion of the general processes involved in leaf senescence and abscission stresses the fact that these are active metabolic processes that occur with demonstrated sequences of physiological processes. In contrast, the desiccation of plant tissues is basically a physical process in which the plants play a passive role. Chemicals with desiccant activity, such as those used as harvest aids in cotton, cause direct injuries, which disrupt cell membranes at or near the point of contact, and rapid water loss in cells. The action of most desiccants is rapid in terms of impacts at the point of contact, with adjacent tissues impacted somewhat later; remote tissues not in contact with the chemicals often remain largely unaffected except through indirect effects associated with damage to other tissues. The severity of injury due to applied desiccants is highly dependent on the type of chemical used, concentration, and degree of plant coverage, and it can also be affected by weather conditions (humidity and temperature). Although the activity of different chemical desiccants can differ, desiccants generally work best and most uniformly under warm, sunny, low- to moderate-humidity weather and work less uniformly in higher humidity or cool weather.

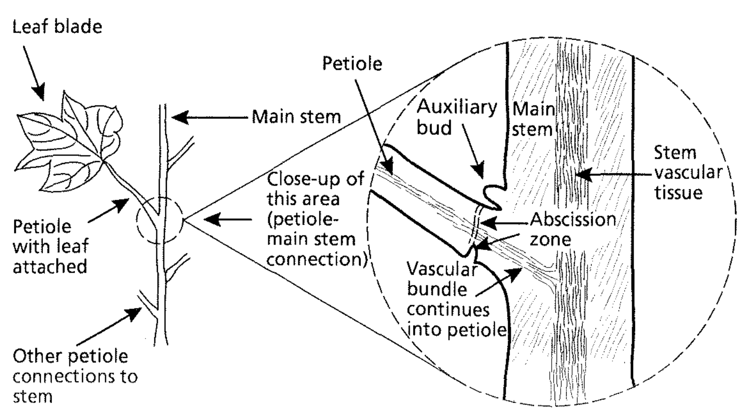


Figure 2. Connection of leaf petiole to stem, showing continuity of vascular tissue and relative location of abscission zone.

Cotton Fiber and Seed Development

Several early developmental stages in cotton initiate the seed and fiber production that are the final products of interest to growers. Initiation of fiber cells begins 3 to 5 days or more prior to the time an open flower is seen, and initiation can continue during several periods for 10 days or more after open bloom. Rapid boll growth begins with pollination of the flower, and nearly final boll diameter is reached within 20 to 25 days. In addition, during the first 18 to 25 days the developing seed within the boll reaches maximum size. However, seed protein and oil synthesis do not dramatically increase until after the embryo is well developed, starting about 20 to 25 days after the flower blooms. Any severe stress during this period can reduce seed quality. During this first 20 to 25 days, maximum fiber length is also reached (Fig. 3). During elongation, fiber cells elongate rapidly to lay down a primary wall that is about 30% cellulose and fairly flexible. Secondary wall deposition starts about 15 days after bloom. For more information on these stages, see Mauney and Stewart 1986 and Walhood and Addicott 1968.

Fiber strength, another important fiber quality characteristic, is related to the length of cellulose molecules deposited in winding secondary sheets around the inside of the primary wall of the fiber. The secondary fiber walls are very high in cellulose content. Most cellulose deposition that determines fiber strength occurs within 35 to 45 days after bloom, but if environmental conditions are suitable and nutrients and photosynthate available, it can continue much longer, up until the embryo matures and bolls prepare to open (see Fig. 3) (Mauney and Stewart 1986). In general, warm weather is favorable for continued cellulose deposition, while cool weather slows it (Mauney and Stewart 1986). Fibers in bolls that fill and mature during cool weather (poor weather or late in the season) will therefore generally be lower in fiber micronaire, maturity, and strength. Similarly, early defoliation and boll opening can shorten the period of secondary wall deposition and also lead to reductions in these same fiber characteristics.

Fiber properties can also be influenced by late-season management practices leading up to harvest aid application, including irrigation management and late-season nutrient status. Fiber length is largely determined within the first 20 to 25 days after pollination, and it can be reduced by severe lack of water or from high temperature stress during boll maturation. In general, however, fiber length is relatively insensitive to other environmental conditions (Mauney and Stewart 1986) and is usually impacted little by harvest aid applications. Fiber strength is determined over a longer time period, ranging from about 40 to over 55 days after bloom, and it can also be affected by more-severe environmental stresses as well as carbohydrate and nutrient (N and K) limitations (Hake, Hake, and Kerby, 1996); Mauney and Stewart 1986). Fiber strength in late-season bolls can be strongly influenced by late-season irrigation practices that produce moderate to severe water stress, and by harvest aid applica-

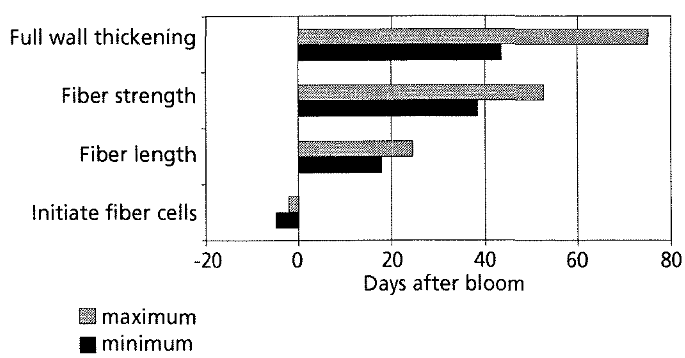


Figure 3. General duration from open bloom required to attain near-maximum development of fiber characteristics such as fiber length, fiber strength, and secondary wall thickening and fiber maturity. Values shown are general ranges that can occur with differences in boll position and time of boll production. *Source:* After Mauney and Stewart 1986; Walhood and Addicott 1968.

tions at rates that are too high or too early for the stage of development of late-season bolls.

Fiber micronaire can also be influenced by the timing of harvest aid applications. Fiber micronaire levels lower or higher than acceptable ranges set by industry marketers and end users of the lint can result in significant price reductions, so any significant impacts due to harvest aid management should be avoided. Reductions in fiber micronaire can result from harvest aid applications that are made too early, before fibers in late-season bolls have a chance to mature. Conversely, particularly in the low desert regions of California and Arizona, applications of harvest aids later in the season allow a longer period for continued cellulose deposition in existing bolls. This can increase fiber micronaire to levels that can yield discounted prices. Impacts of harvest aid timing decisions and other practices on micronaire are discussed in detail in Kerby and Bassett 1993 and briefly in the section on "Timing of Harvest Aid Applications" in this study guide.

Developing bolls attain full size or volume generally within about 20 to 25 days after bloom, but it is important to note that full boll volume does not equate to full fiber maturity, nor does it equate to the amount of time it takes to mature and crack open a mature boll for harvest. More time is needed to finish fiber and embryo development, mature, and open the bolls. The development and maturation of the fiber is highly responsive to temperature. Daily heat unit accumulation above a specific temperature (such as 60°F, or 15.5°C, for cotton) can be expressed as degree days calculated from a base temperature of 60°F, referred to as "DD60." In cotton, degree days have been shown to be a good relative indicator of how long it will take the crop to reach certain morphological and developmental stages. University studies in California have shown that the number of heat units to take a cotton boll from open bloom to cracked open boll averages about 750 to 825 DD60 for late-season Acala varieties and 800 to 900 DD60 for late Pima bolls (Hake, Kerby, and Hake 1996). If the weather is unusually warm, this number of heat units can be accumulated in as little as 45 days in the San Joaquin Valley in late summer or early fall, but when it is cool, may take more than 70 days (Hutmacher 2002).

Table 1 uses long-term average temperature data from sites in Kern County in the southern San Joaquin Valley to demonstrate how long it would take, under average conditions, for cotton blooms occurring on different dates in August to accumulate the 750 DD60 needed to mature and open a boll (Hutmacher 2002). Growers should use caution when assuming that they will be able to fully mature very late bolls without increasing exposure to wet weather conditions and poor conditions for defoliation and harvest. Techniques available to make decisions on the timing of harvest aid applications while avoiding reductions in fiber quality and yields are reviewed in the next section.

Table 1. Estimated periods during which a total of 750 heat units (DD60°F) would be accumulated starting with four different bloom dates. The minimum number of heat units required from open flower (bloom) to mature and open Acala cotton bolls is 750 DD60. The heat unit data set used was long-term average weather data from Shafter (Kern County), California, from 1974 through 2000.

	Heat units (DD60) accumulated during time periods, based on bloom date							Approximate date when 750 DD60 would accumulate (boll should crack open)
Date of bloom	**8/01–8/15**	**8/16–8/31**	**9/01–9/15**	**9/16–9/30**	**10/01–10/15**	**10/16–10/31**	**11/01–11/15**	
8/01	281	262	228	79	—	—	—	9/22
8/08	150	262	228	175	33	—	—	10/06
8/16	—	262	228	175	122	62	—	10/25
8/23	—	147	228	175	122	90	34	11/09

Source: Hutmacher 2002.

Timing of Harvest Aid Applications

TARGET DATES FOR HARVEST

Harvest operations can start when an acceptable percentage of bolls are mature and open (when fiber and seed are mature) and after effective defoliation is achieved. Weather considerations during harvest operations are important with cotton, particularly if dew, fog, or rain are combined with cool weather and poor drying conditions. These conditions can not only delay and slow harvest operations but can also lead to weathering of cotton fiber, high moisture conditions in modules, and other quality problems that can lower the grade and value of the product. For this reason, target dates for harvest are a primary decision that must be made by growers and managers. To make those decisions, growers must balance desires to achieve good crop maturity for optimal yields and quality against harvest equipment and labor availability; the number of hours per day with conditions likely to be favorable for picking; the need to get cotton into modules at acceptable moisture content; and the consequences of delayed harvests in reducing cotton yields and quality as well as in creating problems in preparing the ground for the subsequent crops. An additional consideration for harvest timing under current regulations is that California law requires that roots be dislodged or undercut from the plant stem and plant residues shredded and incorporated by specific dates in cotton growing areas. For example, in the San Joaquin Valley production area, residue incorporation has to be completed by mid to late December as part of the overwintering control measures for the pink bollworm.

Growers managing a large acreage of cotton with limited harvest crews and equipment should avoid applying harvest aids too far in advance of when they can actually get to the fields for harvest. Applications made too far in advance of harvest can leave fields with longer exposure time to insect and weathering problems that could reduce fiber quality. Additional time between harvest aid applications and harvest can also allow enough time for regrowth to become a problem, requiring additional spray applications.

In order to work toward a target harvest date, various management strategies are used during the growing season to produce a high percentage of mature, open bolls. Aiming for acceptable harvest dates begins with choice of variety. It continues with management decisions made during much of the season, including planting dates, protection of early- and mid-season fruit where possible, use of plant growth regulators as needed, timely termination of irrigation, depletion of upper soil nitrogen by late in the season, and good harvest aid decisions. Field conditions such as excessive vegetative growth, plant lodging, high soil water status, and the presence of significant weed populations will make defoliation and regrowth control more difficult, delay and slow harvest operations, and likely increase the amount of cotton left in the field after harvest.

Typical weather patterns and crop management for San Joaquin Valley cotton usually allow harvest to begin in late September or early October, with dry harvest conditions often available through about mid-November. After mid-November, rainfall probability increases significantly in the San Joaquin Valley, often leading to harvest delays and fiber quality concerns. As cool, wet weather sets in, many harvest aid materials decline in efficacy for defoliation and desiccation. In general, these same weather patterns and harvest constraints are seen in the Sacramento Valley production areas, but these northern locations generally have a significantly higher probability of rainfall in damaging amounts during November and December than in the San Joaquin Valley. The desert valleys of southern California normally have a more extended harvest period available, with lower probability of rainfall or fog during the winter months. In the southern desert valleys, harvests typically start earlier and continue later than in the Central Valley.

TECHNIQUES TO USE IN MAKING HARVEST AID TIMING DECISIONS

Decisions on the timing of harvest aid applications represent a balance between avoiding quality loss in the earlier-maturing bolls and the continued development, weight gain, and maturation of later bolls. Avoiding yield losses as well as quality reductions are both valid goals in properly timing harvest aid applications. If applications are too early, boll development can be halted early in late-season bolls, increasing the percentage of immature fibers, which sometimes exacerbates micronaire problems and worsens fiber quality. If applied too late, harvest can be delayed until weather conditions can harm yield and quality through weathering impacts on fibers and the increased chances of high moisture content at harvest. There are three main techniques available to assist the grower or adviser in determining when to apply harvest aids and still retain good quality and near-maximum yields: the percent of open boll and assessment of mature bolls technique, the sharp knife technique, and the nodes above cracked boll (NACB) technique. These approaches help decide when to apply harvest aids, but do not provide information to help decide harvest aid application rates.

For each of these techniques for assessing readiness for harvest aid applications, it is essential to understand the sequence of boll development and opening and acquire some "tools" that allow assessment of boll maturity. Since environmental conditions and plant maturity influence readiness for harvest aid applications, these techniques will help identify which bolls are already mature and which of the later-developing bolls on the plants are likely to have adequate heat units to reach maturity.

The sequence of boll maturity and opening follows the same basic pattern as flowering. During the primary flowering and fruit set period, there is a 3- to 4-day interval between flowering dates for first-position bolls along the main stem. If heat units available for boll development are constant from the time of flowering for each position, that same 3- to 5-day interval would exist between opening of successive first-position bolls up the plant. In the late season, however, this interval between opening of successive first-position bolls can extend to 5 or even 6 days as environmental conditions change and as the plant ages and matures. However, the basic sequence of opening remains useful to consider in terms of the likelihood of boll maturation at different positions on the plant.

Not all green bolls have the right conditions and adequate time to mature and open prior to harvest aid applications, so it is useful to be able to assess boll maturity and the amount of heat units required to finish out and open mature bolls. Mature harvestable bolls have the following general characteristics:

- They are difficult to slice open with a sharp knife.
- It is difficult to dent or depress the boll wall with your fingers when pressing on it.
- Seed coats range from yellowish to tan, or even dark tan, (no seeds have white seed coats).
- When the boll is cut open, lint can begin to string out rather than feeling wet.
- The gelatinous material around seeds is mostly or completely gone.

Because a mature green boll is very difficult to cut in half (across the "suture" lines of the boll wall), attempts at cutting bolls can be used as an estimate of boll maturity. This requires cutting bolls of different ages and from positions on the plant to gain a field average, assessing primarily the uppermost bolls likely to mature and open.

Percent open bolls and assessment of mature bolls

This technique has been in use for many years across the U.S. cotton belt:

- Harvest aids are applied when 90 to 95 percent of the green bolls are mature, as defined above.
- Defoliants are applied when 60 to 65 percent of the expected harvestable bolls are open.
- Desiccants are applied when 80 to 85 percent of the expected harvestable bolls are open.

There are certain disadvantages to the use of this approach under some conditions. Two situations in which results obtained using the percent open boll method can be unclear include: (1) a crop set over an extremely long time period, versus (2) a crop set in a compressed boll-setting period. With the crop set over a long period, it would be possible to have a poor set of mid-canopy bolls, with bolls split between early-season and late-season bolls. In this case, it could be too early to defoliate even with 60 percent open bolls, since a significant part of the crop is in late-maturing bolls. In a crop with a compressed boll-setting period, if bolls set early, on most successive fruiting branches, and with a relatively early vegetative cutout, it could be safe to defoliate at much less than 60 percent open boll. In these situations, other evaluation techniques are more useful.

Sharp knife technique

In this technique, seed and lint development and appearance are evaluated to assess maturity. This technique is called the "sharp knife" method by many people since it requires cutting bolls that are expected to be mature in half (perpendicular to the carpel wall suture lines) with a sharp knife. The technique evaluates the ability to cut through the lint, as well as seed maturity. More mature fibers can be more easily cut with a sharp knife. This characteristic can be used as an index of boll maturity, but it can be fairly imprecise since knives differ in sharpness, and sharpness is at best a relative term that is difficult to quantify. Inspection of the seed for maturity can be done more consistently once the bolls are cut in half, and this can be done without removing the seed from the boll. Mature bolls have the following characteristics:

- Bolls will be hard to slice open across the sutures of the carpel walls.
- Developing fiber will not appear "wet," and there will be no appearance of "free water" or "jellylike" material around seeds.

If fiber is pulled away from seeds, seed coat color will be yellow to tan, not white. Immature bolls have the following characteristics:

- Developing fiber will appear wet, giving appearance of free water in the boll.
- Jellylike quality will develop in the material around seed in the boll.
- Seed coat will be still white instead of tan or brown.
- Cotyledons will be white instead of green.

Nodes above cracked boll (NACB)

This technique was developed during the late 1980s and early 1990s to provide very specific types of plant mapping data. The technique is based on the premise that bolls will crack open and be ready for harvest in roughly the same sequence that flowers were produced on the plant (i.e., there will be a fairly regular progression in opening of bolls from the bottom of the plant toward the top). For example, when flowers bloom, the interval between flowers produced at the first fruiting position on one branch and the first position on the next fruiting branch ranges from about 3 days during early fruiting to as much as 5 days or more late in the fruiting cycle. The technique assumes that boll opening that exposes the developing lint will progress in roughly the same sequence up the plant. This general assumption is a fairly good one, although it is recognized that the amount of time required to open bolls is influenced by stresses (water, nutrients, insects) as well as by weather conditions (largely, temperature).

The NACB measurements can be a quick and reliable supplement to the other two techniques discussed above. It is particularly useful in determining the earliest fields that are mature enough to begin harvest aid applications. To use this technique, bear in mind that a boll is "cracked" when lint is first visible as the carpel wall of the boll starts to dry out and separate along a suture line, but the boll is not sufficiently fluffed out to be harvested completely by a spindle picker.

An efficient way to evaluate NACB is through a field sample based on the selection of five random plants from each of four representative areas of each field, for a total of 20 plants. Locate plants that have a cracked boll on a first fruiting position of a fruiting branch, find the uppermost (closest to the top of the plant) cracked first-position boll, and count this as fruiting branch zero. Count the number of nodes above fruiting branch zero until you reach the uppermost harvestable boll on the plant. A harvestable boll is one that is large enough and far enough along in development that it will open prior to the scheduled harvest date. Use any of the previously described methods to determine the most likely uppermost harvestable boll that can be matured by the planned harvest time.

In multiyear studies conducted in California, Texas, Oklahoma, and Mississippi, some general relationships were developed for Upland (including Acala) cotton between NACB at the first harvest aid application and resulting impacts on yield and on micronaire. The data in Figure 4 were developed using fields that produced 95 percent or more of their harvestable yield on an average of 12 fruiting branches, which is in the range for most current Acala varieties grown in the San Joaquin Valley. For all of these studies, an ethephon (Prep) and tribufos (Folex or Def) mixture was used as the first harvest aid application. It can be seen in Figures 4 and 5 that yield and micronaire loss can generally be kept to a minimum when 4 NACB is used as a target for the first harvest aid application in Upland/Acala varieties.

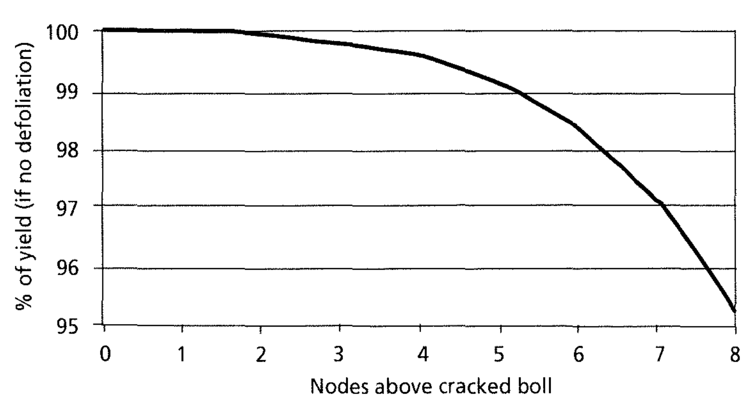


Figure 4. Estimated yield loss for defoliating at various nodes above cracked boll (NACB) for fields in which yield was produced on 12 fruiting branches. *Source:* Roberts et al. 1996; Kerby and Bassett 1993.

Using this approach, the recommended timing of first harvest aid applications is 4 nodes above cracked boll for Upland/Acala varieties. Similar research with Pima varieties in California has recommended the use of 3 NACB as a target for defoliant timing. If defoliant applications on Pima cotton are timed to match these NACB levels, research has similarly shown that there will be little impact on yield or micronaire.

The NACB technique provides better and more consistent information in fields that have uniform boll set than in fields with poor or irregular main stem fruit retention, or in fields with high percentages of fruit on vegetative branches. Since retained bolls are not always evenly distributed throughout cotton plants (due to pest impacts, water stress, or weather-related problems such as high-temperature stress), using NACB to time defoliation usually involves the following special considerations.

Under low plant population conditions, less than 1.5 to 2 plants per foot (5 to 6.5 per m) of row, or where many vegetative branches develop in response to early-season damage from poor weather or insects, alternative NACB targets may be warranted. A NACB of 3 (Acala) or 2 (Pima) may be a better target for harvest aid timing under these conditions, since both situations can result in a less-mature crop with more fruit set on later-maturing vegetative branches and outer fruiting branch positions.

Particularly when there are late-season boll losses due to a variety of causes, the last harvestable boll on the plant may not be in the first position on the fruiting branch. If, for instance, the last harvestable boll is in the second position from the stem on a fruiting branch, rather than first position, the proper way to account for this is to increase the NACB by 2. This is because the age difference between the first- and second-position bolls on the same fruiting branch is about equal to the age difference between two main stem nodes separating bolls in the first position. As a rough estimate of the time between the first harvest aid application and the last harvestable boll cracking open, assume that boll opening follows the same basic sequence and rate of opening as flower production. For example, if 4 NACB is the time of first harvest aid application under normal weather conditions, the top boll determined as a potential harvestable boll should open in 12 to 20 days (4 nodes in 3 to 5 days per node).

As discussed above, the data used to produce Figure 5 averaged about 11 to 12 fruiting branches to produce 95 percent or more of the harvestable yield. If the yield is produced on, for instance, 8 or 14 fruiting branches, there will be a different relative loss if the field is defoliated at 6 or 8 NACB than if only 11 or 12 fruiting branches produced all the yield. To roughly account for the effects of the number of fruiting branches containing 95 percent or more of the harvestable yield on predicted losses of yield and micronaire at different NACB, Kerby and Bassett (1993) developed a table to adjust the loss estimates using plant map data collected over many seasons in the San Joaquin Valley with Acala varieties (Table 2). Although data have not been collected to verify this, similar trends probably apply with Pima varieties.

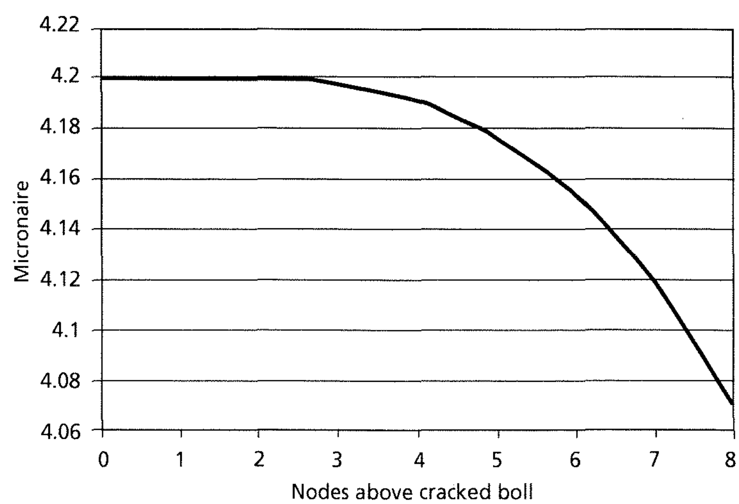


Figure 5. Estimated micronaire loss for defoliating at various nodes above cracked boll (NACB) for fields in which yield was produced on 12 fruiting branches. *Source:* Roberts et al. 1996; Kerby and Bassett 1993.

Timing decisions require judgment in addition to monitoring techniques

Estimates of plant maturity and targets to minimize impacts on yield and fiber quality are not the only criteria to consider in the timing of harvest aid decisions, particularly in years with a bad combination of conditions, such as a late crop and late-season rain. Particularly if the field has heavy soils that are inaccessible when wet, or if the area has a higher probability of rainfall, waiting for a target of 3 or even 6 NACB may put the crop at too much risk in terms of the ability to get in and harvest the crop if adverse weather conditions develop. In these conditions, keep a wary eye on the calendar and be prepared to make difficult judgments about the tradeoffs between yield and quality impacts of earlier-than-desired harvest aid applications and the different risks associated with a very late harvest.

Table 2. Estimated percent yield and micronaire decrease due to defoliation at various NACB, according to the number of fruiting branches for yield.

NACB at defoliation	Percent reduction in yield: Number of fruiting branches with 95% or more of total lint yield				NACB at defoliation	Percent reduction in fiber micronaire: Number of fruiting branches with 95% or more of total lint yield			
	8	10	12	14		8	10	12	14
4	0.6	0.2	0.1	0.1	4	0.7	0.6	0.5	0.3
5	1.3	0.9	0.8	0.6	5	1.9	1.4	1.2	0.9
6	2.8	2.1	1.7	1.2	6	3.8	2.8	2.3	1.7
7	5.3	3.8	3.1	2.3	7	6.5	4.7	3.8	2.8
8	8.9	6.5	5.2	3.9	8	10.2	7.4	5.9	4.3

Source: Kerby and Bassett 1993.

Harvest Aid Chemical Choices

TYPES OF HARVEST AID MATERIALS

The basic categories of chemicals used as harvest aids include boll openers/conditioners, boll openers/defoliants, true defoliants, desiccants, and enhancers. Chemical and trade names of harvest aid materials in each of these categories are shown in Table 3 and also in the appendix to this publication. Also, Adjuvant materials are commonly used to improve efficacy of some applied harvest aids. Commonly used defoliant materials available for California cotton include tribufos or butifos (Def/Folex), sodium chlorate (Defol 6), thidiazuron (Dropp), dimethipin (Harvade), and thidiazuron plus diuron (Ginstar). Commonly used desiccant materials in California cotton include paraquat (Gramoxone Max) and sodium chlorate (Defol-6, other trade names). There can be crossover in classification of certain materials based on the rates used and timing of application, with some defoliant materials having activity more like desiccants. For example, sodium chlorate applied at low rates can be considered a defoliant, promoting leaf drop. However, sodium chlorate applied at high rates can cause rapid desiccation of leaf tissue, with little activity in promoting senescence and leaf abscission.

Growers and advisers should consult chemical labels, other manufacturer information, and representatives of the agricultural commissioner's office in their county as necessary to be aware of information on plantback restrictions and any changes in registration status for any of these chemicals.

Table 3. Chemical names and common names of major types of harvest aid chemicals used on cotton in the United States.

Type of harvest aid	Chemical common name	Trade name
boll openers/conditioners	dimethipin	Lint Plus
	ethephon	Prep, others
boll openers/enhancers	ethephon plus AMADS (aminomethanamide dihydrogen tetraoxysulfate)	Cotton Quik
	ethephon plus cyclanilide	Finish-6 Pro
defoliants	carfentrazone[a]	Shark 40 DF[a]
	dimethipin	Harvade, Harvade 5F
	dimethipin and thidiazuron[a]	Leafless[a]
	sodium chlorate	Defol 6, others
	thidiazuron	Dropp
	thidiazuron plus diuron	Ginstar
	tribufos	Def, Folex
desiccants	paraquat	Gramoxone Max
	sodium chlorate	Defol 6, others
regrowth inhibitors/other chemical activities	endothall	Accelerate
	glyphosate	Roundup Ultra Max, others
Defoliants and desiccants, organic cotton[b]	magnesium chloride zinc sulfate	—
	zinc sulfate plus Chilean nitrate	
	zinc plus citric acid	

Note: [a]As of 2002, not registered for use in California cotton (registration pending).
[b]Mild to moderate activity; all registered for use in California cotton.

HORMONAL AND HERBICIDAL DEFOLIANTS, BOLL CONDITIONERS, AND OTHER HARVEST AIDS

Many harvest aid chemicals are categorized as having either hormonal or herbicidal activity. Defoliants such as thidiazuron (Dropp), thidiazuron plus diuron (Ginstar) and boll openers/enhancers such as ethephon in combination with chemicals such as cyclanilide (Finish) or AMADS (CottonQuik) are generally described as having hormonal activity since they increase ethylene synthesis and also increase activity of cell-wall-degrading enzymes in treated plants. Thidiazuron is a cytokinin-containing material that can promote ethylene synthesis when applied late in the season. Ethephon applications release ethylene, promoting additional ethylene synthesis and earlier formation of the abscission zone. Tribufos (Def/Folex) and dimethipin (Harvade) are examples of materials with herbicidal activity that act to injure plant tissue, causing ethylene production in response to the injury. Increased ethylene synthesis inhibits auxin formation and promotes development of the leaf abscission layer. If the applied rates of these materials are low enough, the injuries to treated leaves will be moderate, allowing adequate time for development of leaf abscission zones. If the application rates are too high, they may produce a more severe injury and act more as desiccants, causing the leaves to stick to the plants, since the leaves are killed before an abscission zone can be completely formed.

Harvest aids commonly classified as boll openers/conditioners (such as ethephon) are often recommended in combination with a range of defoliant materials to increase the percentage of open bolls in preparation for a once-over harvest. The apparent mode of action is that ethephon is absorbed by plant tissues, and ethylene production is increased, which supplements naturally produced ethylene, accelerating leaf abscission and increasing the rate of boll opening. Typical application rates of these chemicals are shown in the appendix. For cotton grown in the San Joaquin Valley, both Acala and Pima can have problems with late-season bolls due to inadequate heat units to open late bolls for a timely harvest. Some generalizations to consider in recommending boll openers/conditioners include:

- Conditioner materials tend to be widely used with late crops when the weather may be too cool to provide enough heat units to open late bolls.
- The relative proportion of the total crop at different boll maturities should be considered when considering the need for boll opener materials.
- These materials can increase the number of small bolls opened for harvest, so lint micronaire and fiber strength may be reduced if too much of the final crop is derived from late, immature bolls.
- The earliness of the crop, uniformity of boll distribution in the canopy, number of open bolls, and costs of a later second picking should be considered in deciding whether boll openers are economical.
- Ethephon used as a conditioner is recommended for application 5 to 10 days prior to first defoliant applications. Pretreatments in advance of the first defoliants have generally shown the best boll opening and defoliation results, but a common practice is to tank mix this material with the first defoliant application.

Some of the same generalizations above apply to materials grouped as boll openers/enhancers, or enhanced ethephons, (Finish and Cotton Quik). These are mixtures of ethephon with chemicals that improve the efficacy of ethephon. With proper application, these materials have been shown to improve boll opening (Finish, Cotton Quik), and improve regrowth suppression (Finish) when compared with ethephon applied alone. With California-grown Acala and Pima varieties, these materials are generally not effective as defoliants. Some of the best results have been obtained with a tank mix of these materials and defoliants to improve efficacy under cool conditions, on cotton that is too vigorous, or in weedy fields to desiccate weeds.

For tank mix applications of harvest aids, combining a lower rate of desiccant to provide enough, but not too much, leaf damage, with a defoliant material to promote leaf abscission can often give a better overall effect than either material alone. Product labels have in many cases been written to give adequate flexibility in application rates and allowable product mixture combinations to allow considerable leeway for suitable tank mixes in many different situations.

Products classified as regrowth inhibitors/other activities have a range of modes of action. Endothall (Accelerate) is a herbicide, and it is usually considered an additive material rather than a true desiccant or defoliant. It can be added to sodium chlorate or to organophosphate defoliants (Def, Folex) to increase the rate of early leaf drop, but when used alone it is not effective as a defoliant. Glyphosate (Roundup Ultra, others) has been used as a pretreatment applied 7 to 14 days prior to defoliation to improve boll opening and to control certain late-season weeds. If applied when close to 40 to 50 percent of bolls are open, data from cotton grown in the western United States indicates that it can also provide some regrowth control with little impact on yields or components of fiber quality such as strength or micronaire. However, glyphosate should not be applied to cotton grown for seed, as seed quality and germination will be negatively affected.

INFLUENCE OF CHEMICAL CHOICE AND APPLICATION RATE ON ACTIVITY AS A DEFOLIANT OR DESICCANT

The application of harvest aid chemicals that act as defoliants or desiccants generally produces an injury or "wounding" of tissue in the cotton plant. Leaf blades intercept a much larger total volume of applied harvest aid chemicals than the petioles or stems, and the visual damage seen on leaf blades generally reflects this greater relative level of exposure. Chemicals used as harvest aids are not classified as defoliants or desiccants based only on the type of chemical, but also by the application rate and resulting intensity and rapidity of impacts on plant tissue. The intensity of the injury produced with the chemical application will affect whether some chemicals are more effective under some conditions for leaf removal (defoliation) or for a quick kill and dehydration (desiccation).

Defoliants

To be effective, defoliants must result in significant injury to leaves but have little short-term impact on the petiole and the ability to form an abscission layer at the petiole-stem junction. If, by contrast, injury to the petiole and is severe enough to prevent the development of an abscission layer, the chemical may be ineffective as a defoliant and may cause retention of dead leaves on the plant. The goal with the use of most of these materials is to senesce the leaves, form an abscission layer, and still have enough leaf weight for the leaf to break the abscission layer and drop off the plant.

Different chemicals with potential defoliant activity can differ in the range and pattern of leaf injury and in the rate of response after applications. To make it even more complicated, the pattern and symptoms seen can also vary with the condition or vigor of the plant, with the concentration and rate of defoliant, and across different environmental conditions. For example, under high-humidity conditions and warm temperatures, some defoliants are more injurious to leaves than under cooler, drier conditions, resulting in injury that is more intense, approximating the impacts of a desiccant rather than a slower-acting defoliant. Similarly, higher application rates of some chemicals can produce much more injury than more moderate rates, again resulting in less-effective activity as a defoliant, with poor development of abscission zones, more leaves left on the plants, and more tissue damage and desiccation.

Desiccants

Desiccants tend to be materials that act as contact herbicides. These chemicals typically produce rapid, severe tissue injury that causes dehydration and death of the tissues exposed to the applied chemical. Generally, the action of chemicals classified as desiccants is so rapid and the injury so severe that the extended changes in hormone balance associated with formation of abscission zones do not begin to take place before tissues are killed. Plant injury is sudden and severe enough that leaves and immature bolls are killed and "frozen," or retained dry on the plant. The degree of injury produced with the application of a desiccant chemical may be proportional to the rate of desiccation, but this is not true for all chemical desiccants. As with defoliants, prevailing environmental conditions can affect the rate of desiccation. The most influential environmental factor is humidity, with lower relative humidity conditions leading to faster desiccation than observed under high-humidity conditions.

Desiccant materials work most effectively when defoliants have been previously used and most bolls have successfully opened. Effective desiccation of leaf and stem tissues with larger plants and denser foliar canopies may require the use of wetting agents and higher spray volumes. Efficacy of the basic desiccant materials is not as strongly influenced by temperature and humidity conditions at the time of application, but materials such as paraquat generally perform more uniformly and faster with warmer weather. Adequate time should be allowed between the desiccant applications and the beginning of harvest to avoid problems such as inadequate drying, staining from green leaf tissue, or increased bark. With high application rates of desiccant, harvest can generally be started within 7 to 10 days after application, while lower rates may require 14 to 20 days or more to achieve relatively good desiccation.

Use of adjuvants

The term "adjuvant" is a fairly imprecise term unless it is applied to specific materials, since the term can refer to any materials mixed with a chemical to influence the properties of the chemical or the solution. In general, adjuvant materials do not have any efficacy as harvest aids by themselves, but rather may enhance formulations to improve drift control, surface wetting, leaf penetration, or solubility. With certain chemicals, some water supplies, and some crop conditions, adjuvants can be very important to achieve desired activity with harvest aids. Adjuvants most often used with both herbicidal and hormonal activity harvest aids include surfactants, vegetable or petroleum-based oils, and crop oil concentrates. Adjuvants typically fall into categories that include:

- **Wetting agents or surfactants.** Wetting agents promote reductions in droplet size and improved contact of solutions with treated surfaces; surfactants tend to improve dispersal and spreading properties of liquids.
- **Thickeners or drift retardants.** These adjuvants act mostly to thicken or increase the viscosity of spray solutions, keeping droplet size larger and reducing drift losses and off-target movement. Some of these materials can also act to retard spray evaporation.
- **Crop oils.** Oils reduce the surface tension of water on treated surfaces and can also increase the penetration of spray solutions through plant cuticles, particularly on water-stressed plants.

In some cases, adjuvants can have a significant impact on the severity of the effect of harvest aid chemicals on plant tissues and the rate at which the damage is produced. This effect could be negative or positive, depending on the desire for slower-acting defoliant activity or faster-acting desiccant activity. Some adjuvants can increase the rate of desiccation, which risks killing leaves before an abscission layer can be developed, resulting in increased leaf sticking. Potential impacts on harvest aid product efficacy and rate of impact should be considered, and product labels and company representatives should be consulted in deciding when adjuvants can be beneficial and what precautions apply based on crop condition, the chemical used, and environmental conditions.

Application Methods

Since the types of chemicals represented by harvest aids cover a broad range of materials with different physical and chemical characteristics, it is difficult to define all of considerations for best application methods. However, some general considerations can be given that can help obtain optimal performance. For more detailed discussion of harvest aid application considerations, see Bader, Sumner, and Culpepper 2001.

IMPORTANCE OF PLANT COVERAGE

In general, harvest aid materials are not translocated in the plant, so the activity tends to be more of a localized contact injury. Only leaves, bolls, and petioles or stems in contact with the sprays are likely to be influenced within the short timeframe desired. Since many of the defoliants cause injury and stimulate ethylene production and other changes in plant hormone balance, it is not required that spray droplets completely cover the tissue. However, some chemical penetration through the canopy is required to allow at least minimal coverage to initiate leaf abscission processes. With defoliant materials, contact of these chemicals with part of a leaf, only the upper side of a leaf, or part of a boll is generally enough to cause sufficient injury and stimulate senescence or begin changes that will lead to the formation of abscission layers.

IMPACT OF APPLICATION METHOD ON PLANT COVERAGE

Harvest aid chemicals can be applied using aircraft or ground rig applicators. The optimal chemical coverage required with harvest aids depends on crop vigor and condition, along with the amount of leaf removal and desiccation desired. The choice of ground versus aerial application may be based on economics, equipment availability, ability to pass ground equipment through fields without undue damage to plants, and local restrictions on chemical use and application methods. In recent years, there have been increasing concerns in many areas regarding application techniques for drift control and restriction on allowable application methods and chemicals near residences and public buildings. In addition, there are some built-in advantages and disadvantages with each general application method; some of these factors will be mentioned here.

Ground application equipment can often achieve better control of plant canopy (leaf) coverage since drop sprays can be located directly within the plant canopy and to some extent can be directed to deal with individual canopy characteristics in specific fields. Ground application equipment can give better coverage when plants are large and have many layers of leaves that are difficult to penetrate. Unfortunately, these large plant canopies are often susceptible to damage from ground rig equipment since large plants are more prone to lodge or have tangled fruiting branches. Since good chemical activity depends in large part on effective penetration of chemicals through the canopy and good coverage, large, leafy plants or lodged plants represent a significant problem in using an effective sequence of harvest aid chemicals. The use of ground-based equipment with fenders, plant lifters, and spray boom drops can improve the effectiveness in distribution of harvest aids into canopies of large or even lodged plants, although travel speeds may be significantly reduced.

The plant coverage of applied chemicals is influenced primarily by the total volume (gallons) sprayed per acre, droplet size, and characteristics of spray solutions (surface tension, viscosity) as influenced by adjuvants. Over the years, many applicators indicate that the best coverage using ground application equipment can be obtained with moderate to large spray volumes, such as 8 to 30 gallons per acre (75 to 281 l/ha), with sprays applied at relatively low pressures of 30 pounds per square inch (2.1 kg/sq cm) or less used in combination with nozzles producing relatively large droplets. When plant canopies are dense and tall, and canopy penetration by chemicals is most difficult, use application volumes toward the upper end of the scale. Selected conditions that favor use of aerial applications over ground application equipment are given in Table 4.

Care must be exerted in how the applicator achieves higher application volumes. Spray volumes applied per acre can be increased via increases in pressure with existing nozzles or by changing nozzles and staying at a lower pressure. As a general recommendation, nozzle sizes should be selected so that desired spray volumes can be achieved at operating pressures within the optimal range for any type of nozzle used (optimal nozzle operating pressure varies greatly with the type of nozzle). Attempts to increase spray volumes by large increases in pressure beyond optimal ranges can produce undesirable results, since higher pressure can reduce droplet size, reduce spray penetration into dense plant canopies, increase drift, and lead to increased wear on pumps and spray equipment. Nozzle types recommended for different applications include cone-type for ground applications as well as a range of other types of specialized nozzles for specific aircraft based on desired droplet size, application speed, atmospheric conditions, and density of plant leaf canopies (see Bader, Sumner, and Culpepper 2001 for a detailed description of choices and considerations).

With aerial application equipment, the same factors influence plant coverage as with ground equipment, but even greater attention may need to be paid to increasing spray volume and droplet size. With aerial applications of harvest aids under conditions of moderately dense to dense plant canopies, special consideration may need to be given to avoiding use of adjuvants that reduce spray solution surface tension (wetting agents), as these reduce droplet size. Smaller droplet size may increase drift and reduce the penetration of chemicals to the lower canopy in such situations.

ENVIRONMENTAL CONDITIONS AND EQUIPMENT CHOICES AFFECTING SPRAY APPLICATIONS

Movement of applied harvest aid chemicals from target sites can occur as a result of several processes, including drift and volatilization. Droplet size can be highly variable with many types of aerial and ground spray equipment used for harvest aid applications. Higher pressures or use of nozzles that produce a high percentage of smaller droplets (50 to 100 micron diameter) can have a major influence on the likelihood of drift. As an indication of relative effect, the velocity at which 200-micron droplets fall is 10 times as fast as the fall velocity of 50-micron droplets (Bader, Sumner, and Culpepper 2001). With aerial applications, smaller droplets falling at much slower rates are subject to much more lateral drift, particularly when winds can move sprays far from the target area. Practices that improve control of drift and off-target movement of applied chemicals are important to consider not only to improve efficiency in chemical use but also to reduce potential damage to neighboring crops. This is particularly true in the highly diversified crop production in California.

Another reason to avoid very small droplet sizes is related to the impact of relative humidity on droplet size and penetration of sprays into the plant canopy. As water-based spray solutions fall to the plant canopy, the diameter of the spray droplet decreases as water evaporates during the fall. This can be an important consideration under low-humidity conditions, as evaporation losses (and therefore reductions in droplet size) at 20 percent relative humidity are more than twice as high as at 50 percent relative humidity at the same temperature. Droplet size can be managed to a significant degree by using larger spray nozzles, low to moderate spray pressures, and antidrift adjuvants.

Most current harvest aid chemicals are not highly volatile compared with many other agricultural chemicals, but there still can be some volatilization and odor problems with decomposition products from the organophosphate defoliants. These problems have been greatly reduced in currently available formulations of the organophosphate defoliants, but they can still be an issue, particularly under high-temperature conditions.

Table 4. Conditions affecting aerial application of harvest aid materials.

Conditions favoring aerial applications	Conditions favoring ground rig applications
tall, rank-growing cotton	shorter, more compact plants
plants that are lodged or partially lodged	erect plants
plants with long fruiting branches	more columnar growth, shorter fruiting branches
narrow-row cotton production	wider-spaced, conventional row spacing
wet soil conditions	relatively dry soil conditions
cotton with loosely held lint	cotton that is more tightly held in bolls

Selecting a Harvest Aid Strategy

Growers need defoliants with different modes of action to ensure continued best results under a variety of environmental and crop conditions. However, it also is important to consider the importance of prevailing environmental and crop conditions in determining a cost-effective approach for each field. Defoliation decisions must be made on a field-by-field basis due to the wide range of crop maturities in and among fields and the impacts of weather and crop conditions when the crop is acceptably mature for harvest preparation. Fields that have gone through a relatively even vegetative cutout and have a good boll load will be much easier to defoliate than fields with a nonuniform fruit set (for example, substantial early and late boll set with a poor middle-canopy crop) or where there is significant late vegetative growth due to factors such as late plantings, late irrigations, or high late-season soil nitrogen levels.

Several crop and environmental conditions impact the efficacy of harvest aids and the choice of the most effective harvest aids (see Table 5). Conditions that can make defoliation more difficult often involve late plantings or abnormal fruiting patterns, such as problems in achieving good retention of early and/or middle-season fruit. Both of these situations often lead to attempts to set a late crop in order to make more acceptable yields. Harvest aid decisions are more complicated under these scenarios, since delayed defoliation to allow maturation of late bolls moves defoliation into cooler weather, where harvest aids are often less effective, and also puts early bolls at greater risk for lint losses and changes in quality associated with prolonged weathering. Other plant characteristics and environmental conditions that can also impact plant responses to harvest aid applications, are briefly summarized in below.

WEATHER CONDITIONS

In many years, the dominant factor going into each harvest season is hard to predict and manage: the weather. The efficacy of harvest aids, the importance of adjuvants, and the need for repeat applications can be strongly influenced by combinations of temperature

Table 5. Primary environmental and management factors influencing defoliation.

Favorable conditions for effective defoliation	Unfavorable conditions for defoliation
Air temperatures relatively high:	Air temperatures relatively low:
daily maximum temperatures over 80°F (26.5°C)	daily maximum temperatures under 80°F (26.5°C)
daily minimum temperatures over 50°F (10°C)	daily minimum temperatures under 50°F (10°C)
Plants in full vegetative cutout	Plants with vigorous vegetative growth
High fruit retention	Poor or uneven fruit retention
Complete spray coverage with harvest aids	Incomplete coverage with harvest aids
Soil basically fertile, but upper soil N and plant N mostly depleted	High soil and plant N at time of defoliation
Timely irrigations during season, with water stress no more than moderate at time of harvest aid applications	Soil moisture low or irregular, soil water and plant water status either too high or too low at defoliation
Plant population relatively uniform, from about 30,000 to 60,000 per acre (75,000 to 150,000 per ha)	Plant populations highly variable or excessive (worst with high population, late-planted crop)
Early-maturing crop	Late-maturing crop
Weed populations under good control	Widespread problems with weeds
Soil conditions that impact crop growth fairly uniform across fields	Uneven ground, variable soils that have saline, alkaline, infiltration problem areas

Source: Adapted from Roberts et al. 1996, p. 306.

and humidity. Under warmer conditions, daytime highs of 80°F (26.5°C) or more, and as long as plant water stress levels are not too severe, cotton plants are generally more physiologically active than at cooler temperatures. These warmer conditions usually promote and accelerate the activity of boll openers and defoliants. However, if defoliants are applied very late and plant water stress is more severe, warm to hot weather can increase desiccant action rather than defoliation.

Although long-term weather predictions are imprecise, it may be useful to consider 5- to 7-day rain and temperature forecasts when choosing harvest aid materials and application rates. The efficacy of harvest aid materials can be influenced significantly by temperatures both at the time of application at for the following 7 days or more. Hake, Hake, and Kerby (1996) prepared a general guide for minimum air temperatures for optimal performance of various harvest aid chemicals (Table 6). Their results indicated that in general:

- harvest aids with hormonal activity such as thidiazuron and ethephon usually require warmer weather for optimal activity than herbicidal-type chemicals
- desiccant materials, which are contact-injury chemicals, are typically less temperature-dependent and are more often used when weather conditions or temperature is less favorable

Weather conditions during the period leading up to crop maturity and harvest aid applications vary with year and location in California. The San Joaquin and Sacramento Valley production areas are characterized by typically warm temperatures through August and early September, followed by more variable weather conditions through November that are characterized by gradual reductions in daily heat unit accumulation and increasing chances for dew accumulation in morning and evening hours and even rain and fog. These late-season adverse conditions can impact harvest aid efficacy and delay harvests. Rain is a particular threat to harvest in the Sacramento Valley production area, which has significantly higher average rainfall than the San Joaquin Valley or southern California low desert production areas. During this period, heat units in the San Joaquin and Sacramento Valleys typically decline from about 10 to 12 DD60 per day in mid-September to early October to less than 4 or 5 DD60 per day during mid-October to early November (see Table 1). Increasing chances of weather-related harvest delays (dew, fog, rain) and slower action and reduced efficacy of most harvest aids under cooler temperatures mean that there is considerable incentive to use management practices (proper irrigation and nitrogen management) to prepare the crop for a timely harvest.

Low desert cotton production areas of California (Imperial, Coachella, and Palo Verde Valleys) experience much warmer air temperatures during the late-summer period than in the San Joaquin or Sacramento Valley production areas. In addition, some periods in July and August experience a change in weather patterns known locally as the "summer monsoon" season, which is characterized by combinations of high daytime temperatures, higher humidity, and higher nighttime air temperatures than experienced during other times of the production season, and the chance of thunderstorms is increased. Cotton managed for shorter-season production in these low desert areas could enter the period of harvest aid applications under these adverse hot and humid conditions during August. With longer-season production management in the low desert, it is more typical to defoliate during lower-humidity warm temperatures in September and October. Many harvest aid chemicals work more effectively and more consistently during these more moderate weather conditions.

Particularly with defoliant-type harvest aid chemicals, the temperature at application and during the days following application play a big role in deciding the optimal application rates and combination of materials to be applied for best results. With some materials, lower rates can be used when warm weather, 80°F (26.5°C) or greater peak daily temperatures, are expected; however, application rates still need to be within product label recommendations and limits. Research conducted in Arizona reviewed by Silvertooth (2001) has produced some general guidelines to consider in adjusting harvest aid application rates under low desert conditions using ranges of heat units expected during the 14 days after harvest aid application, and ranges of expected daily high and low air temperatures. The heat units for Arizona researchers were determined using threshold temperatures of 86°F (30°C) for an upper value and 55°F (12.8°C) as the base (Brown 1991). Table 7 shows general guidelines

Table 6. Minimum temperature for optimal harvest aid performance for specific harvest aid chemicals.

	Minimum temperature	
Harvest aid material	**°F**	**°C (approx.)**
thidiazuron	65	18
ethephon	60	16
tribufos	55 to 60	13 to 16
dimethipin	55 to 60	13 to 16
sodium chlorate	50	10
paraquat	< 55*	< 13*

Source: Hake, Hake, and Kerby 1996.
Note: *The activity of paraquat slows below this temperature, but performance is maintained.

for harvest aid rate decisions suggested for low desert production areas in Arizona based on prevailing weather conditions. It should be noted that expected temperatures are not the only factor to consider in prescribing harvest aid application rates, since interactions with other factors such as plant water or nitrogen status or honeydew deposits (sticky liquid excrement from insects such as the cotton aphid and silverleaf whitefly) on leaves can also influence required rates for good harvest aid performance (Silvertooth 2001). The recommendations propose that lower rates of defoliants would achieve acceptable defoliation (>75% defoliation from a single application) when higher air temperatures and heat units prevail. These same general ideas are likely to apply under California conditions, but no specific heat unit or temperature ranges have been defined.

CROP VIGOR, BOLL LOAD, HIGH NITROGEN LEVELS, AND RANK GROWTH

In general, most harvest aids do best, often even at lower labeled rates, in fields with a uniform distribution of bolls throughout the fruiting branches, strong vegetative cutout, and little late-season vegetative growth. The easiest fields to defoliate effectively and simply are those with uniform boll set, a definite vegetative cutout, and soil water and soil nitrogen that has been drawn down significantly in the postcutout period leading up to harvest aid applications. Under these conditions, plant growth rates have slowed, boll maturity has progressed well, and plant hormone balance is more likely to favor the development of leaf abscission zones.

The plant growth regulator mepiquat chloride (marketed under the trade name PIX, and others) is an anti-gibberellin type hormone that reduces expansive growth when applied at label rates. This plant growth regulator has been widely used in California cotton production since the 1980s and can be effectively used as a management tool to reduce vegetative growth. Using mepiquat chloride at proper rates for specific growth stages can shorten internode and fruiting branch length and reduce the average size and number of leaves. The growth regulator can be an important management tool, particularly when early square and fruit loss is great or under weather or crop conditions that would otherwise produce rank vegetative growth. The effects of a growth regulator such as mepiquat chloride where rank growth concerns exist can include reduced competition for photosynthate and nutrients such as nitrogen and potassium needed for bolls to develop and mature, and reduced total plant leaf area due to internode shortening, reduced leaf size, and fewer leaves, resulting in better penetration of applied harvest aid chemicals through the leaf canopy. For many harvest aid chemicals that act as contact-type herbicides, a dense leaf canopy that is difficult to penetrate with sprays decreases the efficacy of the chemicals and increases the need for additional spray applications to achieve desired levels of defoliation and desiccation.

Choices become more complicated in fields with low and/or extended boll loads, where nonuniform vegetative cutout occurs, and where excess vegetative growth associated with low fruit loads or high soil water or nitrogen have to be considered. With excessive soil water or nitrogen at first harvest aid application, the photosynthate production ability of the plants often exceeds that of the remaining developing bolls, resulting in a greater tendency for significant regrowth. This regrowth can be a major problem, particularly when late-season soil water and nitrogen remain too high, as these late-developing leaves tend to have high concentrations of the hormone auxin. It is difficult to force regrowth leaves to drop from the plants, and it is often necessary to just settle for desiccating these leaves, which usually remain stuck to the plant and lead to increased gin-trash problems.

INSECT CONTROL AND IMPACTS OF FRUIT LOSS

Flower buds (called "squares" by cotton researchers and producers) and fruit (bolls) less than about 10 days old (age in days after flowering) are highly susceptible to loss related to physical damage from a number of environmental and biotic factors. Square or boll loss can be caused by damage from insects such as lygus (also called "plant bugs") and certain types of worms, from water or heat stress at specific growth stages, and from limitations of carbohydrates and nutrients.

Plant responses to prebloom losses of developing squares are influenced by the vigor of the plants as well as the timing and extent of the losses. If insects that influence boll retention are not well managed during the growing season, the result can be uneven and reduced boll loads and increased vegetative growth. During the primary period of square formation or during the first 2 to 3 weeks of flowering, major boll losses due to lygus bug damage or other pests can greatly reduce the potential yield of the plant. In cotton, a typical response to fewer bolls competing for carbohydrates and nutrients is the enhancement of vegetative growth, resulting in a large, leafy plant that can be difficult to defoliate. Efforts to manage insect and mite pests can impact yield, earliness, and uniformity in maturing bolls, and can increase the likelihood of excessive vegetative growth.

In general, however, loss of squares in the first 4 or 5 fruiting branches can be summarized as:

- delayed flowering
- promotion of vegetative growth, with taller plants with more vegetative branches and more total production of flowering sites
- increased retention of midseason and late-season bolls
- delays in crop maturity and boll opening; longer growing season required if water and nutrient availability are adequate to support longer season

In terms of impacts of boll losses on yields, most cotton varieties can compensate for early boll losses by producing additional vegetative growth and flowering sites, and by increased retention of bolls developing in the later part of the growing season. Whether the growing season can be effectively lengthened to make up for early yield losses depends on many factors, including weather conditions, available water, and nutrient resources to extend the growing period and cost-effectiveness of a longer period during which the crop must be protected from insect pests.

REGROWTH

The term "regrowth" as used in cotton defoliation and preparation for harvest refers to new leaf growth occurring late in the season, generally weeks after most vegetative and fruiting branches have stopped forming new leaves. Regrowth is typically described as basal (in the lower part, or "base," of the plant) or terminal (near the plant terminal in the upper part of the plant canopy). Regrowth can occur with or without application of harvest aid materials, as it generally occurs due to the perennial nature of the cotton plant, which initiates new growth to replace lost or damaged leaves. Conditions that favor regrowth include:

- plants with high vigor growth in the late season
- moderate to high available soil water in late season
- moderate or even high soil and plant tissue nitrogen in the late season
- warm temperatures and sunlight to support photosynthesis and leaf growth
- significant prior leaf loss

In terms of crop quality, regrowth management can be important for several reasons:

- Significant regrowth allows the development of new, high-moisture-content green leaves that can become significant contamination problems during harvest.
- When crushed during harvest, fragments of young leaves can be pulled into the harvested cotton, and many fragments will not be separated and removed by a spindle picker.
- Green leaf tissue blended with harvested seedcotton can increase leaf trash in the cotton, reducing lint quality and value.
- Leaf tissue in contact with cotton fiber can stain fibers, decreasing fiber quality, grades, and value.
- Leaf tissue that is not desiccated adds moisture to seedcotton. High moisture in modules can cause higher module temperatures and storage problems, including microbial growth and staining.

A significant amount of regrowth can impact the choice of harvest aid materials and the number of applications required to adequately prepare for harvest. Some harvest aid chemicals provide better regrowth control than others; those with better activity are reviewed briefly in the "Harvest Aid Research Results" section, below, and in the appendix to this study guide. Several guides with information on how to assess regrowth in a semiquantitative manner are also available (see Stichler 2001 and Roberts et al. 1996).

LATE-SEASON WEEDS

Fields with significant populations of weeds can present problems for defoliation and harvest operations. If the weeds are tall and grow into the upper canopy, they can intercept some of the applied chemicals, reducing the amount reaching the cotton. Tall weeds such as

Table 7. University of Arizona guidelines for adjustment of harvest aid application rates on irrigated cotton as a function of heat units after application and prevailing air temperature minimum and maximum for the period of 14 days after harvest aid application.

Weather parameter	Relative application rate for harvest aid chemical*		
	Low	Moderate	High
Heat units (14 days after harvest aid application)**	> 300	200–300	< 200
Approximate average daily maximum air temperatures	> 90°F (32°C)	~80°F (26.5°C)	~70°F (21°C)
Approximate average daily minimum air temperatures	~70°F (21°C)	~60°F (15.5°C)	~40°F (4.5°C)

Source: Silvertooth 2001.
Notes:
*Refer to ranges in rates shown on label for the defoliant material used.
**Heat units calculated using 55°F as base temperature and 86°F as upper threshold air temperature (see Brown 1991).

johnsongrass, pigweed, and nightshade certainly fall in this category. Weeds that become entangled in cotton stalks, such as annual morningglory and field bindweed, can also intercept applied materials and disrupt harvest aid activity. Weeds tall enough to reach into the mid and upper canopy of the crop will likely increase the trash content of the harvested lint. If weed tissue that is green and hydrated at harvest time is not removed with defoliants or dehydrated with desiccants, it may stain the cotton lint. Desiccant materials and/or applications of herbicide materials such as glyphosate may prove beneficial with more severe late-season weeds, particularly if weeds are still actively growing.

Significant weed populations may pose a particular problem for fields grown for foundation, certified, or registered seed. Weed control efforts should be intensified much earlier in the growing season for those fields.

LEAF SURFACE CONTAMINANTS

Exudates from late-season insects such as cotton aphid and silverleaf whitefly can cause sticky cotton and other cotton quality problems, and they can also reduce the penetration and efficacy of harvest aid chemicals. Honeydew exudates from these insects have been shown to reduce the penetration of harvest aid materials into the leaves and decrease efficacy of defoliant and desiccant materials (Snipes and Evans 2001). In fields with severe stickiness, the number and rate of applications may need to be altered to improve efficacy. Under some situations, webs from severe spider mite infestations or large quantities of surface dust (such as in silty soil areas) can also reduce harvest aid penetration to the leaf surfaces and thereby reduce efficacy of applied harvest aids.

PATHOGENS AND LEAF FOLIAR INJURY FROM INSECTS

Fungal diseases such as Verticillium wilt and insect pests that cause direct foliar injury (such as spider mites) can produce significant leaf injury in cotton. This injury can be a major stress on the plant, and like other stresses, if severe enough it can initiate changes in hormone levels that promote the progression toward leaf senescence. Consequently, it may often be easier to defoliate pathogen or insect-damaged plants using lower rates of harvest aid chemicals or making fewer total applications.

WATER STRESS

Plant water status at the time of harvest aid applications can significantly affect the efficacy of harvest aids. The proper water status for effective defoliation is not a set soil water content or level of plant tissue water content. Optimal water status is more of a balance between some water stress but not too much water stress. The goal is plant exposure to sufficient water stress to encourage senescence and the formation of abscission layers, but not so much stress that the plant is unable to respond physiologically to harvest aids. The leaf tissue must be hydrated well enough to be physiologically active and functioning, so that harvest aid chemicals can elicit changes in hormone levels and physiological responses to foliar injury. If plants are too water stressed when harvest aids are applied, the chemical will be more likely to cause tissues to desiccate and leaves to stick on the plants rather than abscising. If plants are too well-watered, with little water stress and continued vegetative growth when harvest aids are applied, defoliation is more likely to be ineffective, and regrowth is more likely to occur.

Fields subject to repeated water stress and drying winds tend to have thicker waxy cuticles (leaf surface wax) than leaves grown in a less-stressful environment where soil water and atmospheric conditions have higher water levels. Increased levels of surface wax can significantly inhibit uptake of harvest aid chemicals; the impacts of these stress periods are not completely relieved by late-season irrigation or rain. If plants have been water stressed, wetting agents, including non-ionic surfactants, should be considered for use with harvest aids, as they are likely to improve harvest aid efficacy.

LEAF AGE AND LEAF CUTICLE CHARACTERISTICS

If plants are naturally progressing toward senescence due to good boll set and low to moderate levels of soil water and nitrogen, leaves that are 50 days old or older tend to senesce and even abscise prior to harvest aid applications. Older leaves, particularly those in shade or semishade in the lower and middle parts of the canopy, senesce due to the combined effects of reduced photosynthate production and the translocation of nutrients, carbohydrates, and soluble proteins from these leaves to developing bolls and younger vegetative tissue. Using low rates and single applications of harvest aids is generally the best way to cause leaves in this declining condition to senesce and abscise. In contrast, younger, fully-grown leaves that are actively photosynthesizing and have adequate water and nitrogen levels are typically much harder to push into senescence and abscission (Cathey 1986). As a general rule, the greater the proportion of relatively young, vigorous leaves, the more difficult it will be to successfully defoliate and desiccate the plants.

An interesting distinction can be made between the sensitivity of young (20 to perhaps 40 days old), fully expanded late-season leaves to defoliants and desiccants, and that of young regrowth leaves that are not fully expanded. Common observations are that young regrowth leaves are more resistant to defoliants (they are unlikely to form an abscission layer), but they are much more sensitive than earlier fully expanded leaves to severe injury and death from desiccants. This means that if there is a large amount of regrowth, avoid high-rate applications of harvest aids, or there may be more problems with dry leaves sticking on the plant and unable to abscise.

A major reason for the higher sensitivity of young regrowth leaves to rapid death and inability to abscise with high rates of defoliants and desiccants is that they have a relatively thinner leaf cuticle. The cuticle is made up of waxy, hydrophobic materials on the leaf surface that can reduce penetration of water-based sprays. The leaf cuticle is thin in young regrowth leaves typically produced under late-summer or fall weather conditions because the younger leaves have not had as long to deposit waxy cuticle layers, and these leaves are produced under cooler weather conditions, which are known to produce thinner, less waxy cuticles (Oosterhuis, Hampton, and Wallschleger 1991). Older leaves, particularly those developing under hotter, low-humidity conditions, typically produce thicker cuticles (Gwathmey et al. 2001).

TYPE OF COTTON

Types of cotton and perhaps even varietal differences in the degree of indeterminate growth habit should be considered when making defoliation decisions. Cotton types widely grown in the San Joaquin Valley have been divided into three basic categories: Acala, non-Acala Upland (or "California Upland"), and Pima.

Acala

Acala varieties are a subgroup of Upland cotton varieties (*Gossypium hirsutum* L.) that in the United States are most widely grown in California. This group of varieties have been separated from other Uplands here in California based on long-term selection of varieties that attain a certain set of standards for high-quality fiber characteristics.

The exceptional fiber quality of approved Acalas and the environmental conditions of the San Joaquin Valley have, to some degree, insulated the California cotton crop from costly fiber quality penalties associated with too-early applications of harvest applications (cotton merchants in today's markets may not be very forgiving of lower-quality fibers). Most of the Acala defoliation studies have been conducted using the Acala Maxxa variety. The mix of varieties that constitute the approved Acalas increasingly represent a range of growth types and leaf characteristics, so some differences in ease of defoliation can be expected among them. Most of the research conducted evaluating harvest aid materials in California has been with Acala varieties, so generalizations made throughout this guide primarily were developed based on research trials and observations in Acala fields.

California Upland

California Upland varieties include any non-Acala Upland varieties (*Gossypium hirsutum* L.) grown in the state of California. The group can be very diverse in terms of state or country of origin, fiber quality, boll size, and number of bolls per plant, as well as other morphological characteristics.

Even though these non-Acala Upland varieties are of the same genus and species (*Gossypium hirsutum* L.) as Acalas, they represent a much broader range of genetic material, plant growth habits, and fiber quality. California Upland varieties available since the late 1990s in the San Joaquin Valley have origins ranging from true Mississippi Delta varieties with southern U.S. origins and adaptations to varieties tested and produced in areas such as New Mexico, Arizona, and even Australia, as well as some varieties with California origins and Acala genetic backgrounds. As a first, safe approximation, growers might assume that harvest aid management practices for non-Acala Upland varieties would be the same as in Acala varieties. However, grower and University of California field experience with most of the non-Acala Uplands available in the San Joaquin Valley since the late 1990s has been that they are easier to defoliate than the commonly grown Acala varieties. As of 2002, there have been few separate harvest aid trials done in California to evaluate differences in responses between California Upland and Acala varieties. Some indications of what to expect with these varieties can be found in University of California farm advisor trials that have compared the efficacy of combinations of harvest aid materials from various U.S. cotton-growing regions. In general, after years of study, many of these "standard" harvest aid treatments performed much better on California Upland cotton in other states than they did on Acala varieties in the San Joaquin Valley. In California, chemical application rates must typically be increased as much as double, and it takes 7 to 10 days longer to achieve the same results with Acala as seen in other states with non-Acala varieties. Limited University of California field tests and observations on grower fields since 1999 have confirmed that most California Uplands that have been grown on significant acreage so far have been easier to defoliate than Acala varieties, requiring lower harvest aid rates or fewer total applications to achieve acceptable preparation for harvest.

With some California Uplands that consistently have lower fiber length and strength when compared with Acala varieties, it can be particularly important to be aware of the potential for improper timing or rates of harvest aid applications to further impact fiber quality. Improper application choices, such as boll opener or defoliant applications made too early on a variety which already has borderline quality characteristics, could greatly reduce the value of the fiber by lowering it into a grade unacceptable for many uses.

As more research and field experience is obtained, growers and consultants should have more confidence in using lower chemical application rates, fewer sequential applications, and an overall lower-input-cost approach in defoliating California Uplands.

Pima

Pima cottons are varieties of *Gossypium barbadense* L., a different species of cotton from the Upland varieties. Pima varieties are significantly different from most Upland varieties in growth habit and certain morphological characteristics, such as their more indeterminate growth habit, more nodes and longer fruiting branches, and smaller bolls, and they have fiber that is longer and stronger than Upland varieties.

Because of its more indeterminate growth characteristics, Pima is generally more difficult and costly to defoliate than Upland varieties. Higher application rates and multiple applications are usually needed to thoroughly desiccate remaining leaves. Most of the Pima defoliation studies on which California harvest aid recommendations for Pima were based from the 1990s to 2002 were conducted on the Pima variety S-7. Among commercial Pima varieties available during that same period, S-7 would be considered about in the middle in terms of plant size and degree of earliness. Although the duration of growth and fruiting of both Pima and Upland can be highly responsive to environmental conditions (soil, nutrients, insects, weather), there still tend to be varietal differences in the degree of earliness. "Earliness" is defined as the tendency for the plant to slow the rate of flower production and begin maturation and opening of most bolls in a shorter time since seedling emergence (fewer days needed to open bolls on the majority of the crop). More-vigorous, later-maturing Pima varieties can often be even harder to defoliate, requiring multiple harvest aid applications to improve leaf removal and desiccation. In contrast, the more-determinate, earlier Pima varieties may be smaller and somewhat easier to defoliate, but it is still typically harder to remove leaves from Pima than most Upland varieties, including the Acalas. The fact that most currently grown Pima varieties have a more indeterminate growth habit than Acala types is the cause of their more difficult defoliation. The longer growing season required for maximum yields in Pima than with Acala also means that irrigations are often applied later in the growing season than in Acala, adding further to the defoliation problems by promoting late-season vegetative growth.

Pima seedcotton yields, and especially lint quality, are highly sensitive to damage from high moisture content in modules and to high levels of green leaf trash. Both can lead to serious problems in long-term module storage and with final lint grades. Since the price premium of Pima cotton is one of the main reasons growers consider Pima production, most cannot afford to sacrifice Pima quality. Late-season vegetative growth would also be subject to partial control through the application of pretreatments such as ethephon to enhance defoliation. Controlling plant height and encouraging uniform maturity make it easier to defoliate Pima cotton. Even though San Joaquin Valley roller ginning capacity (special gins for Pima cotton) has increased greatly since the 1990s, additional expansion in acreage may further extend the length of the ginning season, requiring a longer module storage time prior to ginning.

OTHER CONSIDERATIONS

In addition to the impacts of types of cotton on harvest aids, harvest aid trials in California in the 1980s and 1990s indicated that the most effective chemicals and rates were different in the southern desert region than in the San Joaquin and Sacramento Valleys. Several varieties of California Upland cotton have been grown since the mid-1990s in the Sacramento Valley, in a climate much different than the southern deserts. California Upland varieties that are well adapted to those conditions have been much easier to defoliate (lower rates and fewer applications of harvest aids) than Acala varieties tested in the same environment. As long as fields were well prepared for defoliation, with reduced soil water and nitrogen in the late season, treatments that were very effective in defoliating Upland varieties in the Sacramento Valley or southern desert region were often much less effective in the San Joaquin Valley with Acala varieties. Part of the effect is due to the prevailing varieties grown in each region, and part is undoubtedly related to environment and differences in management practices.

Field Conditions Affecting Defoliation

Considering the wide range of environmental and crop factors discussed in the previous section, some common scenarios and generalizations can be used as examples of how consultants and managers can make harvest aid decisions regarding the treatments most likely to be effective and economical. The following examples are two general situations often seen in the San Joaquin Valley cotton production area, with harvest aid recommendations based upon University of California field tests. Other combinations of crop and weather conditions can certainly exist in California cotton production, but these examples illustrate key crop and weather conditions that can affect harvest aid decisions.

EXAMPLE 1: HEAVY BOLL LOAD, ABRUPT CUTOUT, WARM WEATHER

The first example situation consists of fields with uniform and/or heavy boll load, abrupt vegetative cutout, and warm temperatures greater than 80°F (26.5°C) at the time of defoliant application, with warm weather expected after applications.

- Under this condition, lower labeled rates of most defoliants are effective.
- There is less potential for regrowth, so there would generally be less need for materials used mostly for regrowth control, such as early glyphosate applications, unless preharvest weed control is needed.
- Harvest aid materials that tend to provide good defoliation in well-prepared fields without rank growth (such as Ginstar) should give effective defoliation with a single application. Harvest aid materials such as Def and Folex should also be effective under these conditions.
- Pretreatment or growth regulator harvest aids (such as ethephon) that improve boll opening may be less critical in this condition. However, tank mixes that include ethephon will be useful in areas where late-season aphid or whitefly infestations may be a problem, as these mixes can provide faster leaf drop. These treatments could also be beneficial under shorter-season production conditions in some areas, or with late plantings.
- If a second treatment is needed, harvest aid materials that provide more of a contact-burn type of damage (such as sodium chlorate, paraquat (Starfire, Gramoxone), or cacodylic acid applied alone or in combination) may be more effective than in example 2 (below).

EXAMPLE 2: LATE PLANTING, RANK GROWTH

The second example situation consists of late plantings, or situations with rank growth (which may or may not be associated with poor fruit retention) in Upland and Pima cotton.

- Under these conditions, defoliant performance is generally not as successful in leaf drying and removal.
- Regrowth and boll opening are also a common concern. This often means that harvest aids can be valuable as pretreatments to improve initiation of boll opening and leaf abscission.
- Under field conditions that could promote significant regrowth, or where opening of late-maturing bolls is a concern, University of California harvest aid studies indicate that first treatments with materials such as Ginstar, Dropp, Prep, and Roundup often enhance regrowth control and boll opening.
- Sequential applications will usually be required. Higher rates are usually required on the second application to defoliate or desiccate remaining leaves.

Variability in Performance of Harvest Aids

HARVEST AID PERFORMANCE IN UNIVERSITY OF CALIFORNIA TRIALS

Primary defoliant materials are generally limited to the organophosphate (OP) defoliants (Def or Folex), sodium chlorate, Ginstar, and Dropp. Despite ongoing discussions about restricting the use of organophosphate defoliants in cotton, University of California studies have shown that these materials provide some of the most consistent results year after year. Long-term UC studies have identified specific conditions that influence the performance of certain harvest aid materials more than others. With organophosphates, the best defoliation is usually obtained when they are applied in combination with ethephon. In UC studies, Dropp when used alone has been inconsistent in performance, especially with Acala Upland varieties. Sodium chlorate and Ginstar, when applied at high rates in combination with warm to hot temperatures, can cause leaves to desiccate and stick on the plants.

Multiple applications of sodium chlorate can be used effectively for defoliation under some conditions, but this material is most often used as a second application following an organophosphate (Def or Folex) to desiccate remaining leaves before harvest. There are many defoliant enhancers, such as Accelerate, Cotton-Aid, Harvade, and paraquat (Gramoxone, Starfire). Under situations such as rank growth, poor boll set, or excessive moisture and/or nitrogen levels, these enhancers increase harvest aid efficacy when used in combination with materials such as Ginstar or Def/Folex.

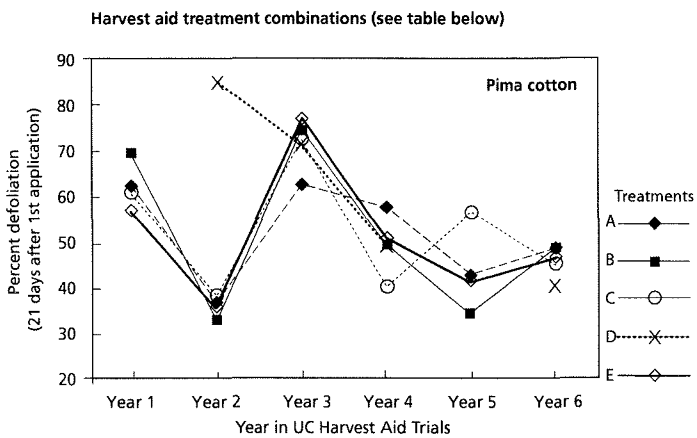
A grower must select a treatment that will perform the best under his or her field conditions. Material cost, number of applications needed, efficacy, local crop, soil and weather conditions, and plantback restrictions all play a role in determining which treatments to use. As discussed earlier in this guide, harvest aid decisions ideally consider a wide range of crop and environmental conditions at the time of application. Difficult choices, however, may still need to be made after the application of the last harvest aid, since weather can always change and harvest aids do not work on a precise schedule. Pay close attention to the crop's progress toward boll opening and remain aware of any regrowth problems, poor harvest conditions, or predictions of poor weather. Growers and consultants should try to watch the fields, not the number of days since harvest aid application, and they should avoid beginning harvest until boll opening, leaf desiccation, and seedcotton moisture conditions are acceptable.

RATIONALE FOR CONTINUED NEED FOR CALIFORNIA-BASED TRIALS

Harvest aid research done in states across the Cotton Belt has been summarized by Supak and Snipes (2001), including many of the findings from earlier University of California field research. These multistate trials have repeatedly shown that chemical materials and application rates for harvest aids developed for varieties and the environmental conditions prevalent in states outside California do not transfer well to California production conditions. Past UC harvest aids research has demonstrated the need for California-specific research to fine-tune management practices such as timing, rates, and types of tank mixes to use. This will continue to be even more the case for Pima grown in California, as there are no other states with enough Pima acreage to warrant similar harvest aid research efforts. Additionally, the reality of the agricultural chemical market is that the availability of specific chemicals (such as harvest aids) is likely to change in the future. It remains important to evaluate alternatives to current defoliation programs to provide information on alternatives that can ensure optimal performance with minimal negative impact on fiber quality.

Another problem seen in past work with both Upland and Pima cottons is the inconsistency in crop responses and efficacy of defoliation and desiccation materials. University of California Cooperative Extension harvest aid research conducted during the mid-1990s through 2002 in the central San Joaquin Valley can demonstrate the impacts of different years (with different crop conditions and weather) on the relative performance of harvest aids. Since all these tests were done on cotton grown at the same location over a 5- or 6-year period, the primary variables each year were weather at and after harvest aid application time and crop conditions. Figure 6 shows the performance of selected harvest aid chemical combinations on Pima cotton 21 days after first application in 6 different years. The materials do not include all harvest aid materials tested or all those registered and available for use with Pima cotton, but rather a sampling of materials (new and old) with a range of efficacy in field trials. This information, along with similar averages shown in Figure 7 from 5 years of Acala harvest aid trials, demonstrates that no one chemical or combination of chemicals has yet been found that consistently performs best across all years.

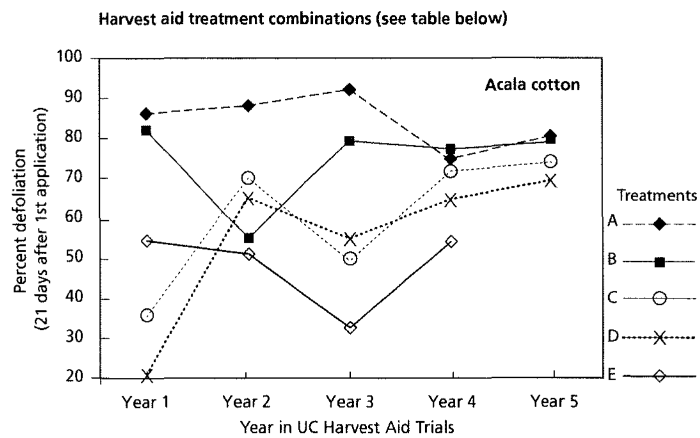
The importance of demonstrating the inconsistency in performance of harvest aid materials from year to year is of particular concern when it comes to retaining Environmental Protection Agency (EPA) and California Department of Pesticide Regulation (CDPR) authorization for continued use of these materials. For example, chemical materials that work well under conditions of warm weather, good boll retention, and timely cutout can differ greatly from materials needed under different environmental conditions (cooler, later harvest) and different crop status (later cutout, more vegetative growth, indeterminate varieties). To provide reasonable efficacy in preparing cotton for harvest, growers would be better served if they can look at crop and environmental conditions at the field level and also have access to a range of chemical product choices that allow a reasonable combination of acceptable price and efficacy.



Treatment combination	Chemicals in treatment combination (application rates per acre are shown in parentheses following each chemical trade name)
A	1st : Prep (2 pt) + Dropp (0.3 lb) 2nd: Ginstar (10 oz) or $NaClO_3$ (1 gal Defol 5) + Harvade (8 oz) or Starfire (21 oz) or $NaClO_3$ (1 gal Defol 5) + Folex (2 pt)
B	1st: Ginstar (13 oz) + Prep (2 pt) 2nd: $NaClO_3$ (1 gal Defol 5) + Starfire (21 oz)
C	1st: Ginstar (6 oz) 2nd: Ginstar (10 oz)
D	1st: CottonQuik (3.5 qt) + Ginstar (13 oz)
E	1st: Ginstar (13 oz)

1st = First harvest aid application in treatment combination
2nd = A sequential, second harvest aid application applied 7 days after the first application

Figure 6. Average percentage of defoliation of Pima cotton (variety S-7) at 21 days after first harvest aid application for selected combinations of harvest aids in University of California Cooperative Extension defoliation trials, as a function of year of study (year 1=1995, year 6 = 2000). *Source:* Wright et al. 2000; Hutmacher et al. 2002.



Treatment combination	Chemicals in treatment combination (application rates per acre are shown in parentheses following each chemical trade name)
A	1st : Folex (2 pt) + Prep (2 pt) 2nd: $NaClO_3$ (1 gal Defol 5) + Starfire (21 oz)
B	1st: Folex (2 pt) + Prep (2 pt) + Agridex (1 pt)
C	1st: Ginstar (10 oz)
D	1st: $NaClO_3$ (1 gal Defol 5) + Starfire (11 oz) 2nd: $NaClO_3$ (1 gal Defol 5) + Starfire (21 oz)
E	Def (2 pt) + Agridex* (1 pt)

1st = First harvest aid application in treatment combination
2nd = A sequential, second harvest aid application applied 7 days after the first application)

Figure 7. Average percentage of defoliation of Acala cotton (variety Maxxa) at 21 days after first harvest aid application for selected combinations of harvest aids in University of California Cooperative Extension defoliation trials, as a function of year of study (year 1=1996, year 5 = 2000). *Source:* Wright et al. 2000; Hutmacher et al. 2002.

Defoliation of Certified Organic Cotton

Organic cotton production has been of significant interest in California and a few other states since the early 1990s, but the amount of acreage in organic production has been highly variable. Relatively low prices, difficulties in securing consistently higher prices, and problems with lint quality and marketing have been implicated as factors limiting acreage increases. The estimated total organic cotton acreage in California has declined from over 2,000 acres (800 ha) in the late 1990s to between 500 and 750 acres (200 to 300 ha) in 2002, according to California Department of Food and Agriculture estimates (2002).

Many agronomic practices, including choice of variety, differ little between conventional and organic cotton production in California. In both production systems, varietal selection, planting strategies, equipment and rates, and fertility and irrigation decisions are based on the same environmental and soil parameters suggested in University of California recommendations. Plant monitoring (plant mapping) and integrated pest management monitoring and principles developed for conventional cotton are being used in organic cotton as well. The difference, of course, is that the organic cotton relies on nonsynthetic materials for fertilization and control of insect and weed pests.

Growers of organic cotton in California have described acceptable defoliation as one of the biggest and most difficult production challenges, since it impacts harvest efficiency, moisture content, leaf trash, and lint quality. In combination with early termination of irrigation, which helps slow vegetative growth and new leaf production, strategies for defoliation in organic cotton include one or more of the following materials applied as a foliar spray:

- magnesium chloride
- zinc sulfate alone or in combination with Chilean nitrate applied to the foliage
- zinc sulfate in combination with citric acid

Applications of these materials are allowed in certified organic fields only if soil levels of these minerals have been analyzed and found to be deficient. If soil levels are not in what can be considered a potentially deficient range, these materials will not likely be approved as harvest aids. One potential problem with magnesium chloride applications is that some sources of it can leave a brown granular deposit on the lint, which can reduce lint quality and grade. Mechanical topping, the physical cutting and removal of the upper part of the plant stem and branches, has been used to help induce boll opening (likely to be effective in part due to changes in hormonal activity associated with plant injury). Topping has also been used in combination with zinc sulfate by some growers. A newer defoliation method that might have some promise if allowed in organic fields is a rapid flaming of the canopy with propane burners. Field evaluations of this approach were initiated in early 2001–2002, and continued evaluations may determine its efficacy and cost-effectiveness for defoliation of conventional or organic cotton of various levels of vigor.

Independent consultants and University of California farm advisors have observed that none of these strategies have been consistent in producing even a moderate degree of defoliation in organic cotton, resulting in staining and high moisture content associated with the presence of large numbers of green leaves at harvest time. In the organic cotton production areas of the northern San Joaquin Valley, it has been common to pick the fields two or more times in order to harvest the most-mature bolls. Ineffective defoliation and desiccation, just as in with conventional production, reduce harvest efficiency and lower lint grades and price. As compared with conventional cotton, lower grades are acceptable with organic cotton, but consistency in quality has still been an issue in organic cotton production to date. Green leaf material present at harvest increases the moisture content of cotton in the modules, which can greatly reduce the amount of time cotton can be stored in modules.

Management Practices Influencing Leaf and Stem Trash Going to the Gin

MINIMIZING TRASH USING GOOD HARVEST AID PRACTICES VERSUS GIN REMOVAL

The advantages of avoiding trash in harvested lint are that lint losses are reduced, lint quality is improved, and fiber quality is higher. Methods exist to remove trash during harvest using on-board cleaners, during ginning, and during spinning. Trash removal at any one of these stages has advantages and disadvantages. The disadvantages of removing trash during harvest or processing include increased lint losses, higher costs for multiple lint cleaning, and reduced prices for grade reductions. High volume instrumentation (HVI) classification of cotton bales allows textile mills to identify in advance bales that contain problematic levels of trash, allowing identification and price adjustments for these bales.

Cleaning processes used in gins to remove trash from lint can represent a significant cost. These costs are associated directly with the purchase price and operating cost of cleaning processes and equipment, the reduced speed of processing, and the higher energy costs to remove moisture from the lint that originated from leaf trash moisture. In addition, part of the reason that higher trash content causes reduced lint grades and lower lint prices is that the cleaning processes can damage fiber quality, including broken fibers, reduced uniformity due to increased short fiber content, and increases in neps. Taken together, the costs of lint cleaning and price reductions associated with impacts on fiber quality give considerable incentive to avoid excessive trash using improved cultural methods and more effective defoliation and desiccation.

FIELD CONDITIONS THAT IMPACT DEFOLIATION EFFICACY AND TRASH

Certain conditions in the field can contribute to poor defoliation. Leaves that do not drop from the plant may require additional applications of harvest aids, and trash can lead to difficult-to-clean lint with lower yield and lower fiber quality. These conditions include:

- **Cool temperatures from approximately 3 to 7 days following harvest aid applications.** Defoliants essentially speed up the natural process of abscission layer development and leaf tissue deterioration, and this process is temperature-sensitive with most chemical materials. Cool weather following harvest aid applications generally reduces uptake of the chemicals and the rate of plant response, leading to reduced efficacy.
- **Plant water stress or low-humidity conditions.** Water stress prior to defoliant applications can reduce the efficacy of chemical defoliants. Plant water stress and low levels of relative humidity in the air encourage development of a waxy layer on leaves that inhibits uptake of many defoliant chemicals. Particularly when water stress conditions exist for a prolonged period, such as weeks, leaves form a thicker waxy cuticle. A stressed plant with depressed growth responds less to harvest aid materials than a nonstressed plant that still uses water and exhibits growth.
- **Rapidly growing plants.** Plants with high vegetative vigor due to late planting or low boll retention can be difficult to defoliate. These plants tend to have higher levels of the hormones auxin and gibberellin, both of which can interfere with abscission of leaves.
- **Excess levels of water and nitrogen.** High soil water availability or high late-season soil and plant nitrogen levels typically produce large, vigorously growing plants that are more resistant to defoliation and prone to higher rates of leaf regrowth.
- **Hairy leaf varieties.** Cotton varieties with significantly higher number of leaf hairs have been less common in California cotton production in the past, but the introduction of new Pima and Upland varieties in the late 1990s may change this trend. Hairy leaf varieties in other areas of the United States have had significantly higher trash content at

harvest, presumably because the leaf hairs prevent harvest aid materials from reaching the leaf tissue, resulting in reduced harvest aid efficacy.

- **Cultural practices, delayed harvests, and environmental conditions that encourage regrowth.** Regrowth consists of young meristematic leaf tissue, which typically does not develop an abscission layer to allow leaf drop. Due to the danger of this high-water-content tissue staining seedcotton, regrowth must usually be chemically desiccated prior to harvest.
- **Inadequate application rates.** Uneven performance of harvest aids is more common with lower-than-recommended application rates. Particularly with large, vigorous plants with low to moderate boll retention, poor chemical distribution or low application rates can result in poor defoliation. Plants with good boll retention and moderate or lower leaf area can still defoliate reasonably well even with reduced application rates due to the better penetration of applied chemicals into the leaf canopy.
- **Excessive application rates.** Higher-than-recommended application rates of many defoliant or desiccant materials can cause rapid death of leaf tissue, preventing formation of a leaf abscission layer and leaf drop, causing leaves to stick on the plant. With many chemicals, more effective leaf drop is achieved with multiple applications at a lower rate.

Safe Use of Harvest Aid Chemicals

State and federal regulatory agencies continuously evaluate the potential impacts of agricultural chemicals on air and water quality. This is especially true in cotton production, where chemicals are used as harvest aids as well as for pathogen, weed, and insect and mite control. Concerns regarding impacts on air and water quality are not limited to coastal valley areas, but also exist in the major inland valley areas of California, where all of the state's cotton is produced and where there is considerable urban growth adjacent to farm fields. Impacts of farm chemicals such as harvest aids are being regulated more tightly to deal with off-target drift, impacts on public health, and issues such as odors. Farming in these inland valleys is also highly diversified, with cotton growing adjacent to crops such as vegetables, grapes, citrus, and deciduous fruit and nuts. Off-target drift of harvest aid chemicals in these diversified farming areas can be a serious and expensive problem if neighboring crops are damaged.

Before a pesticide can be legally shipped in interstate commerce, it must be registered under both federal and California laws. Scientific data are required to establish that the chemical harvest aids, when used as directed on the label, perform as indicated, are manageable in terms of worker safety, do not cause unfavorable effects to the environment, and have acceptable levels of residues in harvestable products. Approval for use of harvest aid chemicals is granted by the federal and state environmental protection agencies through the chemical registration process.

Registered chemicals can also be evaluated through the Food Quality Protection Act (FQPA), under which regulatory agencies review existing tolerances with particular emphasis on exposure to specific classes of active ingredients. An example of a harvest aid material that has been widely reviewed through these processes is the organophosphate tribufos, which is the active ingredient in Def or Folex. Such a review was conducted in the late 1990s, and in the year 2000 new restrictions were imposed on the safe handling of the material. Similar actions may occur over time as new materials are introduced and older materials are reevaluated under new constraints. Because reviews or other actions could be ordered for other chemicals mentioned in this study guide, individuals who use these chemicals must review labels and Manufacturer's Safety Data Sheet (MSDS) information and receive continued technical training to maintain awareness of proper use and handling precautions.

Consultants, growers, and applicators should always refer to product labels, MSDS information, and county agricultural commissioner's offices for specific, up-to-date information on:

- safe material handling requirements
- restrictions on methods and timing of applications
- restrictions on chemicals allowed or application method based on location of field and factors such as proximity to public buildings, occupied dwellings, or city limits
- plantback restrictions

Contact the material manufacturer's representatives if the product label instructions are incomplete or unclear. Information on local restrictions can be accessed by contacting local CDFA agricultural commissioner's offices (under the "County Government" listings in telephone directories).

"Off-label" (not listed on the label) applications or using nonregistered products are illegal and potentially dangerous practices. In many cases, tolerances for nonregistered materials or off-label rates of registered materials have not been established, and these applications could result in serious consequences if detected in crop residues.

Glossary

abscission. The process by which leaves and other parts of a plant are separated from the plant.

abscission zone. Region of a plant in which abscission occurs. The leaf abscission zone is located at the junction of the leaf petiole and stem.

auxin. Naturally occurring plant hormone which, at certain concentrations, can stimulate growth in certain plant tissues.

boll. The fruit of a cotton plant, composed of sections called locules, with walls called carpel walls. The boll, or fruit, includes the seed, fiber that develops from cells on the seed, the walls of the boll (thick green tissue that covers developing fiber and seed), and modified leaves (bracts) at the base of the bolls.

cracked boll stage. Cotton development stage in which the boll walls in maturing bolls begin to separate along the carpel walls, exposing the lint within the boll to drying.

cuticle. Outermost, or surface, layer of a leaf. The leaf cuticle usually has properties somewhat different than internal cells of the leaf, since it typically has openings for gas exchange (water loss and carbon dioxide and oxygen movement associated with photosynthesis). In addition, in plants such as cotton, a hydrophobic, waxy deposition can develop on leaf surfaces, changing the physical structure and chemical reactivity of the leaf surface. The level of waxiness can vary with variety of cotton, age of the leaves, and duration of exposure to certain combinations of higher temperatures and low humidity.

cutout, or vegetative cutout, stage. Cotton development stage characterized by a near cessation of vegetative growth that generally coincides with a marked reduction in the rate of new flower site production. This slowing of vegetative growth and flowering generally signals a shift from growth of vegetative and reproductive structures to a period during which maturation of reproductive parts of the plant (bolls, seed) becomes dominant. **Field cutout** is defined in Acala varieties as the date when the number of nodes above the first-position white flower drops below 5, while in Pima it is generally considered to be 3 nodes above the first position yellow flower.

defoliant. Chemical applied to leaf tissue that causes or enhances the development of an abscission layer, which allows leaves to drop off the plant stem, usually after a period of days or weeks after application.

defoliation. Leaf loss or leaf abscission. In cotton production, it usually refers to leaf loss associated with application of a chemical that injures the leaf. Defoliation can also occur through natural leaf maturation and senescence, particularly with cooling weather after boll development.

desiccant. Chemical that induces rapid desiccation of leaves and other plant parts.

desiccation. Accelerated drying of plant tissue.

determinate. General growth habit of plants in which the main stem ends in an inflorescence and stops growing. Perennial crops such as cotton are not usually classified as determinate; however, in cotton production, the term is often used in a relative sense. A more determinate cotton plant completes the primary fruiting cycle (producing flowers, developing and maturing bolls) in a shorter period than a more indeterminate cotton plant when they are both planted at the same time and under the same conditions. See **indeterminate.**

first-position boll. The first cotton boll encountered on a fruiting branch when moving sequentially outward from the main stem of the plan.. A boll at the second location is a second-position boll, and so on.

harvest aid program. Activities employed in cotton production to ensure maximum harvest efficiency, yield, and quality. These activities include applying harvest aids with consideration given to plant developmental stage, water and nitrogen status, crop maturity, weather, chemicals used, and timing.

harvest aids. Chemicals with various modes of action that facilitate machine harvest by influencing boll opening, reducing the amount of foliage retained on plants at harvest, speeding tissue desiccation, and controlling regrowth.

hormone. A naturally produced, specialized chemical in plants that has the ability to influence the occurrence of and rate of specific metabolic functions. Some hormones can also be synthetically produced or extracted for exogenous applications to plants for specific purposes.

indeterminate. General growth habit of plants in which the main stem continues to elongate indefinitely without being limited by a terminal inflorescence. The term is used as a relative description in cotton flowering and fruiting. See **determinate.**

lint. The fiber that constitutes one of the harvestable products of cotton (the other product is cotton seed for cottonseed meal and by-products such as cottonseed oil).

micronaire. Characterization of the fineness and maturity of cotton fibers; a standard fiber quality test as part of the high volume instrumentation (HVI) testing done by the U.S. Department of Agriculture, Agricultural Marketing Service. The micronaire test uses a controlled stream of pressurized air that is forced through a standard weight of cotton fibers placed in a holder and compressed to a known volume. Micronaire readings are relative measures of weight per unit length or cross-sectional size of the fibers. Optimal ranges of micronaire are set by marketers of cotton. Too high a reading can indicate coarse fibers; too low generally indicates immature fibers. Either of these conditions can result in a discount in the value of the crop.

module. An in-field storage system used for harvested cotton. Modules are made using hydraulic-ram systems to pack harvested cotton in densely packed rectangular blocks that are covered to help shed rain. They can be stored in the field or at the gin for extended periods (weeks if necessary) prior to being moved to a gin.

neps. Tightly tangled knotlike masses of unorganized fibers. In cotton, a greater number of neps produces imperfections in yarn and cloth produced from cotton fibers and can reduce value of the finished product.

petiole. The physical stemlike structure that contains vascular (water and food-conducting) and structural tissue and which connects a leaf blade to the main stem or fruiting branch on a plant.

rank growth. In cotton, excess vegetative growth that occurs during later stages of flowering and boll maturation. Vegetative growth may be considered rank if it is vigorous enough in late season to compete with reproductive tissue for nutrients and photosynthate, and if it is likely to significantly delay harvest.

regrowth. Development and expansion of new leaf tissue after earlier-developing leaves have been removed from the plant through natural senescence or through the action of defoliants or desiccants.

second growth. Regrowth; or, the resumption of growth after cutout, resulting in the production of additional nodes, leaves, and late flowers and bolls.

seedcotton. Cotton yield that consists of both seed and lint.

senescence. Plant tissue deterioration that eventually occurs with aging or damage to plant tissue, typically involving changes in both physical and chemical composition associated with metabolic processes or the breakdown of structural components.

square. Cotton floral bud, from the time the bud is first visible up until it bud changes into an open flower.

terminal. The upper part of the main stem of the cotton plant, where there are young developing leaves that are not fully expanded. The terminal contains stem and some young leaves, along with the vegetative and reproductive growing points from which new main stem leaves and new fruiting branches develop.

vegetative cutout. See **cutout.**

References

Bader, M. J., P. E. Sumner, and A. S. Culpepper. 2001. Harvest aid application technology. In: J. R. Supak and C. E. Snipes (eds.), Cotton harvest management: Use and influence of harvest aids. Memphis, TN: The Cotton Foundation Press. 143–166.

Brown, P. W. 1991. Normal values of heat unit accumulation for southern Arizona. Report 190041. Tucson: University of Arizona, College of Agriculture.

California Department of Food and Agriculture, Agricultural Statistics. 2002.

Cathey, G. W. 1986. Physiology of defoliation in cotton production. In: R. Mauney and J. M. Stewart (eds.), Cotton physiology. Memphis, TN: The Cotton Foundation Press. 143–153.

Cothren, J. T., C. O. Gwathmey, and R. B. Ames. 2001. Physiology of cotton defoliation and desiccation. In: J. R. Supak and C. E. Snipes (eds.), Cotton harvest management: Use and influence of harvest aids. Memphis, TN: The Cotton Foundation Press. 21–50.

El-Zik, K., and V. T. Walhood (eds.). 1978. Defoliation and other harvest aid practices: Study guide for agricultural pest control advisors. Oakland: University of California Division of Agriculture and Natural Resources Publication 4043.

Gwathmey, C. O., J. T. Cothren, K. E. Lege, J. Logan, B. A. Roberts, and J. R. Supak. 2001. Influence of environment on cotton defoliation and boll opening. In: J. R. Supak and C. E. Snipes (eds.), Cotton harvest management: Use and influence of harvest aids. Memphis, TN: The Cotton Foundation Press. 51–72.

Hake, S. J., K. D. Hake, and T. A. Kerby. 1996. Preharvest/harvest decisions. In: S. J. Hake, T. A. Kerby, and K. D. Hake (eds.), Cotton production manual. Oakland: University of California Division of Agriculture and Natural Resources Publication 3352. 73–81.

Hake, S. J., T. A. Kerby, and K. D. Hake (eds.). 1996. Cotton Production Manual. Oakland: University of California Division of Agriculture and Natural Resources Publication 3352.

Hutmacher, R. B. 2002. Heat unit averages and time to mature bolls. California Cotton Review 63 (June): 4–6.

Hutmacher, R. B., R. N. Vargas, B. A. Roberts, S. D. Wright and M. P. Keeley. 2002. Defoliation and harvest aid recommendations. Available online from University of California, California Cotton Production Information Web site, http://cottoninfo.ucdavis.edu/images/defoliation.pdf

Kerby, T. A., and D. Bassett. 1993. Timing defoliations using nodes above cracked boll (NACB). California Cotton Review 31 (Sept.):1–3.

Mauney, R., and J. M. Stewart (eds.). 1986. Cotton Physiology. Monograph No. 1. Memphis, TN: The Cotton Foundation.

Morgan, P. W. 1984. Is ethylene the natural regulator of abscission? In: Y. Fuchs and E. Chalutz (eds.), Ethylene: Biochemical, physiological and applied aspects. Boston: Nijhoff/Junk 231–240.

Nooden, L. D., J. J. Guiamet, and I. John. 1997. Senescence mechanisms. Physiologia Plantarum 101:746–753.

Oosterhuis, D. M., R. E. Hampton, and S. D. Wallschleger. 1991. Water deficit effects on the cotton leaf cuticle and the efficiency of defoliants. Journal of Production Agriculture 4:260–265.

Roberts, B. A., R. G. Curley, T. A. Kerby, S. D. Wright, and W. D. Mayfield. 1996. Defoliation, harvest and ginning. In: S. J. Hake, T. A. Kerby, and K. D. Hake (eds.), Cotton production manual. Oakland: University of California Division of Agriculture and Natural Resources Publication 3352. 305–323.

Silvertooth, J. C. 2001. Defoliation of Pima cotton. Report AZ1241. Tucson: University of Arizona College of Agriculture and Life Sciences.

Snipes, C. E., and L. P. Evans. 2001. Influence of crop condition on harvest aid activity. In: J. R. Supak and C. E. Snipes (eds.), Cotton harvest management: Use and influence of harvest aids. Memphis, TN: The Cotton Foundation Press. 73–112.

Stichler, C. R. 2001. Assessing regrowth after defoliation. In: J. R. Supak and C. E. Snipes (eds.), Cotton harvest management: Use and influence of harvest aids. Memphis, TN: The Cotton Foundation Press. 113–118.

Supak, J. R., and C. E. Snipes (eds.). 2001. Cotton harvest management. Memphis, TN: The Cotton Foundation Press.

Walhood, V. T., and F. T. Addicott. 1968. Harvest aid programs: principles and practices. In: Advances in production and utilization of quality Cotton: Principles and practices. Ames: Iowa State University Press. 419–426.

Wright, S. D., R. N. Vargas, B. A. Roberts, and R. B. Hutmacher. 2000. Defoliating the 2000 crop. California Cotton Review 56 (Aug.).

Appendix

Major Harvest Aid Chemicals Used on Cotton in California as of 2002

Chemical name	Common trade name	Application rates in California (a.i. = active ingredient)		Comments
		Product per acre	Pounds of a.i. per acre	
BOLL OPENERS/CONDITIONERS				
dimethipin	Lint Plus	1.25–2.25 pt	0.3125 per application; 0.5626 per acre per year	A formulation of dimethipin used early in boll opening (20 to 40% open) primarily to enhance defoliation of older leaves and improve senescence of younger leaves. Used more as a stand-alone product 1–2 weeks prior to application of openers and defoliants.
ethephon	Ethephon 6 Prep Prep 6 Super Boll others	1.3–2.6 pt	1–2	Not labeled as a defoliant, but may result in defoliation at higher rates or when crop is well prepared for defoliation. Can reduce micronaire and fiber strength if immature bolls are opened when applied. Often combined with defoliant materials such as Def, Folex, Harvade, or Dropp. Is not compatible with sodium chlorate, as the mix can release chlorine fumes. Do not apply if rain is expected within 6 hours.
BOLL OPENERS/ENHANCERS				
ethephon plus AMADS (aminomethan-amide dihydrogen tetraoxysulfate)	Cotton Quik	3–3.5 qt	1.7–2.0	Also an "enhanced ethephon," with ethephon and a synergist to improve defoliation. Defoliation results are generally found to be best with cotton that is cutout, with mature leaves. Limited regrowth control unless mixed with other harvest aids. Do not tank-mix with sodium chlorate.
ethephon plus cyclanilide	Finish-6 Pro	1.3–2.6 pt	1–2	An "enhanced ethephon," with ethephon and a synergist to improve defoliation, particularly of cutout cotton with mature leaves. Also provides regrowth control, but gives best regrowth control in combination with other materials such tribufos. Can be tank-mixed with other materials (with the exception of sodium chlorate). Do not tank-mix with sodium chlorate because the mixture can release chlorine fumes.

Note: [a] As of 2003, not registered for use in California; listed for information purposes only (registration application submitted).
Metric equivalents: 1 oz = 29.57 ml; 1 pt = 0.473 l; 1 qt = 0.946 l; 1 gal = 3.785 l; 1 lb = 454 g

Major Harvest Aid Chemicals Used on Cotton in California as of 2002, cont.

Chemical name	Common trade name	Application rates in California (a.i. = active ingredient) Product per acre	 Pounds of a.i. per acre	Comments
DEFOLIANTS				
carfentrazone[a]	Shark 40 DF[a]	limited experimental data[a]	NA	Relatively limited research experience with this newer (registration pending) material in California. Causes cell membrane damage and has activity as both defoliant and desiccant. Limited research in western U.S. cotton indicates good efficacy on young leaves but little regrowth control. Good activity in weed desiccation.
dimethipin	Harvade Harvade 5F	8 oz	0.306	Under warm conditions with Acala and Pima varieties, defoliation has been best when mixed with crop oil concentrate if used alone, or much better if mixed with organophosphate materials or thidiazuron plus diuron (Ginstar). Dimethipin combined with ethephon products has been a good boll-opening product with Acala cotton in California. Does not give good control of regrowth. Has been reported to be more effective for defoliation as temperatures drop below 70°F (21°C).
dimethipin and thidiazuron[a]	Leafless[a]	12 oz[a]	0.375	Relatively limited experience with this newer material (registration pending) in California. Based on the chemistry of this mixture, it should offer activity as defoliant and for suppression of regrowth. Research indicates good activity in desiccating many weed species.
sodium chlorate	Defol 6 others	0.5–0.75 gal	3–4.5	Can be used as both defoliant and desiccant, based on timing and rate of application. When used at lower rates, for defoliation, is typically less effective than thidiazuron plus diuron (Ginstar) or organophosphate defoliants on Acala and Pima cotton. Higher rates used for desiccation may stick leaves to plants. No major effect on limiting regrowth and is usually ineffective in preparing young leaves for senescence.
thidiazuron	Dropp	0.2–0.4 lb	0.1–0.2	Works well in controlling regrowth and in removing younger leaves.
thidiazuron plus diuron	Ginstar (when used for preconditioning)	4–6 oz	0.047–0.07	This mixture has been shown to have better activity than thidiazuron alone in California tests. Low to medium rates work well under warm to hot conditions and have good activity on young leaves. Highest allowed rates should be used only under cool conditions, as high rates during warm conditions can desiccate and stick leaves. Label allows mixing with ethephon products, but not with tribufos or other phosphate defoliants.
	Ginstar (when used for defoliation)	6.4–16 oz	0.075–0.1875	
tribufos	Def Folex	1.3–2.6 pt	0.93–1.87	Organophosphate-based defoliant. Effective for defoliation in both Pima and Acala cotton, performs well under wide range of crop and environmental conditions. Very good and fairly quick at removing mature leaves. Not effective in regrowth control or in removing younger leaves.

Note: [a] As of 2003, not registered for use in California; listed for information purposes only (registration application submitted).
Metric equivalents: 1 oz = 29.57 ml; 1 pt = 0.473 l; 1 qt = 0.946 l; 1 gal = 3.785 l; 1 lb = 454 g

Major Harvest Aid Chemicals Used on Cotton in California as of 2002, cont.

Chemical name	Common trade name	Application rates in California (a.i. = active ingredient): Product per acre	Application rates in California (a.i. = active ingredient): Pounds of a.i. per acre	Comments
			DESICCANTS	
paraquat	Gramoxone Max	3.7–21 oz	0.086–0.49	Generally considered a desiccant, not a defoliant, since at label rates it rapidly desiccates leaves and can cause them to stick to the plants rather than abscise. Is used to help open mature bolls by causing direct injury, but is not generally applied as a desiccant until after 80% or more of bolls are open if used, as it can prevent further boll development and opening if applied too early. Other crops may be sensitive to paraquat; follow label precautions and control drift carefully.
sodium chlorate ($NaClO_3$)	Defol 6 others	0.5–0.75 gal	3–4.5	Can be used as a desiccant or defoliant. Is effective in combination with paraquat to desiccate young leaves and regrowth prior to harvest. Has advantages of low cost, relatively low mammalian toxicity for applications near dwellings and public buildings, and less damaging to some other crops than paraquat. Check label for plant-back restrictions.
			REGROWTH INHIBITORS/OTHER CHEMICAL ACTIVITIES	
endothall	Accelerate	0.5–1.5 pt	0.0325–0.097	Usually considered an "additive" material rather than a true desiccant or defoliant. It can be added to sodium chlorate or to organophosphate defoliants (Def, Folex) to increase the rate of early leaf drop, but used alone it is not effective.
glyphosate	Roundup Ultra Max others	13–52 oz	0.5–2.0	Should not be applied to cotton grown for seed, as seed quality and germination percentage will be affected. Has been tested in California and elsewhere and worked well as a pretreatment applied 7–14 days prior to defoliation to improve regrowth control, enhance defoliation, and control some late-season weeds. Western U.S. data indicates that if applied when close to 40–50% bolls are open, it can provide regrowth control with little impact on yields or fiber quality.
			ORGANIC COTTON DEFOLIANTS AND DESICCANTS	
magnesium chloride zinc sulfate zinc sulfate plus Chilean nitrate zinc plus citric acid	available as fertilizer materials from various suppliers	rates vary with producers; rates not established in UC trials		Under limits for certified organic production, these materials can be applied only if the soil is deficient in these minerals, so application and rates may be limited at some locations. Magnesium chloride can leave a brown granular residue on the lint, which can reduce lint grade and value. None of these chemicals used alone works well in promoting leaf drop and desiccation. This can result in significant amounts of leaf trash and high moisture content in picked cotton, which can limit allowable storage time in modules and can cause staining and decomposition problems.

Note: [a] As of 2003, not registered for use in California; listed for information purposes only.
Metric equivalents: 1 oz = 29.57 ml; 1 pt = 0.473 l; 1 qt = 0.946 l; 1 gal = 3.785 l; 1 lb = 454 g