COTTON HARVEST MANAGEMENT:

Use and Influence of Harvest Aids

NUMBER FIVE
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The Cotton Foundation

Edited by
James R. Supak
and Charles E. Snipes

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The Cotton Foundation

THE COTTON FOUNDATION

Reference Book Series

The Cotton Foundation is dedicated to the advancement and economic viability of the cotton industry. Created in 1955 to foster innovative research and education, the Foundation is supported by membership dues and special grants from commercial agriculture. Members include many of North America's finest manufacturers and suppliers of machinery, crop protection products, seed, diagnostic equipment, consulting and financial services, trade media, processing materials, and other inputs used to enhance cotton production, processing, and marketing.

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5. ***Cotton Harvest Management: Use and Influence of Harvest Aids***

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The CDWG, in 1992, implemented a research protocol guided by a single objective:

> **To develop effective, contemporary harvest-aid recommendations that contribute to harvest efficiency and high-quality fiber, by evaluating performance of standard defoliation treatments on a uniform basis and relating this performance to biotic and environmental factors.**

In essence, the CDWG was striving to bring a higher level of science and technology to the art of defoliation. Over the following five years, the CDWG continued to refine and improve its research protocols. The knowledge gained from the effort annually has been applied on-farm and in the marketplace through state-by-state recommendations from the researchers and Extension specialists who participated in the CDWG. The group continues to operate as a self-sustaining entity, gaining funding from commercial companies for uniform testing of various harvest-aid materials and tank mixes.

Administration of the CDWG and budgets to facilitate annual meetings has been and continues to be underwritten by Uniroyal Chemical, a longtime supplier of crop protection products to the cotton industry. Uniroyal Chemical is a leading worldwide manufacturer of agricultural and specialty chemicals and polymers, serving customers in 120 countries. The company's products are used in many markets, including agriculture, rubber processing, plastics, paints and coatings, petroleum, and construction.

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FOREWORD AND DEDICATION

The production of cotton has fascinated and intrigued many for generations. The more effort put into controlling the growth and production of this perennial plant, typically grown as an annual, the more it seems in control.

Man often humanizes inanimate objects. We do this for the cotton plant, either affectionately or with disgust: We commonly refer to cotton as "King Cotton" – does this indicate its upper hand in our motivations?

At one point in history, it could have been said that cotton had us Southerners thinking we could go it alone – without the North. Our struggle to perfect the production of cotton often has left us confounded, except to say that the very nature of cotton production is "to beat it before it beats you."

This certainly is the case during the production phase commonly referred to as defoliation. More appropriately termed crop termination, defoliation is the procedure in which a chemical product, or harvest aid, is applied to cotton at an appropriate physiological stage to remove or desiccate leaves and immature fruiting structures to avoid their interference with harvesting and ginning procedures. As late as the mid 1980s, chemical crop termination using various harvest aids largely was considered an art.

The practice of crop termination came into vogue with the advent of the mechanical harvester during the 1950s. The nature of this practice required the reduction or desiccation of leaf material and foreign matter prior to the harvesting process to minimize negative effects on quality of the finished commodity.

As harvesting practices improved with larger and faster machines, the need for harvest aids intensified. Along with improvements in harvesting, ginning procedures were developed that also emphasized the need for proper preparation of the crop prior to harvest. Today, with earlier-maturing varieties, even faster harvesting and ginning procedures, modules for storage, escalating production costs, and increased scrutiny in the consumer market, emphasis on crop termination has made it one of the most perplexing and difficult decisions a grower faces.

"Defoliation" has become a practice used to capture crop yield and quality produced during the growing season and to ensure timely harvest. The practice is part of an overall effort to meet the demands of a marketplace that requires ever-increasing standards in order to maintain a competitive edge in a global marketplace.

The nature of the cotton plant and the environment in which it is grown often makes the process of crop termination unreliable; it is difficult to predict the effectiveness or outcome of a chemical harvest-aid application.

In the mid to late 1980s, research in the area of chemical termination often was secondary to other factors and relied more on "hearsay" than on actual research results. The wide range of environmental conditions across the Cotton Belt resulted in inconsistent conclusions about similar practices. The "Art and Science of Defoliation" largely was art, with little science. The limited number of products available for the practice with various limitations for effective chemical termination contributed further to the indecisive nature of crop termination.

Concerns about the imperfect nature of the chemical crop termination process were confounded further with the introduction of High-Volume Instrumentation (HVI) for fiber-quality analysis. Such analyses heightened awareness of the need for more reliable information concerning the effects of harvest aids on fiber quality.

At an informal meeting on defoliation and crop termination early in 1991, a group of cotton specialists and researchers voiced a concern over the inexact nature of defoliation. The need for a uniform assessment of defoliation practices was recognized. This need fostered what has become known as the Cotton Defoliation Work Group (CDWG). The Group's well-planned, uniform approach over a five-year period has provided a benchmark for harvest-aid assessment.

This monograph, ***COTTON HARVEST MANAGEMENT: Use and Influence of Harvest Aids***, is, in part, the culmination of the CDWG's original effort in a form that will be useful to the entire cotton industry. It is intended to be a resource guide for growers, consultants, and industry professionals, as well as a comprehensive resource for academic institutions.

Many people made significant contributions to this effort; they are to be commended for their hard work. However, it was through the commitment of Dr. James Supak of Texas A&M University that this Monograph became reality. His leadership of and mentorship to a diverse group of cotton researchers and Extension professionals was the common thread that bound the group. It is with deep appreciation and fond affection that the CDWG dedicates this work to Dr. Supak on the occasion of his retirement after 31 years of devoted service to the cotton industry.

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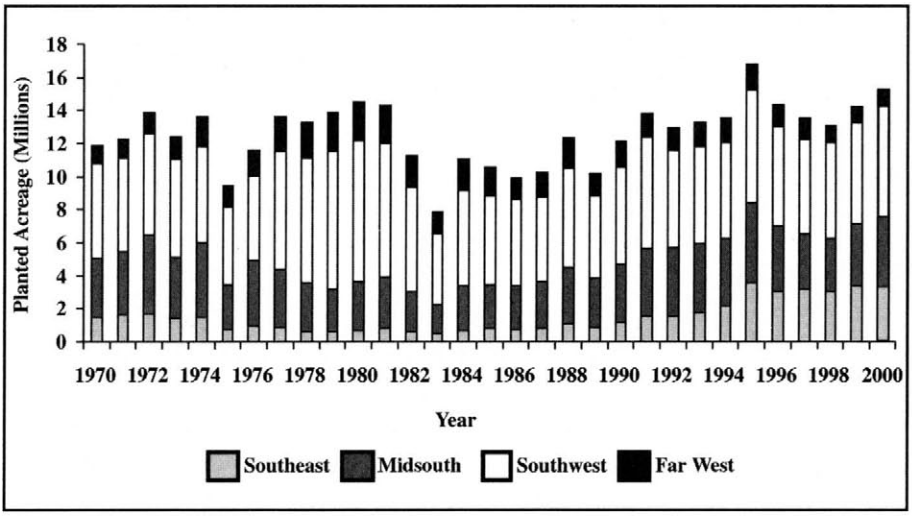
PREFACE

EVOLUTION OF COTTON HARVEST MANAGEMENT

For thousands of years, cotton has been grown widely for use in the manufacturing of domestic textiles. Over time, cotton culture evolved from gathering of the lint and seed from wild plants by indigenous people to the domestication and cultivation of selected species to provide textiles for people in organized agricultural societies. Innovations and improvements in textile manufacture led to increased demand for cotton fiber; as a result, acreage expanded and much progress was made in cotton culture. Presently, cotton is the primary cash crop for many farming operations throughout the world. It is among the most important agricultural commodities produced in the United States, with a recent high of 16.7 million planted acres in 1995 (Figure 1).



Source: Evans, 2000, and Anonymous, 2001.

Figure 1. U.S. upland cotton planted acreage by region, 1970-2000.

Cotton often is viewed as a labor-intensive, high-input crop with harvesting usually regarded as the single most expensive and labor-intensive operation associated with its production. Indeed, even today, about 75 percent of the cotton produced in the world is harvested by hand, one boll at a time. For more than 50 years, mechanical cotton pickers and strippers have provided viable alternatives to hand harvesting. Their rapid acceptance in the United States and elsewhere is attributable in part to the development of harvest-aid materials, which condition and prepare cotton for mechanical harvesting. The purpose of this monograph is to review the biological, environmental, economic, cultural, and societal factors that affect the art and science of cotton defoliation.

UNIQUE ATTRIBUTES OF COTTON

Botanically, cotton is a perennial shrub that originated in the relatively arid tropical and subtropical regions of Africa, the Americas, Australia, the Middle East, and elsewhere (Lewis and Richmond, 1968). Presently, it is grown mostly as an annual crop in environments that range from arid to tropical, with relatively long to very short growing seasons. Cotton typically requires a growing season of more than 160 days when minimum temperatures are above 60 F (15 C) (Waddle, 1984) to produce economically acceptable yields of lint and seed.

In the U.S. Cotton Belt, environments range from the arid West to the Rain Belt of the Midsouth and Southeast. Connecting the two extremes are the subtropical production area of South Texas and the relatively dry, short production seasons of the Southern Plains in Texas and Oklahoma. Growers on the northern fringes of the Cotton Belt, including Kansas and Virginia, also are challenged by short growing seasons.

Cotton is grown as an annual crop, leading to challenges in production management, especially harvest-aid management. Because of cotton's indeterminate growth habit, fruit and leaves do not mature uniformly. Consequently, uniform defoliation and boll opening depend on many factors, including crop and environmental conditions, timing of treatment applications, and the harvest-aid materials used.

The adoption of mechanical harvesting in the United States had a tremendous impact on the need for chemical defoliation. In 1947, 98 percent of the U.S. crop was handpicked or hand-snapped (Fortenberry, 1956). In 1957, only 68 percent was hand-harvested; and, by 1970, 98 percent of the crop was machine-harvested (Ghetti and Looney, 1972). The development of harvest aids in the 1940s and 1950s largely enabled this rapid transition from hand to mechanical harvesting (see Chapter 1).

EARLIER HARVEST

The ultimate goal of harvest-aid use is to protect the quality of the fiber and seed by enabling earlier harvest, in order to reduce field weathering losses, minimize trash content and staining of the lint, and allow for safe storage of seed cotton in trailers and modules. Harvest aids accelerate the physiological processes that induce or contribute to one or more of the following:

- Boll opening
- Removal of mature leaves
- Removal of immature leaves
- Regrowth suppression or inhibition
- Leaf desiccation (required for stripper harvest)
- Desiccation of weeds

Timely harvest of the most valuable fruit (generally the bolls on the lower one-half to two-thirds of the plants) allows the grower to capture much of the yield and quality potential of the crop. Economic value of the fiber is determined by its color, foreign matter content (trash), fiber length, strength, micronaire, and, possibly in the future, other traits, including fiber uniformity and maturity. The proper use of harvest aids primarily affects color and foreign-matter content.

Harvest aids also enable growers to better manage harvesting operations. Individual fields can be prepared and scheduled for harvest to accommodate equipment (farmer-owned or custom-operated) and manpower capacity and availability. Movement of equipment can be minimized by ensuring entire fields uniformly are ready for harvest. Seed cotton can be stored safely in modules, making harvesting operations independent of gin capacities.

SCIENCE COMPLEMENTS ART

Since the introduction of harvest aids, their successful use has been dependent in part on "art" and in part on science. Like the rest of the crop-protection industry, harvest-aid chemistry has changed dramatically in the last 50 years; today, producers have a relatively small, but effective, assortment of products to select from. The use of desiccants and defoliants has been explored and tested since the 1930s (Smith, 1950; Cathey, 1986; Walhood and Addicott, 1968), and harvest-aid management continues to be improved through application of scientific findings. Seasonal assessments of crop and environmental conditions, which constitute essential components of successful cotton harvest-aid programs, still are based largely on human judgement. However, computer-driven models and other techniques based on crop development now are available to assist growers with crop termination decisions.

The application of harvest-aid materials helps to terminate the crop and facilitate harvest scheduling. Improper choice or use of harvest-aid materials – or harvest-aid failures – can reduce quality and, ultimately, the economic value of the crop. Failures also increase costs, because of the need for re-treatment once an initial application has been deemed unacceptable. Ideally, for picker harvest, the harvest-aid treatment selected will promote boll opening and defoliate the entire plant with minimal drying or desiccation. For stripper harvest, high levels of boll opening and defoliation also are desirable, but complete desiccation of remaining green leaves is essential.

Successful harvest-aid performance depends on weather conditions, crop condition, and inherent properties of the materials used. Certain harvest aids have weaknesses that preclude their use under some conditions (e.g., cool temperatures). It has been determined that combinations of two or more harvest aids often provide a suitable hedge against the fallibility of single-product applications.

COTTON DEFOLIATION WORK GROUP

In 1992, a process was developed to uniformly assess harvest-aid performance under a wide range of cultural and environmental conditions. Initially formed as an ad hoc assembly of scientists interested in improving the predictability of harvest-aid practices, these cooperators agreed to form the Cotton Defoliation Work Group (CDWG), which planned, directed, and conducted an active, structured research effort. During the following five years, the CDWG developed a significant database of harvest-aid performance across the U.S. Cotton Belt. The National Cotton Council funded this multistate effort the first year; Cotton Incorporated continued funding in subsequent years. Operations of the CDWG were facilitated with support from Uniroyal Chemical.

The CDWG recognized that standardized practices and protocols were required in order to attain clearer understanding of boll opening, defoliation, and desiccation processes and to further complement the "art of defoliation" with science. The knowledge gained and the database generated during the course of the five-year project was used by CDWG members and others to develop or update numerous state and local harvest-aid guides for use by producers, consultants, certified applicators, and others. In addition to the crop production aspects of the research, the CDWG's efforts also documented that the proper use of harvest-aid materials has no adverse effects on fiber quality (Chapter 7; Anonymous, 1999).

There is a continuing need to evaluate new products and alternatives to current defoliation programs to ensure optimum harvest-aid performance and minimal impact on fiber quality. Procedures developed by the CDWG provide a proven format for conducting such evaluations at multiple locations across the entire U.S. Cotton Belt. In addition to product performance, findings from these trials also address concerns by cotton processors about possible detrimental effects of harvest aids on fiber quality (Anonymous, 1999).

The CDWG continues to operate as a self-sustaining, industry-supported entity; it comprises cooperators who are affiliated with state land grant institutions to ensure integrity of the research. The stated research objective of the CDWG is:

> **To develop effective, contemporary harvest-aid recommendations that contribute to harvest efficiency and high-quality fiber, by evaluating performance of standard defoliation treatments on a uniform basis and relating this performance to biotic and environmental factors.**

MONOGRAPH HIGHLIGHTS

The content appearing in the chapters of this Monograph was developed or supervised by members of the CDWG. Topics range from a history of cotton harvest aids to the economic impact of cotton defoliation to public and environmental issues.

CHAPTER 1 - A HISTORY OF COTTON HARVEST AIDS

Mechanical harvesting of cotton is a relatively new concept. The scarcity of labor during World War II played a large role in the transition from handpicking to machine harvesting. Mechanical harvesting also required chemical defoliation, with the 1938 commercial introduction of calcium cyanamide leading the way. Within 25 years, the transition from hand to mechanical harvest essentially was complete in the United States and other developed countries.

CHAPTER 2 - PHYSIOLOGY OF COTTON DEFOLIATION AND DESICCATION

An understanding of cotton growth and development is necessary to fully appreciate the physiological mechanism of defoliation. Perhaps the greatest challenge in dealing with cotton is its growth habit. Cotton is an indeterminate, deciduous perennial grown as an annual. The plant has a natural mechanism to shed mature leaves, although shedding is not necessarily synchronized with the most appropriate time to harvest lint. Hence, the need exists for harvest-aid technology for timely and efficient harvest, field storage, and ginning.

CHAPTER 3 - INFLUENCE OF ENVIRONMENT ON COTTON DEFOLIATION AND BOLL OPENING

The results obtained from the use of harvest aids on cotton are among the least predictable of the operations a farmer may perform (Cathey and Hacsklaylo, 1971). Factors influencing harvest-aid performance include weather conditions, spray coverage, and absorption and translocation of the materials, all of which are influenced by the environment. The chapter summarizes knowledge about environmental effects on harvest-aid performance and provides perspectives from different regions of the U.S. Cotton Belt.

CHAPTER 4 - INFLUENCE OF CROP CONDITION ON HARVEST-AID ACTIVITY

Although environmental factors have a significant impact on crop termination, crop condition can influence the success or failure of a harvest-aid decision. By applying sound management decisions throughout the growing season, growers can improve the likelihood of successful crop termination in the fall. This chapter explores how the efficacy of harvest aids is influenced by growth habits of the cotton plant and the agronomic practices and decisions made during the growing season.

Assessing Regrowth After Defoliation – A supplement to the chapter offers assessment criteria for rating cotton regrowth after application of harvest aids.

CHAPTER 5 - HARVEST-AID TREATMENTS: PRODUCTS AND APPLICATION TIMING

Harvest aids are applied to enhance boll opening, facilitate leaf removal, or desiccate the crop prior to mechanical harvest. Benefits of this process include a more efficient harvest of a mature crop and a preservation of yield and fiber quality. When cotton is properly treated, ginning efficiency also is enhanced. This chapter discusses different types of harvest aids and their applications and advantages.

CHAPTER 6 - HARVEST-AID APPLICATION TECHNOLOGY

Regardless of harvest-aid type, accurate application to the plant for uptake through the stomates and by penetrating the leaf cuticle is critical to success of the operation. Application decisions largely are based on crop maturity, crop condition, weather conditions, desired harvest schedule, and harvest-aid choices and rates. In addition, adjuvant usage, spray volume and pressure, physical drift, and application equipment are critical aspects that must be considered prior to use of cotton harvest aids.

CHAPTER 7 - UNIFORM HARVEST-AID PERFORMANCE AND LINT QUALITY EVALUATION

Successful cotton production largely depends on the proper use of harvest-aid products designed to defoliate plant leaves, accelerate boll opening, enhance seed cotton drying in the field, and, in some cases, desiccate green plant material. Harvest aids are needed to maintain the highest fiber quality possible by facilitating timely harvest and reducing plant trash created by mechanical harvesting procedures. This chapter provides an analysis and discussion of lint quality (foreign matter, color, strength, maturity, and neps) related to the harvest-aid treatments from the five-year study conducted by the CDWG.

CHAPTER 8 - FACTORS INFLUENCING NET RETURNS TO COTTON HARVEST AIDS

Because of frequent fluctuations in prices and profitability, producers are concerned about reducing the cost of production (Anonymous, 1998). One input that may improve net returns for cotton farmers is applying a harvest aid, at the correct timing, prior to harvest. The purpose of this chapter is twofold: 1) to identify some of the factors that may influence the costs and returns to alternative harvest aids, and 2) to analyze the costs and returns for selected harvest-aid treatments from the five-year field study conducted by the CDWG.

CHAPTER 9 - OVERVIEW OF REGIONAL DEFOLIATION PRACTICES

Cotton production and management practices, such as defoliation, vary significantly across the U.S. Cotton Belt. The five-year study conducted by the CDWG applied a standardized protocol to field research, which recognized and evaluated regional variations in environmental and crop growing conditions. These variances and a summary of the standard and regionally specific treatments evaluated by the CDWG are presented in four segments of this chapter. The regions include the Southeast, Midsouth, Southwest, and Far West. The chapter segments also address variances in harvest-aid use within regions – particularly northern versus southern locales.

CHAPTER 10 - PUBLIC AND ENVIRONMENTAL ISSUES

Many individuals and groups in the United States have developed strong concerns about the potential social, economic, and environmental issues modern U.S. agriculture can raise that relate to food safety, air and water quality, and solid waste. These concerns have resulted in passage of numerous state and federal regulations that affect crop protection, including product use and availability, emissions from processing facilities, and disposal of wastes. Additional issues currently are emerging; others undoubtedly will surface in the future. These issues have affected – and will continue to affect – U.S. farmers and farm economies, as well as those of allied industries. Producers must be knowledgeable of potential problems and concerns and must work to minimize downstream effects. Inappropriate practices, or even inattention, could hurt the availability of agricultural products – including harvest aids – and the U.S. cotton industry as a whole.

CHAPTER 11 - COTTON HARVEST AIDS AND BIOTECHNOLOGY: THE POSSIBILITIES

Use of genetically modified crops has grown dramatically over the past five years; they have revolutionized crop production. Recent advancements in cotton biotechnology predominately have been in the area of transgenic varieties possessing such characteristics as herbicide and insect resistance. Little biotechnological advancement has occurred in the area of cotton harvesting; however, many plant processes lend themselves to genetic modification for the improved efficiency of cotton harvest aids. This chapter discusses how biotechnology can be used to modify plant processes and the potential role of biotechnology in cotton harvesting in years to come.

FUTURE DIRECTION AND NEEDS

The successful development and introduction of new products and technologies for cotton production have advanced the industry in the past and will continue to do so in the future. Challenges to this effort, however, will be significant. Meeting the research and development needs of a vibrant, output-oriented cotton industry will be complicated compared to the previous three or four decades.

Capitalizing public and even private research will become an even bigger issue in the future than it is today. Therefore, it is incumbent on growers, consultants, manufacturers, and others in production agriculture to become better stewards of the products currently available. The industry must keep the present products in the marketplace for the indeterminate future, because higher costs of development and registration, resulting from increased and more restrictive government regulations, have narrowed the pipeline for new products considerably.

New technologies, especially biotechnology, are essential for agriculture to prosper and for the industry to meet the needs of a rapidly growing global population. From the U.S. perspective, bringing these new technologies into production agriculture must add value by decreasing production costs, increasing production, enhancing fiber qualities, and contributing to a safer environment and workplace.

The information age created by a proliferation of the Internet technology platform throughout everyday life provides a conduit for educating and training all audiences, from growers to consumers. It is incumbent on the research and Extension communities, and on the private sector, to educate and train all audiences as advances in agricultural technologies are transferred to the marketplace. The CDWG will participate actively in meeting research-based information needs. This Monograph underscores that commitment.

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Chapter 1

A HISTORY OF COTTON HARVEST AIDS

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INTRODUCTION

Mechanical harvest of cotton is a relatively new concept with little more than 100 years lapsing from the time the first cotton-harvesting machine was developed until it almost entirely replaced manual harvesting.

Cotton harvesters are classified into two broad groups or machine types: pickers and strippers. The first patent for a mechanical cotton picker was granted to S.S. Rembert and J. Prescott of Memphis, Tennessee, on Sept. 10, 1850. In 1895, August Campbell obtained a patent on a spindle that provided the basic principle for the barbed-spindle widely used on modern-day cotton pickers. John and Mack Rust were granted a patent in 1932 on a cotton picker that used a straight, moist spindle (Colwick *et al.*, 1965).

Variations of these spindles were used widely on picker harvesters to selectively remove the seed cotton from open bolls, while burs, unopened bolls, leaves, and other plant components remain attached to the plant. Attempts were made to commercialize mechanical cotton pickers on the heels of these early developments, but widespread acceptance of this harvest technology did not occur until the 1940s and 1950s.

Z.B. Sims, a Bonham, Texas, cotton producer, obtained a patent for a horse-drawn sled (finger-type) stripper in 1872. In 1874, W.H. Pedrick of Richmond, Indiana, patented a stripper using studded revolving rolls, and, in 1884, Benjamin Savage of Scotland Neck, North Carolina, patented a roll stripper with brushes that could be made from wire, hair, steel, or whalebone. Brown and Ware (1958) reported that, in 1914, an unidentified farmer used a sled-type stripper (made by attaching a section of a picket fence to a sled) in the first attempt to strip cotton on the Texas High Plains. Subsequently, farmers and local shops developed horse-drawn cotton sleds. Concurrently, gin manufacturers developed extracting and cleaning equipment that enabled sledded cotton to be ginned and cleaned (Hudspeth, 1977; Sutton, 1984).

Both finger and roll strippers are once-over, nonselective harvesters that remove seed cotton as well as burs, remaining leaves, and portions of stems and branches from the plants. These machines were better suited than were the spindle pickers for harvesting the dryland, short-stature cotton typically produced in the Southwest. Although many refinements were made in finger and roller strippers after their introduction (Kirk *et al.*, 1964; Schroeder and Porterfield, 1954; Smith *et al.*, 1935), low cotton prices, abundant hand labor, harvest losses with the machines, inadequate gin cleaning equipment, and lack of effective harvest aids (primarily desiccants) delayed their widespread acceptance until after World War II.

World War II was pivotal in the developmental process of mechanical harvesters, as the scarcity of labor during wartime forced farmers to investigate and improve mechanical approaches to harvest their cotton. By 1953, approximately 15,000 mechanical pickers and 25,000 cotton strippers were available, accounting for harvest of approximately 25 percent of the 16 million bales produced. By 1960, this percentage increased dramatically, with nearly

60 percent of the cotton grown in the United States being mechanically harvested. Today, virtually all cotton in the United States is mechanically harvested.

The accelerated interest in mechanical harvest was paralleled by increased research relating to the development and use of harvest aids. Studies confirmed that defoliation often was needed to maintain fiber quality and improve picker-harvester efficiency, whereas desiccation was the primary prerequisite in preparing cotton for stripping (Walhood and Addicott, 1968; Williamson and Riley, 1961).

The following is a brief discussion of some of the many chemical defoliants and desiccants developed, tested, and accepted or rejected during the commercial application stage. Efficacy, effect on boll or lint quality, environmental concerns, and economic feasibility are among the factors determining individual product success. Information on the history of chemical defoliants will be presented first, followed by discussion of desiccants.

CHEMICAL DEFOLIATION

Before mechanized harvesting replaced hand harvesting in the cotton industry, interest in defoliation as a harvest preparation aid was limited. With hand harvest, there was little concern over contamination of seed cotton by cotton leaves and petioles, because contact with green foliage was minimal. However, in mechanically harvested cotton, the presence of heavy foliage can reduce picker efficiency and add to trash content and discoloration (staining) of lint. Chemical defoliation effectively removes much of the foliage prior to harvesting, allowing a cleaner harvest.

Defoliants commonly are used in conjunction with picker harvesters. Leaf removal can increase picker efficiency, reduce moisture in seed and seed cotton, lessen the potential for boll rotting, and reduce destructive insect populations by eliminating potential food sources.

On occasion, practices referred to as "pre-conditioning" or "bottom defoliation" have been used, primarily in tall, rank cotton, to reduce boll rotting and to induce plant senescence (Walhood and Addicott, 1968; Colwick *et al.,* 1965). The practice may be applied to whole fields or to portions of fields that exhibit excessive growth and delayed maturity. Typically, in pre-conditioning, defoliants or ethephon-based products are applied at reduced rates to accelerate shedding of mature leaves and induce senescence.

Because of rank growth and wet field conditions, pre-conditioning treatments usually are applied by air. When feasible, ground applicators are used to direct the applications at the lower portion of the plants, commonly referred to as "bottom defoliation." Elimination of the mature foliage near the bottom of the plants allows better light penetration and reduced humidity levels within the plant canopy. Results of pre-conditioning and bottom defoliation often are inconsistent, because of unpredictability, resulting in either poor or excessive defoliation.

The major limitations of using chemical defoliants include added production costs and inconsistent responses in the field. The effectiveness of a defoliant depends on many factors, such as timing and rate of application, type of tank mixtures, crop and environmental conditions, and effectiveness of coverage.

Typically, defoliants will not substitute for desiccants in the preparation of cotton for mechanical stripping except under ideal circumstances. Because stripper harvesters collect extraneous plant materials (burs, leaves, portions of limbs, and stems) along with the lint and seed, complete desiccation of plant tissues is desirable prior to harvest (Miller *et al.*, 1980).

CALCIUM CYANAMIDE

In 1938, calcium cyanamide (Aero Cyanamid, Special Grade) became the first commercially available cotton chemical defoliant. Like many discoveries, the defoliating property of calcium cyanamide, regionally known as "Black Annie," was identified in a circuitous manner. For several years, scientists at South Carolina's Pee Dee Experiment Station had noted that mature cotton defoliated when pulverized calcium cyanamide, which was being evaluated as fertilizer, drifted onto dew-wet cotton foliage. Experimentation with this observation revealed that, under favorable conditions, a dusting grade of the calcium cyanamide effected reasonable defoliation within 7 to 10 days after application of 10 pounds per acre.

Despite the benefit of chemical defoliation, calcium cyanamide remained the only commercially available defoliant for at least 10 years after its introduction. However, in 1942, the first large-scale defoliation research effort was initiated at the Delta Branch Experiment Station near Stoneville, Mississippi. As a result, ammonium thiocyanate (no trade name), monosodium cyanamide (Aero Sodium Cyanamid Dust), and potassium cyanate (Aero Cyanate Weed Killer, Orchard Brand Potassium Cyanate Cotton Defoliant) were introduced as dust defoliants in the late 1940s. These materials did not achieve wide acceptance, probably because of lack of efficacy or economics, and calcium cyanamide remained the only widely used defoliant in the United States into the mid 1950s.

AQUEOUS SPRAYS

In the 1950s, chemical defoliation research efforts focused on the development of aqueous sprays because of the disadvantages of using the dust form. Dust defoliants were bulky, difficult to apply uniformly, dependent on dew for retention and activation on the cotton plant, and highly susceptible to drift. Aqueous spray defoliants introduced during this era included sodium chlorate combined with fire suppressants such as borate (Chipman's Defoliant, Ortho C-1 Defoliant, and several more trade names), magnesium chlorate (De-Fol-Ate), and sodium ethyl xanthate (S.E.X.).

For reasons that were not made clear in early literature, only the chlorates became widely used as cotton harvest aids. Sodium chlorate, sometimes called "salt water," was the most efficacious of these materials; an industrial byproduct, sodium chlorate was available in large supply at relatively low cost.

First used in 1948, the mode of action – chemically induced leaf injury, which stimulated etheylene production in the plant and accelerated leaf abscission – was the predominant reason for sodium chlorate's attractiveness to the grower (Walhood, 2000; Walhood and Addicott, 1968). Later research identified the plant's response to chemical-induced injury and led to the discovery of abcissic acid as a major plant growth hormone. Sodium chlorate remains popular in the United States as a defoliant where it can be used on limited-input, low-yielding picker cotton and as a desiccant in mixtures with paraquat. Sodium chlorate and paraquat mixtures are used extensively in the Far West as defoliation treatments where restricted materials cannot be applied. These materials also are applied as desiccants, following earlier defoliation treatments in preparing Acala™ varieties with high levels of tolerance to *Verticillium* wilt and Pima cotton for harvest in the arid Far West.

Magnesium chlorate often is applied in other cotton-growing regions of the world, particularly where tribufos (Folex® and Def®) is not used. The chlorates defoliate mature foliage, even in relatively cool weather; however, they are inconsistent at removing juvenile foliage and are ineffective for regrowth inhibition. Chlorates also tend to desiccate a higher proportion of foliage than other commonly used defoliants.

An aqueous spray, amino triazole (AMIZOL®), was marketed in 1955 and was hailed as the only chemical known to control second growth in cotton. It also was found to improve the efficiency of other defoliants when used in tankmix combinations.

TRIBUFOS AND SODIUM CACODYLATE

Phosphate defoliants containing tribufos, Folex and Def, were introduced in the 1960s, as was the arsenical defoliant, sodium cacodylate, first marketed as Bolls Eye® and later as Quick Pick®. The phosphate defoliants rapidly gained wide acceptance by producers because of their efficacy, consistency of performance, and relatively low application rates. Tribufos was, at its introduction, the most successful harvest-aid development to date. While it no longer holds the level of prominence that it once did, many authorities regard tribufos as the single most versatile harvest aid used in U.S. cotton. Sodium cacodylate, on the other hand, never achieved prominence in the U.S. defoliant market, although it still is available commercially.

THIDIAZURON AND DIMETHIPIN

In 1975, two new candidate defoliants, thidiazuron and dimethipin, from unique and divergent chemistries, were introduced for evaluation in public research trials. These materials were federally labeled and introduced commercially in 1982.

Dimethipin, developed by Uniroyal Chemical, and marketed as Harvade® 5F, has proven to be essentially equivalent to tribufos in terms of defoliation, active at approximately 25 percent of the rate of the phosphate material. It also is effective as a broadleaf weed desiccant, particularly for annual morningglory (tie vines). Dimethipin is efficacious over a wide range of temperatures and is most effective in harvest-aid tank mix combinations. In 2001, Uniroyal Chemical also released a new formulation of dimethipin (marketed as LintPlus™). This product is being targeted for use primarily as a conditioner in preparing cotton for subsequent harvest-aid treatments (see following section).

Thidiazuron, initially developed by Nor-Am Chemical Co. and now marketed by Aventis Group, is sold under the trade name Dropp®. Thidiazuron also is marketed as FreeFall™ by Griffin LLC. Like Harvade, thidiazuron is active at extremely low rates, compared to phosphate defoliants. Rates of 0.2 to 0.4 pound of product (0.1 to 0.2 pound a.i.) per acre are used when the compound is applied alone; thidiazuron is used at even lower rates in combinations with other harvest aids. The compound is most active as a defoliant under warm, humid conditions. It is unique in its greater activity in defoliation of green, actively growing foliage than on more mature and senescent foliage. It also is unique among defoliants in that it inhibits terminal regrowth and provides some suppression of basal regrowth after defoliation.

An added benefit of both of these new-generation defoliants is their lack of odor and irritant properties. This has proven to be an important advantage, especially in treating fields located near populated areas.

ETHEPHON

In 1981, without much fanfare and with little advance notice, Union Carbide Agricultural Products Co. secured federal registration for ethephon, an ethylene-releasing plant growth regulator, for stimulation of opening of physiologically mature green cotton bolls. The initial formulation labeled for cotton was Ethrel®, a high-cost ethephon product used in tobacco and other specialty crops. In 1982, the second year of registration, Union Carbide introduced Prep™, a formulation of ethephon developed specifically for use on cotton. Later the company introduced another, more concentrated formulation, Prep™ 6 E.C., which now, as a product of Aventis Group, is the standard formulation, simply called Prep™.

In retrospect, the use of a boll opener was revolutionary as a harvest-aid practice, but product use and acceptance grew slowly. Although the potential for ethephon as a boll opener was established in research and demonstration trials across the Cotton Belt, the relatively high cost of the material and the lack of storage capabilities for unginned cotton by growers and ginners at that time impeded grower use of Prep. Rapid acceptance of cotton module field storage and transport systems in the early to mid 1980s reduced growers' storage concerns and encouraged the use of Prep, in conjunction with other harvest aids, to prepare crops for earlier harvest.

In 1986, Rhône-Poulenc Ag Co. absorbed Union Carbide's crop protection business and continued to expand the marketing and use of ethephon. In addition to boll opening, it was demonstrated that use of Prep in tank mixes enhanced defoliation (Snipes and Cathey, 1992). At higher use rates, ethephon also is an effective defoliant, particularly in the removal of physiologically mature foliage. Currently, several additional sources of ethephon are available for use in cotton harvest, including Super Boll® from Griffin LLC, Ethephon 6 from Micro Flo Co., and Boll'd from Agriliance LLC.

CONDITIONERS

Prep is labeled for use at reduced rates to "condition" the crop for subsequent harvest-aid treatments. This practice often is used in tall, rank cotton, and the ethephon is applied 4 to 10 days before normal defoliation applications typically are made. In attempts to "bottom defoliate" rank cotton, low rates of a defoliant also may be tank-mixed with ethephon and applied to lower portions of the plant. After application, ethephon is absorbed into plant leaves, where it is converted to ethylene. In theory, the additional ethylene compliments that already being produced by the plant and accelerates the abscission of mature leaves and opening of mature bolls.

LintPlus, the new formulation of dimethipin released by Uniroyal Chemical in 2001, is intended for use mainly in conditioning cotton for subsequent harvest-aid applications. With this formulation, a relatively low rate of dimethipin is applied to cotton when approximately 20 to 30 percent of the bolls are open, to enhance defoliation of mature, largely non-functional, leaves and to hasten senescence of younger leaves. One to two weeks after the LintPlus treatment, normal use rates of harvest aids are applied to complete boll opening, defoliation, or desiccation of the crop in preparation for harvest.

CARFENTRAZONE-ETHYL

Aim™ (carfentrazone-ethyl) was developed by FMC Corp. and initially registered as a corn, rice, small grains, and soybean herbicide. In 2001, Aim also was labeled and commercially marketed as a cotton defoliant. Aim represents a new class of compounds, commonly referred to as PPO inhibitors, that cause irreversible damage to cell membranes and cell functions in leaves, resulting in their defoliation or desiccation. In addition to Aim, several experimental PPO inhibitors already registered for use as herbicides in other crops currently are being evaluated as cotton harvest aids in research trials.

Research thus far suggests that Aim is a fair to good defoliant when applied alone. The product is more effective when tank-mixed with another defoliant, such as thidiazuron, or with ethephon. It also is effective in removing juvenile growth, but provides little regrowth inhibition. Because it is a herbicide, Aim has excellent weed desiccation activity when used as a harvest aid.

THIDIAZURON MIXTURES

Few commercial developments in cotton harvest-aid technology occurred in the late 1980s and the 1990s. AgrEvo USA Co. introduced a pre-packaged emulsifiable concentrate of thidiazuron + diuron, which uses a special solvent system for improved activity. This product was evaluated in the late 1980s under the trade name Ginstar® 1.5 EC, containing 1.0 pound per gallon thidiazuron and 0.5 pound per gallon diuron. Ginstar was targeted for use as a defoliant in the more arid regions of the U.S. Cotton Belt, including Texas, Oklahoma, New Mexico, and California. Ginstar has proven to provide defoliation superior to that of Dropp in semi-arid and arid environments and under cooler conditions. Ginstar has not been accepted widely in other cotton-production regions because of its tendency to desiccate, rather than to defoliate, foliage. An attempt was made to moderate the desiccating effects of Ginstar by creating a wettable powder formulation with the same ratio of thidiazuron to diuron, marketed under the trade name Dropp® Ultra™. However, grower acceptance of Dropp Ultra was not widespread; the product subsequently was removed from the market.

In 2001, Uniroyal Chemical began marketing a pre-packaged mixture of dimethipin + thidiazuron under the trade name Leafless™. Combination of these two products into a single package helps provide a convenient way to use mutually beneficial compounds to provide good defoliation and regrowth suppression under a relatively wide range of temperatures, and desiccation of weeds, especially annual morningglory.

GLYPHOSATE

During the late 1980s and early 1990s, Monsanto Company broadened existing registrations for glyphosate, marketed in various Roundup® brand formulations, to include pre-harvest applications for cotton. Roundup provides excellent control of several annual and perennial weed species in pre-harvest applications and, in addition, inhibits cotton regrowth. However, because Roundup contributes little to defoliation and boll opening and cannot be used to treat crops grown for seed, it has not been accepted widely as a harvest aid by producers. An additional limitation for Roundup use in the cotton harvest-aid arena has been the development of "Roundup Ready®" cotton varieties, which are resistant to the regrowth-inhibiting properties of glyphosate.

ENHANCED ETHEPHONS

The primary focus of harvest-aid development of the mid to late 1990s has been that of "enhanced" ethephons. Rhône-Poulenc began testing tank mixes of ethephon plus "synergists" in the late 1980s in an effort to expand the activity of an ethephon-based product to include boll opening, defoliation, and regrowth inhibition. Meanwhile, Griffin LLC licensed the enhanced ethephon CottonQuik® that had been developed by Entek Corp. with these same objectives, and introduced it commercially during the 1996 growing season. CottonQuik is a pre-mix of ethephon at 2.3 pounds a.i. per gallon and 1-aminomethanamide dihydrogen tetraoxysulfate (AMADS) at 7.3 pounds a.i. per gallon.

Finish®, a pre-mix containing 4.0 pounds a.i. of ethephon and 0.5 pound a.i. of cyclanilide (1-(2,4 dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid) per gallon, was introduced commercially by Rhône-Poulenc in 1997. This product, currently marketed by Aventis Group as Finish 6, contains 6.0 pounds a.i. of ethephon and 0.75 pound a.i. cyclanilide per gallon.

Neither CottonQuik nor Finish have totally lived up to initial expectations that they would be comprehensive, stand-alone, cotton harvest aids; however, both materials provide greatly enhanced defoliation compared to ethephon alone. Both products perform most effectively when used in combination with other defoliants at reduced rates.

CHEMICAL DESICCATION

Ray and Jones (1960) pointed out the necessity of harvest-aid use, especially desiccants, in areas where cotton was stripper harvested. The use of harvest aids already was becoming more essential in areas where the crop was spindle-picked, because of increases in plant size and a growing emphasis on fiber quality. Prior to and for a few years after World War II, stripper harvesting largely was confined to the High Plains areas of Texas and Oklahoma, where freezing temperatures could be relied on to condition crops for harvest. Hence, there was limited need for cotton harvest aids until adoption of stripper harvesting began to increase in Central and South Texas. Because waiting for a freeze to kill cotton was not a viable option, these producers had to rely on desiccants or other harvest aids to condition cotton for stripping.

The use of desiccants, however, was not limited to the Southwest. By 1968, desiccants were being used on more than 75 percent of the cotton acreage in the United States (Walhood and Addicott, 1968). Although the Southwest region was, and remains, the primary user of desiccants to prepare cotton for stripper harvesting, these products also are used in predominantly picker-cotton production regions, mainly at low rates to complement other harvest aids in tank mixes and to dry leaves and weeds that remain after the use of defoliants.

The advantages of using desiccants include the ability to schedule harvests, increase stripper harvester efficiency, decrease the moisture content of seed and extraneous plant materials, and control weeds. Desiccants essentially are contact herbicides that quickly kill the leaves by causing rapid water loss, but usually leave them attached to the plants. Typically, physiological processes in the plant are disrupted so rapidly and radically that the leaf abscission processes do not have time to occur. High rates of some defoliants (such as sodium chlorate formulations and Folex/Def) applied under high temperature conditions also can result in substantial leaf desiccation.

The rate and extent to which desiccation occurs largely depends on the products used, the environment, and plant conditions. At high temperatures and low humidity, desiccation tends to occur rapidly, especially on plants that are not heavily moisture-stressed. Low temperatures tend to slow the activity and reduce the effectiveness of most harvest aids, including desiccants. The desiccating activity of paraquat is dependent on absorption of the compound by plant tissues and a subsequent light-activated reaction. Consequently, late-afternoon applications of paraquat tend to improve desiccation, especially on drought-stressed cotton.

The number of compounds registered as desiccants for cotton is limited. Over the years, numerous compounds were evaluated, but only three products, pentachlorophenol, arsenic acid, and paraquat, were used widely.

PENTACHLOROPHENOL

Historically, the first desiccant used for cotton was pentachlorophenol (Penta). The *Defoliation Guide* published by the National Cotton Council (Anonymous, 1951) listed pentachlorophenol as an advanced experimental defoliant spray. It was applied with fuel oil, diesel fuel, or kerosene.

Because regrowth often occurs after defoliation and desiccation, considerable emphasis has been placed on products to inhibit this process. Miller and Corbett (1962) examined the possibility of using 2,4-D with pentachlorophenol to enhance desiccation and to prevent undesirable regrowth of green leaves, which interfere with stripper harvest. The ability to suppress new vegetative growth in cotton was one of the major influences of 2,4-D (Ergle and Dunlap, 1949). Unfortunately, 2,4-D applied to the leaves translocated to the immature seed in green bolls (Miller and Aboul-Ela, 1969), which limited the ability of the grower to market the seed or produce seed stocks.

Additional studies were not conducted, as pentachlorophenol was replaced by a more effective and less expensive chemical, arsenic acid.

ARSENIC ACID

Arsenic acid first was sold as a cotton desiccant in 1956. It was the major cotton desiccant for more than 30 years, because it was effective and inexpensive. Arsenic acid was made by reacting trivalent arsenic with nitric acid to yield a 75 percent H_3AsO_4; the compound primarily was used in wood preservatives. The amount of nitric and arsenic acid in the final spray solution typically was less than 0.1 percent. Because of safety concerns related to exposure of textile mill workers to arsenic residues, it was removed voluntarily from the market in 1993 (Environmental Protection Agency, 1993).

However, organic forms of arsenic acid (cacodylic acid; dimethylarsenic acid, EPA Code 012501) still are used, mainly in California. As of 2000, 22 active labels for products containing cacodylic acid and dimethylarsenic were registered for use on cotton in that state (CA EPA). These materials are used as "cleanup" desiccant treatments, following initial defoliation materials. This practice is important for late-season defoliation of upland and Pima cottons.

AMMONIUM COMPOUNDS

According to Walhood and Addicott (1968), anhydrous ammonia induced leaf responses that demonstrated a "desiccant-defoliant" effect. Anhydrous ammonia was released at rates up to 100 pounds per acre into "tunnels" approximately 10 to 12 feet in length and about 3.5 feet in height that were mounted on tractors or "High Boy" sprayers and passed over cotton rows (Elliott, 1967). Maximum effectiveness was obtained when plants filled the tunnels; if the tunnel was too large, much of the ammonia escaped, resulting in poor defoliation.

Treatments needed to be applied to non-stressed plants during sunny conditions, when stomates were open. The leaf blades appeared to be completely desiccated immediately after exposure to the ammonia. But, the petioles and the auxiliary buds in the leaf-stem axis were alive and abscission of leaves typically occurred in 7 to 14 days. By then, however, new leaves (regrowth) already were developing. Equipment and material costs, corrosiveness and toxicity associated with anhydrous ammonia, erratic desiccation and defoliation results, and rapid development of regrowth hindered further development of anhydrous ammonia as a cotton harvest aid.

Ammonium nitrate also was included as a desiccant in the list of harvest-aid chemicals compiled by Walhood and Addicott (1968). This product was registered for use in Arizona and California, but never gained wide acceptance as a cotton desiccant.

PARAQUAT

Paraquat first was marketed as a cotton desiccant and as an additive to defoliants in 1967. For agricultural uses, it is available in varying formulations and marketed under such trade names as Gramoxone® Extra, Gramoxone® Max, Boa®, and Cyclone® Max. Paraquat cannot be classified as a true defoliant, because it desiccates plant tissues and can "stick" leaves, even at relatively low rates (Miller *et al.*, 1978). Paraquat is a quick-acting, nonselective bipyridilium herbicide, which destroys green plant tissue on contact by disrupting photosynthesis. It normally is applied when 80 percent or more of the bolls are open.

The EPA has classified paraquat as a possible human carcinogen and weakly genotoxic, but has concluded that the risks posed to individual applicators are minimal (Environmental Protection Agency, 1987). Because paraquat is absorbed and binds quickly to soil, leaching into water sources is not a problem. However, exposure to the concentrated active ingredient is a concern during mixing and loading sprayers.

SODIUM CHLORATE

Sodium chlorate generally is classified as a defoliant (see previous section), but the compound does have plant-desiccating properties. It frequently is used alone or in combination with paraquat to desiccate residual foliage following the use of defoliants and other harvest aids. The product also is used to some extent as a relatively inexpensive treatment for desiccating drought-stressed leaves on cotton with low yield potential or in proximity of crops sensitive to paraquat (e.g., newly emerged wheat).

SUMMARY

Before mechanization of cotton harvesting, all cotton was handpicked. The average worker needed nearly 100 hours to hand-gather a bale of cotton (Brown and Ware, 1958). Because the crop could be handpicked multiple times and the seed cotton largely was free of extraneous plant materials, there was little need to defoliate or otherwise condition the crop for harvest.

Efforts to develop mechanical harvesters had been ongoing since about 1850, and functional models of spindle pickers and strippers were available by the 1920s and 1930s. But widespread adoption of this technology was hampered by low cotton prices, abundant labor, field losses, and limited ability of cotton gins to gin and clean machine-harvested cotton.

The onset of World War II – and the resultant loss of labor available for handpicking – forced cotton growers to accept and adopt mechanical harvesting. Rapid developments and improvements in pickers, strippers, seed-cotton storage, transport methods, and gin equipment followed. Today, nearly all cotton in the United States is mechanically stripped or picked.

Accelerated interest in mechanical harvest also prompted increased emphasis on the development of cotton harvest aids and research into optimizing their use throughout the Cotton Belt. From these extensive (and still ongoing) efforts, numerous highly effective defoliants and desiccants were identified and commercialized. Most of these are discussed in this chapter.

In recent years, concerns about health, safety, and environmental issues have resulted in the loss of registration for one product (arsenic acid) and increased use restrictions on others. The chemical industry continues to search for and test new chemical formulations, but discovery, development, and registration costs for new products are huge; a new registration typically requires a decade to complete. As a result, only one product representing a new class of chemistry (Aim) has been commercialized in the last decade, and it was a secondary registration to the product's primary registration as a herbicide in other crops. The other introductions during this period primarily have been pre-mixes or enhanced products developed from active ingredients already registered for use as cotton harvest aids.

The advent of recombinant DNA technology provides a promising new avenue to pursue and may result in different, yet highly effective and safe, ways for preparing cotton for mechanical harvesting in the future (see Chapter 11).

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Chapter 2

PHYSIOLOGY OF COTTON DEFOLIATION AND DESICCATION

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INTRODUCTION

An overall understanding of cotton growth and development is necessary to fully appreciate the mechanism of the physiology of defoliation. Cotton is grown as an annual crop, but inherently is a deciduous perennial. The plant has a natural mechanism for shedding its mature leaves, although shedding is not necessarily synchronized with the most appropriate time for harvesting the lint. While leaves function to supply photosynthates to developing fruit during the growing season, their presence at harvest can lead to reductions in harvest efficiency and lint quality (Williford, 1992).

In addition, once the cotton bolls have opened, there is a potential for weight and fiber quality losses caused by weathering (Parvin, 1990). Therefore, leaf senescence and abscission in cotton usually are controlled with the use of harvest-aid chemicals. These products are applied to the crop prior to harvest to facilitate harvest of seed cotton. Harvest-aid programs, which include defoliants and desiccants, are used to insure optimal harvest timing and efficiency and are determined by several factors, including crop maturity and the production year. Defoliation refers to the accelerated leaf abscission brought about by chemicals, frost, or other factors, while desiccation refers to the accelerated drying of a leaf or plant part.

SENESCENCE

Plants develop from the time of germination until their death. The latter part of the developmental process, which leads from maturity to the ultimate loss of organization and function, is the process we call senescence. Senescence may be defined simply as those changes that eventually lead to the death of an organism or some part of it (Sexton and Woolhouse, 1984).

Some tend to equate the terms *aging* and *senescence*. Medawar (1957), however, offered the following distinction between the two processes: Aging is defined as those changes that occur in time, without reference to death as a consequence, and is not confined to living organisms. Senescence, on the other hand, is a highly ordered and genetically programmed process or series of processes within a living organism, leading to death. Senescence frequently is associated with leaf abscission.

A wide variety of factors and metabolic changes can trigger senescence. Determining which of the changes are central (primary) and which are peripheral (secondary) to senescence is difficult. Noodén *et al.* (1997) depicts senescence in three phases, with each phase being linked to initiators of senescence (e.g., temperature extremes, air pollution, and pathogen attack).

The initiation phase of senescence results in a potential shutdown of cell maintenance functions and is paralleled with an increase in key degradative enzymes. Several senescence-associated genes (SAG) that are involved in this phase have been identified (Hensel *et al.*, 1993; Lohman *et al.*, 1994). However, whether the SAG are causally linked to senescence initiation or to macromolecular turnover is not yet known.

The sequence similarity of SAG to cysteine proteases, which have been shown as a requirement for Programmed Cell Death (PCD) in the nematode, *Caenorhabditis elegans*, suggests that proteases may be good candidates for cell-death-initiation genes (Greenberg, 1996). PCD is the process by which individual cells activate an intrinsic senescence program. Ellis *et al.* (1991) indicated that PCD is a physiological cell death process involved in selective elimination of unwanted cells. The senescence process involves cell death on a large scale (Bleecker and Patterson, 1997; Pennell and Lamb, 1997).

Degeneration – The second phase, degeneration, is reflected as a disassembly of key metabolic processes that leads to the third and final stage of senescence, where a loss of homeostasis and cell membrane integrity eventually leads to cell death.

The maturity or senescence stage of development is not always related to the chronological age of the plant, but may reflect the conditions under which the crop is grown. Similar to many other genetically programmed developmental processes, the initiation of senescence is subject to regulation by environmental (external), as well as autonomous (internal), cues (Figure 1).

Plants senesce according to their growth habit. Some may senesce and die all at one time. Others may exhibit a progressive senescence, with some parts remaining active and in the juvenile stage, while older parts senesce and die. Juvenility refers to the early phase of growth during which flowering cannot be induced by any treatment (Thomas and Vince-Prue, 1984). Senescence in monocarpic plants, those plants that flower only once and then die, shows a close relationship to the processes of flowering and fruit growth. For example, senescence may be postponed if flowers or fruits are removed (Noodén and Guiamét, 1989).

Although it is a commonly held view that senescence represents a descent into chaos in terms of cellular and metabolic organization, it is in fact tightly controlled, with a highly ordered sequence of events (Sexton and Woolhouse, 1984). For example, in leaf senescence, some components of the chloroplast, such as the thylakoid membrane and chlorophyll, begin to degrade before other cellular components, such as the chloroplast envelope, mitochondria, and plasma membrane (Woolhouse and Jenkins, 1983).

Two senescence theories commonly are discussed: the nutrient diversion theory and the hormonal theory. The nutrient diversion theory refers to the competition among different parts of the plant for nutrition. Fruit or growing

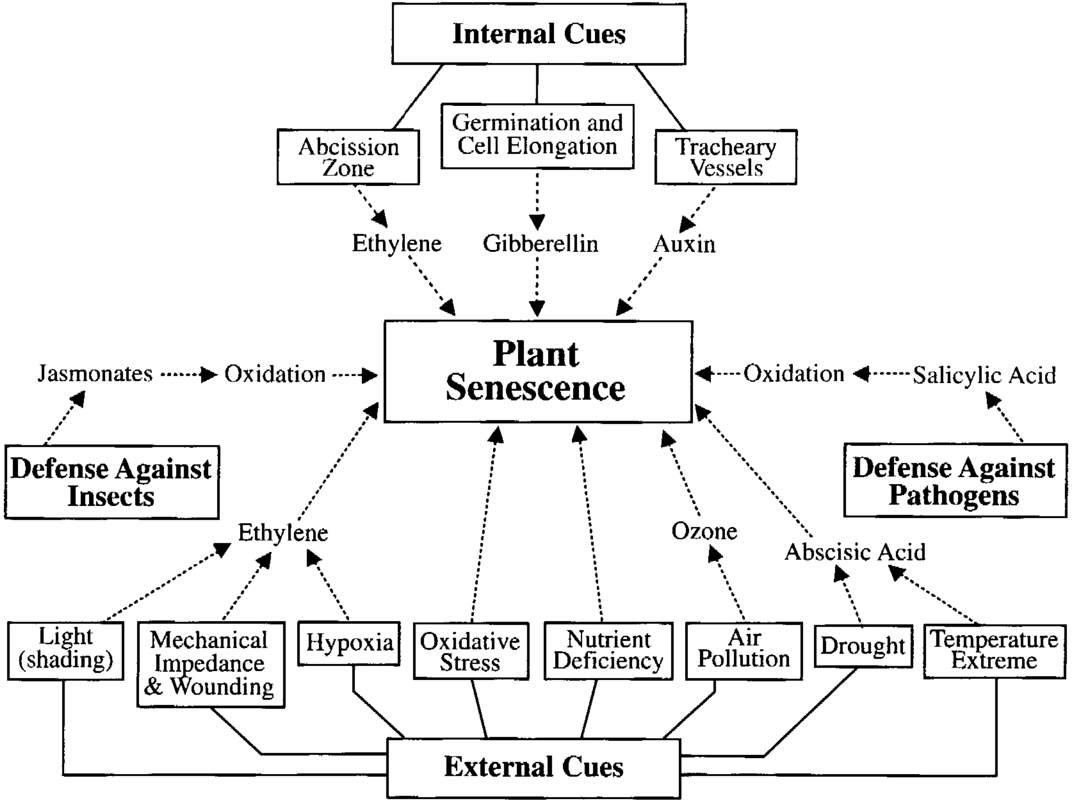


Figure 1. Mechanisms of senescence.

tips, for example, might constitute stronger sinks for translocation and thus accumulate nutrients to the point of starving older leaves. Sinclair and de Wit (1976) referred to a "self-destruct" theory in soybeans. Their theory states that the plant may relocate nutrients to meet immediate carbon demands at the cost of jeopardizing its continued survival. For example, when nutritional requirements for nitrogen exceed the ability of the plant to meet this demand, the plant remobilizes nitrogen contained in Fraction I protein (rubisco, the major CO_2-fixing enzyme) to provide the nutrient. As a consequence, the plant subsequently loses its ability to fix carbon dioxide and self-destructs through deterioration of chloroplast integrity.

A related senescence theory proposed by Kelly and Davies (1988) asserts that diversion of assimilates to developing fruit no longer is accepted by most researchers as the strongest regulator of senescence. Instead, they propose that development of the reproductive phase causes reproductive structures to become stronger sinks than their vegetative organs. The loss of sink strength in the root leads to reduced mineral nutrient and cytokinin transport from root to shoot, both of which are partly responsible for the initiation of leaf senescence. The loss of cytokinin transport to the shoot is important, as numerous experiments have shown cytokinins to delay senescence (Gan and Amasino, 1995; 1996).

The second theory is that senescence is hormonally controlled. Because of the decline of cytokinin levels in senescing leaves and the ability to delay senescence by external application of cytokinin (Gan and Amasino, 1995), the cytokinin class of hormones often is assigned a role in controlling leaf senescence. This has been further supported by the finding that expression of isopentenyl transferase (IPT), the enzyme that catalyzes the rate-limiting step in cytokinin biosynthesis, is suppressed with a senescence-specific promoter (Gan and Amasino, 1995). The involvement of cytokinins and other hormones in leaf senescence and abscission will be discussed later.

LEAF ABSCISSION

The term abscission is derived from the Latin *abscindere* – "to tear" – and therefore is an appropriate term for the process. Leaf abscission is a physiological process that involves an active separation of living tissue from the plant (Cathey, 1986) and usually occurs as a result of maturity, senescence, or injury. Separation of the leaf from the plant occurs at the base of the leaf petiole in an area called the abscission zone (Figure 2) (Addicott, 1982; Sexton et al., 1985). This area is structurally distinguishable and is characterized by a structural line of weakness where abscission occurs. The abscission zone consists of one or more layers of thin-walled parenchyma cells resulting from anticlinal divisions across the petiole, except in the vascular bundle. The "abscission zone," or general region through which the fracture occurs, contains the same cell classes as adjacent tissues (Sexton and Woolhouse, 1984). However, wall breakdown usually is confined to a "separation layer" one to three cells wide in a zone that is five to 50 cells wide. Cells of the abscission zone generally are smaller than their counterparts in adjacent tissues. Toward the end of the senescence process, metabolic activity increases in the abscission layers as a result of alterations in the hormone levels of the leaf blade (Wilkins, 1984).

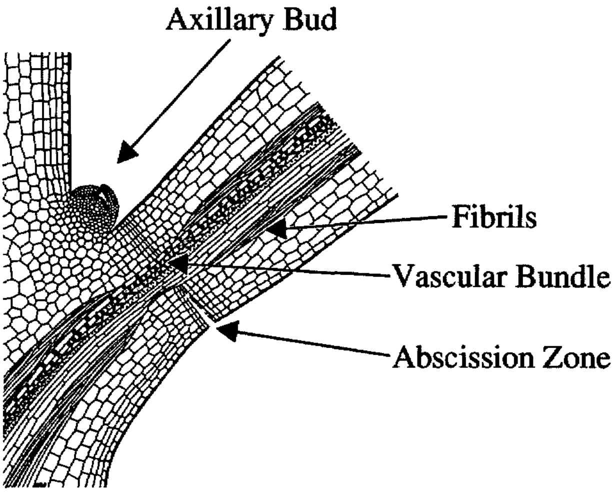


Figure 2. Abscission layer found within a leaf petiole. (Salisbury and Ross, 1992)

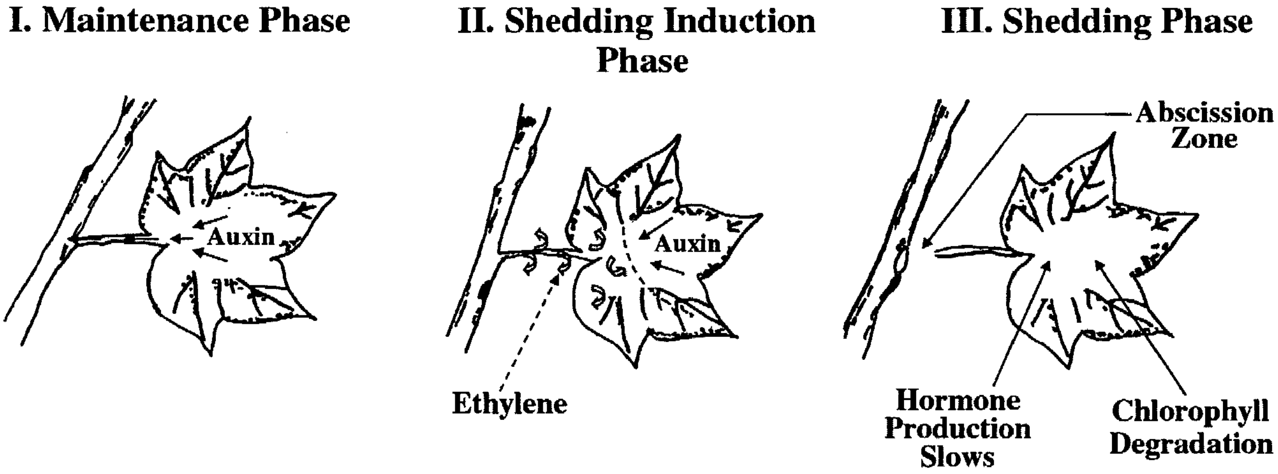
Prior to abscission, a variety of changes associated with senescence occur in the leaf. As an oxidative process, senescence involves a general deterioration of cellular metabolism (Pastori and del Rio, 1997). One of the more observable changes of senescence is a loss of chlorophyll (Noodén *et al.*, 1997), which sometimes is accompanied by a temporary build-up of anthocyanin (Matile, 1992). In addition, complex substances, such as proteins and carbohydrates, that have accumulated in the leaf are broken down to their constituent amino acids and sugars and translocated to other parts of the plant before the leaf abscises. Along with these breakdown products, significant amounts of mineral elements, such as nitrogen, phosphorus, potassium, and magnesium, also are translocated.

Other physiological changes prior to abscission include an increase in lipid peroxidation and membrane permeability (Thompson *et al.*, 1997), enhanced metabolism of activated oxygen species that produce severe cellular damage (Pastori and del Rio, 1997), and the loss of sufficient auxin levels to suppress the action of ethylene and abscisic acid (Morgan, 1984). Although ethylene and abscisic acid are present in leaves throughout their growth and development, higher levels of auxin tend to counter their activity. As senescence progresses, the auxin level subsides or its transport is inhibited, allowing ethylene and abscisic acid to enhance the senescent changes in the leaf blade, as well as the abscission process at the base of the petiole.

Such physiological changes include the increased activation of cell wall-degrading enzymes, such as cellulase and polygalacturonase, at the abscission layer. These enzymes degrade the pectic substances of the middle lamella and cell wall, and allow the leaves to fall from the plant. The significance of auxin in the abscission process is shown in the work of Abeles *et al.* (1992), who found that removal of the leaf blade promoted petiole abscission and that the process could be delayed by exogenous application of auxin to the petioles from which the leaf blades had been removed.

The primary regulator of the abscission process appears to be ethylene, while auxin acts as a suppressor of the ethylene effect. Morgan and Hall (1962), Hall and Morgan (1964), and Morgan *et al.* (1968) showed that ethylene stimulates IAA-oxidase activity and decarboxylation of IAA in cotton. Ethylene has been found to slow auxin transport (Morgan and Gausman, 1966; Morgan *et al.*, 1968; Beyer and Morgan, 1969; 1970; 1971) and, by inhibiting auxin transport, promotes abscission (Morgan and Durham, 1975). Because auxin prevents or delays abscission, both the destruction and the slowed transport of auxin to the abscission zone should promote abscission (Guinn, 1986).

Morgan (1984) describes the process of leaf abscission in three distinct sequential phases in his hormonal control model (Figure 3). The three phases include a leaf maintenance phase, a shedding induction phase, and a shedding phase. In the maintenance phase (I.), the leaf is healthy and fully functional.



I. Maintenance Phase

II. Shedding Induction Phase

III. Shedding Phase

Figure 3. Three distinct sequential phases of the hormonal control of leaf abscission. (Morgan, 1984)

During this stage, high levels of auxin synthesis in the leaf prevent abscission by repressing the synthesis of the hydrolytic enzymes involved in abscission. During the shedding induction phase (II.), the auxin level decreases and the ethylene level increases. Ethylene may affect auxin activity by reducing its synthesis and transport, as well as by promoting its destruction (Sexton *et al.*, 1985; Kende and Zeevaart, 1997). After the enzymes associated with formation of the abscission layer increase and the concentration of ethylene increases relative to auxin, hormone production slows, chlorophyll degrades, and leaves drop in the shedding phase (III.).

HORMONES AND SENESCENCE

In higher plants, regulation and coordination of metabolism, growth, and morphogenesis often are dependent on signals from one part of the plant to another. Chemical messengers called hormones mediate this intercellular communication. Although theories regarding senescence differ as to the controlling force behind the process, the communication role of hormones is undisputed.

Until recently, five classes of plant hormones were recognized: auxins, gibberellins, abscisic acid, ethylene, and cytokinins. However, additional hormones, including jasmonic acid, salicylic acid, and brassinosteroids, have been proposed. Their functions in plant growth and development are not completely understood, but the brassinosteroids appear to have a more direct role in accelerating senescence, while the roles of salicylic acid and jasmonic acid are less direct. Hormones interact with specific proteins, called receptors, on the cell surface, causing the initiation of a cascade of enzyme activation steps. This cascade, often referred to as a *signal transduction pathway*, results in the production of "second messengers" that directly stimulate the responses and amplify the hormone signal.

One of the more common elements in the different signal transduction pathways is the participation of GTP-binding proteins (G proteins), which act as intermediates between the hormone-receptor complex and the enzyme systems that produce second messengers. The following outlines the role of G proteins in signal transduction in plants, as shown in Figure 4:

1) Binding of a hormone to its receptor on the cell surface causes activation of a G protein (i.e., guanosine triphosphate [GTP] exchanged for gua-nosine diphosphate [GDP]).
2) A series of molecular events is initiated by the activated G protein, including activation of phospholipase A_2 (PLA_2).
3) PLA_2 cleaves phospholipid (PL) to release lycophosphatidylcholine (LPC) and lycophosphatidylethanolamine (LPE).
4) LPC, LPE, and calcium activate a protein kinase (PK). Activated protein kinase will activate a phosphorylase and thereby activate an ATPase (the enzyme that hydrolyzes adenosine triphosphate [ATP]).
5) Ultimately, the ATPase hydrolyzes ATP and drives hydrogen ions across the plasma membrane.

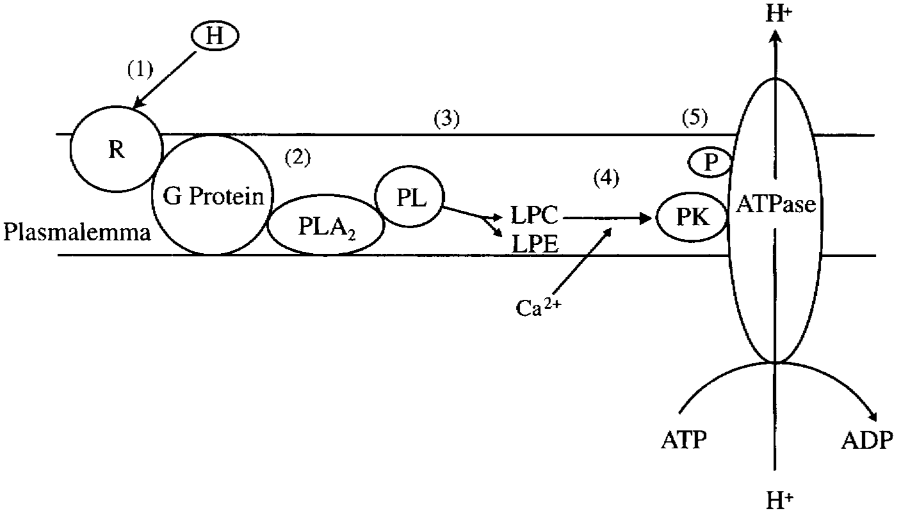


Figure 4. Proposed model for hormone-signal transduction in plant cells. (Adapted from Andre and Scherer, 1991) H - hormone; R - receptor; PLA2 - phospholipase A2; PL - phospholipase substrate; LPC - lycophosphatidylcholine; LPE - lycophosphatidylethanolamine; PK - protein kinase; P - high-energy phosphate; ATP - adenosine triphosphate; ADP - adenosine diphosphate; ATPase - the enzyme that hydrolyzes ATP.

In further support of the proposed model for signal transduction (Figure 4), evidence of G proteins, phospholipase A_2, and protein kinase have been identified in plant membranes (Blum *et al.*, 1988; Tate *et al.*, 1989; Millner and Causier, 1996). In addition, strong indications exist that inositol triphosphate (IP_3) causes the release of calcium from mitochondria and vacuoles in a manner similar to that in animals, indicating that it may serve as a second messenger in plant cells (Einspahr and Thompson, 1990). Perhaps the best-understood signal transduction pathway for plants is that of ethylene, as its hormone receptor has been identified, its gene sequenced (Hua *et al.*, 1997), and several steps in the pathway elucidated (Kieber, 1997).

Among the hormones and hormone-like compounds, most have some influence on regulation of senescence. Ethylene and abscisic acid generally accelerate senescence, while auxins and cytokinins delay it. In addition, some studies indicate that gibberellins may play a role in delaying senescence (Saks *et al.*, 1992; Jordi *et al.*, 1995; Kappers *et al.*, 1997; Zhu and Davies, 1997). The following is a brief discussion on the role of the hormones believed to play a significant role in senescence and abscission.

Ethylene – Studies have shown that ethylene increases the rate of chlorophyll, protein, and RNA degradation in leaf tissue. Rates of chlorophyll degradation decrease when inhibitors such as silver nitrate and aminoethoxyvinylglycine (AVG) block ethylene production. Although ethylene plays an important role as a signal to initiate senescence as plant tissue ages, the process can occur without it. Zacarias and Reid (1990) found that ethylene-insensitive mutants of *Arabidopsis thaliana* senesce at a slower rate than the wild type. In these situations it usually is best to think of ethylene as a senescence-promoter hormone, rather than as the cause of the senescence process.

Abscisic Acid – Although ethylene is recognized as the hormone that triggers abscission, ABA is involved in the process. For cotton, the ABA-induced abscission of fruits results from the ability of ABA to stimulate ethylene production. The effects of ABA on leaf senescence do not appear to be mediated by ethylene. While ethylene stimulates chlorophyll loss from wild-type *Arabidopsis*, it has no effect on ethylene-insensitive mutants. When both types were treated with ABA, chlorophyll loss was stimulated, indicating that promotion of senescence by ABA did not occur through its stimulation of ethylene production (Zacarias and Reid, 1990.)

Cytokinin – The ability of cytokinins to delay leaf senescence is widely known. When cytokinin is sprayed directly on a leaf, that leaf remains intact when other leaves of equal developmental age have yellowed and dropped off the plant. Cytokinins promote nutrient mobilization into areas that have been treated, which may occur because of the creation of a new source-sink relationship.

Auxin serves a dual role in abscission. The level of auxin progressively decreases from a high level in young leaves to a relatively low level in senescing leaves. At the onset of leaf abscission, addition of IAA inhibits leaf abscission, but, during the latter stages, IAA hastens the process, probably as a result of inducing ethylene synthesis. Younger leaves appear less sensitive to ethylene than older ones, which may be a reflection of the high level of auxin in the younger leaves.

Gibberellin – In addition to cytokinins and auxins, gibberellins also are considered promotive hormones that delay senescence (Whyte and Luckwill, 1966; Osborne, 1967).

HARVEST-AID CHEMICALS

Although cotton leaves senesce naturally and abscise, the use of chemical defoliation for more timely leaf removal is widely practiced. Harvest-aid chemicals can be used to control physiological processes such as growth, boll opening, and leaf drop. Through the control of these processes, more and better-quality lint is harvested, with less dry matter loss. The condition of the crop affects the response of the plant to harvest-aid chemicals. Generally, senescing cotton is more responsive to harvest-aid chemicals than less mature cotton, especially if the crop has a high sink strength through the presence of a heavy boll load.

A variety of commercially available harvest-aid chemicals exist (Table 1); however, two general categories are recognized: those with *herbicidal*, or contact, activity and those with *hormonal* or other growth regulant activity.

Herbicidal defoliants injure the plant, causing it to produce ethylene, which inhibits auxin and promotes abscission and, thus, leaf drop. Among the herbicidal defoliants are tribufos and endothall. Excessive rates of herbicidal defoliants cause rapid leaf death to occur before ethylene can be produced to cause formation of the abscission layer. As a result, desiccation or leaf stick occurs instead of leaf drop. Dimethipin is known to alter water diffusion and, therefore, can be classified as a mild desiccant, although it does not interfere directly with senescence metabolism.

Hormonal harvest aids enhance ethylene production, which leads to increased activity of cell wall-degrading enzymes. The abscission zone forms more rapidly and promotes leaf drop. Thidiazuron and ethephon are examples of hormonal harvest aids, which are widely used for picker harvest and, in some instances, in combination with desiccants for stripper harvest.

Defoliants are less harsh treatments than desiccants, which are compounds that have the ability to disrupt membrane integrity. The loss of membrane integrity from application of these compounds leads to rapid loss of moisture and ultimately causes desiccation of the leaves.

Ethephon and other products can be used to accelerate boll opening and to enhance the activity of defoliants. Although harvest-aid chemicals promote leaf drop, they do so in a variety of ways. The following is a brief description of the mode of action of the harvest-aid chemicals listed in Table 1.

BOLL OPENERS/CONDITIONERS

Ethephon – The breakdown of ethephon to ethylene occurs primarily on the leaf surface (Beaudry and Kays, 1988). According to the abscission model, cell wall hydrolases are induced by ethylene into the separation layer of abscission zones to promote leaf shedding (Walhood and Addicott, 1968). The effectiveness of ethephon is increased by treating plants with formulations that are auxin transport inhibitors.

Ethephon + cyclanilide – Cyclanilide is an auxin transport inhibitor that, when combined with ethephon, enhances cellulase activity in abscission zones more than does ethephon alone (Pedersen *et al.*, 1997). Activity is enhanced at two different pH optima, suggesting that cyclanilide and ethephon may induce more than one type of cellular isozyme.

Ethephon + AMADS – Ethephon stimulates production of ethylene, and AMADS is an ethylene synergist.

DEFOLIANTS

Dimethipin causes an initial inhibition of protein synthesis that is responsible for the loss of stomatal control. Loss of stomatal control is associated with high rates of transpiration and loss of leaf turgor that leads to desiccation and, ultimately,

Table 1. Harvest-aid chemicals registered for use in cotton production as late as 2001.

Type	Common Name	Trade Name[1,2]	Manufacturer	Active Ingredient		Chemical Name
				%	lb per gal	
I. Boll Openers/ Conditioners	ethephon	Prep™ Super Boll® Ethephon 6 Boll'd	Aventis Group Griffin LLC Micro Flo Co. Agriliance LLC	55.4 55.4 55.4 55.4	6.0 6.0 6.0 6.0	(2-chloroethyl)phosphonic acid
	dimethipin	LintPlus™	Uniroyal Chemical	22.4	2.0	2,3-dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetraoxide
II. Boll Openers/ Defoliants	ethephon + cyclanilide	Finish® Finish® 6	Aventis Group Aventis Group	32.1 + 4.3 51.4 + 6.4	4.0 + 0.5 6.0 + 0.75	(2-chloroethyl)phosphonic acid + 1-(2,4-dichloro-phenylaminocarbonyl)-cyclopropane carboxylic acid
	ethephon + AMADS	CottonQuik®	Griffin LLC	18.3 + 58.6	2.28	(2-chloroethyl)phosphonic acid + 1-aminomethanamide dihydrogen tetraoxosulfate
III. Defoliants	carfentrazone-ethyl	Aim™	FMC Corp.	40.0	40% w/w a.i. per lb[3]	ethyl *a*,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoate
	dimethipin	Harvade®	Uniroyal Chemical	48.0	4.9	2,3-dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetraoxide
	butifos, merphos, tribufos, tribufate (proposed)	Folex® Def®	Aventis Group Bayer AG, Germany	70.5 70.5	6.0 6.0	*S,S,S*,-tributyl phosphorotrithioate
	thidiazuron	Dropp® FreeFall™	Aventis Group Griffin LLC	50.0 50.0	50% w/w a.i. per lb[3]	N-phenyl-N'-1,2,3-thidizaol-5-ylurea
	thidiazuron + diuron	Ginstar®	Aventis Group	12.0 + 6.0	1.0 + 0.5	N-phenyl-N'-1,2,3-thidizaol-5-ylurea + 3-(3,4-dichlorophenyl)-1,1-dimethylurea
	sodium chlorate	Sodium chlorate	Several manufacturers	28.0 to 47.0	3.0 to 6.0	$NaClO_3$
	dimethipin + thidiazuron	Leafless™	Uniroyal Chemical	32.7 + 8.4	3.2 + 0.8	2,3-dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetraoxide + N-phenyl-N'-1,2,3-thidizaol-5-ylurea
IV. Desiccants	paraquat	Cyclone® Max Gramoxone® Extra Gramoxone® Max Boa®	Syngenta Syngenta Syngenta Griffin LLC	43.8 37.0 43.8 37.0	3.0 2.5 3.0 2.5	1,1'-dimethyl-4,4'-bipyridinium dichloride
	sodium chlorate	Sodium chlorate	Several manufacturers	28.0 to 47.0	3.0 to 6.0	$NaClO_3$
V. Products with Other Applications	endothall	Accelerate®	Cerexagri	15.9	0.52	7-oxabicyclo[2,2,1]heptane-2,3-dicarboxylic acid (IUPAC) used as sodium, potassium, or amine salts
	glyphosate	Roundup Original™ Roundup Ultra® Roundup UltraMax™	Monsanto Co. Monsanto Co. Monsanto Co.	41.0 41.0 50.2	4.0 4.0 5.0	isopropylamine salt of N-(phosphonomethyl)glycine
	cacodylic acid	Quick Pick®	Platte Chemical Co.	31.0	3.1	hydroxydimethylarsine oxide or dimethylarsinic acid

[1] Partial list of trade names. Trade names listed are not intended as endorsement.

[2] Bolls Eye®, Cyclone®, Dropp® Ultra™, Ethrel®, Roundup®, Starfire®, and the original formulation of Prep™ have been discontinued or are no longer available under their original names.

[3] Dry formulation, measured in pounds.

abscission (Metzger and Keng, 1984). Labeling work with ^{14}C-leucine and ^{3}H-uridine suggests that dimethipin acts primarily on the processes associated with translation rather than transcription. Auxin synthesis and transport also are inhibited and ethylene synthesis is triggered, subsequently inducing cellulase production. With the induction of cellulase, digestion of cellulose occurs in the abscission zone of the petiole base. This activity weakens the abscission layer, and the leaf falls. The mode of action for dimethipin is summarized as an induced, slow disintegration of epidermal cell walls and a subsequent gradual water loss that triggers the release of ethylene and abscission. It is classified as a hormonal defoliant.

Butifos, merphos, tribufos, tribufate (proposed) – These are herbicidal defoliants that injure the palisade cells of leaves, causing release of ethylene and leaf abscission. These defoliants also cause an upsurge of stress-induced ethylene production through a mild leaf injury that stimulates the enzymes cellulase, pectinase, and polygalacturonase. These enzymes are involved in the hydrolysis of insoluble pectates and cellulose associated with the adherence of cells in the abscission zones. The juvenile plant hormones, auxin and gibberellin, which antagonize the abscission process, also appear to be impaired.

Thidiazuron enhances ethylene production; it also has been shown to disrupt the polar auxin transport system and is an excellent inhibitor of regrowth (Suttle, 1988). It is classified as a hormonal defoliant. Thidiazuron has been reported to have cytokine-like activity in sieva bean callus culture (Mok *et al.*, 1982).

Thidiazuron + diuron (DCMU) – Diuron is used to inhibit photosynthetic electron transport. The site of action for diuron is at the quinone acceptor complex in the electron transport chain between the two photosystems, PSI and PSII (Figure 5). Compounds such as diuron occupy the secondary quinone (Q_B) binding site of D1 and D2 proteins, two membrane proteins that make up the core of PSII reaction centers (Zer and Ohad, 1995). Because diuron is unable to accept electrons, the electron cannot leave Q_A, the first quinone acceptor. As such, diuron binding effectively blocks electron flow and inhibits photosynthesis. An ensuing chain reaction of lipid peroxidation results in leaky membranes, which cause cells to dry rapidly (Weed Science Society of America, 1994). The combination of both chemistries thus enhances the potential for defoliation.

Endothall is a post-emergence herbicide that can be mixed with certain defoliants or desiccants to enhance their performance. Its mode of action is not well understood.

Cacodylic acid is a nonselective herbicide; its mode of action is not well understood.

DESICCANTS

Paraquat (methyl viologen) acts by accepting electrons from the early acceptors of Photosystem I (between bound ferredoxin acceptors and NADP) (Figure 5). Paraquat then reacts with oxygen to form superoxide, $O_2^{\cdot}$. Superoxide is a free radical that reacts nonspecifically with a wide range of molecules in the chloroplast, such as lipids, to reduce chloroplast activity (Scandalios, 1993). Production of the free radicals also causes disruption of membranes and a rapid moisture loss that leads to desiccation.

Sodium chlorate is a strong oxidizing agent in plants (WSSA, 1994). It is reduced to sodium chlorite by reaction with nitrate reductase. Sodium chlorite acts as a cotton desiccant and as a nonselective contact herbicide.

REGROWTH INHIBITORS

Glyphosate isopropylammonium – Evidence indicates that glyphosate blocks production of an enzymatic step in the shikimic acid pathway (Figure 6). It inhibits 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), the enzyme that condenses shikimate-3-phosphate (S3P) and phosphoenolpyruvate (PEP)

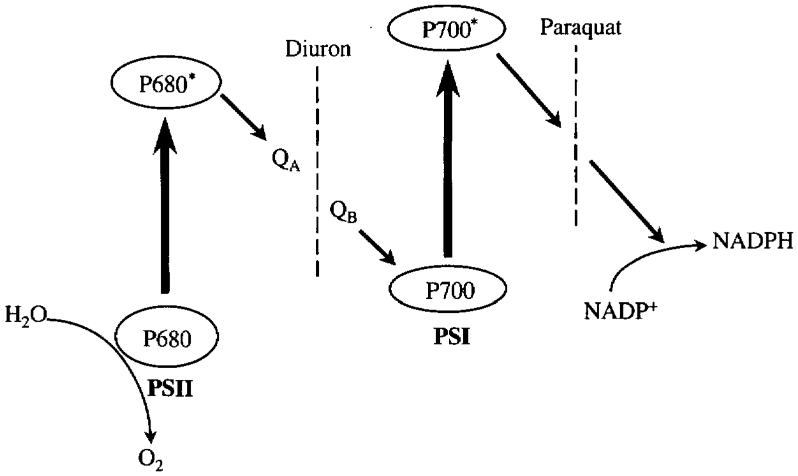


Figure 5. Z-scheme with location of diuron and paraquat action sites.

to yield EPSP and inorganic phosphate (Duke, 1988). As a result of this inhibition, production of three aromatic amino acids – phenylalanine, tyrosine, and tryptophan – is prevented, resulting in suppression of regrowth. Glyphosate has shown the ability to suppress regrowth in cotton when applied at various stages of boll opening (Landivar et al., 1994).

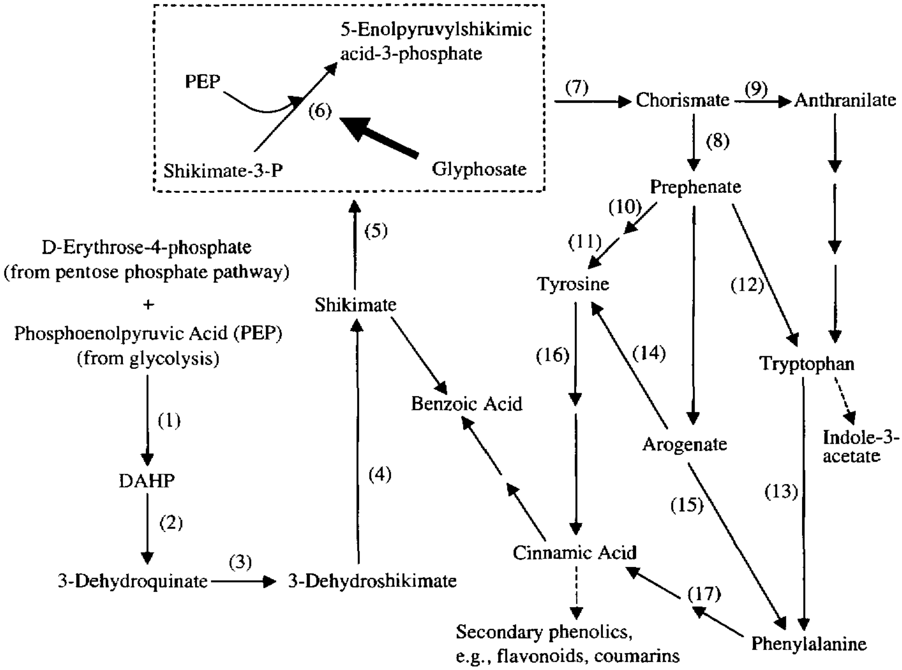


Figure 6. Glyphosate blocks production of an enzymatic step in the shikimic acid pathway. (1) 3-deoxy-*D*-arabino-heptulosonate-7-phosphate (DAHP) synthase; (2) 3-dehydroquinate synthase; (3) 3-dehydroquinate dehydratase; (4) shikimate dehydrogenase; (5) shikimate kinase, (6) 5-enolpyruvylshikimic acid-3-phosphate synthase (EPSPS); (7) chorismate synthase; (8) chorismate mutase; (9) anthranilate synthase; (10) prephenate dehydrogenase; (11) tyrosine aminotransferase; (12) prephenate dehydratase; (13) phenylalanine aminotransferase; (14) arogenate dehydrogenase; (15) arogenate dehydratase; (16) tyrosine ammonia-lyase; (17) phenylalanine ammonia-lyase.

NEW AND EXPERIMENTAL COMPOUNDS

Carfentrazone-ethyl[1] induces inhibition of the enzyme protoporphyrinogen oxidase (Protox), which stops the formation of protoporphyrin IX, a precursor to chlorophyll biosynthesis. This results in the accumulation of reactive oxygen species inside the cell, which causes peroxidation of membrane lipids and leads to irreversible damage to cell membranes and functions. This mode of action is referred to as PPO inhibition. Carfentrazone-ethyl (Aim™) initially was registered as a corn, small grains, and soybean herbicide; the label was expanded in 2001 to include use as a defoliant in cotton.

Fluthiacet-methyl[2] has a similar mode of action (PPO inhibition), and the compound also has undergone evaluation as a potential cotton defoliant. Other PPO inhibitors, most of which are labeled for use as herbicides on other crops, also are being tested for efficacy as cotton harvest aids.

APPLICATION OF TANK MIXES

One of the more frustrating aspects of harvest aids is the lack of consistency achieved with individual compounds. After nearly 60 years of using defoliation compounds, many failures still are encountered each year; strategies that producers have employed successfully for many years can falter. Most failures are linked to either plant or environmental conditions that are not conducive to maximum plant response toward the chemicals being used.

The major factors that limit defoliation efficiency are condition of the plant and prevailing weather at time of application. Although an ample supply of moisture and nutrients is desired throughout the growing season to ensure uniform growth and development, the supply of each of these should be near depletion at defoliation time. Activity of harvest-aid chemicals is greatest when temperature, sunlight intensity, and relative humidity are high. An especially important factor is a night temperature above 16 C (61 F), as plant response to defoliants doubles for each 10-degree Celsius rise between 15 C and 35 C (59 F and 95 F) (Lane *et al.*, 1954).

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[1] A product from FMC Corp. marketed as Aim™.

[2] A compound developed by Kumiai Chemical Industry Co. (KIH-9201) and tested as an experimental cotton desiccant/defoliant by Syngenta as CGA-248757, or Action™.

Unless the harvest-aid compound is formulated in a carrier that facilitates distribution across and penetration through a foliage surface, its potential biological activity may be negligible. Therefore, efforts to reduce the frequency of failures in harvest-aid strategies center on tank mixes consisting of harvest-aid chemicals and adjuvants, such as surfactants and wetting agents.

Adjuvants are materials that facilitate action of a herbicide or that facilitate or modify characteristics of herbicide formulations or spray solutions (McWhorter, 1982).

Surfactants – surface active agents – and wetting agents are two types of adjuvants. The Weed Science Society of America (1994) specifically defines surfactants as materials "that improve the emulsifying, dispersing, spreading, wetting, or other properties of a liquid by modifying its surface characteristics." They provide two definitions of wetting agents: 1) "a substance that serves to reduce the interfacial tensions and causes spray solutions or suspensions to make better contact with treated surfaces" and 2) "a substance in a wettable powder formulation that causes it to wet readily when added to water."

Adjuvants tend to concentrate on the surfaces of liquids in which they are dissolved. This translates to a situation in which the concentration of the surface-active agent is greater on the surface than in the bulk phase. Ordinarily, such molecules comprise two segments: lipophilic and hydrophilic. The lipophilic portion resembles a hydrocarbon and is relatively non-polar and water-insoluble. Adjuvant use improves the interface between the leaf surface and active ingredient, resulting in a greater degree of active ingredient available for biological activity. The hydrophilic portion is polar and more readily soluble in water. Surface active agents generally are classified by the polar portion of the molecule and, as such, usually are categorized as being anionic, cationic, non-ionic, or ampholytic.

The particular adjuvant selected for use in the tank mix also can influence rate of absorption. A comparison of a diverse group of adjuvants in a tank mix with Action™[1] showed enhanced absorption of this experimental desiccant/defoliant. Of the adjuvants tested, Eth-N-Gard® (ENG, an oil-based, non-polar adjuvant) showed the greatest absorption rates (Figure 7) (Stair *et al.*, 1998). In some cases, a combination of adjuvants is found to increase

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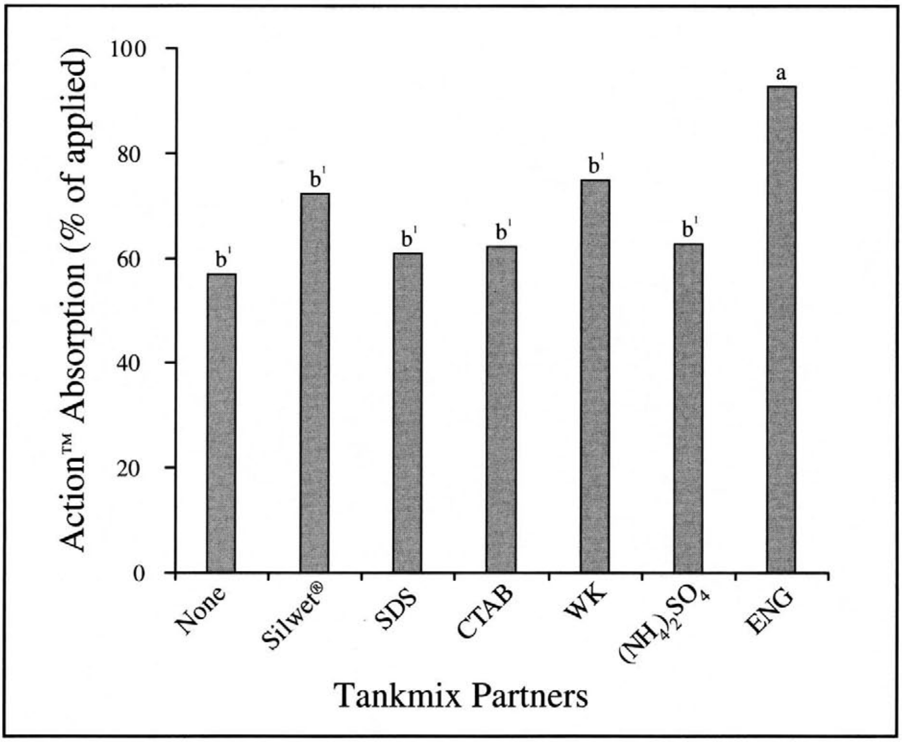
[1] Action is Syngenta's name for CGA-248757, an experimental desiccant/defoliant product developed by Kumiai Chemical Industry Co. as KIH-9201.

absorption rates. For example, thidiazuron absorption was increased by approximately 30 percent with the addition of crop oil concentrate, approximately 10 percent with the addition of ammonium sulfate, and approximately 60 percent with the addition of both (Figure 8) (Snipes and Wills, 1994). As expected, defoliant absorption correlated positively to percentage of leaf drop. In addition, adjuvants are beneficial in cases where the leaf cuticle is relatively thick. See Chapter 3 for the effect of cuticular waxes on harvest-aid materials.

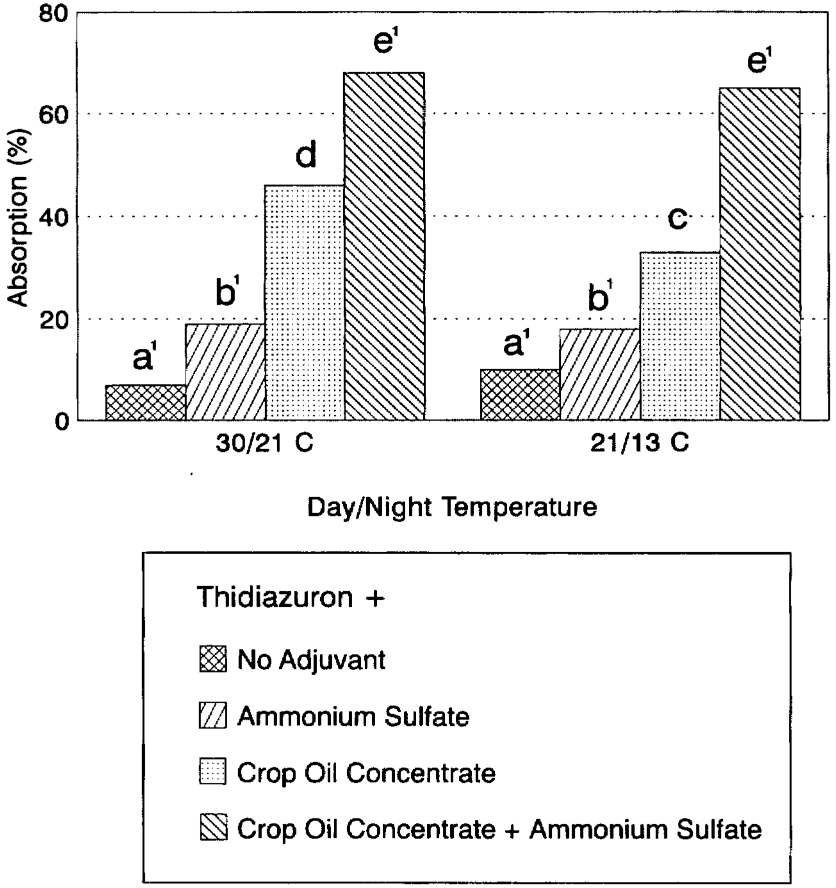


[1]Adjuvant combinations with the same letter demonstrated statistically similar Action™ absorption.

Figure 7. Effect of adjuvants on Action™ activity in tank mixes. (Stair *et al.*, 1998) Silwet® (Silicone), SDS (sodium dodecyl sulfate - anionic), CTAB (cetyl trimethyl ammomium bromate - cationic), WK (non-ionic), $(NH_4)_2SO_4$ (ion coupler), and ENG (Eth-N-Gard®, oil-based, non-polar).

SUMMARY

Growth and development of the cotton plant is genetically programmed and subject to regulation by many environmental (external) and autonomous (internal) factors. Programmed Cell Death is a term that refers to a process by which cells promote their own death through the activation of self-destruction



[1] Adjuvant combinations with the same letter demonstrated statistically similar thidiazuron absorption.

Figure 8. Effect of adjuvants on thidiazuron absorption in combinations. (Snipes and Wills, 1994)

systems. The plant developmental processes achieved through operation of PCD include senescence and the activation of the abscission zone.

Leaf senescence is the final stage of leaf development. High levels of auxin in juvenile or younger leaves prevent translocation of ethylene to the abscission zone and subdue formation of the abscission layer. During senescence, levels of leaf auxin decrease relative to the concentration of ethylene and abscisic acid. The increased levels of ethylene increase activity of the hydrolytic enzymes, cellulase and polygalacturonase, which are involved with cell wall degradation. These enzymes degrade the pectic substances of the middle lamella and cell wall and allow the leaves to fall from the plant.

Application of harvest-aid chemicals is accepted widely as a cultural practice to induce leaf abscission of cotton foliage. These compounds allow timely and efficient harvest of the lint to reduce harvest losses from weathering and to reduce leaf stain. Categories of harvest-aid chemicals include herbicidal and hormonal defoliants (including growth regulants), boll openers, and desiccants. Herbicidal defoliants injure leaf tissue, causing production of ethylene, which induces activation of enzymes associated with the formation of the abscission layer and subsequent leaf drop. This process also is induced by enhancing endogenous ethylene concentrations with hormonal defoliants. The boll openers are used to enhance ethylene production, which leads to quicker separation of the carpel walls. Desiccants are contact chemicals that cause disruption of membrane integrity, leading to rapid loss of moisture, which produces the desiccated leaf.

The previous growing conditions of the crop and prevailing weather conditions at time of application have great impact on performance of these chemicals. In addition, adjuvants commonly are used with harvest-aid compounds to enhance their uptake and activity. Consult Extension agents and specialists, farm consultants, and company representatives in your production area for available performance ratings in use of these compounds.

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Chapter 3

INFLUENCE OF ENVIRONMENT ON COTTON DEFOLIATION AND BOLL OPENING

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INTRODUCTION

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

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

GROWING SEASON CONDITIONS

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

MOISTURE EFFECTS ON THE LEAF CUTICLE

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

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

NITROGEN NUTRITION EFFECTS

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

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

TEMPERATURES FOR BOLL MATURATION

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

ENVIRONMENTAL CONDITIONS DURING HARVEST-AID APPLICATION

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

TEMPERATURE AND SUNLIGHT

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

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

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

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

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

Source: Hake *et al.*, 1996.

[1] Activity slows but performance is maintained below this temperature.

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

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

RELATIVE HUMIDITY

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

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

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

CROP WATER STRESS

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

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

PRECIPITATION SHORTLY AFTER APPLICATION

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

ENVIRONMENTAL CONDITIONS AFTER APPLICATION

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

HEAT UNIT ACCUMULATION EFFECTS

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

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

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

Q_{10} OF BIOLOGICAL ACTIVITY

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

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

FREEZING CONDITIONS

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

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

UNIFORM HARVEST-AID EVALUATION

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

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

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

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

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

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

Source: Logan and Gwathmey, 1998.

[1] Q1= upper threshold for 1st quartile.

[2] Q4= lower threshold for 4th quartile.

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

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

REGIONAL PERSPECTIVES

SOUTHEAST

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

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

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

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

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

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

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

MIDSOUTH

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

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

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

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

SOUTHWEST

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

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

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

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

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

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

FAR WEST

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

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

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

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

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

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

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

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Chapter 4

INFLUENCE OF CROP CONDITION ON HARVEST-AID ACTIVITY

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INTRODUCTION

Cotton is a perennial plant that will shed its mature leaves naturally as the growing season progresses and the crop matures. Stresses such as drought, disease, starvation, or frost may cause natural leaf senescence (Cathey, 1986); however, growers rarely wait for natural defoliation, using harvest aids to remove leaves and hasten boll opening artificially in preparation for harvest. Successful defoliation of cotton requires ideal environmental conditions at the time of – and during the two to three days following – application of defoliants, correct selection of harvest-aid chemicals, and proper condition of the plant at time of harvest-aid application. Of these factors, the influences of weather and condition of the crop at the time of defoliation probably have the most impact on successful defoliation (McCarty, 1995). Obviously, weather is a factor over which the grower has little control; however, with good management decisions throughout the growing season, the grower can have significant impact on the condition of the crop at the end of the season.

CROP CONDITIONS DURING THE SEASON

VEGETATIVE VS. REPRODUCTIVE GROWTH

The relationship or balance between vegetative and reproductive growth of a cotton plant during the season is one of the more important factors that affects a crop's response to harvest-aid application (Walhood and Addicott, 1968). Any agronomic practice or environmental factor that promotes vegetative growth, rather than reproductive growth, can lead to problems in harvest preparation and reduced efficacy of harvest aids.

During the early stages of growth, the cotton plant will produce two cotyledonary leaves, followed by five to nine main stem nodes and leaves. After this initial vegetative growth phase, the cotton plant begins its reproductive phase. The auxiliary buds located at the main stem leaf axis begin to differentiate and produce reproductive branches. This process typically begins at the fifth to ninth nodes; once buds along the main stem begin to produce fruiting branches, most of the subsequent nodes also will produce fruiting branches. However, the continuation of flowering is a function of continued vegetative growth, which produces sites for additional fruiting branches, and the formation of additional nodes on existing branches (Mauney, 1986).

The cotton plant has an indeterminate growth habit with the ability to sustain growth, either vegetative or reproductive, as long as weather and nutrients allow. If reproductive growth proceeds normally and first-position bolls – the fruiting structures closest to the main-stem on a fruiting branch – are set, they act as carbohydrate sinks, slowing later vegetative growth. Setting first-position bolls early and retention of these bolls throughout the growing season forces a plant to shift increasingly available carbohydrates from vegetative shoot and root growth to boll (lint and seed) development. If first-position bolls are lost or development of these bolls is delayed, growth will continue and natural senescence will begin later in the season. Therefore, to maximize the performance of harvest-aid chemicals, a grower's production practices should be designed to obtain a balance between vegetative and reproductive growth, to favor early flowering and fruit set, and to retain first-position bolls throughout the growing season, such that physiological maturity coincides with the end of the effective fruiting season.

VARIETAL DIFFERENCES

Although botanically cotton is considered an indeterminate plant because it flowers and sets fruit over an extended period of time, breeders have developed cultivars that are referred to as "determinate." Determinate cultivars tend to fruit at nodes lower on the plant (Ray, 1972), shed fewer early squares, and require fewer days between fruiting position development on each branch and between successive branches (Namken *et al.*, 1975). These cultivars mature early and fruit heavily during the early growing season. Terminal buds then become dormant, the growth of fruiting branches and rate of flower production decline, and all or most of the late flowers are shed (Tharp, 1960). Indeterminate cultivars continue to flower throughout the growing season and may not develop enough fruit to stop growth later in the season. Over a long growing season, an indeterminate variety most likely will have higher yields than a more determinate variety. However, when the growing season is shortened because of poor weather conditions, an indeterminate variety will be less responsive to harvest aids, because the plant will not have reached natural senescence.

The extent to which different cotton varieties respond to harvest-aid chemicals generally depends on the conditions under which the varieties were developed. Varieties developed under Rain Belt conditions were more susceptible to chemical injury in Arizona than Acala™ varieties developed in the irrigated Far West region (Walhood, 1949). Acala varieties, which have larger and thicker leaves than upland varieties, tend to be more tolerant to harvest-aid chemicals, even when grown in the Rain Belt regions of cotton production.

There does not seem to be evidence that varieties developed for the region under which they are grown have significant impact on performance of harvest aids. Variety selection and how it fits into a management program, however, is an important consideration. For example, plant height and maturity are influenced strongly by plant populations, water management, and use of plant growth regulators.

Transgenic Bt (*Bacillus thuringienesis var. Kurstaki*) varieties with full-season characteristics typically produce rank growth under good growing conditions. A small-statured variety will mature earlier in high planting densities than a tall-statured variety. In order to optimize harvest-aid performance, growers must have knowledge of how a particular variety will interact under their field conditions and what varieties best suit their particular management practices.

PLANTING DENSITY

Growing a cotton crop for successful use of harvest aids begins at planting with selection of optimum plant populations and establishment of a uniform plant stand. Plant spacing directly influences soil moisture extraction, light interception, humidity, and wind movement. These factors, in turn, influence plant height, branch development, fruit location and size, crop maturity, and, ultimately, yield (Hake *et al.*, 1991a).

Whenever fruit initiation or retention is delayed, crop maturity also is delayed. Ironically, either a very thin or dense crop stand may result in delayed maturity (Hake *et al.*, 1991a). Cotton plants in thin or "skippy" stands grow large vegetative branches to fill the open space. Fruit set on these vegetative branches occurs later in the season; consequently, maturity is delayed. On the other hand, dense stands can result in delayed square initiation, increased fruit shed, and slower nodal development. This is because of poor light penetration into the leaf canopy where leaves do not receive sufficient light to supply assimilates required for boll retention (Johnson, 1969). The relationship between planting densities and maturity depends on the variety. Kerby *et al.* (1990) found that higher plant densities delayed maturity of more indeterminate genotypes but had no effect on shorter, more determinate genotypes. Early maturity was associated with a lower node number of the first fruiting branch, more rapid production of early main-stem nodes, and an increase in retention of early fruiting structures. Optimum plant densities, therefore, generally are related to ultimate size of the plant (Kittock *et al.*, 1986; Kerby *et al.*, 1990), which primarily is controlled by genetics. If plants are small, higher densities can be established without detrimental affect on crop maturity, whereas larger plants perform better under lower plant densities. Recommended planting densities for most picker cotton varieties are three to four plants per foot of row in conventionally spaced (38 to 40 inches) cotton or two to three plants per foot of row in narrow-row (30 inches) cotton. With short-stature stripper varieties, three to four plants per foot of row are recommended.

CROP STATURE AND THE ROLE OF PLANT GROWTH REGULATORS

Plant stature is affected by many factors, both environmental (nutrient availability, moisture) and cultural (planting density, cultivar, use of mepiquat chloride).

Tall plants with excessive rank growth may have more square and boll abscission due to insect damage and shading of lower leaves. These plants will mature later in the season; the presence of excessive foliage may interfere with penetration of harvest-aid chemicals into the crop canopy.

The plant growth regulator mepiquat chloride is a management tool used by many cotton growers to inhibit plant growth, even when the crop has been affected adversely by other factors. Cotton treated with mepiquat chloride puts less energy into growth of leaves and stems and more into fruit retention and boll development. The benefits of mepiquat chloride use have been well documented. They include reduced plant height and length of fruiting branches (Willard and Kupelian, 1977), improved ratio of fruit dry weight to aboveground dry weight (Wells and Meredith 1984), and improved earliness (Willard and Kupelian, 1977; Briggs, 1981; Kerby *et al.*, 1983; Kerby, 1985). Height reductions vary according to growth conditions (York, 1983, Stuart *et al.*, 1984; Kerby, 1985), with greatest response achieved under conditions that produce taller plants (York, 1983). Conditions that warrant the use of mepiquat chloride to control excessive growth and enhance maturity include late-planted cotton (Cathey and Meredith, 1988), fields that have a history of producing cotton with rank growth due to soil type or water and nutrient availability, and cotton planted in narrow rows (30 inches or less) (Hake *et al.*, 1991b).

PLANT STRESS EFFECTS

Water, in either excessive or insufficient quantities, can affect the plant's response to harvest aids and, depending on when the stress occurs, either can be detrimental or beneficial to harvest-aid efficacy. If moisture is abundant prior to fruit set, vegetative growth and plant height will be excessive. Plants that have been exposed to excessive amounts of moisture during the growing season usually have rank growth and long internode lengths.

If plants are stressed from lack of water, square and boll retention may be reduced, resulting in delayed maturity (Guinn, 1982a). Water stress does not cause major square shedding if it occurs early in the season, prior to flowering

(Bruce and Romkens, 1965; Mauney *et al.* 1980), but will increase square shedding if the stress occurs after flowering has begun (McMichael and Guinn, 1980). The effect of drought stress on fruiting and boll abscission occurs through a number of mechanisms. These include decreased photosynthetic activity due to smaller (Boyer 1973; Marani and Levi, 1973), or the loss of, leaves (McMichael *et al.*, 1973); decrease in translocation of assimilates (Ackerson and Hebert, 1981); and alteration of the hormonal balance within bolls (Guinn 1976). If water then becomes available without the carbohydrate sink of developing bolls, energy will be diverted to vegetative growth and later-maturing bolls.

Cotton plants that are water-stressed during the growing season develop a thick, waxy cuticle that is relatively impenetrable to harvest aids. Oosterhaus *et al.* (1991) concluded that the efficacy of foliar-applied harvest aids was substantially reduced when the cotton had received inadequate rainfall or irrigation during the growing season. Leon and Bukovac (1978) found that the composition of the cuticular wax of water-stressed plants had higher molecular weight waxes than well-watered plants. This trend towards longer-chain waxes results in a greater hydrophobicity of the cuticle contributing to reduced leaf uptake of harvest aids.

Because harvest aids typically do not translocate within the plant, adequate penetration into the plant canopy is essential for activity under water-stress conditions. To maximize canopy penetration, high application gallonage should be used. Five to 10 gallons per acre is recommended for aerial application of harvest aids. By ground, harvest aids should be applied in spray volumes ranging from 10 to 20 gallons per acre. When spraying rank or tall cotton, the top end of the spray ranges are necessary to achieve good penetration and adequate coverage.

If water stress occurs late in the growing season just prior to harvest-aid application, it can be beneficial, because it promotes natural plant senescence. Lack of water during the boll-opening period will hasten boll maturation, stimulate leaf senescence, and retard regrowth. Fields that are depleted of moisture before harvest-aid application generally can be defoliated with lower rates of harvest-aid chemicals (Hake *et al.*, 1996).

Nitrogen is an essential nutrient for growth and development of cotton. It plays an important role as a molecular component of chlorophyll, nucleic acids, membrane proteins, enzymes, and plant hormones. Although availability of adequate nitrogen throughout the growing season has significant impact on fruit-set patterns, boll retention, and crop maturity (Kerby *et al.* 1987), excessive levels can negatively affect the efficacy of harvest-aid chemicals.

Unduly high nitrogen levels during the growing season will promote excessive vegetative growth, shifting the available supply of carbohydrates from reproductive growth. Because leaf size is dependent on nitrogen (Jackson and Gerik, 1990) and water availability, leaf size can become very large when nitrogen levels are high. Large leaves that shade lower boll positions cause them either to mature more slowly or to abscise (Guinn, 1982b). Subsequent bolls that are retained will be delayed in opening and the plant will reach senescence later in the season.

If soil nitrogen is not depleted by the time of harvest-aid application and moisture is available, plants will continue to produce healthy, vigorous growth. This late-season, vigorous growth, not having reached the state of senescence required for rapid abscission, is very undesirable (Cathey, 1986). Brown and Rhyne (1954) found that defoliation efficiency was directly related to the age of leaves when plants were in a continuous stage of growth. Addicott (1969) and Thomas (1965) found that leaves on the lower part of the plant and leaves subtending mature bolls are more responsive to most defoliant chemicals than leaves of newer growth. Application of harvest aids therefore most likely would result in poor leaf drop of young, juvenile leaves.

Diseases, such as *Verticillium* wilt (*V. dahliae* Kelb.), a fungal disease that infects cotton, blocking the xylem and interfering with translocation of water and nutrients, can affect harvest-aid performance. Mild infections cause leaves to wilt, while more severe infections cause leaf and boll shed (Presley, 1953). If a mild infection of *Verticillium* occurs late in the season, it will trigger the production of ethylene (Wiese and Devay, 1970), which will initiate formation of abscission zones, making the plant more susceptible to defoliation (Hake *et al.*, 1996).

Insect feeding can seriously damage cotton by causing leaf malformation or abscission, by increasing the shedding of squares and bolls, by damaging the seed and lint, or by a combination of these. The stimulus for square and boll shedding either may be direct (feeding on the square or boll) or indirect (by withdrawing nutrients from leaves, petioles, or stems, or by causing loss of leaf area due to malformation or abscission) (Guinn, 1982b).

Depending on the extent of the injury and when it occurs during the growing season, insect injury may result in excessive or abnormal vegetative growth and abortion of early-season squares and bolls, resulting in a delay in plant maturity. Good insect control therefore is essential for maintaining the balance between vegetative and reproductive growth and early plant maturity, thus preparing the plant for successful harvest. In addition, disruption in fruiting, leading to nonuniform boll set, can complicate timing of harvest-aid application.

The damage caused by insects can occur at any stage of crop growth. However, because of fruit loss and subsequent compensatory growth, damage that occurs early to mid season is most likely to disrupt normal maturity and senescence and to cause excessive vegetative growth, which will have the greatest impact on harvest-aid performance.

Plant bugs (***Lygus spp.***) feed primarily in the terminals of the cotton plant, puncturing developing squares and growing points (Leigh, Kerby and Wynholds, 1988). Feeding on cotton plants prior to fruit development will damage the plant terminal, resulting in an undesirable many-branched, candelabra-shaped plant, commonly referred to as “crazy cotton.” When small- to medium-sized squares are fed upon, they will abort in three to four days (Leigh and Goodell, 1996). The critical period for plant bug control and, thus, protection of early fruit set, is during the first to sixth week of squaring.

Cotton bollworm *(Helicoverpa zea Boddie)* and tobacco budworm *(Heliothis virescens Fabricius)* cause damage from larvae feeding on leaves, squares, blossoms, and young bolls (Wilson *et al.*, 1980). Their feeding stimulates ethylene production (Guinn, 1982b), triggering shedding of the damaged squares and bolls.

Pink bollworm *(Pectinophora gossypiella Saunders)* moths feed on plant nectar and lay eggs on the surface of squares, bolls, or leaves. The larvae burrow into and feed internally on squares or bolls. They normally feed on the immature pollen and anthers within the fruit, rarely causing squares to abscise. However, if the larvae feed on the stigma of squares or on the ovule of young bolls, the boll will abscise soon after anthesis (Guinn, 1982a).

Boll weevil *(Anthonomus grandis grandis Boheman)* adults prefer to feed on squares (about one-quarter inch in diameter). Adult weevils also will feed on young bolls when weevil populations are high. The females oviposit in squares and young bolls, where eggs hatch and larvae feed and develop to the adult stage. Oviposition and egg hatch trigger abscission of squares. Feeding-damaged and larval-infested bolls usually remain on the plant but sustain damage to seed and lint.

Leaf-feeding insects and mites destroy leaf photosynthetic tissue, depriving the plant of its source of food. Inadequate carbohydrates cause premature cessation of square development and boll growth. Pests causing this type of damage include the cotton leafperforator (*Bucculatrix thurberiella* Busck), beet armyworm (*Spodoptera exigua* Hübner), other foliage-feeding caterpillars, spider mites (*Tetranychus spp.*), and thrips (*Frankliniella* spp.).

HERBICIDE INJURY

Herbicide use plays an important role in modern cotton production. If applied in accordance with label recommendations, herbicides will not affect the growth and development of cotton negatively. However, misapplication, uneven application, or unfavorable weather, which slows crop growth, may cause injury to the crop such that early growth and fruiting patterns are disrupted, maturity is delayed, and efficacy of harvest-aid chemicals is reduced.

Cotton herbicides may cause injury under adverse environmental conditions. Stunting or lack of growth can result from application of pre-plant incorporated or pre-emergence cotton herbicides under adverse conditions. Residues in the soil from these herbicides restrict root growth and development, especially when temperatures are cool and compensatory growth is slowed. Post-emergence herbicide application also may delay maturity, depending on growth stage of the cotton when the exposure occurred. Snipes and Byrd (1994) observed that MSMA and a combination of MSMA and fluometuron, applied post-emergence over the top to cotton in the cotyledon to one-leaf growth stage, elevated the node number of the first fruiting branch by one and 1.5 positions, respectively, indicating a delay in maturity of three to five days.

Carryover may occur when cotton is grown in rotation with other crops. Persistence of herbicides used in the previous crops may result in delayed plant development and stunting. Regions of the United States that would be most affected are the Southwest and Far West, where conditions are dry, temperatures are cool, and soil pH is high. The most common offenders are chlorsulfuron and metsulfuron used in wheat; atrazine and propazine used in sorghum or corn; and metribuzin, chlorimuron, imazaquin, and formesafen sodium used in soybeans (Wiese *et al.*, 1992).

Spray drift onto cotton may occur in areas where nonselective herbicides are used on crops grown adjacent to cotton fields. This can be a significant problem in regions of the country where cotton is grown next to rice, because some currently registered rice herbicides can injure cotton. In addition, recent introduction of genetically altered cotton varieties tolerant to over-the-top applications of glyphosate or bromoxynil increases the risk of drift further.

The potential for drift or accidental overspray from rice herbicides is significant because of the widespread use of fixed-wing aircraft for application. Smith *et al.* (1977) demonstrated that propanil, the most widely used herbicide in rice, delayed maturity when applied post-emergence to cotton. The extent of injury to cotton is affected by growth stage of the crop when the drift occurs. In general, drift from contact herbicides such as propanil or acifluorfen is more injurious to young cotton than that from systemic herbicides such as triclopyr, 2,4-D, or quinclorac (Snipes *et al.*, 1992). Conversely, when cotton is in the reproductive phase of growth, systemic herbicides have a more profound effect on cotton yield than contact herbicides.

In recent years, cotton varieties have been developed that are resistant to over-the-top application of glyphosate; however timing of application is critical to avoid disruption of fruiting. Presently, over-the-top applications of glyphosate can be made from emergence of the cotton seedling up to the four-leaf (node) stage of growth. Over-the-top applications made after the four-leaf stage of development may result in boll loss, delayed maturity, and yield loss.

CROP CONDITION DURING HARVEST-AID APPLICATION

MATURITY AND BOLL LOAD

A heavy boll load prior to harvest-aid application forces the cotton plant to stop vegetative – and reduce further reproductive – growth. This stage of development commonly is referred to as cutout. Cutout is the stage where the harvestable crop is approaching physiological maturity and any further fruit set is of little commercial value. Harvest aids usually perform best when plants have completely reached the cutout stage. During cutout, growth in the immature bolls proceeds and available carbohydrates and nitrogen are partitioned into developing, immature bolls, rather than supporting further vegetative growth. Furthermore, root growth is restricted by the presence of developing bolls (Eaton, 1931; Eaton and Joham, 1944), such that new exploration of soil for moisture and nutrients ceases. Plant senescence therefore is encouraged because of the direct competition by developing bolls for carbohydrates and nitrogen, and the indirect effect of reductions in nutrient and water uptake by roots.

ENDOGENOUS HORMONE ACTIVITY AND NATURAL SENESCENCE

Plant senescence, whether natural or induced by application of harvest aids, is accompanied by a number of changes in the leaf. These include loss of chlorophyll, a temporary increase in levels of anthocyanin, and a breakdown in leaf proteins and carbohydrates, which then are translocated along with inorganic ions to other parts of the plant (Walhood and Addicott, 1968; Addicot, 1969). In addition, as leaves age, the concentration of auxins, hormones associated with actively growing plant tissue, declines and the levels of ethylene and abscisic acid (ABA) increase. The latter plant hormones are associated with plant senescence and leaf abscission.

The time at which these changes appear and the rate at which they progress can vary because of many factors. The senescence state of development is not always related to chronological age but, more often, is a reflection of the condition under which the plant develops (Cathey, 1986). Leaf senescence can be delayed by the abundant supply of nitrogen or accelerated by drought, frost, mineral deficiencies, and certain toxic chemicals (Addicott, 1969).

PLANT STRESS AND LEAF ABSORPTION BARRIERS

Plant stresses affect harvest-aid uptake and activity once it has been absorbed into the leaf. Because the internal leaf cells, where enzymatic activity necessary for harvest-aid performance occurs, require a saturated condition to function, it is desirable that leaves have a high moisture content at time of harvest-aid application (National Cotton Council, 1950). Under conditions of prolonged drought, not only do leaf cuticles become thickened, such that uptake of harvest-aid chemicals is reduced (Osborne, 1974), but physiological activity within the leaf also is reduced.

Addicott and Lynch (1957) demonstrated that defoliation is especially enhanced when nitrogen levels are depleted in the soil. The lack of nitrogen promotes senescence and aging, and stimulates the separation zones in leaf petioles and immature boll walls, whereas high nitrogen levels will delay abscission zone formation in both leaf petioles and boll walls.

CHANGES IN CROP CONDITION AFTER APPLICATION

Abscission of leaves is an active physiological process controlled by hormonal interactions within the leaf blade. It involves separation of living tissue from the plant through the breakdown of cells within the separation zone, a restricted band of cells located at the base of the leaf petiole (Webster, 1973; Sexton and Hall, 1974). Hormones within the leaf blade play a major role in this process. They include auxins, such as indole and naphthalene acetic acid (IAA and NAA), abscisic acid (ABA), ethylene, gibberellic acid, and cytokinin (Addicott and Wiatr, 1977). Auxins are strong inhibitors of abscission, while ABA and ethylene are promotive. Gibberellic acid and cytokinin have variable effects depending on concentration, site of application, and tissue involved. (See Chapter 2 for further discussion.)

The auxin gradient theory proposed by Addicott *et al.* (1955) may describe a major factor in the control of the abscission process. The theory is based on the observations that, before leaves abscise, the auxin concentration in leaf blades decreases, whereas the concentration of auxin in the stem remains unchanged. Abscission occurs when the shift in the auxin gradient across the abscission zone favors the stem side. In support of this theory, Addicott and Lynch (1955) demonstrated that, when IAA is applied to the petiole side of the abscission zone, leaf abscission is inhibited, whereas when IAA is applied to the stem side, abscission is stimulated. These observations led Addicott *et al.* (1955) to suggest that the auxin gradient across the abscission zone is more important than absolute concentration of auxin in cotton leaves. As growth and maturation of the cotton plant proceeds, there is a decrease in auxin production by leaf blades. This decrease results in a gradual shift in the auxin gradient across the abscission zone, which initiates abscission in senescent leaves (Cathey, 1986).

Harvest-aid chemicals artificially stress or injure the leaves of a cotton plant, inducing a change in the hormonal balance between the leaf petiole and stem such that leaf abscission will occur. Because respiratory metabolism is essential for abscission to occur, the abscission zone must be alive and fully functional for the process of abscission to take place. Any treatment that is so severe that it damages or kills cells within the abscission zone will prevent abscission. Leaves will be desiccated but remain attached to the stem, contributing to excessive trash in seed cotton. If leaf injury from harvest-aid application is minimal, the hormonal processes required to initiate leaf abscission will not occur, and leaves will remain green and attached to the plant (Roberts *et al.*, 1996).

Defoliation may be achieved in two ways: 1) application of a chemical that injures the leaf, resulting in increased concentrations of endogenous hormones (ethylene and ABA) that promote abscission; or 2) application of chemicals that act as plant growth regulators, which directly stimulate ethylene production. Defoliants such as tribufos injure the palisade cells in leaves (Morgan, 1983), while dimethipin causes leaf cells to lose water slowly. Application of both harvest aids caused the leaf to generate ethylene (Hake *et al.*, 1990) and promote leaf abscission. Thidiazuron is a synthetic cytokinin-type hormone that stimulates the production of ethylene relative to auxin in leaf petioles, activating the leaf abscission layer (Suttle, 1985, 1988). Ethephon is a precursor to ethylene, stimulating production of ethylene in the plant, resulting in formation of the abscission zone in immature boll walls and leaf petioles. Although used primarily as a boll-opening chemical, ethylene may enhance defoliation (Snipes and Baskin, 1994; Gwathmey and Hayes, 1997). Hormone-type harvest aids rarely cause desiccation, leaf freezing, or even visual injury but are more dependent on crop condition and environment than contact-type materials.

Though the degree of injury varies with plant condition, defoliant used, concentration of defoliant, and environmental conditions at application, injury usually is visible on the leaf blade within 48 to 72 hours of application (Walhood and Addicott, 1968). The separation layer in the abscission zone can be seen in photomicrographs one to two days later. Within 7 to 14 days, the defoliation process is complete under normal conditions; however, it may take as long as 30 days if conditions are unfavorable.

Desiccants, such as paraquat or sodium chlorate applied at high rates, cause rapid water loss from plant cells on contact, killing all aboveground portions of the plant. Unlike defoliation, in which the leaf blade and abscission zone play an active physiological role in leaf shed, desiccants severely injure plant tissues such that plant tissues are killed (Addicott and Carns, 1964; Addicott and Lynch, 1957; Carns, 1966).

Sometimes the plant response to a particular harvest-aid chemical may not be so clear-cut. High doses of defoliants under ideal environmental conditions will result in desiccation of plant parts. On the other hand, low rates of desiccants, especially paraquat, may result in defoliation, if only the leaf blade is injured, but petioles remain uninjured.

CARBOHYDRATE RESERVES AND REGROWTH

When maturing bolls are not present to act as carbohydrate sinks, undesirable regrowth may occur if temperatures remain warm and water and nitrogen are available in the soil. Terminal (growth from the tips of stems or branches in the upper portion of the plant) or basal (growth from auxiliary buds at the base of the plant) regrowth can occur prior to or after leaves have been removed by harvest aids. Regrowth occurring prior to leaf removal generally is referred to as juvenile growth, whereas regrowth occurring after leaf removal is either terminal or basal regrowth.

The level of auxin in young leaves tends to be higher than in mature leaves. This makes younger leaves highly resistant to chemical removal. Application of harvest aids generally will remove mature leaves more easily than younger leaves. Though highly resistant to defoliation, young leaves that still are expanding have thin cuticles and are very sensitive to desiccation.

SUMMARY

The condition of the cotton crop throughout the growing season has a significant impact on the efficacy of harvest-aid chemicals. The "ideal" crop condition for optimal harvest-aid performance includes an early and uniformly maturing crop, a heavy boll load, adequate but not excessive moisture availability throughout the growing season, nitrogen levels that have been depleted, a crop that has stopped vegetative and reproductive growth (reached cutout), and a crop that is senescing naturally. Though all these conditions rarely are met, a grower's agronomic practices should be designed through fertility and water management, insect control, plant stand establishment, use of plant growth regulators, and other practices to prepare the crop for the best possible harvest-aid performance.

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PHOTOGRAPHIC PLATES

ACKNOWLEDGEMENT

The following pages of photographs depict a progression of harvest technology, as well as examples of various factors affecting harvest efficiency. The editors of this Monograph gratefully acknowledge the generosity of Col. Harris Barnes, USMCR (Ret), for supplying many of the photographs. Also contributing photographs (in order of appearance): Delta Research and Extension Center, James Supak, Jerry Duff on behalf of Uniroyal Chemical, Charles Snipes, and T.B. Freeland, Jr.

DELTA RESEARCH AND EXTENSION CENTER

Prior to the development of aqueous sprays, agrichemicals, including harvest aids, were applied with mule-drawn "dusters" that relied on wet foliage to "stick" the active ingredient to the plant.

HARRIS BARNES

Aerial application contributed to the acceptance of harvest aids, with products such as calcium cyanamide, which also was called cyanamid powder, or "Black Annie."

HARRIS BARNES

Mechanical harvesting gained acceptance in the 1940s, beginning with one-row models initially introduced by International Harvester™.

JAMES SUPAK

Experimentation with different machinery was commonplace in the 1950s and 1960s.

HARRIS BARNES

In the 1950s, several manufacturers, such as Allis-Chalmers®, built affordable two-row pickers and strippers.

HARRIS BARNES

Tractor-mounted pickers and strippers provided farmers with affordable mechanical harvesting capability.

JAMES SUPAK

Two-row pickers and strippers dominated the harvest scene for more than 20 years, until manufacturing technology and production economics drove the market to wider, multi-row models.

UNIROYAL CHEMICAL

A cost-effective defoliation/desiccation operation in the fall begins in the preceding spring with a uniform stand of healthy seedlings.

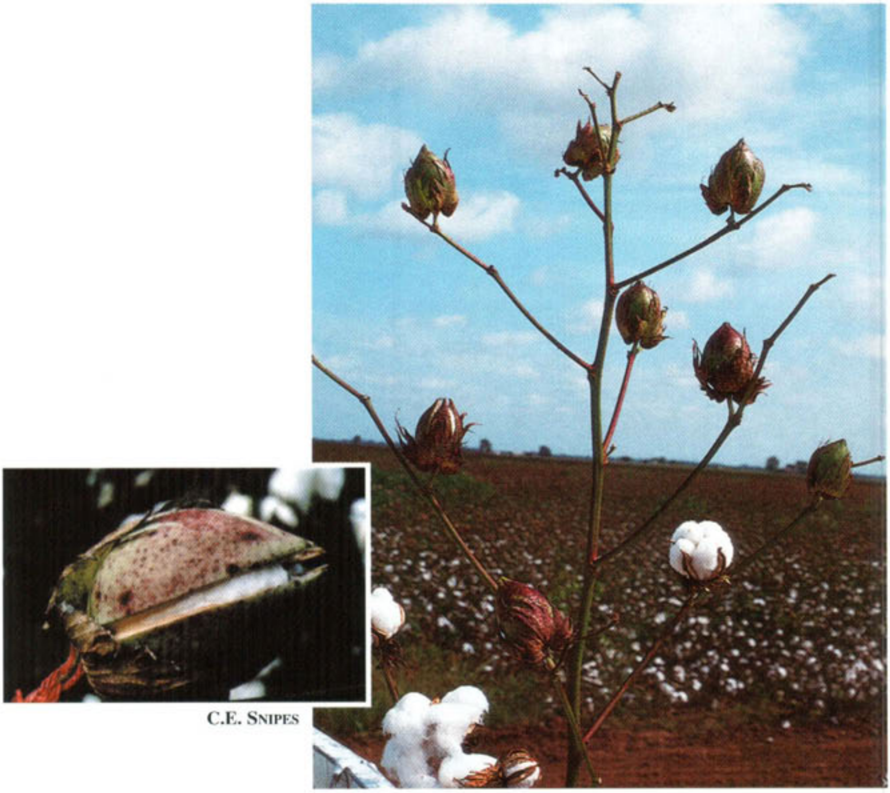
UNIROYAL CHEMICAL

UNIROYAL CHEMICAL

Weed management during the growing season is vital to a cost-efficient harvest. Morningglory (*Ipomoea* sp.) is one of the most troublesome weeds that plagues harvest.

UNIROYAL CHEMICAL

Understanding boll maturity is critical to obtaining high-quality lint. Look for back seed coats and well-defined cotyledons to delineate a mature boll from one that is immature.



C.E. SNIPES

JAMES SUPAK

Location of the uppermost cracked boll can be used to determine crop readiness for harvest-aid application with the "nodes above cracked boll" method. Research has shown that four first-position bolls above the uppermost cracked boll are safe to defoliate.

(Inset) A mature boll is considered cracked if lint can be seen through the sutures.

HARRIS BARNES

Basal regrowth is the first to form and hardest to control, but generally is less troublesome to a harvest operation.

UNIROYAL CHEMICAL

The new leaves subsequent to defoliation can appear as terminal regrowth and often are a source of green staining, fine leaf trash, and excessive moisture in seed cotton.

UNIROYAL CHEMICAL

Leaves desiccated by a harsh harvest-aid treatment are essential for stripper harvesting, but can increase hard-to-remove trash in spindle- and stripper-harvested seed cotton.

UNIROYAL CHEMICAL

A crop stressed by drought, hot weather, disease, or other factors generally is more difficult to defoliate.

UNIROYAL CHEMICAL

Ground units are widely used for harvest-aid application, especially in smaller fields and near populated areas. Harvest aids are most effective on crops that are physiologically mature, or "cut out," and free of undue stresses.

UNIROYAL CHEMICAL

Choosing the right combination of harvest-aid products for crop and weather conditions can improve the overall defoliation/desiccation operation.

UNIROYAL CHEMICAL

A significant percentage of the U.S. cotton acreage is defoliated with ground-application equipment.

UNIROYAL CHEMICAL

Aerial application of harvest aids allows cotton producers to cover large acreages in a timely manner.

HARRIS BARNES

Turbine-powered aircraft largely have replaced rotary engines. Turboprops carry a larger payload than conventional spray planes and can cover a greater number of acres per day.

JAMES SUPAK

Good defoliation and desiccation allow for timely stripper harvesting.

HARRIS BARNES

Modern cotton pickers have far greater capacity than could be imagined even as recently as 1980. Advances in the use of harvest aids have facilitated development of larger, faster harvesting and ginning equipment.

HARRIS BARNES

Effective defoliation allows a high-capacity harvest, keeping pickers operating efficiently by using "boll buggies" to transport cotton to module builders.

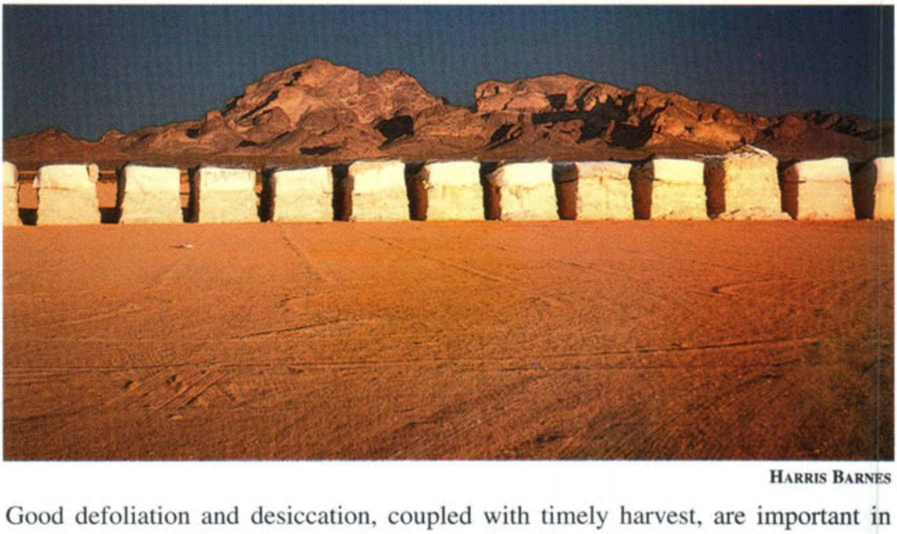
UNIROYAL CHEMICAL

Manufacturing technology meets demand, as growers rush for greater harvest efficiency.

UNIROYAL CHEMICAL

Module building made harvester capacity independent of ginning capacity, enabling growers to get crops "off the stalk" and minimize field weathering losses.

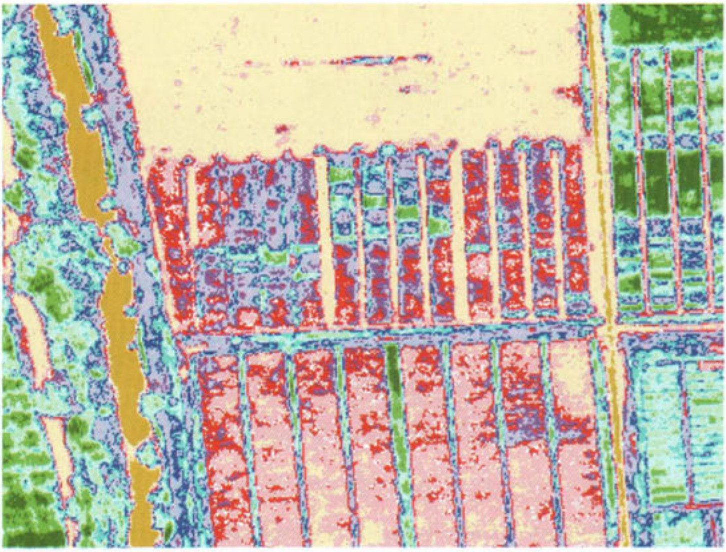
UNIROYAL CHEMICAL



HARRIS BARNES

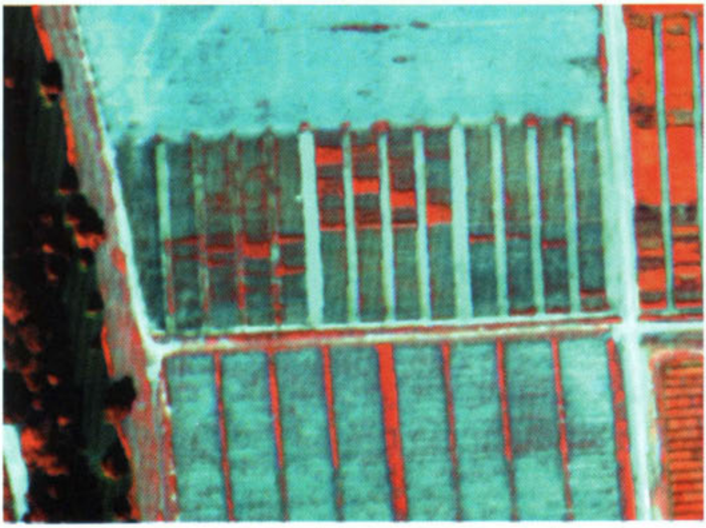
Good defoliation and desiccation, coupled with timely harvest, are important in allowing for safe field storage of seed cotton in a densely packed module.

The images on the following page were processed by T.B. Freeland, Jr., and C.E. Snipes from data provided by Mississippi State University's Remote Sensing Technologies Center and NASA.



MISSISSIPPI STATE UNIVERSITY AND NASA

In the future, precision application of harvest-aid materials will be possible by using remotely sensed data. Classified net vegetative indexing (shown above) indicates areas of full foliage (green) and areas completely defoliated (tan/cream). Decreasing levels of foliage are indicated by blue, followed by purple, then red, then pink.



MISSISSIPPI STATE UNIVERSITY AND NASA

Multi-spectral infrared imaging may be used to identify defoliated (grayish-blue) and non-defoliated (red) areas in a single field.

Uniroyal Chemical

Harvest-aid programs allow for timely harvest and fit into overall crop management systems, by eliminating food and overwintering sources for insects and by facilitating fall tillage operations.

Harris Barnes

Cotton harvest in the new millennium has advanced greatly with the wise use of harvest aids and advances in manufacturing technology.

Supplement to Chapter 4

ASSESSING REGROWTH AFTER DEFOLIATION

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No standardized criteria have been accepted universally for visually estimating cotton regrowth following the application of harvest aids. Because subjective ratings assessing the amount of regrowth vary among individuals – researchers, industry, and Extension specialists – it is almost impossible to compare product performance from trial to trial. The set of drawings that follow[1] constitute one approach to standardizing visual regrowth ratings, regardless of whether the test is from California or South Carolina, to allow easy visualization and estimation of the amount of regrowth in a field.

Quantified measurements, such as those reported by the Cotton Defoliation Work Group (Anonymous, 1999), are labor-intensive and time-consuming. Thus, a uniform method of visual estimation is desirable.

Properly used, the illustrations will encourage standardized ratings and allow statistical comparison of the regrowth from different harvest-aid treatments. Such ratings can be made by almost anyone; they do not require technical knowledge and can be done quickly and efficiently with practice, without specialized equipment. Practice and experience should minimize any differences in rating from one individual to another. Ratings are visual and do not involve collecting, drying, weighing, or measuring leaves.

Most plants in a field will have different amounts of regrowth, so it is important to determine how many plants or row-feet are necessary to form a fair evaluation zone. Once this is established, an overall rating number can be determined for the plot or field. Cotton regrowth in the same field will

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[1] Original artwork by Octavio Tierranegra, Agricultural Communications, Texas Cooperative Extension, and Charles R. Stichler.

vary widely – from none, to plants that may be dead, to plants with lush, new growth. A composite based on the average number of leaves on plants in the rated zone should be used to establish the best fit with the drawings. The illustrations allow each evaluator a standardized reference for making regrowth ratings in the field.

The artist's drawings are from actual plants and represent six distinct stages of regrowth. The range is from 0 to 5, with 0 being no terminal or basal regrowth and 5 being a full canopy of new leaves. Decimals may be used to indicate intermediate levels of regrowth, if desired, or the scale can be expanded to spread data points for statistical evaluation. Because the ratings are numerical, they can be averaged if replication is used.

The following abbreviations are used in the illustrations:
T - top of plant (upper 6 inches of growth)
B - lower half of plant (area below 6 inches of top growth)

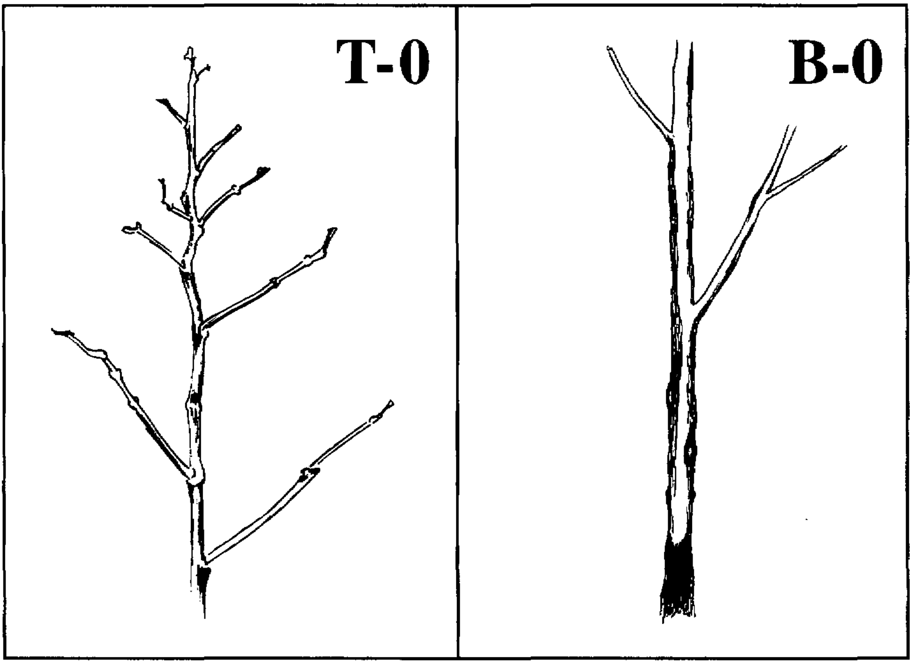

Figure 1. Stages T-0 and B-0: No terminal or basal regrowth.

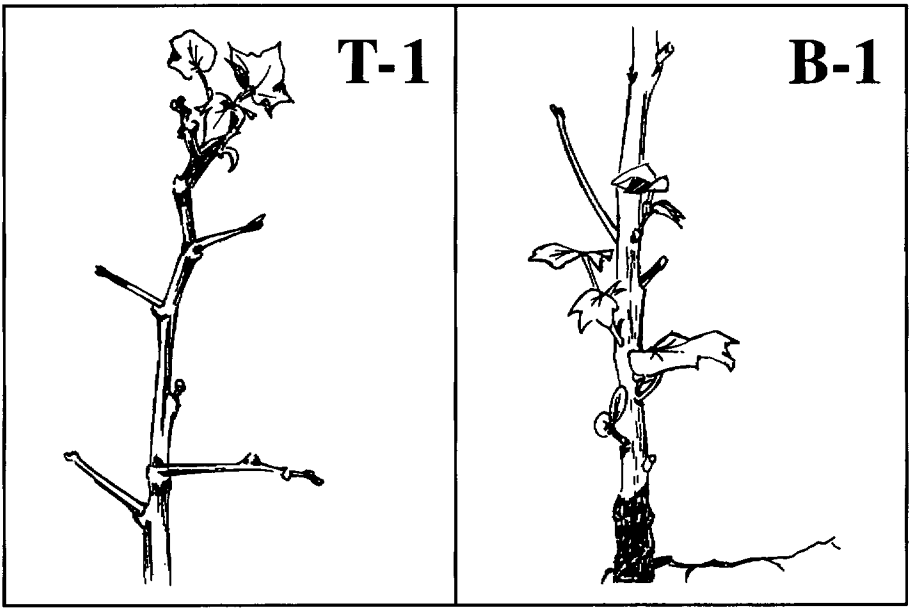

Figure 2. Stages T-1 and B-1: New leaves less than or equal to ¼ inch in length in terminals; no basal regrowth.

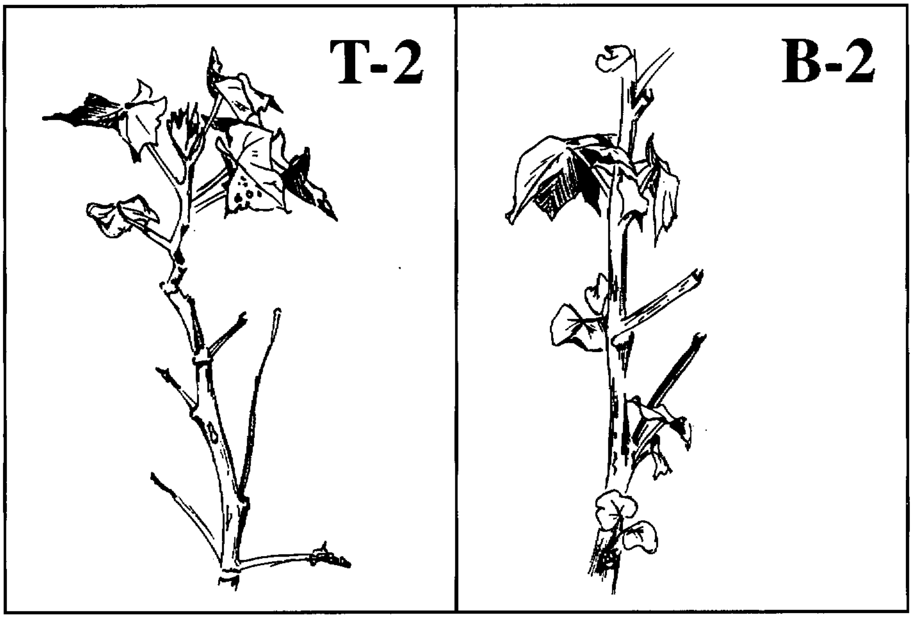

Figure 3. Stages T-2 and B-2: Leaves in terminal unfurling and typically less than ½ inch in size; new leaves (less than ¼ inch) forming at basal buds.

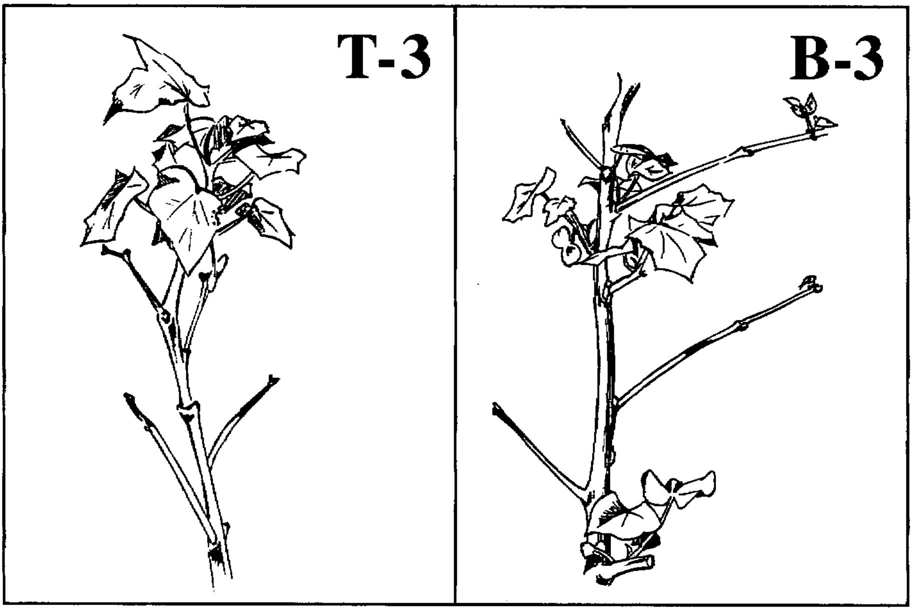

Figure 4. Stages T-3 and B-3: Terminal leaves ½ to 1 inch in diameter and expanding rapidly; leaves and stems forming at basal nodes.

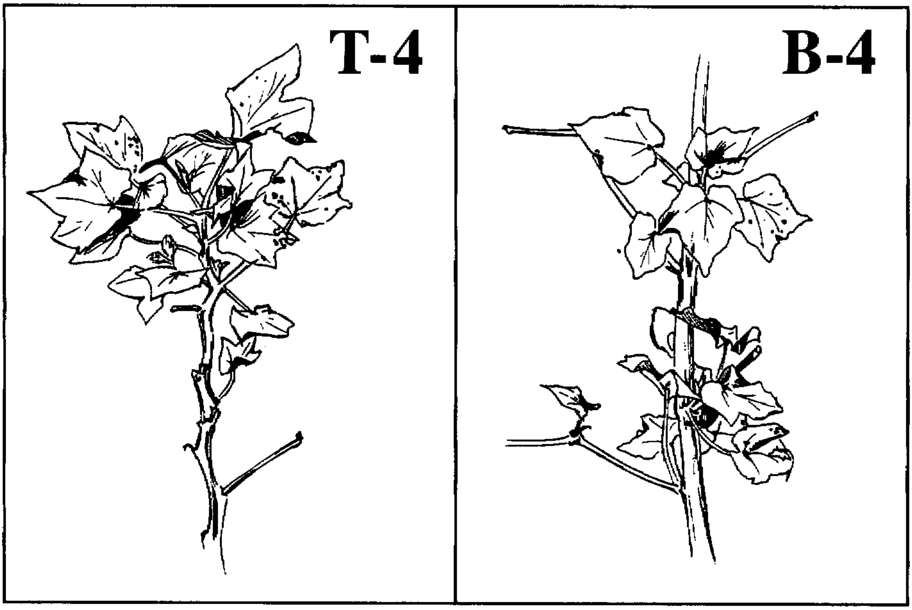

Figure 5. Stages T-4 and B-4: Terminal leaves 1 to 2 inches in diameter; stems with leaves attached at basal buds.

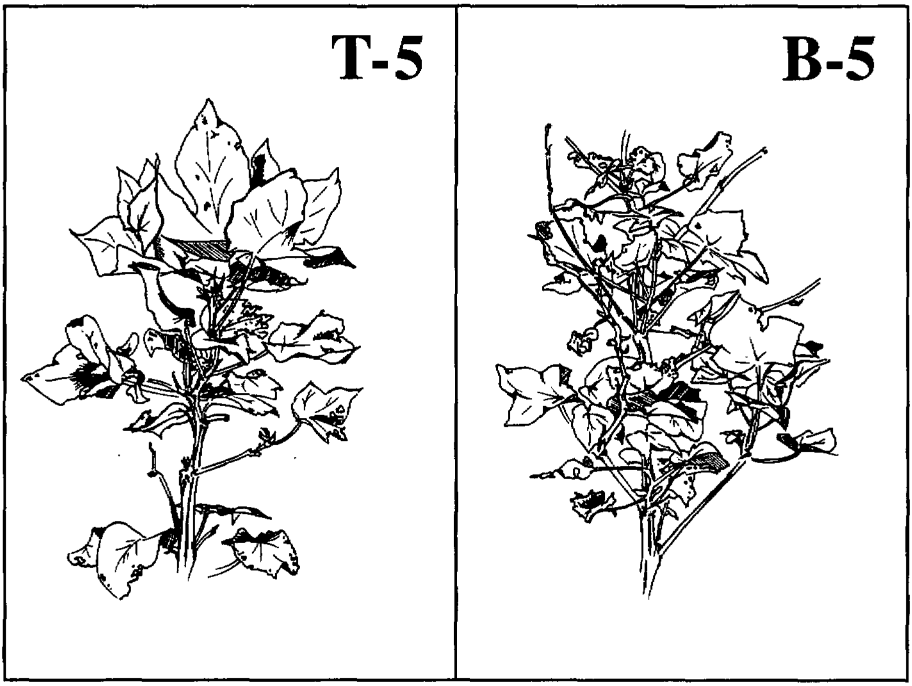

Figure 6. Stages T-5 and B-5: Full canopy of leaves, some more than 3 inches in diameter.

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Chapter 5

HARVEST-AID TREATMENTS: PRODUCTS AND APPLICATION TIMING

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INTRODUCTION

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

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

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

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

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

PREPARING COTTON FOR HARVEST-AID APPLICATION

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

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

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

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

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

DEFOLIATION TIMING

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

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

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

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

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

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

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

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

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

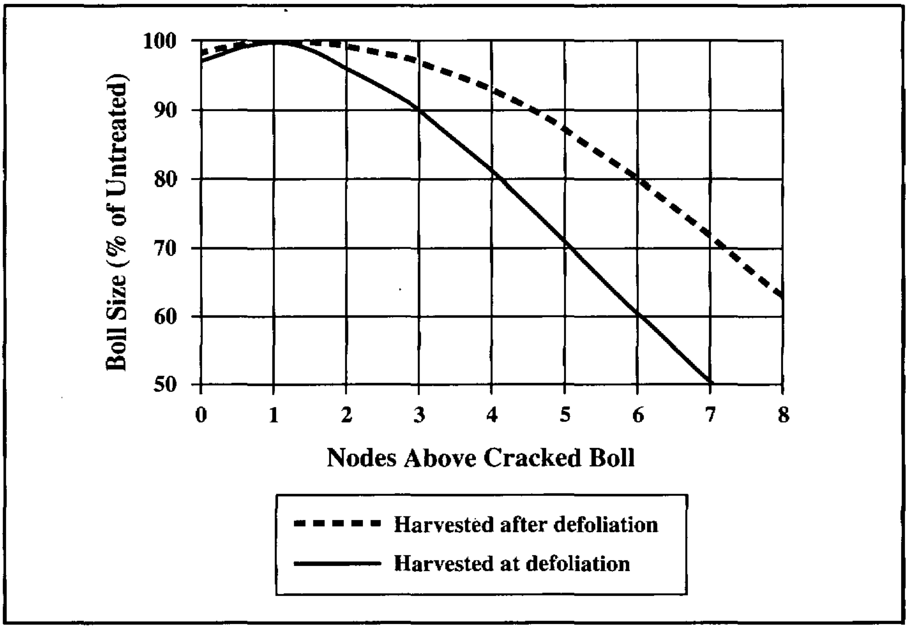
Plot B. On the day of defoliation, the fruiting branch with an FB1 cracked boll was tagged, and the plot was defoliated with 1.0 pound a.i. per acre of Prep™ tank-mixed with 2.0 pounds per acre of Folex® or Def®. When the effects of the harvest aid were fully expressed, the plots were harvested by position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

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

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

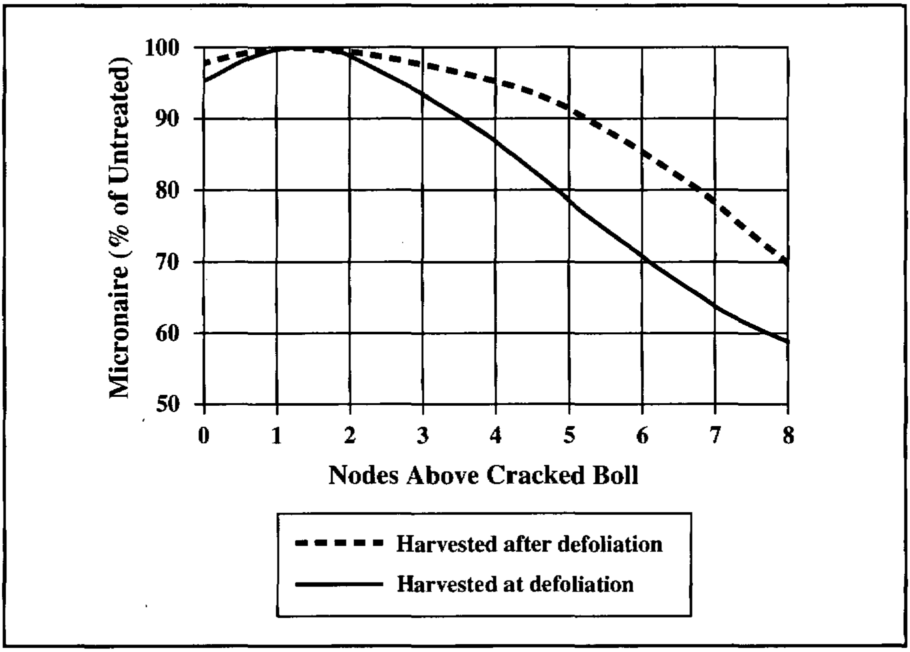
Boll Size – The difference in boll size between plots that were harvested on the day of defoliation and those that had been treated with a harvest aid is illustrated in Figure 1. The difference between the lines shows the amount of boll growth that took place after the plants were defoliated. This differential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

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



Source: Kerby *et al.*, 1992.

Figure 1. Effect of defoliation on boll size.



Source: Kerby *et al.*, 1992.

Figure 2. Effect of defoliation on micronaire.

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

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

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

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

HARVEST-AID PRODUCTS

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

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

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

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

BOLL OPENERS

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

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

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

ENHANCED ETHEPHONS

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

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

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

DEFOLIANTS

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

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

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

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

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

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

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

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

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

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

DESICCANTS

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

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

PRODUCTS WITH OTHER APPLICATIONS

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

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

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

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

COMMON MIXTURES AND SEQUENTIAL TREATMENTS

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

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

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

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

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

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

ADDITIVES/ENHANCERS

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

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

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

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

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

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

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

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

HARVEST-AID PERFORMANCE

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

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

BELTWIDE

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

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

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

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

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

REGIONAL DIFFERENCES

SOUTHEAST

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

MIDSOUTH

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

SOUTHWEST

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

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

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

FAR WEST

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

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

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

SUMMARY

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

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

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

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

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

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Chapter 6

HARVEST-AID APPLICATION TECHNOLOGY

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INTRODUCTION

Cotton maturity, senescence, and injury are key components of leaf abscission (Cathey, 1986). Although leaf abscission often occurs naturally, it may not lead to a timely harvest. Therefore, defoliants are used by producers to promote leaf abscission and leaf drop.

Harvest aids often are classified as either herbicidal or hormonal. Although they differ in activity, both types of harvest aids enter the plant through the stomates (minor route) and by crossing the cuticle (major route) (Currier and Dybing, 1959). The ability of a harvest aid to pass into a leaf primarily is a function of the chemical and physical nature of the cuticle, as well as of the properties of the harvest aid and accompanying formulation ingredients, and the environment in which the leaf has developed. At present, the actual process of pesticide – including harvest aid – movement into the plant primarily is limited by a lack of knowledge of the physical and chemical properties of the cuticle (Devine *et al.*, 1993).

Once herbicidal and hormonal harvest aids enter the plant, they act quite differently. Herbicidal defoliants slowly injure or stress the leaf, causing epidermal cell wall disruption, thus stimulating ethylene synthesis. In contrast, hormonal defoliants and boll openers release or promote the production of ethylene without relying on contact injury. Regardless, both herbicidal and hormonal defoliants have a common mode of action by altering hormone balance in the plant, thereby initiating the abscission process (Cathey, 1986).

A successful defoliation encourages or forces cotton leaves to drop from the plant, improving picker efficiency, grade, and the quantity of lint harvested. Defoliation also may retard boll rot and stimulate boll opening, which, in turn, may promote earlier harvest and increased yield and profit.

Although it is quite apparent that a proper defoliation is beneficial, many factors must be considered prior to applying harvest-aid chemicals. Harvest-aid application decisions largely are based on crop maturity, crop condition, weather conditions, desired harvest schedule, and harvest-aid choices and rates. However, adjuvant usage, spray volume and pressure, defoliant drift, and application equipment also are critical aspects that must be considered prior to cotton defoliation.

ADJUVANTS

Adjuvants are chemicals added to agricultural chemical formulations or tank mixes to improve mixing and application or to enhance performance (Bohmont, 1990; Devine *et al.*, 1993; Foy, 1989). Most agricultural chemicals are not applied alone or in pure solutions but, instead, are used in combination with a variety of ingredients to improve efficacy. This variety of ingredients often includes surfactants and oil-surfactant concentrates used to enhance leaf-surface wetting and penetration; these formulations also include a number of biologically inert materials that improve the stability and rainfastness of the pesticide formulation (Bohmont, 1990; Devine *et al.*, 1993; Foy, 1989). Inorganic salts, phosphate esters, and chelating agents also have been used to enhance pesticide activity (Devine *et al.*, 1993).

In addition to inclusion as inert ingredients in pesticide formulations, adjuvants are added with pesticides in the spray tank to further increase efficacy. These adjuvants often decrease droplet surface tension and enhance leaf wetting and leaf contact angle. Surfactants, widely used as an adjuvant, have been shown to enhance pesticide activity by facilitating contact between pesticide spray droplets and leaf surfaces (Bohmont, 1990; Devine *et al.*, 1993; Foy, 1989). Surfactant structures and physical properties vary widely; however, surfactants share the common property of having hydrophilic and lipophilic portions. Having both hydrophilic and lipophilic properties causes surfactants to orient themselves along the droplet-cuticle interface, thus potentially enhancing diffusion through the cuticle (Devine *et al.*, 1993).

Although the functions of many adjuvants still are poorly understood, their use is increasing. Research has shown that pesticide penetration, translocation, metabolic fate, phytotoxicity, selectivity, and persistence often are altered by chemical adjuvants (Devine *et al.*, 1993; Foy, 1989). Used correctly, adjuvants often increase agricultural chemical effectiveness as much as five- or tenfold (Valkenburg, 1982). However, some pesticides require avoiding adjuvants altogether.

Similar to other agricultural chemicals, harvest-aid formulations include adjuvants as inert ingredients. Harvest aids often require additional adjuvants tank-mixed to improve efficacy. Adjuvants most often recommended with herbicidal and hormonal harvest aids include surfactants, petroleum- or vegetable-based oils, and crop oil concentrates. These adjuvants must be matched to particular harvest aids, crop maturity, and environmental conditions to ensure that they enhance – and do not detract from – the effectiveness of the harvest aid.

When adjuvants and harvest aids are properly matched, adjuvants may perform one or more of the following functions, enhancing harvest-aid defoliation:

Enhance wetting of foliage – Adjuvants often increase foliage wetting, thereby providing good retention and plant coverage by the harvest aid. Greater plant coverage and retention often allow for more harvest-aid absorption into the plant.

Improve uptake and translocation – Harvest aids perform most effectively when they have been absorbed by the plant. Typically, the level of activity is directly related to the quantity of the harvest aid absorbed into the leaves or bolls.

Enhance uniformity of deposit – Leaf penetration, rather than surface deposition, most often is the goal when using harvest aids. Adjuvants may enhance foliage coverage and uniformity of harvest-aid deposit, thereby increasing foliar uptake and harvest-aid efficiency.

Reduce spray evaporation – Evaporation of spray or vapor drift during and just after application often can be reduced by using a suitable adjuvant; this benefit is most apparent when applications are made in ultra-low volumes.

Although adjuvants may enhance the activity of some harvest aids, they also may hamper the goal of producing cotton that is free of trash. For example, when some mixtures of adjuvants and defoliants are applied, desiccation of the crop may occur too rapidly. With rapid leaf kill, the cotton leaves may become stuck on the plant, creating unnecessary trash. The potential for creating unnecessary trash at harvest exemplifies the need to match harvest aids, adjuvants, crop maturity, and the environment for a successful defoliation.

APPLICATION

The purpose of defoliation is to maintain lint quality, to facilitate harvesting, and, in some cases, to preserve yield. Thorough spray coverage is essential for good defoliation, because harvest aids are not translocated from one leaf to the other. Each leaf must be covered to cause the abscission process. A second application may be needed on rank cotton with dense foliage, because initial coverage may not be sufficient on the lower leaves of plants. Complete coverage also is the reason for high gallonage rates on labels. Coverage is even more important in a non-ideal environment.

Nozzle selection also affects defoliation applications. The type of nozzle affects the amount of spray applied to a particular area, uniformity of the applied spray, coverage obtained on the sprayed surfaces, and amount of drift. Each nozzle type has characteristics and capabilities designed for use under specific application conditions.

Much previous chemical application research has focused on improving the deposition and reducing the quantity of chemicals applied. Studies have concentrated on producing and delivering spray droplets hydraulically or mechanically, or on using air-assisted methods. These efforts have resulted in the development of several different types of chemical application equipment and techniques of delivering spray droplets, including air-assisted and electrostatically charged delivery. More recent research has focused on reducing the amount of off-target pesticide drift. The research has resulted in development of spray nozzles that produce more large, uniform droplets.

The effectiveness of new spray devices has been the subject of several research projects. Most of the studies focused on weed control, insect control, and canopy deposition. Some of the earliest attempts to improve spray coverage and reduce pesticide usage employed spray atomizers that mechanically generated a narrow range of droplets. Several spray atomizers were evaluated for foliar-applied weed control in soybeans. None of the atomizers performed better than flat-fan nozzles, and it was concluded that the non-conventional devices could not be justified for weed control (Walker *et al.*, 1989). These types of units no longer are in production for use in ground application.

Womac *et al.* (1993) evaluated the spray deposition obtained by air-assisted sprayers. He found that higher spray rates and greater levels of air assistance increased canopy penetration. Air-assisted sprayers force the spray particles down into the canopy with turbulent air flow. Air-assisted hydraulic sprayers presently are superior in placing spray material into dense cotton canopy. These sprayers are more suited to higher-valued crops; their feasibility is questionable in normal cotton production.

Coverage can be significantly affected by spray volume. The higher the spray volume, the better the canopy penetration. Another important factor is droplet size: Smaller drops will give better coverage, but they are more susceptible to drift.

DRIFT

Particle drift is the actual movement of spray particles away from the target area. Drift occurs by two methods: vapor drift and particle drift. Drift of defoliants away from the target area is an important, potentially costly problem facing both commercial and private applicators. Drift causes many problems, including damage to susceptible off-target sites; a lower application rate than intended, which can reduce the effectiveness of the defoliant, wasting harvest aid and money; and increased environmental contamination, such as water pollution and illegal pesticide residues.

DRIFT DYNAMICS

A solution dispersed through a hydraulic spray nozzle is broken into droplets that are spherical or nearly spherical in shape. Droplets smaller than 100 microns in diameter are considered highly "driftable." They are so small that they cannot readily be seen unless in high concentrations, such as fog. For comparison, a human hair is about 100 microns thick. As a result of the small size, drift is more dependent on the irregular movement of turbulent air than on gravity.

Many factors affect drift, but the most important is the initial size of the droplet. Small droplets fall through the air slowly and are carried farther by air movement. Table 1 shows the effect of droplet size on the rate of fall. The longer the droplet is airborne, the greater the potential for drift.

Table 1. Effect of droplet size on drift potential.

Diameter (microns)	Spray Type	Time to Fall 10 Feet in Still Air (seconds)
1	Fog	100,800
10	Fog	1,020
100	Mist	11
200	Fine	4
400	Coarse	2
1,000	Coarse	1

Source: Ross and Lembi, 1985.

Volume Median Diameter (VMD) is a term used to describe the droplet size produced from a nozzle tip. VMD is the droplet size at which one-half the spray volume consists of large droplets and one-half consists of smaller droplets. Since it takes many more small droplets to make up one-half the spray volume, there always will be more small droplets present in a typical spray pattern. A general droplet size guide is given in Table 2.

Table 2. Basic droplet size guide.

Application	Droplet Size Based on Volume Median Diameter (VMD) (microns)
Fungicide	150-250
Insecticide	150-300
Contact Herbicide	250-400
Phenoxy and Incorporated Herbicide	400+

When leaving the nozzle, the solution may have a velocity of 60 feet per second (41 mph) or more. Unless the spray particles are electrostatically charged, two forces act on the emerging droplets: gravity and air resistance. These forces greatly influence the speed and movement of spray droplets.

Droplet speed is reduced by air resistance, which breaks up the droplets. After their initial speed slows, droplets continue to fall under gravitational pull. With low boom heights, the initial speed may be great enough that the droplet reaches the target before drift occurs. Large droplets maintain a downward velocity longer than smaller ones. Small droplets also evaporate quickly and move farther in wind (Figure 1).

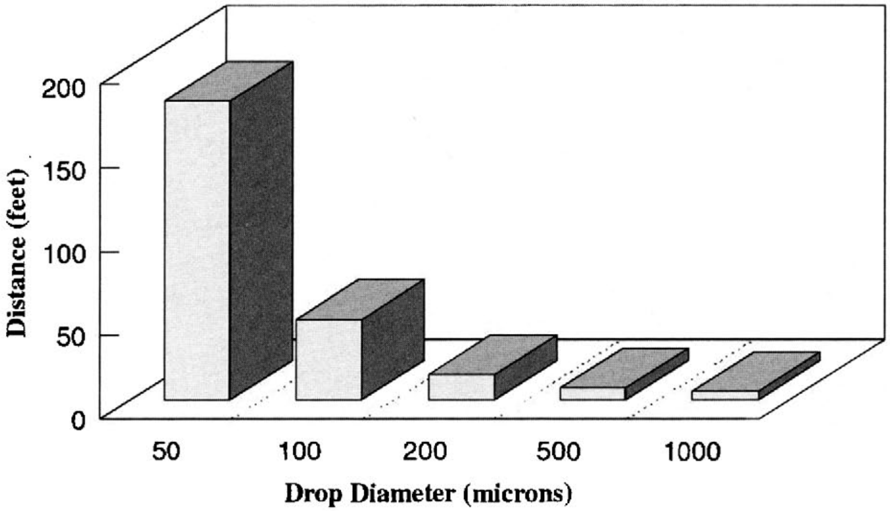


Figure 1. Effect of wind and droplet size on drift in a 10-foot fall at 3 mph wind speed. (Hoffman *et al.*, 1986)

Ideally, most of the volume should be contained in larger droplets. When the pressure is increased, a higher percentage of the droplets are smaller in size. With a greater proportion of the total spray volume in smaller droplets, the potential for drift to off-target sites increases.

ALTERING DROPLET SIZE

Many components of a sprayer can be adjusted to alter droplet size. Of these, nozzle selection is one of the most critical.

Nozzle Type – Droplet sizes are influenced by various nozzle types and different spray pressures. Spray droplets are produced from nozzles in different ways. A *fan nozzle* forces the liquid under pressure through an elliptical orifice; the liquid spreads out into a thin sheet that breaks up into different-sized droplets. A *flood nozzle* deflects a liquid stream off a plate that causes droplets to form. A *whirl chamber nozzle* swirls the liquid out an orifice with a circular motion and aids droplet formation with a spinning force. A *rotary nozzle* meters liquid through an orifice and releases it into a rotating wire basket to atomize the spray.

Spray Pressure – Spray pressure influences droplet formation. The spray solution emerges from the nozzle in a thin sheet; droplets form at the edge of the sheet. Higher pressures cause the sheet to be thinner, and the sheet breaks up into smaller droplets.

Small droplets are carried farther downwind than larger drops formed at lower pressures (Figure 1). The relationship between flow rate (gpm) and pressure (psi) is not linear: Pressure would have to be increased by four times to double the flow rate. Higher pressures decrease the droplet size, greatly contributing to drift potential. Table 3 shows the mean droplet size for a nozzle when spraying at three different pressures.

Table 3. Effect of spray angle and various pressures on fan nozzle droplet sizes.

	Pressure (psi)		
Spray Angle (degrees)	15	40	60
	Volume Median Diameter (microns)		
65	600	550	530
80	540	470	450
110	410	380	360

Source: Spraying Systems Co., 1998.

Spray Volume – The size or capacity of the nozzle also influences droplet size. A larger orifice will increase droplet size at a common pressure. It also will increase the volume applied, but the increased application rate improves coverage and, in some cases, increases pesticide effectiveness.

Spray Thickeners – Some spray adjuvants act as thickeners when added to a spray tank. These materials increase the number of larger droplets and decrease the number of fine droplets. They tend to give water-based sprays a "stringy" quality and reduce drift potential.

Oil Carriers – Droplets formed from an oil carrier tend to drift farther than those formed from a water carrier. Oil droplets usually are smaller and lighter, and they remain airborne for longer periods, but don't evaporate quickly.

ENVIRONMENTAL FACTORS

The effectiveness of pesticide application varies with environmental conditions. Several pesticide labels now contain information on the environmental conditions needed during application.

Wind Speed – Both the amount of pesticide lost from the target area and the distance it moves increase as wind velocity increases (Figure 2). However, severe drift injury also can occur with low wind velocities, especially under temperature inversion. Most recommendations are to stop spraying if wind speeds exceed 10 mph. Wind influences can be minimized by using shielded booms and lowering boom height.

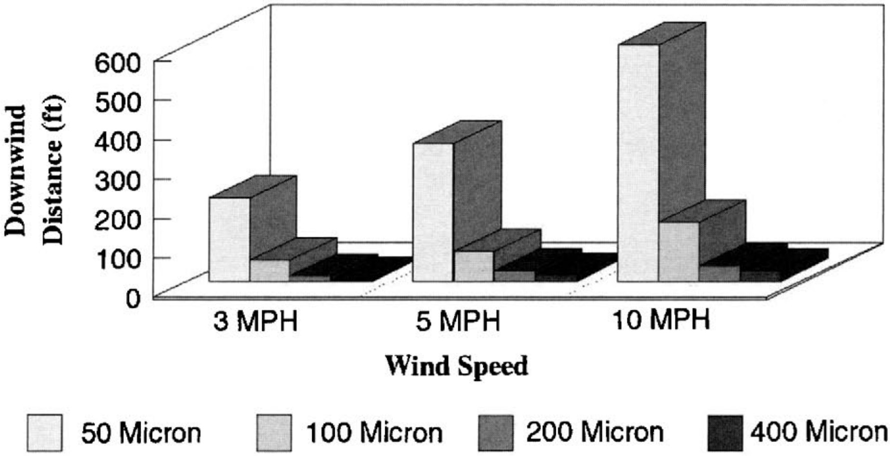
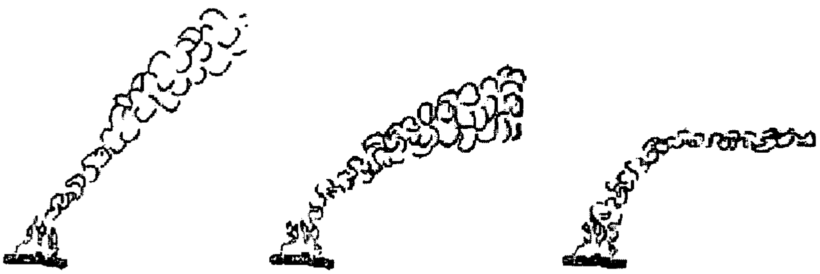


Figure 2. Effect of wind speed on drift in a 10-foot fall. (Hoffman *et al.*, 1986)

Wind Direction – Pesticides should not be applied when the wind is blowing toward a nearby susceptible crop or a crop in a vulnerable stage of growth. Select a time when there is little wind or when the wind blows gently away from susceptible crops. If these conditions do not exist, consider another method of control or time of application.

Air Stability – Air movement largely determines the distribution of spray droplets. Wind generally is recognized as an important factor, but vertical air movement often is overlooked. Temperature inversion is a condition where cool air near the soil surface is trapped under a layer of warmer air. A strong inversion potential occurs when ground air is 2 F to 5 F cooler than the air above. Under inversion conditions, little vertical mixing of air occurs, even with a breeze. Spray drift can be severe under inversion conditions. Small spray droplets may fall slowly or may be suspended by a gentle breeze and move several miles to susceptible areas.

Avoid applying harvest aids near susceptible crops during temperature inversion conditions. Inversions can be identified by observing smoke from a smoke bomb or fire (Figure 3). Smoke moving horizontally, close to the ground, would indicate a temperature inversion.



Midday thermal — Proper application condition — Temperature inversion-Beware!

Figure 3. Smoke rising with wind velocity of less than 5 mph. (Samples and Seigler, 1982)

Relative Humidity and Temperature – Low relative humidity or high temperature conditions cause faster evaporation of spray droplets, posing higher potential for drift. During evaporation, the droplets become smaller. Evaporation is greater from the same deposit in small droplets than in larger drops, because the small droplets have greater surface area relative to their volume. Thus, the smaller the droplet, the less harvest-aid material that gets to the target.

Evaporation increases the drift potential, so crops should be sprayed during lower temperature and higher humidity conditions. Harvest aids evaporate at different rates. Use formulations and adjuvants that reduce evaporation.

As a rule of thumb, if the relative humidity is above 70 percent, conditions are ideal for spraying. However, a relative humidity below 50 percent should warrant special attention.

Water Contamination – The most critical problem posed by chemical drift, by far, is contamination of surface water. Water contamination causes fish kills in lakes, streams, and farm ponds, both on the lands being treated and on other lands in the vicinity. Contamination can be minimized by leaving an untreated buffer zone of 100 to 300 feet along the water line. Aerial application patterns parallel to a stream or pond should never be used unless the wind direction is directly away from the water.

GROUND APPLICATION

Nozzle selection is one of the most important decisions to be made related to pesticide applications. The types commonly used for ground application of agricultural chemicals are flat-fan, even flat-fan, and cone nozzles.

Flat-fan – Regular flat-fan nozzles are used for most broadcast spraying of herbicides and for certain insecticides when foliar penetration and coverage are not required. These nozzles produce a flat, oval spray pattern with tapered edges. This pattern is illustrated in Figure 4, where nozzles are offset five degrees to reduce distortion of spray from adjacent nozzles. They are available in spray-fan angles of 65, 80, and 110 degrees. The 65- and 80-degree nozzles usually are spaced 20 inches apart; 110-degree nozzles usually are spaced at 30 inches. At these respective spacings, the nozzles are operated at boom heights of 15 to 24 inches. The wide-angle (110-degree) nozzles frequently are operated at more narrow (20-inch) spacing and lower boom height to minimize drift caused by windy conditions at application.

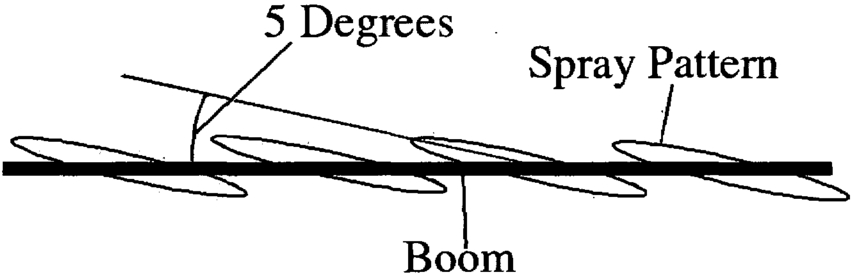


Figure 4. Overhead view of flat-fan nozzles angled 5 degrees from the boom, to illustrate spray patterns. Patterns overlap, but do not intersect.

Overlap of flat-fan nozzles is required, because spray volume at the outer edges of the spray patterns is tapered or reduced. The most uniform pattern is achieved when this overlap is 40 to 50 percent of the nozzle spacing (Figure 5). Check spray overlap by spraying clean water onto a hard, flat surface (concrete) and observing drying patterns. Because of their ability to produce a very uniform pattern when correctly overlapped, the flat-fan type of nozzle generally is the best choice for broadcast application of harvest aids.

Normal recommended operating pressure for regular flat-fan nozzles is 20 to 30 psi. At these pressures, this type of nozzle will produce medium to coarse drops that are not as susceptible to drift as the finer drops produced at pressures of 40 psi or greater. At these higher pressures, the possibility of drift increases significantly, so appropriate precautions must be taken.

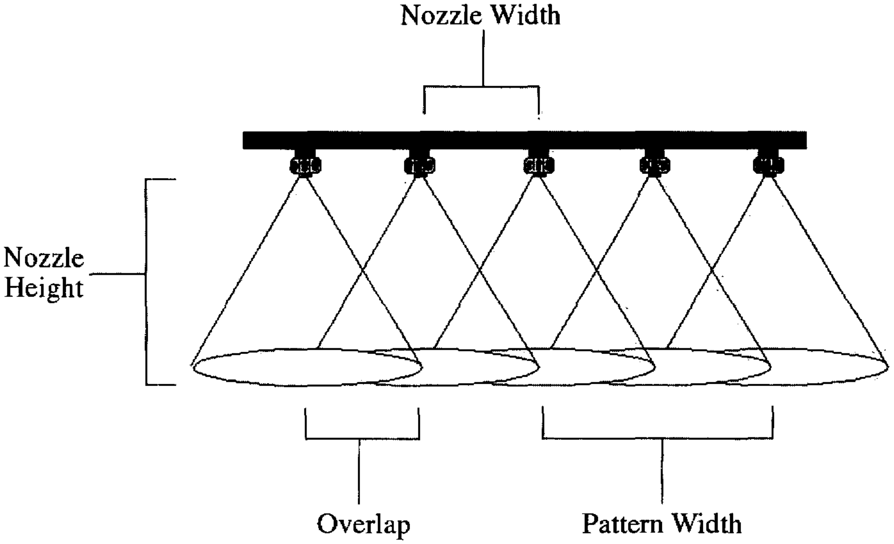


Figure 5. Spray pattern overlaps 40 to 50 percent for flat-fan nozzles.

Extended-Range flat-fan nozzles vary droplet size and flow rate by alternating pressures. These flat-fan nozzles hold their pattern at lower pressure than standard flat-fan nozzles (15 psi), ensuring uniform coverage along the boom. Extended-range flat-fan nozzles are available in both 80- and 110-degree fan angles. Smaller drops are produced at pressures from 30 to 60 psi, increasing the likelihood of drift. High pressures should be used only to apply foliar pesticides that must penetrate into the plant canopy or that require maximum coverage. Spray drift is a major concern at pressures higher than 40 psi.

Drift-Reduction pre-orifice nozzles produce a standard flat-fan pattern while effectively lowering the exit pressure at the nozzle. The lowered exit pressure creates a larger droplet spectrum with less driftable fines, minimizing off-target movement of the spray pattern.

Two styles of drift-reduction flat-spray nozzles currently are available. The RF Raindrop® flat spray nozzle is available with fan angles of 105 to 115 degrees, and the DG TeeJet® flat spray nozzle is available in both 80- and 110-degree fan angles. With a larger droplet size, drift-reduction pre-orifice nozzles can replace conventional flat-fan 80- and 110-degree tips in broadcast applications where spray drift is a problem. The recommended pressure for this nozzle is 30 to 60 psi. An alternative to the pre-orifice nozzle is use of a larger extended-range flat-fan nozzle operated at a lower pressure.

Turbo flat-fan nozzles are designed to produce less turbulence within the nozzle body, thus reducing wear and increasing the nozzle's life. These nozzles produce large droplets that will not drift. This nozzle is available in 110-degree fan angle. A cutaway view is shown in Figure 6.

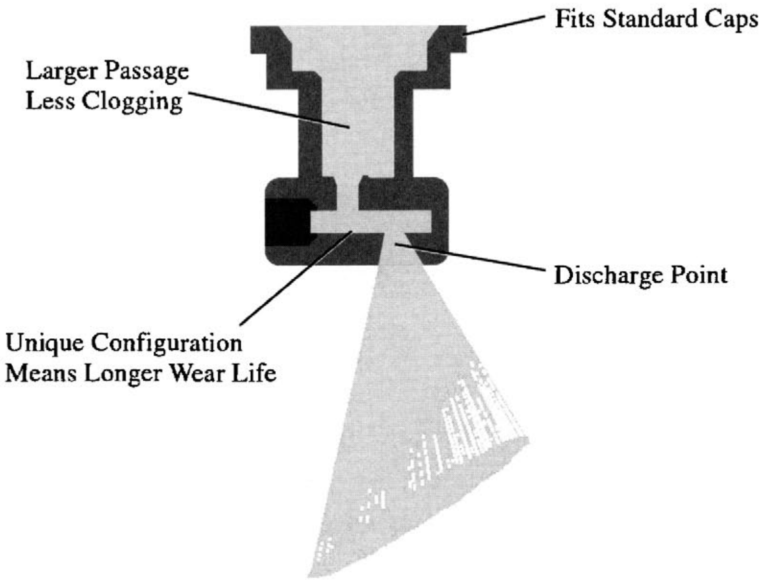


Figure 6. Turbo TeeJet® flat-fan nozzle.

Air-Assist nozzles are designed to produce large droplets and reduce the percentage of fine droplets. As with other low-drift nozzles, air-assisted nozzles contain a pressure reduction chamber with a narrow port. The liquid passing through the orifice plate causes a pressure drop. This venturi effect draws air into the nozzle body, blending air and spray solutions in the mixing chamber, much like a water aspirator. As the liquid is discharged from the nozzle tip, air-filled droplets are produced. Upon leaving the nozzle orifice, the air included in the droplet expands, increasing the size of droplets; this expansion causes the droplet velocity to increase. The higher velocity improves the chances of the droplet reaching the target. The large droplets shatter and splatter on contact, causing the small air-filled drops to spread out on the target for better coverage.

These nozzles produce an average droplet size of 400 to 600 microns. Spray volumes for this type of nozzle should be above 15 gpa at a spray pressure of 70 psi or greater. A cutaway view of this nozzle is shown in Figure 7.

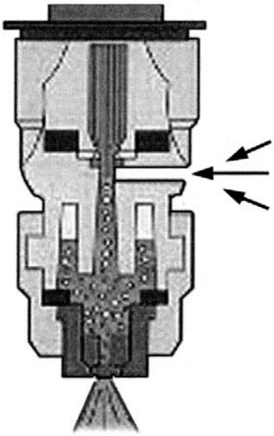


Figure 7. Air-assist nozzle. (Greenleaf Technologies, 1999)

Cone nozzles primarily are used when plant foliage penetration is essential for effective insect or disease control and when drift is not a major concern. At pressures of 40 to 80 psi, these nozzles produce small droplets that readily penetrate plant canopies and cover the underside of the leaves more effectively than any other nozzle type.

Cone nozzles are available in two configurations, nozzle body and disc-core (Figure 8). The spray angle for the nozzle body is fixed by the manufacturer. Spray angles and volume can be changed in disc-core nozzles by using different pressure, disc, and core combinations. The narrower the spray angle, the better the penetration into the canopy.

However, because of the small droplets and high operating pressures, these nozzles produce patterns very susceptible to drift. Therefore, they never should be used with any chemical for which drift can cause a problem. They also are very difficult to arrange along a boom for uniform distribution and are not recommended for broadcasting harvest aids.

The two common styles of cone nozzles are solid-cone and hollow-cone. Solid-cone nozzles produce a cone-shaped pattern with a uniform distribution of chemical throughout the pattern. Hollow-cone nozzles produce a cone-shaped pattern with the spray concentrated in a ring around the outer edge of the pattern (Figure 8).

Table 4 gives the effect of nozzle type and pressure on droplet size for several nozzles.

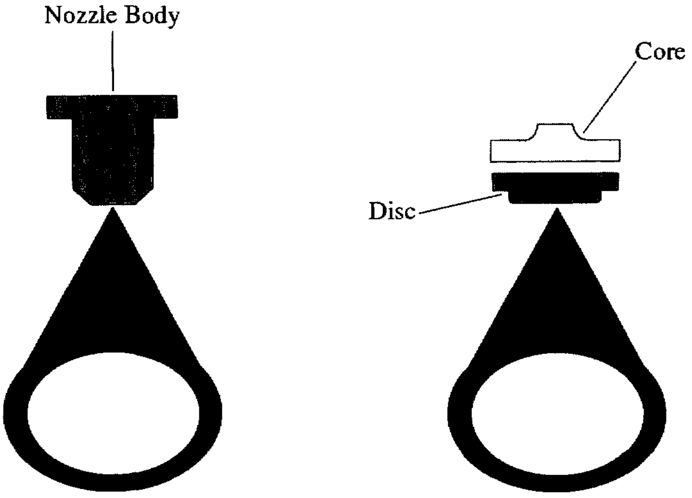


Figure 8. Hollow-cone nozzles: nozzle body and disc-core.

AERIAL APPLICATION

Aerial pesticide application offers several advantages: rapid coverage of large areas, accessibility to crops when ground equipment is not suitable, and, when properly managed, reasonable cost. The danger of contamination of adjacent nontarget areas from drift or misapplication should remain a constant concern.

Table 4. Effect of nozzle type on droplet size. Volume Median Diameter ($D_{V0.5}$, microns).

Nozzle Type, Pressure, Flow Rate	**15 psi**	**20 psi**	**30 psi**	**40 psi**	**50 psi**	**60 psi**	**90 psi**
XR TeeJet® Extended Range Fan XR-80° (Spraying Systems Co., 40 psi and 0.2 gpm)	239	214	177	159		141	
Lo-Drift® Flat-Fan LD-80° (Lurmark Ltd., 40 psi and 0.2 gpm)	367		264	223		189	157[1]
Raindrop® Fan RF-80° (Delavan Corp., 40 psi and 0.2 gpm)		339	290	248	215	200	
DG TeeJet® Fan DG-80° (Spraying Systems Co., 40 psi and 0.2 gpm)			350	292	260	234	
XR TeeJet® Extended Range Fan XR-110° (Spraying Sytems Co., 40 psi and 0.2 gpm)	199	185	166	153		142	
Lo-Drift® Flat Fan LD-110° (Lurmark Ltd., 40 psi and 0.2 gpm)	335		238	209		183	156[1]
DG TeeJet® Fan DG-110° (Spraying Systems Co., 40 psi and 0.2 gpm)			296	241	219	206	
Turbo TeeJet® Flat-Fan TT-110° (Spraying Systems Co., 40 psi and 0.2 gpm)	392		311	271		215	179
Flood CP® (CP Products Inc., 20 psi and 0.25 gpm)		418	341	300			
FloodJet® TK (Spraying Systems Co., 10 psi and 0.2 gpm)	236	224	213	207			
Turbo Floodjet® TFVS (Spaying Systems Co., 10 psi and 0.2 gpm)	598	552	492	427			
Raindrop® RA (Delavan Corp., 40 psi and 0.2 gpm)		549	468	422	394		
TurboDrop® TD 110° (Greenleaf Technologies, 40 psi and 0.25 gpm)				610		511	374[1]
ConeJet® Hollow Cone TXVS (Spraying Systems Co., 40 psi and 0.2 gpm)				178	173	169	

Source: Bouse, 1991, 1994.

[1] Droplet sizes at 100 psi.

Aerial application may be by either fixed- or rotary-wing aircraft. Metering and dispersal equipment must deliver adequate quantities of liquids or solids accurately and in a short period of time. An aircraft with a ground speed of 120 mph and a swath width of 70 feet covers 17 acres per minute.

Liquid application systems consist of pump, tank, hose, boom, filters, regulators, pressure gauge, and metering nozzles. Flow meters are valuable aids in monitoring system output and improving application performance. The hydraulic pumps either are wind driven or direct-powered from the aircraft engine. Fairly low-pressure, high-volume centrifugal pumps generally are used. Air shear across the nozzle pattern aids in breaking the liquid into spray; thus, high pressure is not required for atomization. Some pesticides may require pumps made of special materials or of specific designs. Special requirements and cautions usually are noted on pesticide labels. Nozzle screen sizes of 50 to 100 mesh, or an equivalent slotted strainer, should be used, depending on nozzle orifice size and materials being applied. Nothing finer than 50-mesh screens should be used with wettable powders.

Booms are required to support nozzles along the wingspan of fixed-wing craft. Booms are airfoil-shaped and are located behind and below the trailing edge of the wing to reduce drag and to place the nozzles in cleaner airflow. Location of outboard nozzles on booms is critical, because wingtip and main rotor vortices influence pattern width and drift. End nozzles must be sufficiently inboard to minimize entrapment of fine droplets by wingtip vortices. Such entrapment adversely affects both distribution and drift. Boom length should not exceed three-quarters of the wingspan.

NOZZLE SELECTION

Nozzles are a critical part of aircraft spray equipment. Usually, the same nozzle tips, discs and cores, caps, and strainers are used on both aerial- and ground-application equipment. Nozzle pattern is a major factor in distributing spray across the swath in ground application. In aerial application, spray distribution across the swath is affected considerably by aircraft wake. Thus, nozzle features affecting spray droplet size, droplet size distribution, flow rate, and tendency to clog are more critical than is nozzle spray pattern.

All nozzles used on aircraft produce a wide range of droplet sizes. The versatile disc and core-type hollow cone probably is the most popular. The range of droplet sizes may be changed by varying internal parts and components of these nozzles. Whirl chamber-type hollow-cone nozzles also are quite popular.

Droplet size is greatly affected by nozzle orientation and placement. Nozzles are mounted straight back to minimize small droplet formation caused by wind shear. Two- to four-inch drops on each nozzle place the nozzle in clean air (Figure 9).

Table 5. Droplet size distribution for various nozzles at 40 psi. Water in 115- to 120-mph airstream and parallel to airflow.

Nozzle	**GPM**	**VMD (microns)**	**% <100 microns**	**% <200 microns**
D6 Disc	1.05	697	0.05	0.60
Accu-Flo™; 32 Tubes (Bishop Equipment Mfg. Inc.)	1.90	409	0.14	1.95
M.L. Tips No. 6 Plastic (Lund Flying Service Inc.)	1.08	718	0.11	1.49
6510 Fan	0.93	397	0.08	2.58
D6-46 Cone	0.96	423	0.06	1.59
⅛ B5-5 WhirlJet® (Spraying Systems Co.)	0.84	325	0.29	5.30
TK5 FloodJet® (Spraying Systems Co.)	0.91	339	0.18	5.26
Nylon CP® 0.078 - 30° Deflection (CP Products Inc.)	0.97	403	0.09	2.07
Nylon CP® 0.078 - 60° Deflection (CP Products Inc.)	0.97	321	0.37	7.64
Nylon CP® 0.078 - 90° Deflection (CP Products Inc.)	0.97	273	1.11	13.15
REGLO JET® 0.078 - 45° (ICI Agrochemicals)	0.98	348	0.31	7.20
A&C Hi-Tek Rotary Mosquito Nozzle – 80 Mesh Screen (Davidon Inc.)	1.12	319	1.19	7.94

Source: Bouse, 1991, 1994.

ULTRA-LOW VOLUME

Ultra-Low Volume (ULV) application rates range from a few ounces to 2 gallons per acre. Special metering and atomizing attachments such as Micronair™, mini-spin, and airfoil frequently are used to achieve more uniform-sized droplets. Rotating nozzles may be wind driven or driven from the power unit. Wind-driven nozzles are dependent on aircraft speed and may fail to provide desired atomization when the craft is operating at reduced speeds. Ultra-Low Volume systems may be furnished with smaller diameter mainline hoses and fittings than normal for standard systems. Ultra-Low Volume nozzles may require individual supply lines for each nozzle. Concentrate sprays (no water added) may vary in density and other properties that alter flow characteristics and rate of fall. ULV droplets have unique drift characteristics; the technique is not suitable for all materials. Flying heights of 5 to 15 feet above ground contribute to uniformity and tend to minimize drift.

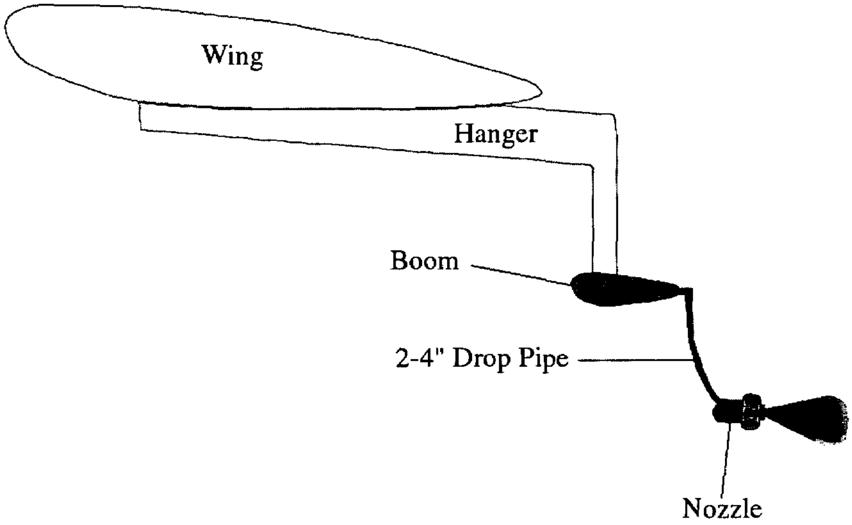


Figure 9. Uniform droplets can be attained by lowering the nozzle into cleaner air.

FUTURE NEEDS

The population shift into rural areas requires the development of new harvest-aid application technology. As more housing units are located around cotton fields, drift, odor and general application will be more in the public eye. More precise placement will be needed to avoid off-target harvest-aid drift. The costs of harvest aids will drive the development of more efficient methods of application.

Harvest-aid drift currently is being addressed by the development of new types of nozzles. Several nozzle manufactures are addressing drift by developing new, improved configurations. The development of techniques to enhance the canopy penetration of harvest aids would be of great benefit. This technology would allow for better defoliation in rank foliage and possibly the elimination of one or more spray applications.

Traditionally, combinations of harvest aids are applied across entire fields without regard to the variability of plant conditions in the field. New developments in site-specific crop management practices, such as variable-rate technology, may help lower the cost of applying harvest aids. This could be accomplished by two methods. Areas in fields that contain cotton plants that are fully cut out and plants that still have lush foliage could be treated with different rates of harvest aids.

In fields with nonuniform growth conditions – uneven distribution of unopened bolls, different regrowth potential, etc. – the mixture of harvest aids could be adjusted for each distinct location. Fields would have to be pre-mapped to facilitate applying different rates or combinations of harvest aids to different areas. This could be achieved by analyzing prior field history, by aerial mapping, or, perhaps, by satellite mapping.

These technologies currently are under development. As advancements occur in spray technology, they will become more practical and economically feasible.

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Chapter 7

UNIFORM HARVEST-AID PERFORMANCE AND LINT QUALITY EVALUATION

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INTRODUCTION

Today, successful cotton production largely is dependent on the use of harvest-aid products designed to defoliate plant leaves, accelerate boll opening, enhance seed cotton drying in the field, and, in some cases, desiccate green plant material. The application of chemical harvest-aid materials also can have varying effects on quality of the fiber.

FIBER QUALITY

Proper application of harvest-aid materials is important for preserving fiber quality by facilitating timely harvest and reducing plant trash created by mechanical harvesting procedures. Conversely, harvest aids can affect fiber quality adversely if applied at the wrong developmental stage of cotton (Snipes and Baskin, 1994).

The indeterminate growth habit of the cotton plant results in longer periods of exposure for lower, open bolls, relative to upper, less-mature bolls that remain unopened at optimum physiological maturity. Certain types of harvest-aid materials are used to facilitate the opening of these younger, unopened bolls, in order to achieve an earlier, once-over harvest.

Application of harvest-aid materials is a chemical termination of the crop to facilitate harvest and to preserve optimum fiber quality. Long-term exposure to weather can reduce lint yield and lead to degradation of fiber quality (Ray and Minton, 1973). Thus, chemical termination of the crop is a compromise between further gains in yield and the risk of weather-related losses from extended periods of exposure of more-mature bolls.

Harvest aids facilitate timely harvesting, reduce seed cotton moisture, and improve storage conditions after harvest (Wooten and Montgomery, 1960), and they improve lint grades (Parker and Wooten, 1964; Whitwell and Walker, 1985).

Harvest aids also have been shown to reduce yield (Barker *et al.*, 1976; Williford, 1992). In two years of a four-year study, defoliation reduced cotton yield when compared to non-defoliated cotton. However, the lint grade index was increased in two of the four years. Grade loss was associated with green plant material. On the average, one out of five bales in the non-defoliated plots was reduced one grade because of green chlorophyll stains (Williford, 1992).

TIMING

Williford (1992) also reported that the use of ethephon to accelerate boll opening allowed for an earlier harvest, but that, when applied at or prior to 60 percent open bolls, ethephon resulted in lint yield and quality loss. Lint grade reduction was associated with the loss of lint color and, to a lesser degree, additional trash. Williford concluded that twice-over harvest appears to be the best harvest system with respect to yield and grade, but the economic implications of twice-over harvest should be considered in the management decision.

In another study, it was shown that application of harvest-aid materials, with or without ethephon, reduced yields and lowered micronaire if applied at 20 percent or 40 percent open bolls (Snipes and Baskin, 1994). Once cotton had reached the 60 percent or 80 percent open-boll stage, there were no adverse affects to yield or fiber quality regardless of the type of harvest-aid material used.

An earlier study reported that the use of combination treatments, usually including ethephon as a component, provided better defoliation than when either component was used alone (Snipes and Cathey, 1992). Thus, ethephon is a plant growth regulator frequently used in harvest-aid strategies for cotton. When applied at the appropriate rate to cotton that has a sufficient load of mature, unopened bolls, ethephon accelerates boll opening and enhances defoliation, while also removing immature fruit structures (Hope and Needham, 1987; Snipes and Cathey, 1992). When applied in combination with another harvest-aid material, ethephon allows for the possibility of a once-over harvest with spindle pickers. However, defoliation enhancement with ethephon may affect lint quality by reducing micronaire, especially if applications are made prior to maximum physiological crop maturity.

It stands to reason that harvest aids should be applied only when all plant processes are complete. However, many times other factors come into play in the application of harvest-aid treatments. The condition of the plant prior to application and environmental factors during and after application play important roles in the efficacy of a harvest-aid product or mixture of products (Supak, 1995; Snipes and Baskin, 1994).

Studies conducted in the Mississippi Delta showed that harvest aids should not be applied until at least 60 percent of the cotton has reached the open-boll stage (Snipes and Baskin, 1994). Another study conducted in Alabama also indicated that terminating the crop prior to 60 percent open bolls may decrease yield and adversely affect fiber quality (Whitwell *et al.*, 1987).

Snipes and Baskin (1994) confirmed yield losses when harvest-aid materials (tribufos, thidiazuron, ethephon, and a combination of tribufos or thidiazuron plus ethephon) were applied at 20 percent and 40 percent open bolls. They also showed that micronaire was decreased when harvest aids were used prior to 40 percent open bolls. However, an increase in fiber strength and length was observed when harvest aids were used at 20 percent open bolls. This was attributed to the physiological abscission of immature bolls, leaving a higher percentage of older, more-mature bolls for harvest.

The study concluded that treatments should not be applied prior to 60 percent open bolls in order to safeguard against potential losses in yield and undesirable changes in fiber quality. Yield losses and quality reductions occurred because of improper timing, irrespective of harvest aid used. Increases in yield in the non-defoliated control plots in these studies indicated a higher trash content in the harvested sample and the additional yield gained by approximately two weeks of additional growth, relative to the defoliated plots. These slight increases occur when small areas are harvested in a timely fashion and risk of weathering loss is minimal, both of which conditions are difficult to achieve on a commercial scale.

Field studies were conducted in Alabama to evaluate early and normal application of several harvest aids: ethephon, tribufos, and thidiazuron (Whitwell and Walker, 1985). Early application was made when bolls were 30 percent to 50 percent open; normal application was delayed until bolls were 65 percent to 75 percent open. Early application of ethephon increased the percent of lint picked from the first harvest and reduced total yield in only one year out of three.

In this study, fiber quality was influenced more by application time than by chemical treatment. Fiber length, uniformity, strength, and elongation were increased with early application of harvest aids in one year, while they showed no effect the other years. This study concluded that, during the years of evaluation, early application of harvest aids had minimal negative effects while increasing percent of yield from first harvest.

Thibodeaux *et al.* (1993) showed that, when ethephon was applied to cotton prematurely (10 percent open bolls), there was a decrease in fiber maturity or fiber wall development for the top portion of the cotton plant, with a corresponding increase in neps (hopelessly entangled masses of fibers). However, this study also indicated that there was no significant reduction in fiber strength or length.

Stripper harvest of cotton requires defoliating leaves with some desiccation of the cotton plant. Evaluations of harvest-aid materials by Supak *et al.* (1994) have shown their effectiveness as defoliants and desiccants in the stripper cotton-growing areas.

Although some desiccation of the plant is necessary, it is not desirable to kill and completely dry the cotton plant prior to harvest. If the plant is completely desiccated, harvest will remove excessive amounts of foreign matter, such as leaves, stems, and even slivers of bark. Subsequent routine cleaning in the gin process may not adequately remove this foreign matter. Excess lint trash requires additional non-routine cleaning procedures that may result in lower fiber quality. However, harvest aids should sufficiently dry the seed cotton and foreign matter to permit storage prior to ginning without loss of fiber quality.

A study on the Texas High Plains evaluated four harvest-aid combinations – including defoliants, desiccants, and boll openers. The results from treated plots were compared to results obtained from harvesting one treatment without chemicals, after a freeze (Brashears *et al.,* 1997). The treatment that received no harvest-aid material had higher levels of sticks and fine trash and lower fiber qualities than the treatments that included harvest-aid materials. This was attributed to the extended exposure of the untreated cotton to weather. This study indicated that early stripper harvest using harvest-aid materials gave consistently better fiber quality, as opposed to waiting to harvest the cotton after a killing freeze.

BELTWIDE PROJECT

In 1992, a Beltwide project was designed to evaluate the influence of harvest-aid materials on fiber quality. The overall objective of the project was to develop effective, practical harvest-aid recommendations that would contribute to harvest efficiency and high-quality fiber, specifically by evaluating performance of standard defoliation treatments on a uniform basis and relating this performance to biotic and environmental factors. The following is a discussion of the fiber quality portion of the five-year project.

MATERIALS AND METHODS

The specific details of this experiment are described in previous manuscripts (Anonymous, 1999). In these trials, seven core harvest-aid treatments (Table 1) were applied at 16 test sites located in Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, North and South Carolina, Oklahoma, Tennessee, and four sites in Texas. These locations were combined into four regions, Southeast (Alabama, Georgia, North Carolina, South Carolina, and Florida), Midsouth (Arkansas, Louisiana, Missouri, Mississippi, and Tennessee), Southwest (Texas and Oklahoma), and Far West (California only).

Table 1. Core harvest-aid treatments used in the Uniform Harvest-Aid Performance and Lint Quality Evaluation (1992-1996).

Core Treatment	Application Rate (per acre)
Untreated check	
Folex®/Def® (tribufos)	1.5 pt
Dropp® (thidiazuron)	0.2 lb of product
Harvade® (dimethipin) + COC[1]	8 oz of product 1 pt
Harvade + Prep™ (ethephon) + COC[1]	6.5 oz 1.33 pt 1 pt
Folex/Def + Prep	0.75 pt 1.33 pt
Dropp + Prep	0.1 lb of product 1.33 pt

Source: Anonymous, 1999.

[1] Crop Oil Concentrate.

The Beltwide project evaluated seven "core" treatments and a number of "regional standards" in a multiyear study conducted at multiple locations in four major production regions of the Cotton Belt. Standard agronomic practices for optimum cotton productivity were used at each of the test sites. Pre-selected cotton varieties were used at each test site in the four regional locations. Harvest-aid chemicals were applied at about 60 percent open bolls. Standardized evaluation data were collected and recorded by each of the investigators at 7 and 14 days after treatment (DAT). Plots were mechanically harvested at approximately 14 DAT. The three stripper sites (two in Texas and one in Oklahoma) were desiccated with paraquat prior to harvest.

Two groups of seed cotton samples were collected at each site. One group of small samples (approximately 2.5 pounds) was collected by plot for all treatments. These small samples were shipped to the Texas A&M Research and Extension Center in Lubbock for ginning. Each year all samples were ginned at the same relative time period. The gin was equipped with an inclined cleaner, extractor feeder, 10-saw gin, and single stage of lint cleaning.

Lint data collected from ginned samples were subjected to HVI (High-Volume Instrumentation) analysis, which included micronaire, strength, length, percent trash, reflectance (Rd), yellowness (+b), length uniformity index (LUI), short fiber content (SFC), and leaf grade. The 1994 to 1996 data also were analyzed using the Uster AFIS (Advanced Fiber Information System) instrument for all samples from selected locations. These included five spindle-picked locations (Louisiana, Mississippi, Georgia, North Carolina, and California) and two stripper-harvested locations (Lubbock, Texas, and Oklahoma). Lint data collected were nep counts, visible foreign matter (VFM), upper quartile length (UQL), and SFC.

A second set of samples was collected for each core treatment. These large samples were approximately 50 pounds and represented a composite of all plots within a treatment. From 1992 through 1994, these samples were sent to the USDA, ARS Cotton Ginning Laboratory, in Stoneville, Mississippi, for ginning using the micro gin and one lint cleaner. The lint was sent to the USDA, ARS Cotton Quality Research Station, at Clemson University, where the samples were spun into yarn and knitted into fabric. The fabric was dyed and white speck counts were made. White specks are defined as entanglements of very immature fiber that have different reflective characteristics from those of surrounding fiber.

A preliminary analysis of variance of the data combined over year and location indicated that treatment interacted with year and location in a similar manner.[1] Therefore, in a subsequent analysis, year and location were considered environment and were used as replications for comparing treatments. Differences in treatment means were declared significant at the five percent level of probability and were separated by Least Significant Difference (LSD).

In a separate analysis, percent defoliation at 14 DAT was used as a continuous effect (X) to describe the treatment effect on selected fiber quality measurements (Y). Slopes were estimated and tested for significance ($p<0.05$) to evaluate the overall effect of percent defoliation on fiber quality. This report includes five years of lint-quality data collected from the seven core treatments. However, not all test locations had five years of data. Because of the large number of samples (about 2,100), relatively small measurement differences were statistically significant.

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[1] Data were analyzed with the assistance of Debbie L. Boykin, Statistician, USDA, ARS, in Stoneville, Mississippi.

RESULTS AND DISCUSSION

Percent defoliation – At 7 DAT and 14 DAT, Folex® at 0.75 pint per acre plus Prep™ at 1.33 pints per acre had the highest percent defoliation and a corresponding low trash content and high reflectance (Table 2). As expected, the percentage of trash content from the untreated check was slightly higher than for all other treatments, with the Folex + Prep treatment having the lowest percentage of trash.

It is important to note that percent defoliation is only one component in overall evaluation of a harvest aid. Folex + Prep provided a high level of defoliation, but the treatment has been shown to lack regrowth-inhibition properties that may be desirable in many cases (Legé *et al.*, 1997).

Table 2. Influence of harvest-aid treatments on percent defoliation and selected HVI lint quality measurements at all test sites (1992-1996).[1]

TREATMENT DESCRIPTION	% DEFOLIATION 7 DAT	14 DAT	TRASH (% area)	MICRONAIRE	Color Rd[2]	+b[3]	Color Grade[4]
1. Untreated check	23.2 d	36.5 e	0.40 b	4.43 c	74.2 b	8.58 b	41-3
2. Folex® @ 1.5 pt	59.7 b	72.7 bcd	0.37 ab	4.39 b	74.9 a	8.35 a	31-2
3. Dropp® @ 0.2 lb	51.2 c	67.8 d	0.37 ab	4.40 b	74.9 a	8.38 a	31-2
4. Harvade® @ 8 oz + Agri-Dex® @ 1 pt	56.2 c	69.5 cd	0.39 ab	4.37 b	74.9 a	8.34 a	31-2
5. Harvade @ 8 oz + Prep™ @ 1.33 pt + Agri-Dex @ 1 pt	63.1 b	74.3 bc	0.38 ab	4.31 a	74.8 a	8.39 a	31-2
6. Folex @ 0.75 pt + Prep @ 1.33 pt	69.0 a	80.7 a	0.35 a	4.31 a	75.0 a	8.37 a	31-2
7. Dropp @ 0.1 lb + Prep @ 1.33 pt	63.3 b	77.2 ab	0.37 ab	4.31 a	74.9 a	8.41 a	31-2

Source: Anonymous, 1999.

[1] Means within columns followed by the same letter are not statistically different. Location and year had an equal impact on error structure, thus were considered environment and used as replications for comparing treatments.

[2] Reflectance.

[3] Yellowness.

[4] All color grades are based on the Nickerson Hunter Color/Grade Translator.

Color trash – The color measurements, Rd and +b, for the untreated check, had lower reflectance and higher yellowness when compared to all harvest-aid treatments (Table 2). However, no significant differences in reflectance or yellowness were noted among harvest-aid treatments. Color grades, based on the Nickerson Hunter Color/Grade Translator, were 31 for all treatments, while the untreated check had a color grade of 41. Other HVI measurements showed no significant differences among treatments.

Micronaire – Treatments containing Prep had lower micronaire values when compared to the untreated control or treatments without Prep (Table 2). Differences in levels of defoliation for each treatment were reflected by these micronaire values. As percent defoliation increased, micronaire tended to decrease. Because the removal of leaves typically stops all plant processes, the untreated check had additional developmental time relative to the treated plots, resulting in higher micronaire values. Lower percent defoliation in treatments without Prep resulted in partial continued fiber development of the crop and slightly higher micronaire values than treatments with higher percent defoliation. Harvest-aid treatment did not reduce micronaire sufficiently to produce unacceptable fiber.

Average white speck counts showed little variation among harvest-aid treatments (Table 3). There was considerable variation between years or production seasons, but no trend to indicate that any of the defoliation treatments increased white speck counts. This indicated that white specks largely were a product of the conditions encountered during the growing season.

Fiber quality measurements – A more sophisticated analysis of selected lint samples using the AFIS instrumentation is shown in Table 4. Nep counts, VFM, and UQL were not affected by any treatment evaluated. There were no significant differences in SFC measurements among any treatments evaluated.

To determine if the efficacy of the various harvest-aid methods affected lint quality, a slope comparison using linear regression analysis for micronaire, white speck, neps, and short fiber content versus percent defoliation at 14 DAT was performed (Table 5). Slopes differing from zero, where a zero slope indicates no effect, defined the impact of percent defoliation on the chosen quality parameter measured. The negative slope of the linear regression lines indicated that, irrespective of the harvest aid used, as percent defoliation increased, micronaire was reduced in both spindle-harvested and stripper-harvested cotton. Therefore, when defoliation is more complete, subsequent or continued development of the cotton fiber is diminished.

Table 3. Number of white specks[1] observed in 40 square inches of dyed jersey knit fabric over a three-year period.

TREATMENT DESCRIPTION	1992 (n=12)	1993 (n=16)	1994 (n=18)
1. Untreated check	293	136	88
2. Folex® @ 1.5 pt	300	132	83
3. Dropp® @ 0.2 lb	261	128	82
4. Harvade® @ 8 oz + Agri-Dex® @ 1 pt	294	136	91
5. Harvade @ 8 oz + Prep™ @ 1.33 pt + Agri-Dex @ 1 pt	269	123	86
6. Folex @ 0.75 pt + Prep @ 1.33 pt	289	131	85
7. Dropp @ 0.1 lb + Prep @ 1.33 pt	278	119	74

Source: Anonymous, 1999.

[1] White specks are entanglements of very immature fiber that have different reflective characteristics from those of surrounding fibers.

It was concluded that changes in micronaire occurred because of the process of defoliation rather than the effect of any specific harvest-aid material, which agreed with earlier findings that timing also plays a role (Snipes and Baskin, 1994). White speck count did not change with increased defoliation values for either harvest method. Thus, any changes in micronaire did not result in poor fabric quality, as measured by white speck count.

Based on AFIS measurements, neither neps for spindle-harvested cotton nor short fiber content for stripper-harvested cotton was influenced by an increased level of defoliation (Table 5). Conversely, neps in stripper-harvested cotton and short fiber content in spindle-harvested cotton increased as level of defoliation increased. However, departures from zero slope were relatively small and indicated these changes were well within acceptable limits.

Table 4. Influence of harvest-aid treatments on selected AFIS[1] fiber quality measurements from selected 1994-1996 test locations.[2]

TREATMENT DESCRIPTION	NEP[3] (ct)	VFM[4] (%)	SFC[5] (%)	UQL[6] (in)
1. Untreated check	182.0 ab	1.60 ab	9.59 a	1.152 ab
2. Folex® @ 1.5 pt	184.6 a	1.49 b	9.76 a	1.147 ab
3. Dropp® @ 0.2 lb	175.1 b	1.52 ab	9.59 a	1.157 b
4. Harvade® @ 8 oz + Agri-Dex® @ 1 pt	186.9 a	1.66 a	9.62 a	1.145 ab
5. Harvade @ 8 oz + Prep™ @ 1.33 pt + Agri-Dex @ 1 pt	181.5 ab	1.55 ab	9.75 a	1.145 ab
6. Folex @ 0.75 pt + Prep @ 1.33 pt	189.2 a	1.58 ab	9.86 a	1.150 ab
7. Dropp @ 0.1 lb + Prep @ 1.33 pt	184.8 a	1.64 ab	9.72 a	1.131 a

Source: Anonymous, 1999.

[1] Advanced Fiber Information System.

[2] Means within columns followed by the same letter are not different at the five percent level of probability.

[3] Neps are hopelessly entangled masses of fibers.

[4] Visible Foreign Matter.

[5] Short Fiber Content by weight.

[6] Upper Quartile Length.

Table 5. Linear regression comparisons of selected quality measurements and harvest methods vs. percent defoliation at 14 DAT.[1]

Quality Measurement	y-intercept	Slope	Pr>T[2]
1992-1994 Micronaire and white speck quality measurements			
Micronaire (spindle)	4.48	-0.0015	0.0001
Micronaire (stripper)	4.52	-0.003	0.0002
White speck (spindle)	96.72	-0.022	0.8528 (ns[3])
White speck (stripper)	93.33	0.27	0.5599 (ns[3])
1994-1996 AFIS[4] quality measurements			
Neps[5] (spindle)	169.88	-0.0599	0.4705 (ns[3])
Neps[5] (stripper)	81.97	1.6628	0.0053
SFC[6] (spindle)	9.58	0.0052	0.0289
SFC[6] (stripper)	8.84	0.0023	0.7613 (ns[3])

Source: Anonymous, 1999.

[1] Percent defoliation at 14 DAT (x) is used to describe treatment effect on fiber quality (y) and tested for significance to evaluate the overall effect.

[2] Probability that the dependent variable is greater than the test value (T).

[3] ns = not significant at the 0.05 percent level.

[4] Advanced Fiber Information System.

[5] Neps are hopelessly entangled masses of fibers.

[6] Short Fiber Content by weight.

SUMMARY

This study revealed few differences among harvest-aid treatments and lint quality when recommended production practices were followed. Harvest aids reduced trash, reduced micronaire slightly, and improved color. Harvest aids did not appear to increase white specks or neps, and did not reduce strength, length, or uniformity. Even though differences in defoliation efficacy were measured, ginning and lint cleaning tended to normalize differences in trash content. More important, it was shown that proper application of harvest-aid materials served as an acceptable means of crop termination while capturing and preserving fiber quality.

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Chapter 8

FACTORS INFLUENCING NET RETURNS TO COTTON HARVEST AIDS

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INTRODUCTION

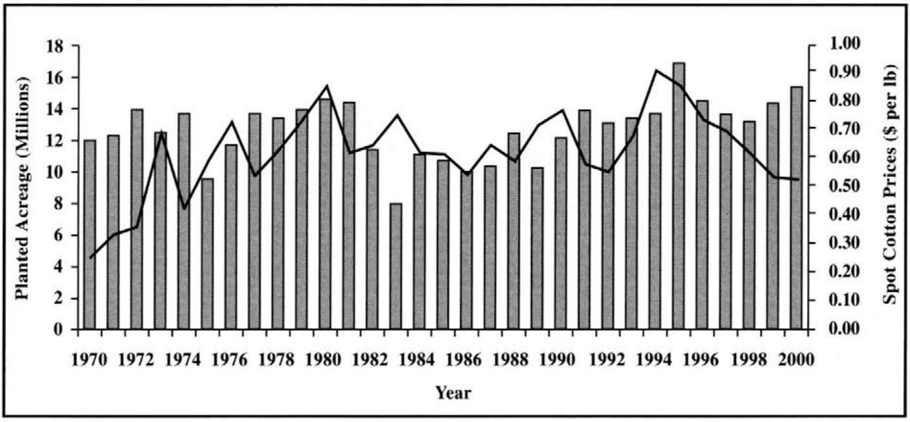
United States cotton [*Gossypium hirsutum* L.] production has rebounded from the lows experienced in the late 1970s and early 1980s. Planted acreage increased from 7.9 million acres in 1983 to a high of 16.7 million acres in 1995 (Figure 1). Higher demand and prices for cotton and new production technologies, which have improved yields, influenced the increase in acreage. However, cotton prices declined sharply after reaching a peak in 1995 (Figure 1), causing the profitability of cotton production to deteriorate.

Because of lower prices and profitability, producers are concerned about reducing the cost of production (Anonymous, 1998a). One input that may influence net returns for cotton farmers is applying a harvest aid before harvest. Many researchers have evaluated harvest aids in cotton production (Teague *et al.*, 1986; Whitwell *et al.*, 1987; Hoskinson and Hayes, 1988; Crawford *et al.*, 1989; Stair and Supak, 1992; Chu *et al.*, 1992; Williford, 1992; Larson *et al.*, 1997; Gwathmey and Hayes, 1997). Most of these studies analyzed the timing of application and the subsequent impact of the chemicals on yield and fiber characteristics.

Larson *et al.* (1997) found that certain harvest aids may enhance net returns by reducing trash, preserving fiber quality, and increasing the proportion of total yield picked at the first harvest under Tennessee growing conditions.

Harvest efficiency also may be positively influenced through harvest aids (Gwathmey and Hayes, 1996). However, prior research also has suggested that mistimed application of a harvest aid can result in significant reduction in yield and fiber quality (Crawford *et al.*, 1989). Also, if harvest is delayed by inclement weather after application, revenue loss in a harvest-aid-treated crop could be greater than in an untreated crop (Stair and Supak, 1992).

In general, information on the costs and returns to alternative cotton harvest-aid treatments is lacking. The purpose of this chapter is twofold: 1) to identify some of the factors that may influence the costs and returns to alternative harvest aids; and 2) to analyze the costs and returns for selected harvest-aid treatments from a five-year field study (1992 through 1996) conducted by the Cotton Defoliation Work Group (Anonymous, 1999).



Source: Anonymous, 2001a; Anonymous, 2001b; and Evans, 2000.

Figure 1. U.S. upland cotton planted acreage and spot market lint prices, 1970-2000.

HARVEST-AID COST AND RETURN CONSIDERATIONS

Partial budgeting can be used to evaluate the profitability of harvest aids (Boehlje and Eidman, 1984). A partial budget includes only the specific items of income and expense that change with the addition of the harvest aid and the effect of these items on profit and loss. Other factors that influence the profitability of production – such as choice of cultivar, fertilization, irrigation, and other inputs for cotton – are not considered in the partial budget.

The following partial budgeting equation can be used to evaluate the costs and returns of harvest aids:

$$\Delta NR_{ij} = \Delta Y_i^{lint} \times (P_j^{base} + \Delta P_{ij}^{diff} - C^{gin}) + \Delta Y_i^{seed} \times P_j^{seed} + \Delta C_i^{hc} - C_i^{ha},$$

where ΔNR_{ij} is the change in cotton enterprise net return ($ per acre) with harvest-aid treatment *i* using marketing year *j* cotton prices (August through July of the next year), ΔY_i^{lint} is the change in harvested lint yield (pounds per acre) with harvest-aid treatment *i*, P_j^{base} is the base quality price (¢ per pound) of lint for marketing year *j*, ΔP_{ij}^{diff} is the change in premium or discount (¢ per pound) for variation in lint fiber characteristics from the base quality with harvest-aid treatment *i* using marketing year *j* prices, C^{gin} is the cost (¢ per pound) of ginning and bale handling per pound of harvested lint yield, ΔY_i^{seed} is the change in harvested cottonseed yield (pounds per acre) with harvest-aid treatment *i*, P_j^{seed} is the price (¢ per pound) of cottonseed for marketing year *j*, ΔC_i^{hc} is the change in harvest cost with harvest-aid treatment *i*, and C_i^{ha} is the materials and application cost ($ per acre) of harvest-aid treatment *i*.

If $NR_{ij} > 0$ in the equation, then harvest-aid treatment *i* will increase the profitability of cotton production. Economic tradeoffs influence the decision to apply a harvest aid before cotton harvest. As indicated in the partial budgeting relationship, the net return to a harvest aid is influenced not only by the change in harvested yields and the cost of applying the harvest aid, but also by the change in premiums and discounts for fiber quality and harvesting and handling costs. Weather effects on mature cotton in the field before it is harvested also may have a significant influence on the profitability of harvest aids. The potential impacts that each of these factors has on the harvest-aid decision are discussed in the following sections.

QUALITY PRICE DIFFERENCES

The effective lint price that a farmer receives for cotton is influenced by a number of market factors. The base price, P_j^{base}, indicates general supply and demand conditions for a base quality of cotton (color 41, leaf 4, staple 34, micronaire 35-36 and 43-49, and strength 23.5-25.4). The lint quality price difference, P_{ij}^{diff}, is positive, negative, or zero, depending on the fiber property mix for grade (color and leaf), staple (fiber length), micronaire, and fiber strength. Two or more of these characteristics may be correlated in the market determination of the price difference for a particular attribute (Bowman and Ethridge, 1992). Base quality and quality-difference prices also change with supply and demand conditions (Table 1) (Anonymous, 1993-1998). For example, if base prices are high, suggesting tight supplies, leaf grade discounts may decline, because buyers cannot discount trash as much as when cotton is plentiful.

Table 1. Average U.S. base quality lint prices and example leaf grade price differences, marketing years 1993-1994 through 1997-1998.

Marketing Year[1]	Base Quality Price[2]	Color 41, Staple 34 Price Differences		
		Leaf Grade 5	Leaf Grade 6	Leaf Grade 7
	¢ per lb			
1993-1994	66.12	-4.58	-8.05	-11.50
1994-1995	88.14	-3.28	-6.99	-10.89
1995-1996	83.03	-3.38	-7.32	-10.72
1996-1997	71.59	-3.32	-6.41	-10.12
1997-1998	67.79	-2.70	-5.26	- 8.79

Source: Anonymous, 1993-1998.

[1] August through July.

[2] Color 41, leaf 4, staple 34, micronaire 35-36 and 43-49, and strength 23.5-25.4 cotton quality.

Fiber characteristics – Harvest aids and other factors may affect one or more of the fiber characteristics of cotton. For example, color grade may be affected adversely by exposure to weathering after boll opening (Ray and Minton, 1973). Leaf is one component of trash (cotton plant leaf particles, stalk materials, and extraneous matter such as grass) in cotton lint. Leaf grade is affected by cultivar, harvest methods, and weather conditions at harvest (Anonymous, 1993). Example cotton spot price differences for color 41, staple 34 cotton with different leaf grades are presented for marketing years 1993-1994 through 1997-1998 in Table 1 (Anonymous, 1993-1998). Leaf grade has whole number designations from 1 to 7, with 7 associated with the highest high-volume instrument (HVI) trash content (Anonymous, 1993). Leaf grade 4 is the base quality for this characteristic. Price discounts widen with higher leaf grades, varying in the 1997-1998 marketing year from -3¢ per pound for leaf grade 5 to -9¢ per pound for leaf grade 7 for all of the United States. These premiums and discounts vary by production region. In addition to leaf grade discounts, other trash materials, such as bark and grass, also are discounted. These discounts are especially important in stripper cotton production in Texas and Oklahoma. Harvest aids may have an important impact on reducing price discounts for trash in cotton.

Micronaire (mike) is a measure of fiber fineness and maturity and is affected by variety and by weather and seasonal growing conditions. Fiber fineness is important in determining yarn appearance, yarn uniformity, and yarn strength. U.S. season-average micronaire price differences for marketing years 1993-1994 through 1997-1998 are shown in Table 2 (Anonymous, 1993-1998). The base micronaire range is between 35-36 and 43-49. The micronaire premium range is from 37 to 42. Micronaire values above 49 and below 35 are discounted.

Fiber strength largely is determined by cultivar but also may be influenced by growing conditions, weathering, and ginning. Strength is measured as the force in grams required to break a bundle of fibers one tex unit in size. A tex unit is equal to the weight in grams of 1000 meters of fiber. Fiber strength is important in determining yarn and fabric strength and spinning efficiency when the fiber is processed. U.S. season-average fiber-strength price differences for marketing years 1993-1994 through 1997-1998 are presented in Table 3 (Anonymous, 1993-1998). Strength premiums and discounts relative to other cotton fiber characteristics are relatively small but do vary from year to year.

HARVEST COSTS

As indicated in the partial budgeting equation, harvest aids also may have a positive influence on the cost of cotton harvest. The ability to defoliate and enhance boll opening with certain harvest aids may allow farmers to make only one pass through the field with a picker, rather than two passes. The impact on production costs of eliminating a second picking is illustrated in Table 4. In the example budget, the equipment for estimating seed cotton picking and handling costs includes a four-row, self-propelled cotton picker, a module builder with a tractor, and three trailers with a tractor for overflow when the module builder is full (Larson *et al.*, 1997). This complement is sized to cover 625 acres for the first harvest in 18 field days. Equipment, materials, and labor costs per acre were calculated using machine hours

Table 2. Average U.S. micronaire price differences, marketing years 1993-1994 through 1997-1998.

Marketing Year[1]	Micronaire Units									
	24 & Below	25-26	27-29	30-32	33-34	35-36	37-42	43-49	50-52	53 & Above
	¢ per lb									
1993-1994	-14.08	-12.07	-91.4	-5.01	-2.22	0	0.11	0	-2.99	-4.79
1994-1995	-12.80	-11.93	-97.3	-4.71	-2.16	0	0.09	0	-2.91	-4.73
1995-1996	-14.35	-12.38	-95.6	-4.84	-2.33	0	0.33	0	-3.10	-5.16
1996-1997	-15.65	-12.91	-92.8	-4.81	-2.34	0	0.33	0	-2.97	-5.13
1997-1998	-13.42	-11.97	-96.0	-4.47	-2.02	0	0.14	0	-2.72	-4.68

Source: Anonymous, 1993-1998.

[1] August through July.

Table 3. Average U.S. fiber-strength price differences, marketing years 1993-1994 through 1997-1998.

Marketing Year[1]	Fiber Strength (grams per tex[2])											
	18.5-19.4	19.5-20.4	20.5-21.4	21.5-22.4	22.5-23.4	23.5-25.4	25.5-26.4	26.5-27.4	27.5-28.4	28.5-29.4	29.5-30.4	30.5 & Above
	¢ per lb											
1993-1994	-2.65	-2.65	-1.49	-1.00	-0.42	0	0	0	0.10	0.25	0.43	0.59
1994-1995	-1.67	-1.22	-1.18	-0.76	-0.26	-0.01	0	0	0	0.12	0.27	0.39
1995-1996	-1.11	-0.86	-1.17	-0.69	-0.16	-0.01	0	0	0.01	0.13	0.27	0.39
1996-1997	-1.06	-1.03	-1.15	-0.80	-0.34	0	0	0	0	0.13	0.28	0.41
1997-1998	-0.97	-0.97	-1.11	-0.78	-0.31	0	0	0	0	1.14	0.28	0.41

Source: Anonymous, 1993-1998.

[1] August through July.

[2] The force in grams required to break a bundle of fibers one tex unit in size. A tex unit is equal to the weight in grams of 1000 meters of fiber.

Table 4. Cotton harvest equipment ownership and operating costs.[1]

Item	Once-Over Harvest	Twice-Over Harvest
Picker ownership and operating costs:		
Capital recovery per acre	$38.29	$38.77
Taxes, insurance, and housing per acre	1.64	1.64
Repair & maintenance per acre	6.40	14.59
Fuel & lube per acre	2.33	3.73
Operator labor per acre	1.64	2.62
Total picker costs per acre	$50.30	$61.35
Seed cotton handling costs:		
Capital recovery per acre	$8.25	$9.22
Taxes, insurance, and housing per acre	0.55	0.55
Repair & maintenance per acre	3.24	4.00
Fuel & lube per acre	1.40	2.15
Support labor per acre	3.29	4.29
Total picker costs per acre	$16.73	$22.22
Total ownership and operating costs per acre	$67.03	$81.57

Source: Larson *et al.*, 1997.

[1] Assumed machinery and labor compliment: 1 four-row, self-propelled picker; 1 module builder; 2 125-hp tractors; 3 trailers; 3 laborers for the first harvest, and 2 laborers for the second harvest.

required to cover 625 acres for the first and second harvests. Forgoing the second harvest reduces hours of operation per year and the total costs of picking and handling per acre. In the example budget, the cost for a once-over operation is $67.03 per acre, compared with $81.57 per acre for a twice-over harvest. By avoiding the second harvest, the total cost of picker harvest is reduced by $14.54 per acre.

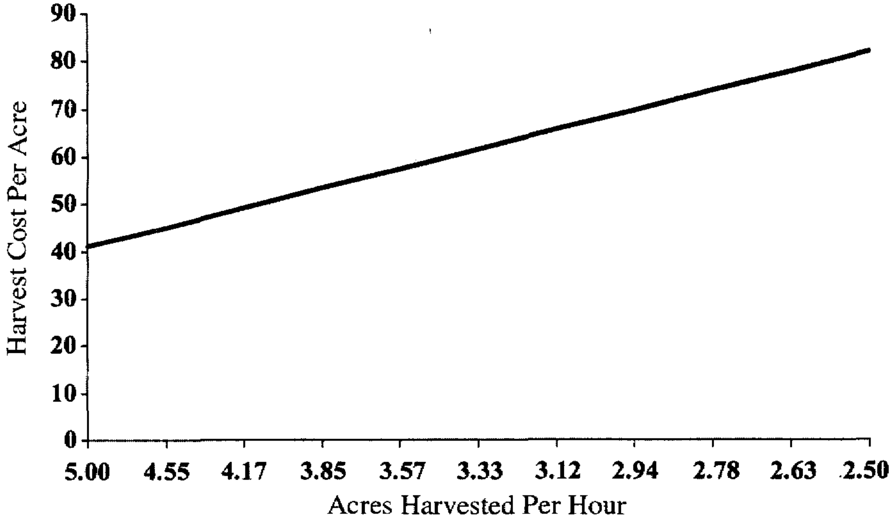
Harvest aids also have an impact on machine efficiency. In undefoliated cotton, more green plant material going into the harvester may force operation of the picker or stripper at reduced speed, cutting field efficiency. Slower picker and stripper speeds and increased downtime cleaning the machine lead to higher picking costs per hour of operation (Boehlje and Eidman, 1984). The effect of reduced field efficiency can be examined using the following relationship:

$$Acres\ picked\,/\,hour = \frac{S \times W \times E}{8.25}$$

The number of acres a picker or stripper can cover in one hour depends on the speed, width, and efficiency of the harvester. This can be expressed as follows: S is speed of the machine in miles per hour, W is width of the harvester in feet, E is machine efficiency expressed as a decimal between 0 and 1, and 8.25 is the number of square feet in an acre (43,560) divided by the number of feet in a mile (5,280). The hours required to cover one acre can be calculated using the reciprocal of acres covered per hour. Consequently, harvest cost per acre can be calculated by dividing the ownership and operating expenses of the machine per hour of operation by the acres harvested per hour:

$$\textit{Harvest cost/acre} = \frac{\textit{Ownership and operating cost/hour}}{\textit{Acres picked/hour}}.$$

The relationship between acres harvested per hour and harvest cost per acre is illustrated in Figure 2. This example assumes hourly ownership and operating costs of $205 for a four-row, self-propelled cotton picker covering 625 acres per year. A 10 to 20 percent reduction in field speed can raise the cost of harvest by $5 to $10 per acre. A 50 percent reduction in acres harvested per hour – from 5.0 to 2.5 acres per hour, for instance – doubles the cost per acre of running the picker over the field.



Source: Boehlje and Eidman, 1984.

Figure 2. Relationship between acres harvested per hour and harvest cost per acre.

The value of a harvest aid also may be influenced by the method of handling and storage between harvest and ginning. Harvest systems using a module builder to handle seed cotton have become increasingly important, with more than three-quarters of all cotton being moduled nationwide (Glade *et al.*, 1996). The potentially detrimental effect of wet plant material on fiber quality in a tightly packed cotton module may influence the profitability of harvest aids (Valco and Bragg, 1996).

WEATHER

To avoid problems with harvest efficiency in undefoliated cotton, farmers in the more northerly areas of the Cotton Belt have the option of delaying harvest until after a killing freeze. However, delaying harvest also may expose open bolls to excessive weathering. Williford (1992) found that weathering from delayed harvest reduced fiber quality and yields in Mississippi. One important potential benefit of using harvest aids is to expedite harvest to avoid yield losses caused by unfavorable weather late in the fall. Certain practices, including selection of early maturing cultivars, use of plant growth regulators, and timely applications of harvest aids, can be used to prepare the crop for earlier harvest (Gannaway, 1991).

The potential impact of rainfall on lint yield losses and revenues from a delayed harvest is illustrated in Table 5. The delay in cotton harvest while waiting for a killing freeze was assumed to be 28 days (4 weeks). Predicted yield losses from delayed harvest are presented for rainfall amounts ranging from 1 to 6 inches. The yield loss example assumes a 2.15 percent yield loss for each inch of rainfall (Larson *et al.*, 1999). Reductions in yield range from 2 percent for 1 inch of rain to 13 percent for 6 inches of precipitation. Deterioration in fiber quality also can occur with weathering.

The potential impact of lint yield losses and deterioration of fiber quality on net returns because of a delayed harvest also are reported in Table 5. Revenue losses were estimated using the lint price relationship reported by Larson *et al.* (1997) for November 1993 through May 1995. Net return losses are reported for a low cotton base price ($0.57 per pound) scenario and a high cotton base price ($1.07 per pound) scenario. For the low-price scenario, net return losses vary from 2 percent with 1 inch of rain to 17 percent with 6 inches of rain for color 31, leaf grade 4 cotton. The estimated net return loss also is influenced by the leaf grade price discount structure. If the leaf grade is 6 or 7, the potential loss of net returns from precipitation is not as great as for leaf grades 4 or 5.

The probability of receiving rainfall that causes yield damage changes from period to period during the harvesttime for cotton. As an example, Table 6 presents probabilities of getting rainfall amounts of 1 to 6 inches for specified four-week periods in late summer and fall for Jackson, Tennessee (Fribourg *et al.*, 1973). These translate into probabilities of net return losses occurring from rainfall (Table 5). Average rainfall for alternative four-week periods varies from 3 to 4 inches. Probabilities of receiving various precipitation amounts change from period to period. For example, the probability of receiving at least 3 inches of rainfall varies from 33 percent for the periods beginning September 20 and October 4 to 62 percent for the period beginning November 29. Maximum rainfall probabilities during the period for cotton harvest vary by cotton production region. For example, fall precipitation probabilities are at a maximum in mid-October for Central Texas (Dugas, Jr., 1983).

ANALYSIS OF NET RETURNS FOR SELECTED TREATMENTS

Costs and returns for selected harvest aids were evaluated using yield and quality data collected by the Cotton Defoliation Work Group (Anonymous, 1998b). The cotton yield, price, and cost data used to estimate net returns with the partial budgeting equation are presented first, followed by the methods used to analyze lint yields, lint prices, and net returns.

YIELD DATA

Lint yield and fiber quality data were obtained from a five-year harvest-aid study (1992 through 1996) conducted at 16 sites across the U.S. Cotton Belt by the Cotton Defoliation Work Group (Anonymous, 1999). The sites represent a range of production, including picker cotton in the Midsouth and Southeast, stripper cotton in Texas and Oklahoma, and Acala™ cotton in the San Joaquin Valley of California. Seven core harvest-aid treatments were evaluated at each location. In addition to the seven core treatments, researchers in each region included up to eight additional treatments for evaluation in the study.

Table 5. Estimated lint yield and revenue losses due to a delayed cotton harvest.

Loss at harvest	Rainfall during four-week harvest delay period (in) 1	2	3	4	5	6
	--------------	------	%	------	------	--------------
Lint yield	2	4	6	9	11	13
Revenue (Base lint quality price of $0.57 per lb)[1]						
Pre-delayed harvest quality of color 31, leaf 4	2	4	6	13	15	17
Pre-delayed harvest quality of color 31, leaf 5	2	4	6	10	12	15
Pre-delayed harvest quality of color 31, leaf 6	2	4	6	9	11	13
Pre-delayed harvest quality of color 31, leaf 7	2	4	6	9	11	13
Revenue (Base lint quality price of $1.07 per lb)[1]						
Pre-delayed harvest quality of color 31, leaf 4	2	4	6	14	16	18
Pre-delayed harvest quality of color 31, leaf 5	2	4	6	10	13	15
Pre-delayed harvest quality of color 31, leaf 6	2	4	6	9	11	13
Pre-delayed harvest quality of color 31, leaf 7	2	4	6	9	11	13

Source: Based on an estimated yield loss of 2.15 percent per inch of rainfall (Larson *et al.*, 1999).

[1] Revenue losses were estimated using the lint price relationship reported by Larson *et al.* (1997) for November 1993 through May 1995.

Table 6. Rainfall probabilities for Jackson, Tennessee.

Four-week period starting	Four-week rainfall total (in) 1	2	3	4	5	6	Average (in)
	----------------	----------	Probability of rainfall (%)	----------	----------	----------------	
Sep 06	80	57	38	25	16	10	2.95
Sep 13	80	57	40	27	18	12	3.08
Sep 20	74	51	33	21	14	9	2.72
Sep 27	76	52	35	22	14	9	2.76
Oct 04	77	52	33	20	12	7	2.71
Oct 11	77	53	35	22	13	8	2.79
Oct 18	85	61	40	25	15	9	3.00
Oct 25	88	67	47	31	20	12	3.37
Nov 01	91	72	51	34	22	14	3.58
Nov 08	92	72	51	34	21	13	3.53
Nov 15	97	82	60	39	24	13	3.82
Nov 22	94	77	56	38	24	15	3.78
Nov 29	97	83	62	42	27	16	3.99

Source: Fribourg *et al.*, 1973.

The seven core treatments were evaluated in this analysis to look at differences in cost and returns at and among locations. Stripper cotton data from Texas and Oklahoma and Acala cotton data from the San Joaquin Valley in California were excluded from the assessment of net returns. Information about extraneous matter in lint (bark and grass) that is important in the pricing of stripper cotton was not available for the Texas and Oklahoma locations. Because of the unique cotton variety and climate conditions in the San Joaquin Valley, the seven core treatments did not perform as well when compared with the other regional locations.

The experiment station locations where research for the Midsouth portion of the study was conducted were: the Delta Research Center, Portageville, Missouri; the West Tennessee Experiment Station, Jackson, Tennessee; the Southeast Branch Station, Rohwer, Arkansas; the Delta Research and Extension Center, Stoneville, Mississippi; and the Northeast Research Station, St. Joseph, Louisiana.[1] A map showing the locations of the experiment stations in the Midsouth is presented in Figure 3. The experiment station locations for the Southeast portion of the study were the Peanut Belt Research Station, Lewiston-Woodville, North Carolina; the Tennessee Valley Substation, Belle Mina, Alabama; the Pee Dee Research and Education Center, Florence, South Carolina; the Coastal Plain Experiment Station, Tifton, Georgia; and the West Florida Research and Extension Center, Jay, Florida.[2] A map showing the Southeast experiment station locations is presented in Figure 4.

For each year of the experiment, standard agronomic practices were followed at each site until treatment with alternative harvest aids in the fall. As the crop approached maturity, readiness for treatment with the harvest aid to prepare the crop for picking was determined through daily field inspection. Harvest aids were applied to the crop when approximately 55 to 60 percent of the bolls had opened. Treatment dates varied by site and year.

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[1] Participating Cotton Defoliation Work Group members in the Midsouth were Charles Guy and Eric Webster (Arkansas); Merritt Holman, Steve Crawford, and Dan Reynolds (Louisiana); Charles Snipes (Mississippi); Dave Albers, Gene Stevens, and Bobby Phipps (Missouri); and Bob Hayes and Owen Gwathmey (Tennessee).

[2] Participating Cotton Defoliation Work Group members in the Southeast were Mike Patterson and Charles Burmester (Alabama); John Wilcut and E. Ford Eastin (Georgia); Keith Edmisten (North Carolina); Ken Legé and Mitchell Ruf (South Carolina); and Barry Brecke (Florida).

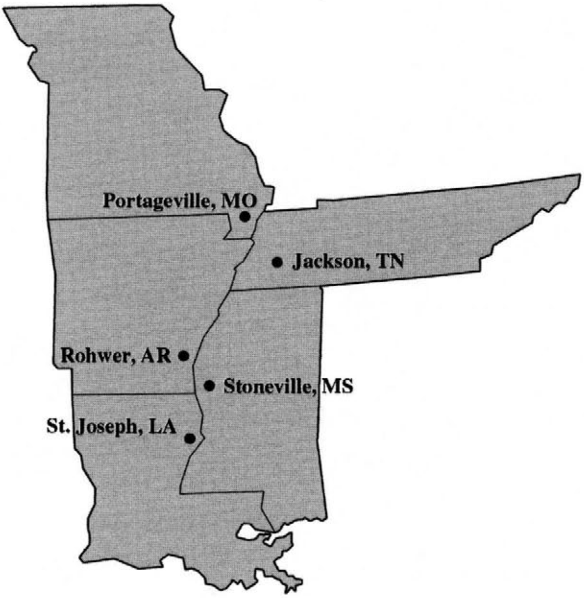

Figure 3. Midsouth cotton harvest-aid study locations.

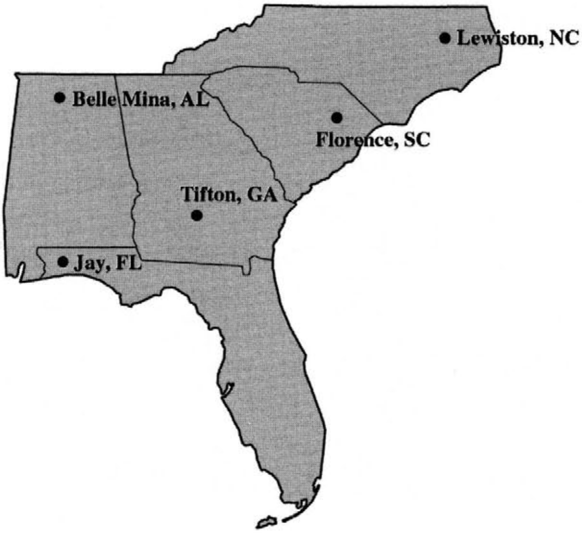

Figure 4. Southeast cotton harvest-aid study locations.

Commercial harvest aids approved for use on cotton and evaluated in this study were: Folex® 6 EC (tribufos), Dropp® 50WP (thidiazuron), Harvade® 5F (dimethipin), and Prep™ (ethephon). Table 7 presents the combinations and application rates used to formulate the treatments. The control was not treated with harvest aids. Application rates for the six other treatments were based on label recommendations current in 1991. Each treatment was replicated four times using a randomized complete block design.

Plots were mechanically harvested approximately two to four weeks after the harvest-aid treatment. The two middle rows were harvested in each plot to determine yields and to obtain seed cotton samples. Seed cotton samples were collected by plot for all treatments and sent to the Texas A&M Research and Extension Center in Lubbock, Texas, for ginning. Fiber characteristics from each treatment were determined using HVI testing (Anonymous, 1993).

Table 7. Treatment descriptions and costs for the cotton harvest-aid analysis.

Treatment Number	Treatment Name	Rate[1]	Treatment Cost ($ per acre)[2]
1	Control	NA	0.00
2	Folex®	1.125	11.01
3	Dropp®	0.100	14.06
4	Harvade®[3]	0.300	10.48
5	Harvade[3] + Prep™	0.250 1.000	17.18
6	Folex + Prep	0.560 1.000	15.19
7	Dropp+ Prep	0.050 1.000	16.72

Source: Anonymous, 1999.

[1] Pounds of active ingredient applied per acre.

[2] Treatment expenses include the cost of harvest-aid materials (chemicals) and an aerial application cost of $4.07 per acre. Materials costs were based on chemical application rates and 1996 materials prices from an informal survey by the authors and *Agchemprice*. Specific prices used were $37.02 per gallon for Folex, $49.95 per pound for Dropp, $81.64 per gallon for Harvade, and $46.02 per gallon for Prep. The prices farmers currently pay for these harvest aids may be different from those used in this analysis.

[3] The surfactant Agri-Dex® was used with treatments containing Harvade (1 pint of product per acre at a cost of $1.91 per pint).

PRICE DATA

The only published source of producer price data for the study area that also reported premiums and discounts from a base quality (price differences) were quotations collected by Agricultural Marketing Service of the U.S. Department of Agriculture (Anonymous, 1993-1998). These spot price quotations were compiled daily by market reporters for seven major market areas.

Relevant prices for the Midsouth were taken from the North Delta and South Delta market quotations. The North Delta includes northeast Arkansas, Missouri, and Tennessee. The South Delta includes southeast Arkansas, Louisiana, and Mississippi. Southeast quotations are for Alabama, Georgia, North Carolina, South Carolina, Virginia, and Florida.

Under accepted procedure, the area market reporter estimates prices by interviewing market participants and collecting sales information (Kuehlers, 1994). These spot price quotations are not weighted by trading volume, are not based on a statistical sampling procedure and are not reproducible (Hudson *et al.*, 1996). Moreover, in the absence of actual trading in a market, quotations were based on prices paid for other qualities or prices paid for the same quality in other markets. Consequently, the premiums and discounts actually received in a given market may have deviated from those reported in the quotations.

Irrespective of these data limitations, this analysis assumed that spot quotes reflected price differences in the Midsouth and Southeast. Season-average base quality and quality-difference prices for the 1996-1997 marketing year were used for this analysis (Anonymous, 1993-1998). Cottonseed prices for the 1996-1997 marketing year were obtained from USDA's National Agricultural Statistics Service offices in each state included in the study (Anonymous, 2001b).

COST DATA

The specific costs that varied by harvest-aid treatment in this analysis were for the different harvest aids evaluated in the Cotton Defoliation Work Group study (boll opener, defoliant, and desiccant materials), the cost of applying the harvest aid materials, and the ginning and handling costs per pound of harvested lint yield (C_i^{ha} and C^{gin} in the partial budgeting equation). The potential change in harvest cost (picker materials, machinery, and labor expenses) with a harvest aid was not evaluated in this analysis (C_i^{hc} in the equation).

The harvest-aid treatment costs in Table 7 were based on the application rates used in the field study and the cost of aerial application. Prices of harvest-aid materials used to calculate those costs were from an informal survey by the authors and the publication, *Agchemprice* (1996). Ginning and handling costs per pound of harvested lint yield included expenses for ginning, warehouse receiving, compression of the bale to universal density, one month of insured storage, and out-handling before the bale is sold (Glade *et al.*, 1994, 1995, 1996).

ANALYSIS OF LINT YIELDS, LINT PRICES, AND NET RETURNS

Lint Yields – Perhaps the most important factor influencing the profitability of harvest aids is lint yield response. Lint yields from the seven harvest-aid treatments for the Midsouth and Southeast regions are presented in Tables 8 and 9, respectively.

Yield responses to the harvest-aid alternatives were not consistent across the 10 sites. None of the harvest-aid treatments at the North Carolina or South Carolina locations produced lint yields that were higher than the untreated check. All but one of the harvest-aid treatments produced a negative yield response at the Louisiana site. At the other seven sites, two or more of the harvest-aid treatments produced lint yields that were greater than the untreated check. All six of the harvest-aid treatments at the Georgia and Florida sites produced lint yields that were greater than the untreated check. All but one of the treatments at the Missouri, Tennessee, and Mississippi locations produced larger yields than the untreated check.

In general, harvest-aid treatments that combined the boll opener Prep with a defoliant produced the largest numeric yield increase over the untreated check. Treatment 7, combining Dropp (0.05 pound a.i. per acre) and Prep (1.0 pound a.i. per acre), produced the largest numeric lint yield gain at the Florida (144 pounds per acre), Tennessee (127 pounds per acre), and Missouri (67 pounds per acre) sites. Moreover, Treatment 7 produced the second-largest numeric yield gain – 110 pounds per acre – at the Georgia site. However, the yield difference for Treatment 7 was statistically significant at the five percent probability level only at the Florida and Tennessee sites.

By contrast, Treatment 6, combining Folex (0.56 pound a.i. per acre) and Prep (1.0 pound a.i. per acre), produced the largest positive lint yield response over the untreated check at the Georgia (127 pounds per acre), Arkansas (46 pounds per acre), and Mississippi (30 pounds per acre) locations. A numeric yield gain with Folex and Prep also occurred at the Tennessee (99 pounds per acre) and Florida (91 pounds per acre) sites. However, the only location where the yield gain for Treatment 6 was statistically significant was at Georgia ($p<0.10$). Conversely, a statistically significant yield decrease (-84 pounds per acre) resulted from this treatment in Louisiana.

Treatment 5, combining Harvade (0.25 pound per acre) with Prep (1.00 pound per acre), also produced yield gains at the Tennessee (115 pounds per acre), Florida (98 pounds per acre), Georgia (92 pounds per acre), and

Table 8. Average lint yields for alternative cotton harvest-aid treatments for the Midsouth region, 1992-1996.

Harvest-aid Treatment[1]	Location				
	Missouri	Tennessee	Arkansas	Mississippi	Louisiana
	lb per acre				
1	863	885	1,173	903	1,167
2	846	905	1,141	893	1,179
3	879	916	1,185	913	1,149
4	925	878	1,165	905	1,140
5	925	1,000[3]	1,164	920	1,129
6	887	984	1,219	933	1,083[3]
7	930	1,012[2]	1,160	924	1,121

Source: Anonymous, 1999.

[1] See Table 7 for descriptions of the harvest-aid treatments.

[2] [3] Lint yield for the harvest-aid treatment was significantly different from the untreated control (Treatment 1) at the 0.05 and 0.10 probability levels, respectively.

Table 9. Average lint yields for alternative cotton harvest-aid treatments for the Southeast region, 1992-1996.

Harvest-aid Treatment[1]	Location				
	North Carolina	Alabama	South Carolina	Georgia	Florida
	lb per acre				
1	975	1,072	978	1057	831
2	971	1,077	886	1126	839
3	958	1,090	862	1141	836
4	965	1,070	908	1108	865
5	975	1,086	959	1149	929
6	968	1,081	915	1184[3]	922
7	968	1,061	894	1167	975[2]

Source: Anonymous, 1999.

[1] See Table 7 for descriptions of the harvest-aid treatments.

[2] [3] Lint yield for the harvest-aid treatment was significantly different from the untreated control (Treatment 1) at the 0.05 and 0.10 probability levels, respectively.

Missouri (62 pounds per acre) sites. Smaller positive yield differences for Harvade and Prep also were observed at the Mississippi (17 pounds per acre) and Alabama (14 pounds per acre) locations. However, Tennessee was the only site where the yield gain for Treatment 5 was statistically significant at the 10 percent probability level.

Lint Prices – Lint prices for cotton receiving the various harvest-aid treatments, estimated using 1996-1997 marketing year base prices and premiums and discounts, are presented for the Midsouth and Southeast Regions in Tables 10 and 11. As with lint yields, harvest-aid treatments that combined the boll opener Prep with a defoliant tended to yield the highest estimated lint prices among the seven treatments. However, no specific harvest-aid treatment consistently produced higher lint prices than the untreated check across all 10 locations.

Dropp and Prep (Treatment 7) yielded a price gain of 1¢ to 3¢ per pound over the untreated check at the Missouri, Tennessee, Arkansas, North Carolina, South Carolina, and Georgia locations. On the other hand, the estimated price for lint from Treatment 7 (Dropp and Prep) at Mississippi was 2¢ per pound lower than for the untreated check. Folex and Prep (Treatment 6) produced a 2¢ to 3¢ per pound higher lint price at South Carolina, North Carolina, and Missouri. Harvade and Prep (Treatment 5) yielded a 2¢ per pound higher lint price at Missouri when compared to the untreated check. For the other treatments, estimated lint prices varied by only 1¢ per pound across locations. The Dunnett's t-test indicated that none of the harvest-aid treatments produced lint prices at any location that were significantly different from the untreated check ($p<0.10$).

Net Return Differences – The net impacts of yield, price, and cost changes on cotton net returns (profit) from using harvest aids are presented for the Midsouth and Southeast Regions in Tables 12 and 13, respectively. The impacts of harvest-aid treatments on net returns from cotton were not uniform across locations because of the inconsistent effects of harvest-aid treatments on yields and prices.

None of the harvest-aid treatments at the Louisiana, North Carolina, Alabama, or South Carolina sites produced a positive impact on cotton net returns. For these locations, the partial budgeting analysis indicated that the change in yields and prices brought about by harvest aids did not cover the materials and application costs of the chemicals.

In addition, only one of the harvest-aid treatments at the Arkansas and Mississippi locations had a small positive impact on net returns. Folex and Prep (Treatment 6) produced $15 per acre and $11 per acre gains, respectively, at the Arkansas and Mississippi sites. By contrast, all seven harvest-aid treatments produced net return gains at the Georgia location.

Table 10. Lint prices for alternative cotton harvest-aid treatments for the Midsouth region, using 1996-1997 season average prices.

Harvest-aid Treatment[1]	Location				
	Missouri	Tennessee	Arkansas	Mississippi	Louisiana
	¢ per lb				
1	70	70	71	69	72
2	71	70	72	70	71
3	71	71	72	69	72
4	71	71	71	68	71
5	72	69	72	69	71
6	72	70	71	70	72
7	72	73	72	67	72

Source: Anonymous, 1999.

[1] See Table 7 for descriptions of the harvest-aid treatments.

Note: None of the harvest-aid treatment lint prices were significantly different from the untreated control (Treatment 1) at the 0.05 and 0.10 probability levels.

Table 11. Lint prices for alternative cotton harvest-aid treatments for the Southeast region, using 1996-1997 season average prices.

Harvest-aid Treatment[1]	Location				
	North Carolina	Alabama	South Carolina	Georgia	Florida
	¢ per lb				
1	71	73	70	72	73
2	70	72	69	72	73
3	72	72	71	72	73
4	72	72	71	73	72
5	72	73	71	72	73
6	73	72	73	73	73
7	73	73	73	73	72

Source: Anonymous, 1999.

[1] See Table 7 for descriptions of the harvest-aid treatments.

Note: None of the harvest-aid treatment lint prices were significantly different from the untreated control (Treatment 1) at the 0.05 and 0.10 probability levels.

Two treatments combining Prep with a defoliant had the largest positive impact on net returns at the Tennessee, Florida, Missouri, and Georgia locations. Dropp and Prep (Treatment 7) produced the largest gain in net return at the Tennessee ($108 per acre), Florida ($86 per acre), and Missouri ($44 per acre) sites. For Georgia, Treatment 7 also produced a sizable net return gain, $69 per acre. Folex and Prep (Treatment 6) produced the largest net return of $82 per acre at the Georgia location.

Table 12. Net return differences from the untreated check for alternative cotton harvest-aid treatments for the Midsouth region, using 1996-1997 season average prices.

Harvest-aid Treatment[1]	Location				
	Missouri	Tennessee	Arkansas	Mississippi	Louisiana
	$ per acre				
2	-14	11	-23	-12	-15
3	-2	24	-3	-8	-34
4	37	-1	-21	-12	-40
5	33	67	-19	-5	-62
6	15	58	15	11	-79
7	44	108	-17	-18	-52

Source: Anonymous, 1999.

[1] See Table 7 for descriptions of the harvest-aid treatments.

Table 13. Net return differences from the untreated check for alternative cotton harvest-aid treatments for the Southeast region, using 1996-1997 season average prices.

Harvest-aid Treatment[1]	Location				
	North Carolina	Alabama	South Carolina	Georgia	Florida
	$ per acre				
2	-18	-6	-81	36	-6
3	-20	-13	-85	44	-14
4	-11	-12	-53	32	14
5	-13	-3	-24	47	52
6	-4	-13	-37	82	49
7	-7	-21	-53	69	86

Source: Anonymous, 1999.

[1] See Table 7 for descriptions of the harvest-aid treatments.

SUMMARY

Economic tradeoffs influence the decision to apply a harvest aid before cotton harvest. The net return from a harvest aid is influenced not only by the change in harvest yields and the cost of applying the harvest aid, but also by the change in premiums and discounts for fiber quality and harvesting and handling costs. Weather effects on mature cotton in the field before it is harvested also may have an important influence on the profitability of harvest aids.

The cost and return analysis of alternative harvest-aid treatments from a five-year study conducted by the Cotton Defoliation Work Group indicated that no single harvest-aid regime improved net returns at the 10 Southeast and Midsouth sites examined in the analysis. The primary impact of harvest aids was on harvested lint yields. Combining the boll opener Prep with a defoliant was effective in increasing harvested lint yields at several sites that conducted only a once-over harvest. Harvest-aids did not significantly influence lint prices based on fiber quality, when compared to the untreated check.

In general, harvest-aid treatments that combined the boll opener Prep with a defoliant produced the largest net return gains over the untreated check. Dropp (0.05 pound a.i. per acre) and Prep (1.0 pound a.i. per acre) yielded the largest net returns of any harvest-aid treatment at the Tennessee, Florida, and Missouri sites. Folex (0.56 pound per acre) and Prep (1.0 pound a.i. per acre) produced the largest net returns at the Georgia, Arkansas, and Mississippi sites. However, the gain in net returns over the untreated check were relatively small at the Arkansas and Mississippi locations. None of the harvest-aid treatments at the Louisiana, North Carolina, Alabama, or South Carolina sites produced a positive impact on net returns. For these locations, the partial budgeting analysis indicated that the change in yields and prices brought about by harvest aids did not cover the materials and application costs for the chemicals.

No clear-cut recommendation can be made as to which harvest aids maximize cotton net returns in the Midsouth or Southeast regions. Additional research is required to better understand the reasons for the inconsistent effects of harvest aids on net returns at the 10 locations examined in this analysis. Defoliated cotton may have been exposed to more weathering at some locations, compared to other sites in the defoliation field study. On the other hand, favorable conditions may have led to further yield development in untreated cotton, compared to cotton terminated with harvest aids. A better understanding of these and other factors could lead to more consistent recommendations about harvest aids. Potential reductions in harvest efficiency and yield losses during handling and storage with undefoliated cotton were not measured in the field study and could have an important positive impact on the profitability of harvest aids.

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Chapter 9

OVERVIEW OF REGIONAL DEFOLIATION PRACTICES

AND RESULTS OF REGIONAL TREATMENTS CONDUCTED BY THE COTTON DEFOLIATION WORK GROUP

INTRODUCTION

Cotton production and practices, such as defoliation, vary significantly across the U.S. Cotton Belt. Although the five-year study conducted by the Cotton Defoliation Work Group (CDWG) applied a standardized protocol to field research, regional variations in environmental conditions were recognized and evaluated. These environmental variances and a summary of regional treatments conducted by the CDWG are presented in four segments of this chapter. The regions include the Southeast, Midsouth, Southwest, and Far West. The chapter segments also address defoliation variances within regions.

SOUTHEAST[1]

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OVERVIEW

The Southeastern region is, for the purpose of cotton production, Alabama, Georgia, Florida, North Carolina, and South Carolina (Figure 1). The area has a long history of growing cotton, with some fields growing the crop continuously for more than 100 years. Cotton defoliation has been a standard practice in the Southeast for many years and correlates with the rise in machine harvest and use of more modern techniques such as moduling. No two areas of the country are the same with regard to weather patterns and cotton growth, but much of the Southeast is under the dual influences of the Gulf of Mexico and the Atlantic Ocean, which can exacerbate the variability of weather patterns within the area each year. The five-state area currently grows about three million acres of cotton.

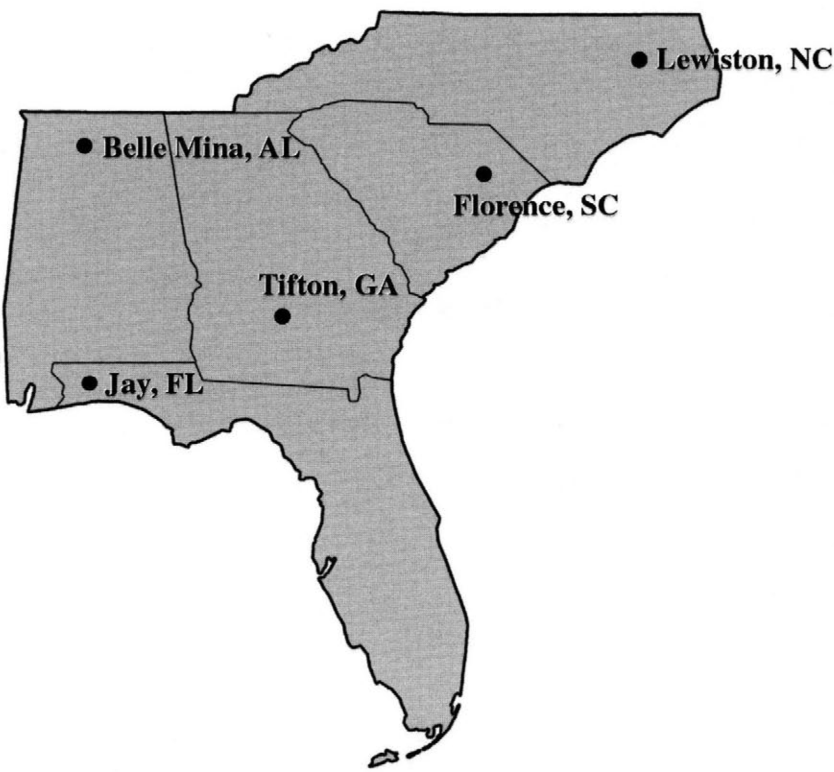

Figure 1. Southeast cotton harvest-aid study locations.

ENVIRONMENTAL CONSIDERATIONS

Weather during the defoliation season in the Southeast is never the same from one year to the next. Examining September weather patterns for temperature and rainfall from 1993 through 1996 will validate this statement (Table 1). September and early October can be very hot and dry or wet and relatively cool. Because the activity of harvest aids is dependent to a large degree on temperature, recommendations seldom are identical from one year to the next. Several soil types and topographies are represented in the Southeast. Although Southeast cotton-growing areas primarily are located on the Coastal Plain, some of the crop is grown in the Tennessee Valley region of Alabama, and some is produced in the Piedmont areas of Georgia and North Carolina. Soil types where cotton is grown range from loamy sands to clay loams.

Yearly rainfall amounts vary significantly within the Southeast. Areas along the Gulf Coast, including the Florida Panhandle and adjacent Alabama Gulf Coast, may average more than 70 inches of precipitation per year. Most areas in the Southeast average from 45 to 50 inches per year (Table 2). A large portion of the southeastern crop is grown without irrigation. The combination of differing soil types and rainfall amounts results in significant differences in crop condition at the end of the season. The same field may have knee-high cotton at the end of the season one year and chest-high cotton the next year. A harvest-aid recommendation that worked well last year may not be as successful this year. Cotton that has gone through an extended summer drought followed by late-season rainfall may exhibit significant regrowth problems.

In the 1990s, the Southeast was victimized by hurricanes with alarming regularity. Cotton growers in the Florida Panhandle, Alabama Gulf Coast region, and eastern North Carolina all incurred losses from mid- to late-season hurricanes between 1993 and 1999. The fear of crop losses from hurricanes has prompted some growers to delay planting from mid-April until mid-May in hopes of not having open bolls in the event of a late summer hurricane. Harvest-aid application, especially with ground equipment, is more difficult in hurricane-damaged cotton; the injured crop may respond differently to harvest aids than a normal crop.

Although the Southeast can experience drought conditions for much of the growing season, relative humidity seldom drops below 40 percent, even during extended dry periods. Relative humidity can influence the activity of most harvest aids, with products generally more active at higher humidities.

Table 1. September temperatures and precipitation for selected sites in the southeastern United States (1993-1996).

Location	Extreme Temperatures (min/max – degrees F)				Precipitation (in)			
	September				September			
	1993	1994	1995	1996	1993	1994	1995	1996
Charlotte, NC	46/96	51/90	48/88	53/90	0.9	1.0	2.5	3.2
Columbia, SC	46/101	52/94	52/94	50/94	3.9	3.3	5.5	2.3
Plains, GA	47/96	54/92	54/93	54/92	4.8	3.4	3.5	2.9
Tifton, GA	52/92	56/89	54/93	55/92	3.9	3.9	0.6	4.0
Belle Mina, AL	43/96	44/90	48/98	46/90	5.3	4.0	7.6	8.0
Brewton, AL	43/96	45/95	50/96	54/93	8.3	3.5	2.0	5.4
Pensacola, FL	53/96	55/94	61/97	57/92	7.2	6.0	5.2	9.7

Source: Agricultural Weather Information Service, 1735 E. University Dr., Auburn, AL 36831-3247.

Table 2. Thirty-year (1961-1990) average temperatures and precipitation for selected locations in the southeastern United States.

Location	September			October			Yearly
	min (F)	max (F)	pcp[1] (in)	min (F)	max (F)	pcp[1] (in)	pcp[1] (in)
Hamlet, NC	60	85	3.6	47	75	3.7	48
Lewiston, NC	58	82	3.8	46	73	3.0	47
Lumberton, NC	60	84	3.9	46	75	3.0	47
Darlington, SC	62	86	3.5	51	77	2.9	47
Manning, SC	61	87	3.5	48	78	2.6	46
McColl, SC	63	85	3.5	51	76	2.8	44
Cordele, GA	65	88	3.0	53	80	1.8	45
Tifton, GA	66	87	3.0	55	79	2.1	48
Waynesboro, GA	61	86	3.0	49	77	3.0	45
Belle Mina, AL	60	83	3.6	47	73	3.2	55
Brewton, AL	63	88	4.5	50	79	3.1	65
Marion Jct., AL	63	86	3.5	50	77	2.8	54
Pensacola, FL	70	86	5.3	59	79	4.2	62

Source: Agricultural Weather Information Service, 1735 E. University Dr., Auburn, AL 36831-3247.

[1] pcp = precipitation.

Air temperatures during September, when a large portion of Southeast acreage is defoliated, often are in the high 80s to low 90s (degrees Fahrenheit; 27 C to 32 C). Harvest-aid activity generally is correlated with temperature a few days before and for several days after application. High temperatures often seen in the Southeast during September can cause defoliants to act much more quickly than normal, causing leaves to stick on the plant rather than dropping. For this reason, lower rates of defoliants often are used in periods of high temperatures. Conversely, when air temperatures drop into the 50s at night and 70s during the day (degrees Fahrenheit; 10 C to 21 C), harvest-aid activity decreases significantly. Higher rates are used under these cooler conditions, and a longer time from application until picking should be anticipated.

STANDARD AND RECOMMENDED PRACTICES

Several cotton varieties are used in different tillage systems throughout the Southeast. Most years, planting dates vary from early April to mid June. Tillage systems ranging from conventional to strict no-till are used, and cotton is grown in various row spacings. Most growers would like a once-over harvest, which usually requires the use of boll-opening products. However, the use of boll-opening products often will depend on a farmer's picker capacity, crop potential, and other economic factors. Thus, no two growers use exactly the same cultural practices. Cotton planted on the same day in adjacent fields may vary significantly in the way it grows and the treatments required to terminate the crop at the end of the season.

University workers and private consultants, as well as agricultural chemical distributors, have offered Southeastern growers cotton harvest-aid recommendations and advice for several years. Until recently, only a handful of products were available for use as harvest aids – primarily Folex®/Def®, Dropp®, Harvade®, and Prep™ (ethephon). Each product has advantages and disadvantages, depending on the crop growth stage and weather during treatment.

Because of the unpredictable nature of growing conditions in the Southeast, product-use recommendations have evolved into a "shotgun" philosophy: Seldom would a grower consider using a single product alone. Application rates generally can be decreased when multiple products are used in mixtures;

different types of activity can be obtained by using products in combination. For example, mixtures of Folex/Def, a poor regrowth inhibitor, with Dropp, a good regrowth inhibitor, provide acceptable defoliation, as well as regrowth inhibition. Ethephon can be added to the mix to provide boll opening; it also increases the level of defoliation obtained. Harvade with Prep is a standard mix for defoliation and boll opening, but it also provides weed desiccation, especially for morningglory. Adding Dropp to this mix will enhance regrowth inhibition. Two- and three-way mixtures are the norm, not the exception.

Most growers would like to make only one application of a harvest aid and then pick; but, in many cases, the best job is obtained with two applications, especially on tall, rank cotton.

Economics plays an important role in the selection of harvest-aid treatments: Any treatment should be evaluated for cost effectiveness as well as for physical activity (something that often is easier to say than to do). The high cost of running a picker over the field has caused many growers to seek treatments that will enable a once-over harvest.

SUMMARY OF RESULTS

During a five-year period, specific Southeast treatments (Table 3) and seven core treatments were applied by the Defoliation Work Group during September (in most cases). Temperatures were warm for the most part; therefore, the activity of the treatments should be considered optimal. Prep + Dropp + Folex, Dropp + Folex, and Harvade + Dropp + crop oil concentrate (COC) were applied in all five years of the study. Quick Pick® + Prep and Quick Pick + Dropp were applied for the first three years of the study (1992-1994), and Prep alone and Finish were applied the last two years of the study (1995 and 1996). Therefore, averages from the last four regional treatments cannot be directly compared to the first three regional treatments or to the core treatments, because they were not tested all five years. Data from Southeast regional treatments containing Quick Pick, Prep alone, and Finish will be discussed, but no direct comparisons with the other regional treatments or core treatments will be made.

FIVE-YEAR REGIONAL AVERAGES

Prep + Dropp + Folex/Def is a treatment widely used in the Southeast (Table 3). This treatment was chosen because it generally provides defoliation, boll opening, and regrowth control in one mixture. Dropp + Folex/Def is another combination often used in our region when boll opening is not needed. Harvade + Dropp with crop oil concentrate was the third regional treatment applied all five years.

Performance Index (PI) is an overall evaluation of the effectiveness of a treatment, including defoliation, boll opening, regrowth, desiccation, and leaf sticking (Anonymous, 1999). PI at 7 days after treatment (DAT) was greater than 78 for Harvade + Prep + Agri-Dex®, Folex + Prep, and Prep + Dropp + Folex (Table 4). PI at 14 DAT was higher than 84 for Folex + Prep, Dropp + Prep, and Prep + Dropp + Folex. All other PIs were less than 82 for this rating period. The addition of Prep tended to increase PI ratings at both 7 DAT and 14 DAT. Combinations also provided generally higher PI ratings than any product applied alone.

Table 3. Southeast regional harvest-aid treatments.

Trt No.	Treatment	Rate Per Acre	Years Studied
8	Prep™ + Dropp® + Folex®	1.33 pt 0.1 lb 1 pt	1992-1996
9	Dropp + Folex	0.125 lb 0.75 pt	1992-1996
10	Harvade® + Dropp + COC[1]	6.5 fl oz 0.125 lb 1 pt	1992-1996
11	Quick Pick® + Prep	1.3 pt 1.33 pt	1992-1994
12	Quick Pick + Dropp	1.3 pt 0.125 lb	1992-1994
13	Prep	1.33 pt	1995, 1996
14	Finish®	2 pt	1995, 1996

Source: Anonymous, 1999.

[1] COC = crop oil concentrate.

Table 4. Influence of harvest-aid treatments on performance, defoliation, and desiccation at Southeast test sites (1992-1996).

Treatment Description	Performance Index[1]		% Defoliation		% Desiccation	
	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
Untreated Check	31.9	38.7	36.0	47.8	1.6	3.1
Folex®	70.1	75.4	66.2	77.3	15.5	11.6
Dropp®	62.2	74.6	57.6	71.7	5.5	8.7
Harvade® + Agri-Dex®	73.8	77.4	68.9	79.6	18.9	13.0
Harvade + Prep™ + Agri-Dex	78.5	80.2	72.9	82.6	15.4	12.2
Folex + Prep	79.8	84.2	75.0	85.2	15.8	13.6
Dropp + Prep	76.1	84.4	70.2	83.3	7.5	10.0
Prep + Dropp + Folex	79.6	87.6	73.8	88.1	18.1	16.4
Dropp + Folex	72.3	81.7	65.9	79.1	10.4	13.0
Harvade + Dropp + Agri-Dex	75.3	80.9	69.4	80.7	18.0	12.1
LSD ($p<0.05$)	9.9	10.3	6.8	8.5	10.8	5.3

Source: Anonymous, 1999.

[1] Performance Index is an overall evaluation of the effectiveness of a treatment, including defoliation, boll opening, regrowth, desiccation, and leaf sticking, on a 0 to 100 scale.

Defoliation closely paralleled the Performance Indices, with the highest rating given to the three-way mixture of Prep + Dropp + Folex (73.8 at 7 DAT and 88.1 at 14 DAT). Although this was not significantly different from several other treatments, it was higher than three of the core treatments and the Dropp + Folex regional treatment.

Desiccation was lowest at both 7 DAT and 14 DAT for the Dropp alone and Dropp + Prep core treatments. The highest desiccation rates generally were observed for treatments containing Harvade and the Prep + Dropp + Folex treatment, although no desiccation ratings above 19 percent were observed.

Boll opening – The Dropp + Prep regional treatment showed a numerically higher percent open bolls at 7 DAT than all other treatments, but it was not significantly higher than other treatments containing Prep (Table 5). Treatments containing Prep generally provided four to five percent more open bolls than those without Prep at 7 DAT. By 14 DAT, all treatments containing Prep were approximately 89 to 90 percent open, five to 11 percent higher than those treatments without Prep.

Terminal regrowth was significantly lower ($p<0.05$) for the Prep + Dropp + Folex treatment (19.7 percent) than all other treatments except Dropp + Prep, Dropp + Folex, and Dropp alone. Treatments containing Dropp generally had lower terminal regrowth than those without Dropp. Basal regrowth was higher with all treatments than terminal regrowth; although there were differences, all treatments had basal regrowth of 53 percent and higher.

Seed cotton and lint yields were statistically similar for all treatments (Table 6). Percent lint varied between 38.8 and 39.1. Harvade + Prep + Agri-Dex, Folex + Prep, Dropp + Prep, and Prep + Dropp + Folex all provided lint yields of more than 1000 pounds per acre. Gin turnout was similar for most treatments, varying from 36.3 to 36.7 percent.

TWO- AND THREE-YEAR REGIONAL AVERAGES

Additional Southeast regional treatments that were not tested for the entire five-year period include Quick Pick + Prep, Quick Pick + Dropp, Prep alone, and Finish (Table 3). Because these treatments were not tested all five years, the averages for yield, gin turnout, and percent lint cannot be compared fairly to the core treatments or to the three regional treatments tested all five years. Two- and three-year averages for overall performance, defoliation, desiccation, open bolls, and regrowth associated with the additional regional treatments are presented in tables 7 and 8.

Quick Pick + Dropp provided good overall performance and defoliation in the three years this mixture was tested (Table 7). Desiccation was no greater numerically than with the other regional or core treatments. Prep alone did not provide adequate defoliation or overall performance. Finish provided good defoliation and performance as a stand-alone treatment during the two years it was tested. The percentage of open bolls with the Finish treatment was numerically equal to that of core treatments containing Prep (Table 8). Terminal regrowth ratings for Quick Pick and Finish treatments were numerically equal to the three-way regional mix of Prep + Dropp + Folex.

SUMMARY

The three-way regional harvest-aid mixture of Prep + Dropp + Folex/Def performed well across the Southeast over the five-year period of our study. Folex/Def + Prep and Harvade + Prep + Agri-Dex also performed well. Addition of Prep tended to increase overall performance and defoliation. Combinations of harvest aids generally performed better than single products alone. Finish performed well as a stand-alone product during the two years in which it was tested.

Table 5. Influence of harvest-aid treatments on percent open bolls, terminal regrowth, and basal regrowth at Southeast test sites (1992-1996).

Treatment Description	**% Open Bolls**		**% Terminal Regrowth**	**%Basal Regrowth**
	7 DAT	**14 DAT**	**21-28 DAT**	**21-28 DAT**
Untreated Check	65.1	75.8	80.0	64.0
Folex®	65.4	78.2	51.3	63.1
Dropp®	65.7	79.2	30.4	53.2
Harvade® + Agri-Dex®	69.7	83.1	48.4	59.0
Harvade + Prep™ + Agri-Dex	70.8	90.1	42.8	67.7
Folex + Prep	71.6	88.8	39.6	74.7
Dropp + Prep	73.7	89.9	26.6	66.6
Prep + Dropp + Folex	70.4	89.4	19.7	62.4
Dropp + Folex	66.6	82.8	32.1	58.5
Harvade + Dropp + Agri-Dex	66.5	82.2	33.9	55.2
LSD ($p<0.05$)	5.7	4.2	13.7	11.9

Source: Anonymous, 1999.

Table 6. Influence of harvest-aid treatments on seed cotton, lint yield, percent lint, and gin turnout at Southeast test sites (1992-1996).

Treatment Description	Seed Cotton (lb per acre)	Lint Yield (lb per acre)	Lint (%)	Gin Turnout (%)
Untreated Check	2504	980	38.9	36.3
Folex®	2500	985	39.0	36.6
Dropp®	2516	981	38.8	36.3
Harvade® + Agri-Dex®	2495	982	38.9	36.5
Harvade + Prep™+ Agri-Dex	2617	1024	39.1	36.7
Folex + Prep	2581	1018	39.0	36.7
Dropp + Prep	2610	1020	38.9	36.6
Prep + Dropp + Folex	2635	1029	38.9	36.5
Dropp + Folex	2538	997	39.0	36.5
Harvade + Dropp + Agri-Dex	2504	989	39.1	36.7
LSD ($p<0.05$)	120	41	0.2	0.3

Source: Anonymous, 1999.

Table 7. Influence of additional regional harvest-aid treatments on performance, defoliation, and desiccation at Southeast test sites (1992-1996).

Treatment Description	**Performance Index**[1]		**Defoliation (%)**		**Desiccation (%)**		**Years Studied**
	7 DAT	**14 DAT**	**7 DAT**	**14 DAT**	**7 DAT**	**14 DAT**	
Untreated Check		30	36	48	2	3	
Quick Pick® + Prep™	62	81	61	79	7	13	1992-1994
Quick Pick + Dropp®	80	88	71	88	13	11	1992-1994
Prep	56	74	55	71	6	18	1995, 1996
Finish®	80	90	70	88	18	10	1995, 1996

Source: Anonymous, 1999.

[1] Performance Index is an overall evaluation of the effectiveness of a treatment, including defoliation, boll opening, regrowth, desiccation, and leaf sticking, on a 0 to 100 scale.

Table 8. Influence of additional regional harvest-aid treatments on percent open bolls, terminal regrowth, and basal regrowth at Southeast test sites (1992-1996).

Treatment Description	**Open Bolls (%)**		**Terminal Regrowth (%)**	**Basal Regrowth (%)**	**Years Studied**
	7 DAT	**14 DAT**	**21-28 DAT**	**21-28 DAT**	
Untreated Check	74	87	44	38	
Quick Pick® + Prep™	74	84	18	43	1992-1994
Quick Pick + Dropp®	75	88	20	48	1992-1994
Prep	80	90	40	54	1995, 1996
Finish®	79	90	19	48	1995, 1996

Source: Anonymous, 1999.

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Anonymous. (1999). Uniform harvest aid performance and fiber quality evaluation. *MAFES Information Bulletin* (No. 358, September). Mississippi State: Office of Agricultural Communications; Division of Agriculture, Forestry, & Veterinary Medicine; Mississippi State University.

MIDSOUTH[1]

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OVERVIEW

The Midsouth cotton production region includes the states of Arkansas, Louisiana, Mississippi, Missouri, and Tennessee. This region is a major cotton-production area of the United States, as well as of the world. In 1996, Midsouth states produced 6.1 million bales of cotton, or 33 percent of U.S. production. During the years from 1992 to 1996, cotton harvested in the Midsouth ranged from a high of 4.7 million acres in 1995 to a low of 3.2 million acres in 1992.

Of the five Midsouth states, Mississippi was the highest producer at 1.9 million bales in 1996, followed by Arkansas, Louisiana, Tennessee, and Missouri. When averaged over a five-year period (1992-1996), Arkansas produced the highest yields per acre at 734 pounds per acre, followed by Mississippi (716 pounds per acre), Missouri (694 pounds per acre), Louisiana (690 pounds per acre) and Tennessee (588 pounds per acre) (Anonymous, 1997).

The Midsouth region has many advantages for cotton production because of large areas of relatively flat topography and almost unlimited water availability for irrigation, supplied by underground aquifers during dry summer months (Raney and Cooper, 1968). Cotton is almost 100 percent spindle-harvested; a very high percentage is stored in modules after harvest

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[1] Members of the Midsouth team who worked on the Cotton Defoliation Work Group included Merritt Holman, Dan Reynolds, and Steve Crawford - Louisiana State University Agricultural Center, St. Joseph, Louisiana; Charles Snipes - Mississippi State University, Delta Research and Extension Center, Stoneville, Mississippi; Eric Webster and Charles Guy - University of Arkansas at Monticello; C.O. Gwathmey and R.M. Hayes - University of Tennessee, Jackson; and Dave Albers, Gene Stevens, and Bobby Phipps - Delta Research Center, Portageville, Missouri.

(Crawford, 1996). Weather risk is high, however: The production challenge of growing cotton in the Midsouth region is characterized by management of either too much moisture or not enough.

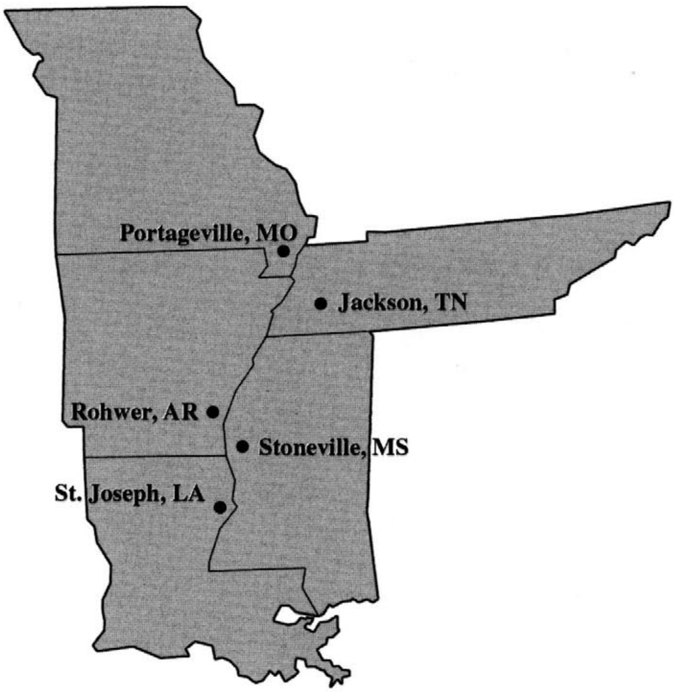

Figure 1. Midsouth cotton harvest-aid study locations.

Cotton production largely is concentrated in the alluvial valley soils and stream bottomlands along the Mississippi River flood plain. These soils are rich in all nutrients, although they can vary widely in texture, structure, depth, frequency of overflow from rivers and bayous, and drainage. The riverbank soils are sandy and well drained, but, as production moves farther from the riverbank soils, clay content increases, resulting in poor drainage (Raney and Cooper, 1968).

Yearly rainfall amounts range from approximately 48 inches in the more northern areas of the region to 56 inches per year as production moves south towards the Gulf coast (Anonymous, 1996). Although rainfall is adequate, much of the rainfall occurs during the months in which cotton is not actively growing. Data collected at Stoneville, Mississippi, over a 30-year period shows that 72 percent of the yearly rainfall occurred from September to April, whereas only 28 percent occurred during May, June, July, and August (Boykin *et al.*, 1995).

This pattern of rainfall distribution, paired with a low to inadequate soil infiltration rate, can result in a crop that is difficult to terminate or in delayed harvest during the fall. In the upper areas of the Midsouth (northeast Arkansas, west Tennessee, and Bootheel of Missouri), weather delays mean fewer days to harvest, insufficient heat to mature late-set bolls, and the threat of freeze damage to unopened bolls. In the lower region of the Midsouth, monsoon-type rains become a threat late in the season because of tropical storms originating near the Gulf Coast.

USE OF HARVEST AIDS

Management of the crop during the dry summer months and timely application of effective harvest aids to terminate the crop are critical for successful cotton production in the Midsouth. Weather patterns and condition of the crop can vary widely across the region. Therefore growers always should consult local Extension agents or crop consultants for regional recommendations. Although use of a single harvest-aid material may be more economical and may result in satisfactory defoliation, more flexibility can be obtained if a mixture is used (Snipes and Cathey, 1992). In order to reduce the risk of poor performance, tank mixtures often are recommended (Brandon *et al.*, 2000).

Folex®/Def®, Dropp® – The phosphate-type products, Folex/Def (tribufos), are effective over a broad range of environmental conditions and promote more rapid leaf drop than Dropp (thidiazuron). These materials, however, are not as effective as Dropp in removing juvenile growth (younger growth that occurs prior to defoliant application) or inhibition of regrowth (growth that occurs after defoliation). Dropp provides defoliation equal to the phosphate materials, but performs best under warm, humid conditions when the minimum daily temperature is 70 F or higher.

Harvade® (dimethipin) provides effective defoliation of mature cotton and usually desiccates mature morningglory (*Ipomoea* sp.) and prickly sida (*Sida spinosa*). Harvade is not effective in removing juvenile growth, nor is it a strong inhibitor of terminal regrowth.

Prep™/Super Boll®/Ethephon 6 (ethephon) are used to both open mature bolls and enhance defoliation. Application of ethephon increases the ethylene synthesis that occurs naturally during boll opening, as well as stimulating ethylene production in the leaf petiole where abscission occurs. Because of the complex plant processes involved with application, ethephon is rate- and temperature-sensitive.

Finish®, a combination of ethephon and cyclanilide, provides boll opening and higher defoliation than with ethephon alone.

CottonQuik® is a combination of ethephon and AMADS (1-Amino-methanamide dihydrogen tetraoxosulfate) and provides substantial defoliation and boll opening activity, as well as mild regrowth inhibition. It is, however, recommended for tankmix combinations with low rates of Dropp or Folex/Def to provide consistent defoliation activity.

Sodium chlorate, paraquat – Defoliants/desiccants such as sodium chlorate and paraquat commonly are used in areas where cotton is mechanically stripped. In the Midsouth, where the majority of cotton is mechanically picked, desiccants generally are avoided, but they are recommended as sequential treatments following defoliants to improve unacceptable first-application results or to remove juvenile growth missed by the first application. Lower rates of sodium chlorate or paraquat deliver a certain level of defoliation without excessive desiccation, whereas higher rates serve as desiccants and are more suited to stripper harvest when used as a first-application method. Paraquat usually is considered a good tankmix partner with Folex or Def during periods of cool, wet weather. Applying Dropp at proper physiological maturity, followed five to seven days later with paraquat plus sodium chlorate, has become a standard practice through much of the Midsouth.

FIVE-YEAR SUMMARY

Experiments were conducted from 1992 through 1996 at the University of Arkansas Southeast Research and Extension Center, Monticello, Arkansas; Louisiana State University Northeast Research Station, St. Joseph, Louisiana; Mississippi State University Delta Branch Experiment Station, Stoneville, Mississippi; University of Missouri-Delta Center, Portageville, Missouri; and West Tennessee Experiment Station, Jackson, Tennessee.

Refer to Table 1 for cotton variety used, soil type, and crop condition at application timing for each location. Summarized weather data from 1992 through 1996 for various locations throughout the Midsouth can be found in Table 2. Table 3 indicates that average heat unit accumulation over the five-year period was much lower in the more northern regions of the Midsouth (Tennessee and Missouri) than for locations in Mississippi, Louisiana, and Arkansas.

Table 1. Cotton variety, soil type, and percent open bolls at application for Midsouth locations.

Location	Variety	Soil Type	% Open Bolls at Application (1992–1996)
Louisiana	Deltapine® 50	Commerce Silt Loam	41-65
Mississippi	DES 119 (1992–1995) Deltapine 50 (1996)	Bosket Very Fine Sandy Loam Bosket Very Fine Sandy Loam	51-63
Missouri	Deltapine 50	Tiptonville Silt Loam	43-56
Tennessee	Deltapine 50	Loring Sandy Loam	49-52
Arkansas	Deltapine 51 (1992–1995) Deltapine 50 (1996)	Loring Sandy Loam Loring Sandy Loam	55-61

Source: Anonymous, 1999.

Table 2. September temperatures and precipitation for selected sites in the Midsouth (1992-1996).

	Average Temperatures (min/max F)					Precipitation (in)				
Location	**1992**	**1993**	**1994**	**1995**	**1996**	**1992**	**1993**	**1994**	**1995**	**1996**
Jackson, TN	60/81	58/81	57/81	59/81	60/80	4.12	4.24	2.02	1.55	7.90
Monroe, LA	64/87	62/89	62/88	62/88	62/85	4.89	2.47	1.60	1.49	3.78
Stoneville, MS	63/84	62/87	61/87	60/87	63/84	2.96	4.34	1.14	1.63	4.39
Stuttgart, AR	62/83	59/86	59/85	59/85	62/83	2.22	0.90	1.55	0.48	5.86
Sikeston, MO	58/80	58/78	60/80	60/79	60/79	3.49	6.42	3.12	2.07	4.25

Source: National Climatic Data Center, Asheville, North Carolina, 2000.

Table 3. Heat units (DD60) from treatment application to first harvest for each Midsouth location.

Location	1992	1993	1994	1995	1996	5-Year Average
Stoneville, MS	90	158	248	272	199	194
Jackson, TN	46	102	85	105	162	100
Portageville, MO	34	85	80	55	90	69
St. Joseph. LA	226	279	290	288	240	265
Rohwer, AR	172	235	144	231	232	203
Midsouth 5-Year Average						166

Source: Anonymous, 1999.

Standard agronomic practices and recommended pest management procedures were followed to ensure normal crop growth at each location. Treatments were applied with standard high-clearance ground application equipment calibrated to deliver 10 to 15 gallons per acre, depending on location. In addition to the seven core treatments used throughout the Cotton Belt, the Midsouth cooperators included eight treatments with specific regional importance (Table 4). Treatments were chosen for anticipated response within the region and were considered regional standards or treatments that were, or have been, in wide use throughout the region. These data have no bearing on performance of the same treatments in other regions.

Criteria for evaluation parameters are defined in Table 5. Performance, defoliation, desiccation, and open boll evaluations were conducted at 7 and 14 days after treatment (DAT). Terminal and basal regrowth was determined as defined in the study's protocol at 21 DAT to 28 DAT except in 1992. In 1992, a visual estimation of general regrowth was recorded. Plots were harvested 14 DAT (±2) with a spindle-type picker modified for plot harvest. Seed cotton was harvested from the two center rows of each plot and sampled for lint percent. Lint yields are reported.

Data from the Midsouth region for the years 1992-1996 were subjected to analysis of variance and means were separated by least significant difference (LSD) ($p<0.05$). Data were averaged over replications and combined across years and locations. Years and location were treated as random environmental effects. Mean comparisons for treatments were performed using appropriate environmental error components. Because of an unequal number of observations per mean, the LSD value reported is not constant for all comparisons of means. Therefore, the LSD reported is the weighted average of all LSDs calculated.

Table 4. Midsouth harvest-aid treatments (1992-1996).

Treatment Description	**Product Rate Per Acre**	**Years Tested**
Untreated Check		
Folex®	1.5 pt	1992-1996
Dropp®	0.2 lb	1992-1996
Harvade® + Agri-Dex®	8 oz + 1 pt	1992-1996
Harvade + Prep™ + Agri-Dex	6.5 oz + 1.33 pt + 1 pt	1992-1996
Folex + Prep (Low)	0.75 pt + 1.33 pt	1992-1996
Dropp + Prep	0.1 lb + 1.33 pt	1992-1996
Harvade + Dropp + Agri-Dex	6.5 oz + 0.125 lb + 1 pt	1992-1996
Dropp + Folex	0.1 lb + 0.75 pt	1992-1996
Sodium Chlorate (47% a.i.)	4.5 lb	1992-1996
Folex + Prep (High)	1 pt + 1 qt	1992-1996
Dropp + Prep	0.125 lb + 5.33 oz	1992-1996
Prep	1.33 pt	1995-1996
Finish® (EXP 31039C)	1 qt	1995-1996
Roundup® + Folex	1 qt + 0.75 pt	1995-1996

Source: Anonymous, 1999.

Table 5. Harvest-aid data collected, 1992-1996.

Term	Timing	Definition
Performance Index	7 DAT and 14 DAT	Overall harvest-aid performance on a scale of 0 to 100, where 0 equals no performance and 100 equals perfect performance. (Evaluated in 1993-1996 only.)
Defoliation (%)	7 DAT and 14 DAT	Visual estimate of percentage of leaves present at time of application that were removed by treatment.
Desiccation (%)	7 DAT and 14 DAT	Visual estimate of leaves remaining on plant that were desiccated as a result of treatment.
Open Bolls (%)	7 DAT and 14 DAT	Determined by counting total bolls and open bolls in a pre-defined 1-meter row segment.
Terminal Regrowth (%)	21-28 DAT	Determined by counting number of plants in a pre-defined 1-meter row segment with new leaves larger than 10 mm in size that had regrowth on stem terminals. (In 1992, visual estimation of overall regrowth was recorded and included with 1993-1996 data.)
Basil Regrowth (%)	21-28 DAT	Determined by counting number of plants in a 1-meter row segment with new leaves larger than 10 mm in size that had regrown from the main stem. (Evaluated in 1993-1996 only).
Lint (%)	After Harvest	From a ginned sample, lint weight divided by seed weight plus lint weight.
Gin Turnout (%)	After Harvest	From a ginned sample, lint weight divided by total sample weight.

Source: Anonymous, 1999.

REGIONAL RESULTS AND DISCUSSION

PERFORMANCE INDEX

Performance Index (PI) is an overall evaluation of the effectiveness of a treatment, including defoliation, boll opening, regrowth, desiccation, and leaf sticking. The PI of the various treatments at 7 DAT and 14 DAT ranged from 48 to 77 and 59 to 84, respectively (Table 6). At 7 DAT, application of the high-rate regime of Folex + Prep resulted in a PI of 77, which improved to 84 by 14 DAT. Other treatments that compared favorably at 7 DAT were Harvade + Prep, the low-rate regime of Folex + Prep, Dropp + Prep, and Finish.

Table 6. Influence of harvest-aid treatments on performance, defoliation, and desiccation at Midsouth test sites (1992-1996).

Treatment Description	**Performance Index[1]**		**Defoliation (%)**		**Desiccation (%)**	
	7 DAT	**14 DAT**	**7 DAT**	**14 DAT**	**7 DAT**	**14 DAT**
Untreated Check	6.9	19.9	15.2	25.2	2.5	2.6
Folex®	67.7	76.4	67.4	80.0	9.4	6.0
Dropp®	53.2	69.2	54.1	71.4	7.1	4.4
Harvade® + Agri-Dex®	56.9	70.6	58.7	73.5	11.4	5.8
Harvade + Prep™ + Agri-Dex	67.1	75.7	65.4	77.7	7.2	4.9
Folex + Prep (Low)	74.2	81.3	74.0	85.2	8.9	4.2
Dropp + Prep	67.0	81.5	64.5	81.4	7.5	4.5
Harvade + Dropp + Agri-Dex	61.6	77.8	63.3	80.1	12.3	7.2
Dropp + Folex	58.4	76.5	59.8	79.0	14.7	9.4
Sodium Chlorate	59.1	71.9	60.3	75.8	19.3	9.3
Folex + Prep (High)	76.8	84.6	75.9	87.2	10.4	5.1
Dropp + Prep (5.33 oz per acre)	58.8	74.5	58.4	75.1	5.5	4.0
Prep	48.6	59.0	49.7	62.0	3.7	3.0
Finish® (EXP 31039C)	69.8	79.3	66.6	78.9	4.1	2.9
Roundup® + Folex	60.2	72.8	59.4	75.3	12.3	7.1
<u>ANOVA results</u> F-test Trt (Pr>F)	15.01	18.48	17.67	19.62	7.26	6.11
LSD Trt ($p<0.05$)[2]	12.40	10.52	9.85	9.67	4.90	2.51

Source: Anonymous, 1999.

[1] Performance Index is an overall evaluation of the effectiveness of a treatment, including defoliation, boll opening, regrowth, desiccation, and leaf sticking, on a 0 to 100 scale.

[2] Because of an unequal number of observations per mean, the LSD value is not constant for all means comparisons. Therefore the LSD given is the weighted average of all LSDs calculated.

By 14 DAT results of several additional treatments were similar to those from the Folex + Prep (high) treatment. In addition to the treatments mentioned previously, they included Folex, Folex + Dropp, Harvade + Dropp, and Dropp + Prep (at 5.33 ounces per acre). Treatments that included Dropp tended to improve more from 7 DAT to 14 DAT than all other treatments.

In general, PI was better when combinations were used than with single treatments. Prep at 1.33 pints per acre did not provide acceptable performance. Tank mixes of Prep with defoliants typically performed better than the defoliant-only treatments.

DEFOLIATION

Generally, defoliation followed the same trend as PI (Table 6). Because defoliation considered only the percentage leaf drop, ratings for treatments were slightly higher, not reflecting other factors considered in PI ratings such as regrowth, desiccation, and boll opening.

Percent defoliation with Folex + Prep (high rate) was 76 percent at 7 DAT, but was not statistically higher than Finish, Folex + Prep (low rate), or Folex. At 14 DAT, the Folex + Prep (high) treatment had the best defoliation at 87 percent, although it was not statistically better than the low rate of Folex + Prep (85 percent), Dropp + Prep (81 percent), Harvade + Dropp (80 percent), Folex (80 percent), Dropp + Folex (79 percent), Finish (79 percent), and Harvade + Prep (78 percent). More treatments were similar at 14 DAT than at 7 DAT, indicating a difference in time to maximum defoliation for certain treatments.

DESICCATION

At 7 DAT, desiccation did not exceed 20 percent with any treatment (Table 6). Desiccation was 19 percent and 15 percent for sodium chlorate and Dropp + Folex, respectively. Other treatments with greater than 10 percent desiccation were Harvade, Harvade + Dropp, Folex + Prep (high), and Roundup + Folex. By 14 DAT, none of the treatments resulted in desiccation levels that exceeded 10 percent. However, the sodium chlorate and Dropp + Folex treatments at nine percent dessication were statistically higher than all other treatments except Harvade + Dropp and Roundup + Folex.

BOLL OPENING

For the Midsouth, boll opening at 7 DAT for all treatments containing ethephon (except Dropp + Prep at 5.33 ounces per acre) was significantly higher than the check (Table 7). Open bolls at 7 DAT averaged 5.8 percentage points higher than the check where ethephon was used and ranged from 65.6 percent in the check to 76.1 percent for Finish, which contains ethephon. At 14 DAT, the highest percentage of open bolls resulted from six treatments containing ethephon and from Harvade + Dropp (Table 7). At 14 DAT, Finish resulted in 91.3 percent open bolls, which was statistically higher than all other treatments except Dropp + Prep and Folex + Prep (high rate).

REGROWTH

Terminal regrowth was 51.8 percent in the untreated control (Table 7). Terminal regrowth was reduced by all harvest-aid treatments although several treatments reduced regrowth more than others. Roundup + Folex and Dropp + Folex were the best treatments, with only 0.6 percent and 15.1 percent terminal regrowth, respectively. Treatments with statistically higher percentages of regrowth were Folex alone, Harvade alone, Harvade + Prep, sodium chlorate, Prep alone, and Finish. As a general trend, treatments that contained Dropp had better terminal regrowth inhibition than treatments that did not contain Dropp.

The Roundup + Folex treatment resulted in excellent terminal regrowth inhibition. Roundup's mode of action is herbicidal, and it primarily is recommended for late-season weed control. However, Roundup does not have any defoliation activity; its regrowth inhibition properties generally are considered secondary to its use for late-season weed control. Use of Roundup to inhibit terminal regrowth would be desirable in areas with cooler temperatures where Dropp may perform poorly. However, without the economic benefits of weed control from the Roundup application, rates of Roundup necessary for high levels of regrowth inhibition may be cost prohibitive.

Basal regrowth was higher than terminal regrowth for all treatments (Table 7). Dropp at the full use rate and Roundup + Folex were the only treatments that reduced basal regrowth below that of the untreated check ($p<0.05$). Basal regrowth with several treatments, including Folex + Prep (both low and high rates) and Finish, actually was significantly higher than the untreated check

TREATMENTS PROTECTED QUALITY

Average seed cotton and lint yields, percent lint, and percent gin turnout for the Midsouth from 1992 through 1996 are shown in Table 8. Defoliation treatments evaluated and described in this chapter did not adversely influence yields, lint percent, or gin turnout.

Table 7. Influence of harvest-aid treatments on percent open bolls, terminal regrowth, and basal regrowth at Midsouth test sites (1992-1996).

Treatment	**Open Bolls (%)**		**Terminal Regrowth (%)**	**Basal Regrowth (%)**
Description	**7 DAT**	**14 DAT**	**21-28 DAT**	**21-28 DAT**
Untreated Check	65.5	79.3	51.8	49.2
Folex®	68.3	83.0	36.2	51.6
Dropp®	65.7	81.0	22.3	36.2
Harvade® + Agri-Dex®	67.8	81.4	32.3	42.3
Harvade + Prep™ + Agri-Dex	72.5	86.9	31.8	57.4
Folex + Prep (Low)	70.9	86.8	27.2	64.7
Dropp + Prep	72.2	88.2	17.7	54.1
Harvade + Dropp + Agri-Dex	67.8	84.5	20.1	41.2
Dropp + Folex	68.0	83.4	15.1	46.3
Sodium Chlorate	68.1	82.8	30.0	53.9
Folex + Prep (High)	72.6	88.6	23.0	64.4
Dropp + Prep (5.33 oz per acre)	67.7	82.4	24.2	46.3
Prep	72.4	87.7	36.2	59.3
Finish® (EXP 31039C)	76.1	91.3	30.7	66.5
Roundup® + Folex	66.9	82.2	0.6	21.0
ANOVA results				
F-test Trt (Pr>F)	4.48	8.60	5.72	8.93
LSD Trt (p<0.05)[1]	3.96	3.28	13.37	10.59

Source: Anonymous, 1999.

[1] Because of an unequal number of observations per mean, the LSD value is not constant for all means comparisons. Therefore the LSD given is the weightened average of all LSDs calculated.

Table 8. Influence of harvest-aid treatments on seed cotton, lint yield, percent lint, and gin turnout at Midsouth test sites (1992-1996).

Treatment Description	**Seed Cotton (lb per acre)**	**Lint Yield (lb per acre)**	**Lint (%)**	**Gin Turnout (%)**
Untreated Check	3016	1073	35.92	33.25
Folex®	2963	1058	36.09	33.80
Dropp®	2983	1063	36.02	33.60
Harvade® + Agri-Dex®	2994	1069	36.10	33.81
Harvade + Prep™ + Agri-Dex	3022	1077	36.01	33.57
Folex + Prep (Low)	2998	1070	36.08	33.78
Dropp + Prep	3008	1076	36.11	33.84
Harvade + Dropp + Agri-Dex	2966	1060	36.10	33.75
Dropp + Folex	2968	1058	35.91	33.53
Sodium Chlorate	2928	1041	35.93	33.45
Folex + Prep (High)	3006	1076	36.10	33.90
Dropp + Prep (5.33 oz per acre)	2941	1048	36.00	33.65
Prep	3119	1110	35.91	33.35
Finish® (EXP 31039C)	300[illegible]	1072	36.09	33.78
Roundup® + Folex	2948	1051	36.05	33.98
ANOVA results F-test Trt (Pr>F) LSD Trt ($p<0.05$)[1]	 1.08 111.54	 0.99 42.72	 0.78 0.27	 1.62 0.47

Source: Anonymous, 1999.

[1] Because of an unequal number of observations per mean, the LSD value is not constant for all means comparisons. Therefore the LSD given is the weightened average of all LSDs calculated.

SUMMARY

Harvest-aid practices in the Midsouth region may differ widely because of variations in weather patterns as production moves from areas along the warm, humid Gulf Coast to the more northern, cooler boundaries of the Midsouth in Missouri and Tennessee. This region is exclusively picker-harvested; therefore, effective use of harvest aids to terminate the crop is crucial for successful cotton production.

Results from a five-year study conducted by Midsouth cooperators of the Cotton Defoliation Work Group indicated that overall harvest-aid performance is best when tank mixtures are used rather than single products; boll opening is enhanced by the inclusion of ethephon in the tank mixture; and terminal regrowth is reduced by the use of Dropp.

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SOUTHWEST[1]

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OVERVIEW

Southwest (Texas, Oklahoma, and a portion of northeastern New Mexico) farmers plant in excess of five million acres of cotton annually. Cotton production in the Southwest occurs in several relatively distinct areas, as illustrated in Figure 1. These areas represent a broad range of soil types, elevations, climatic conditions, irrigation capabilities, pest complexes, and cropping systems. Cotton planting typically is initiated in the Lower Rio Grande Valley in February, with harvest in July and August; in the Rolling Plains, planting occurs in late May and early June, with harvest in October and November. About 10 percent of the planted acreage is abandoned annually (mainly on the High and Rolling Plains) because of drought or other adverse weather conditions.

Year-to-year production fluctuates widely (Figure 2) because of variations in acreage planted, moisture availability, and seasonal growing conditions. Since the early 1970s, the number of active gins has declined, while the capacity of the remaining facilities has expanded. The percent of bales that are moduled has increased significantly since the module builder was introduced in 1974 (Supak, 1996).

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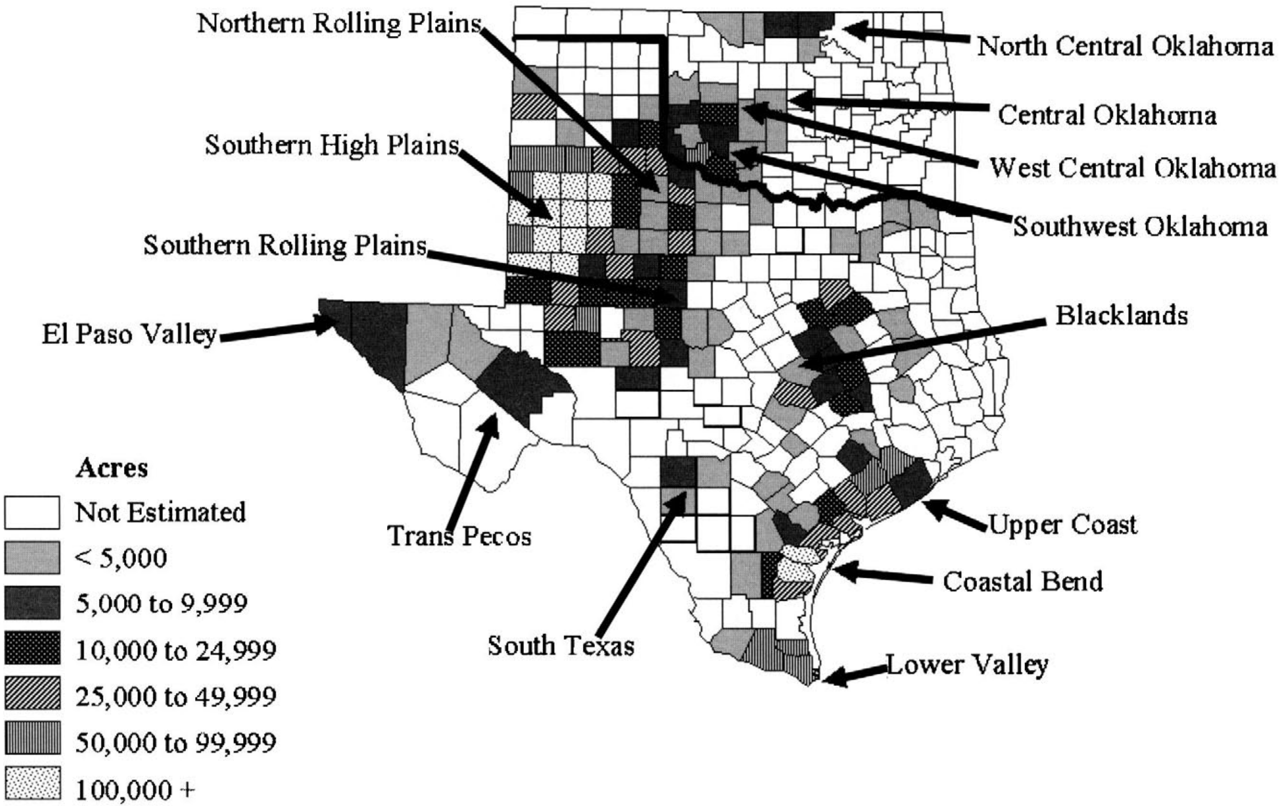
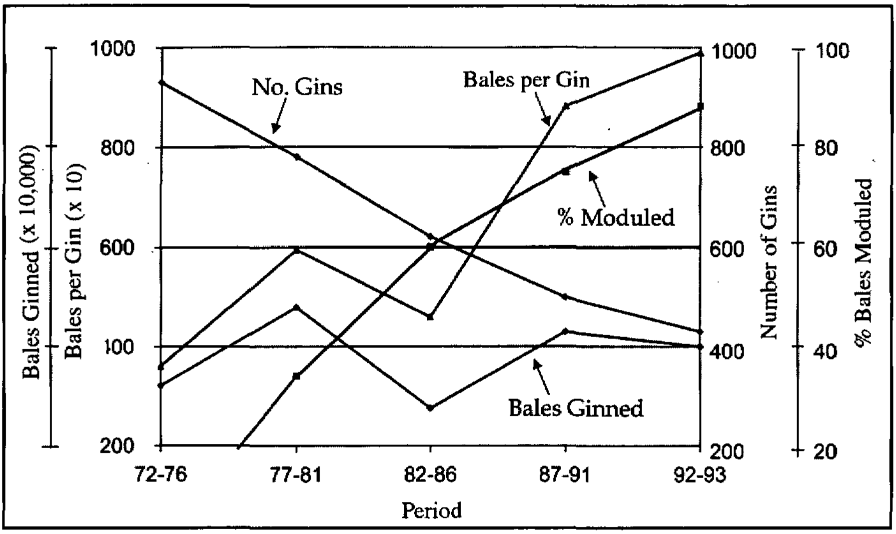
[1] Members of the Southwest team who participated in the Cotton Defoliation Work Group project included Tom Cothren, Texas A&M University at College Station; Wayne Keeling, Texas Agricultural Experiment Station at Lubbock; J.C. Banks, Oklahoma Cooperative Extension Service at Altus; and John Bremer and James Supak, Texas Agricultural Extension Service at Corpus Christi and College Station, respectively.



Source: Adapted from USDA National Agricultural Statistics Service, 2000.

Figure 1. Acres of upland cotton harvested by county in Texas and Oklahoma during 2000.



Source: Supak, 1996.

Figure 2. Cotton production and ginning trends in Texas, 1972-1993.

Early acceptance of high-volume instrument (HVI) fiber testing by Southwest growers stimulated a strong emphasis on producing and maintaining fiber quality. This led to the adoption of varieties that produce better-quality fibers and also helped expand and optimize the use of harvest aids.

Since the adoption of mechanical harvesters in the 1950s and 1960s, cotton harvest aids have been used extensively in the southern and central sections of the Southwest. But prior to the mid 1980s, growers in the High and Rolling Plains of Texas and portions of Oklahoma tended to rely as much or more on freezing temperatures (typically in early November) as on harvest aids to condition crops for mechanical harvest.

Since then, the emphasis on preservation of yield, lint and seed quality, management of insect pests, and other considerations has led to more widespread use of cotton harvest aids in the northern sections of the Southwest. Throughout the region, growers also have become more knowledgeable and conscientious about properly using and timing harvest-aid applications to minimize reductions in yield or quality and to use these products in a safe and environmentally conscientious manner.

ENVIRONMENTAL CONSIDERATIONS

Water – The primary factor limiting cotton production in the Southwest is water. Annual rainfall varies from 40 inches or more in the Upper Gulf Coast of Texas, to 15 or 20 inches on the Plains, to less than 10 inches in the Far West (Dugas, 1983). Only 35 to 40 percent of Texas cotton acreage is irrigated. Because both underground and surface water resources are limited, most irrigation water is used strictly to supplement rainfall; in drier years, crop water requirements may not be met fully, even with the combined utilization of rainfall and irrigation water.

Seasonal rainfall patterns vary substantially, but the probability of receiving precipitation at some point during the harvest season is relatively high throughout the Southwest. In the southern areas, late rains often are associated with tropical storms and hurricanes in the Gulf of Mexico. Rains disrupt harvest activities, but the storms also can cause extensive damage if they make landfall in the cotton production areas.

Temperature is another important variable that heavily influences cotton growth and development, especially in the Southwest. Heat unit (DD60) accumulations during the typical growing season range from more than 2600 in southern Texas to less than 2000 in the northern portions of Texas and Oklahoma (Dugas and Heuer, 1984). The southern and central sections have the longer growing season; but, high temperatures, coupled with dry conditions that typically occur during the bloom period, often create stress conditions that contribute to early cutout, excessive fruit shed, toughening of leaves, and high potential for regrowth should late-season rains occur. In contrast, the growing season is much shorter in the northern areas; low nighttime temperatures, which slow boll maturation, are more likely to be a concern during the latter stages of boll development.

Such variations in temperatures and crop conditions are important considerations in the selection and use of the most appropriate harvest-aid options for the area and the season. For example, Dropp® frequently is used to defoliate cotton in southern Texas (from the Rio Grande Valley to the southern Blacklands/Brazos River Valley), but rarely is used alone in the central and northern regions, where both maximum and minimum temperatures tend to be lower during the defoliation season. Results of trials conducted near College Station in 1995 show that Dropp, used alone, provided good defoliation and some regrowth suppression; the test showed no advantage from using a tank mix of Dropp + Prep™ (Table 1). In a similar test conducted at Prosper, Texas (200 miles north of College Station), Dropp alone resulted in very poor defoliation, whereas the combination of Dropp + Prep was among the better treatments seven days after application (Table 2). In contrast, Ginstar® exhibited less temperature sensitivity than other defoliants and provided levels of defoliation comparable to the best treatments in "Uniform Harvest Aid Performance and Quality Evaluation Trials" (Table 3).

CROP YIELD POTENTIAL

Potential crop yields and quality also are important considerations in the selection of harvest-aid programs in the Southwest, where yields in a given year may range from less than 0.25 bale per acre to more than 2.5 bales per acre. Because so many factors – water (rainfall and irrigation), length of growing season, seasonal growing conditions, pest pressures, and management, etc. – have a significant impact on yield potential in any given year, harvest-aid programs have to be specifically adjusted for each area and even for individual farms (Stichler *et al.*, 1995).

Harvesting cotton as soon as practical after all harvestable bolls are open minimizes the potential for weather-related deterioration of yield and quality. If properly used, defoliants, boll openers, and desiccants can prepare crops for earlier harvest with no detrimental effects on yield or quality. Defoliation removes leaves and thus can contribute to better leaf grades by reducing the trash content in the fiber, even in stripper-harvested cotton. The use of boll openers (ethephon) can accelerate opening of mature bolls and lead to earlier harvest. Frequently, a combination of treatments, including both a defoliant and a boll opener, is more effective than a single product in preparing cotton for harvest, by both increasing and accelerating the rate of boll opening and defoliation. Desiccants often are needed to dry leaves and other plant tissues to allow stripper harvesting.

The potential gains from the harvest-aid program are dependent on cost and crop yield potential as well as efficacy. Anderson (1995) illustrates the relationship between yields and harvest-aid costs in Table 4, with the premise that chemical and application costs are limited to $0.05 per pound of lint produced. His analysis shows that as much as $30 per acre could be expended

Table 1. Defoliation and regrowth suppression obtained in 1995 with core treatments at College Station, Texas.

Treatment	**Rate (per acre)**	**Defoliation (%)**		**Terminal Regrowth (%)**
		7 DAT	**14 DAT**	
Untreated Check	—	29	54	100
Folex®/Def®	1.5 pt	50	71	100
Dropp®	0.2 lb	83	87	44
Harvade® + COC	0.5 pt 1.0 pt	45	65	100
Harvade + Prep™ + COC	0.4 pt 1.3 pt 1.0 pt	59	70	100
Folex/Def + Prep	0.75 pt 1.3 pt	62	74	97
Dropp + Prep	0.1 lb 1.3 pt	71	80	91

Source: Anonymous, 1999.

Table 2. Defoliation, desiccation, and regrowth suppression obtained in 1995 with core treatments at Prosper, Texas.

Treatment[1]	**Rate (per acre)**	**Defoliation (%)**		**Defoliation + Desiccation (%)**	**Basal Regrowth (%)**
		7 DAT	**14 DAT**	**14 DAT**	**21 DAT**
Untreated Check	-	4	5	100	6
Folex®/Def®	1.5 pt	40	48	100	9
Dropp®	0.2 lb	9	13	96	11
Harvade® + COC	0.5 pt 1.0 pt	21	21	99	12
Harvade + Prep™ + COC	0.4 pt 1.3 pt 1.0 pt	37	35	99	13
Folex/Def + Prep	0.75 pt 1.3 pt	56	77	100	11
Dropp + Prep	0.1 lb 1.3 pt	49	61	99	12

Source: Anonymous, 1999.

[1] Followed by 2.0 pints Cyclone® at five to seven DAT.

Table 3. Defoliation and regrowth suppression obtained in 1995 with "best" core treatment and with Ginstar®.

Treatment	Rate (per acre)	Defoliation (%)		Terminal Regrowth (%)
		7 DAT	14 DAT	
Weslaco, Texas				
Dropp®+ Prep™	0.1 lb 1.3 pt	63	52	
Ginstar®	0.5 pt	78	82	
College Station, Texas				
Dropp	0.2 lb	83	87	44
Ginstar	0.5 pt	83	93	24
Prosper, Texas[1]				
Folex®+ Prep	0.75 pt 1.30 pt	56	77	0
Ginstar	0.50 pt	62	90	0
Lubbock, Texas[1]				
Folex + Prep	0.75 pt 1.30 pt	79	93	0
Ginstar	0.50 pt	67	93	0

Source: Anonymous, 1999.

[1] Followed by 2.0 pints Cyclone® at five to seven DAT.

Table 4. Harvest-aid chemical and application costs per pound of lint produced for five yield levels.

Cost ($ per acre)	Yield (lb per acre)				
	200	300	400	500	600
	¢ per lb of lint produced				
10	5.00	3.33	2.50	2.00	1.67
15	7.50	5.00	3.75	3.00	2.50
20	10.00	6.67	5.00	4.00	3.33
25	12.50	8.33	6.25	5.00	4.17
30	15.00	10.00	7.50	6.00	5.00

Source: Anderson, 1995.

in fields with yield potential of 600 pounds per acre, but only $10 per acre could be spent in fields yielding only 200 pounds per acre. In the latter case, harvest-aid options would be determined largely by the cost of achieving the level of defoliation or desiccation needed for efficient harvest and safe field storage, and less by the desire to accelerate boll opening and eliminate potential sources of fiber contaminants.

HARVEST METHODS

The Southwest is somewhat unique in that both spindle picking and stripping are used widely to harvest cotton. Data compiled by the Commodity Economics Division, ERS, USDA, shows that approximately 71 percent and 72 percent of the bales harvested in Texas and Oklahoma, respectively, during the period 1993-1994 were stripper-harvested (Anonymous, 1996).

Stripper harvesters have several advantages, including lower equipment purchase and operating costs, higher harvesting capacity, and the capability to efficiently harvest short-stature, low-yielding crops. A disadvantage is that stripping is a once-over harvest method that collects more trash (leaves, burs, and fragments of limbs) than spindle picking. Consequently, stripped cotton requires more cleaning at the gin, entails higher ginning costs, and frequently results in reduced leaf grades because of contaminants embedded in the lint. Additionally, preparation of cotton for once-over stripper harvesting requires that all harvestable bolls are open and that the crop is desiccated either with chemicals or by a killing freeze. This ensures that the moisture content of stripped cotton is less than 12 percent, minimizing the possibility of heating during field storage in modules or trailers.

In contrast, the primary requirements for preparing cotton for spindle picking are boll opening and defoliation. Boll openers may be used in conjunction with defoliants to prepare cotton for once-over picker harvest.

Often the factors that determine choice of harvest method include crop yield potential, harvest-aid costs, seasonal conditions, plant size and condition, acres to be harvested, and equipment availability. Of these, yield potential may be the most important. Results of field trials indicate that spindle picking becomes an economically viable option when yields reach or exceed approximately one bale per acre (Anderson, 1995).

COMMON HARVEST-AID PRACTICES

Selection of the most effective harvest-aid treatment(s) varies somewhat by year, by region, and even by community. Growers and consultants are encouraged to review the most current harvest-aid guidelines developed by local Extension and research personnel and by industry to identify treatments, especially those involving tankmix combinations, recommended for specific areas. The following general recommendations are based on harvest method and apply to the Southwest region.

STRIPPER HARVEST

Producers typically have three basic options to consider in preparing cotton for stripper harvesting. These include: 1) use of only a desiccant (currently, paraquat is the primary material registered for this use) as a single treatment or in sequential applications; 2) application of a defoliant (or tankmix combination of two or more defoliants) followed by a desiccant; or, 3) application of a defoliant + boll opener tankmix combination followed by a desiccant.

The single application of a desiccant (paraquat) is most applicable for use on short-stature cotton with limited yield potential. Typically, this treatment results in very little defoliation (20 percent or less) but provides adequate desiccation of leaves and other plant tissues. The use of sequential applications of the desiccant (e.g., 0.125 pound a.i. per acre of paraquat at 60 to 70 percent open bolls, followed by 0.375 pound a.i. per acre five to seven days later) is a lower-cost alternative to option 2, above, and primarily is applicable in the northern regions of the Southwest. The low rate of paraquat in the sequential treatment results in some defoliation (usually 40 to 60 percent) and conditions the crop for more complete desiccation with the second treatment.

The desiccating effects of paraquat are the result of a light-activated reaction that produces superoxide radicals that rupture plant cell membranes. Limited paraquat penetration into stressed, toughened leaves under sunny conditions results in rapid death of tissues in the immediate vicinity of droplet deposition, eliminating potential for further translocation. Studies have confirmed that late-afternoon and early-evening applications result in better desiccation than morning or midday treatments (Bremer, 1995; Biles and Cothren, 1996).

With option 2, defoliation prior to desiccation removes most leaves and also conditions the crop for more complete desiccation with the second (desiccant) treatment. Removal of most leaves reduces the amount of trash in the harvested cotton, which can contribute to better leaf and, possibly, color grades. Tank-mixing a boll opener with the defoliant (option 3) hastens the opening of mature bolls and may further improve defoliation.

In situations where the treatments (options 2 and 3) remove 95 percent or more of the leaves, it may be possible to strip the crop without applying the desiccant treatment. Also, in the northern sections, only the initial treatment (no desiccant) may be applied and used as a means of conditioning the crop for a killing freeze. The use of harvest aids prior to a hard freeze can speed defoliation, allow more mature (or nearly mature) bolls to open, and, ultimately, result in earlier harvest.

PICKER HARVEST

In most instances, a single application of a proven defoliant or defoliant tank-mix combination is sufficient to prepare cotton for spindle picking. Fields with tall, rank cotton may warrant sequential applications of defoliants to induce sufficient leaf shedding to minimize green leaf fragments and lint staining during harvest. Preparation of cotton for once-over harvest with pickers also can be accomplished with a single tankmix application of a defoliant + boll opener, especially in high-yielding cotton and in areas where cooler temperatures occur at the time of defoliation. In fields with tall, often-lodged plants and dense foliage, a defoliation treatment followed by subsequent application of a boll opener + defoliant may be needed to prepare cotton for once-over picking.

Typically, desiccants are not used in preparing cotton for spindle-type harvest. Occasionally, however, low rates of paraquat are mixed with a defoliant to enhance leaf shedding. Full labeled rates of paraquat alone or in combination with other harvest aids also may be used to desiccate weeds and remaining cotton leaves that otherwise would interfere with harvesting operations.

REGROWTH CONTROL

Control of regrowth may be a consideration in fields intended for either picker or stripper harvest, especially in the southern regions of Texas. Some defoliants (e.g., Dropp, Ginstar) will suppress regrowth, but only for limited periods (two weeks or less in South Texas). Landivar *et al.* (1994) have shown that relatively low rates of Roundup® (0.375 to 0.5 pound a.i. per acre) applied at approximately 40 percent open bolls to conventional (not Roundup Ready®) cotton provided extended regrowth control (55 days or more) with no adverse effects on yield or quality. Applying Roundup in combination with defoliants also can be effective in suppressing regrowth, but requires higher rates of the herbicide and does not impart defoliation activity. This combination treatment is less effective in heavily drought-stressed cotton and can result in decreased levels of defoliation (compared to a defoliant-only treatment).

REGIONAL TRIALS

Uniform cotton harvest-aid field trails were conducted at five locations in the Southwest region during the period 1992-1996 (Figure 3). Test plots at Weslaco, Texas (Rio Grande Valley), and College Station, Texas (Brazos River Valley), were picker-harvested, whereas those located at Prosper, Texas (northern Blacklands), Lubbock, Texas (Southern High Plains), and Altus, Oklahoma (Southwest Oklahoma), were stripper-harvested. Standard production

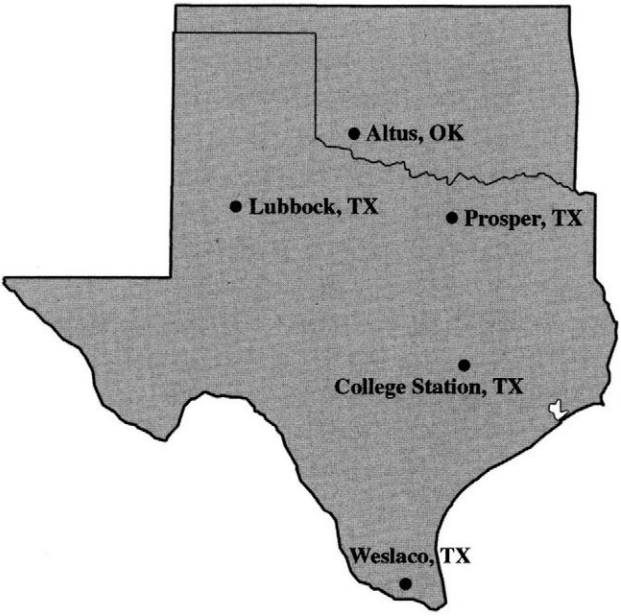


Figure 3. Southwest cotton harvest-aid study locations.

and pest management practices were used at all test locations. Cotton at Prosper was grown under dryland conditions, whereas irrigation was used at the other locations. Common treatments (which included seven core and five to seven regional standards) and standardized application timings and rating procedures were used at all locations. Geographically, the picker tests were located in the southern end of the Southwest region, whereas the stripper trials were more in the northern sections. In the stripper tests, all plots were treated with a desiccant (paraquat) five to seven days before harvest; only designated plots were desiccated at the picker test sites.

Core treatments remained constant, while the regional standards (Table 5) were modified three times during the five-year study. The regional treatments noted in Table 5 were those used during the last two years of the study. A

Table 5. Core and regional harvest-aid treatments used in the stripper-harvested trials in the Southwest region, 1992-1996.[1]

Core Treatments:
Untreated Check[2]
Folex®/Def®(1.5 pt per acre)[2]
Dropp® (0.2 lb per acre)[2]
Harvade® + Agri-Dex® (0.5 + 1.0 pt per acre)[2]
Harvade + Agri-Dex + Prep™(0.4 + 1.0 + 1.33 pt per acre)[2]
Folex/Def + Prep (0.75 + 1.33 pt per acre)[2]
Dropp + Prep (0.1 lb + 1.33 pt per acre)[2]
Regional Treatments:
Cyclone® + NIS (0.5 pt per acre + 0.25% v/v) followed by Cyclone + NIS (0.5 pt per acre + 0.25% v/v)
Folex/Def or Dropp (1.5 pt per acre or 0.2 lb per acre followed by glufosinate-ammonium (0.5 lb a.i. per acre)[2]
Ginstar® (0.5 pt per acre)[2]
Folex/Def + Dropp (0.75 pt + 0.1 lb per acre)[2]
Folex/Def + Roundup® (1.5 + 1.0 pt per acre)[2]
Prep (1.33 pt per acre)[2]
Ginstar + Prep (0.4 pt + 1.33 pt per acre)[2]

Source: Anonymous, 1999.

[1] Regional standard treatments varied slightly among the five test locations. These variations are noted in the summary report (Anonymous, 1999).

[2] In stripper-harvest tests, all plots were treated with Cyclone® + NIS (non-ionic surfactant) (2.0 pints per acre + 0.25% v/v) five to seven days after the initial harvest-aid application.

regional summary for the picker and stripper trials follows. The harvest-aid efficacy, fiber quality, and yield data collected during the course of this study are too extensive to be included in this chapter, but are contained in the overall project summary report (Anonymous, 1999). In addition, the harvest-aid evaluation results from these and other trials have been extensively used to develop cotton harvest-aid recommendations for specific areas within the Southwest region and are, for the most part, updated annually (e.g., Banks and Kelley, 1998; Boman et al., 1999; Bremer, 1997; Lemon et al., 1999).

PICKER TRIALS

Of the seven core treatments, Dropp was the most consistent and received the highest Performance Index (PI) ratings at 7 days after treatment (DAT) at both picker-harvested test locations. The average PI ratings consistently were above 80 and 70 at College Station and Weslaco, respectively. At College Station, PI ratings also were above 80 for Ginstar and for all treatments containing Dropp in tank mixes with other products. At Weslaco, Ginstar and Ginstar tank-mixed with Prep were the best treatments based on PI scores, which typically were 70 or higher.

At 14 DAT, Dropp had the highest PI ratings of all the core treatments at both College Station and Weslaco (multiyear averages of 90 and 81, respectively). With the exception of Prep, all regional treatments averaged PI ratings of 85 or higher at College Station. A similar trend was observed at Weslaco, with average PI ratings of 70 or higher for the better treatments. While acceptable PI ratings were recorded for the treatments that included Cyclone® (paraquat), as much as 15 percent desiccation was noted in those plots at both locations.

At College Station, Dropp was the only core treatment to provide defoliation ratings above 70 percent in all five years at seven DAT. Dropp also was the best defoliation treatment at Weslaco, with an average rating of 68 percent; but, on a year-by-year basis, defoliation ranged from 46 percent in 1995 to 94 percent in 1994. At both College Station and Weslaco, Ginstar was the only regional standard treatment that resulted in 85 percent or more defoliation at seven DAT.

Dropp and Dropp + Prep, with defoliation ratings of 75 percent and 74 percent, respectively, were the best core defoliation treatments in Weslaco at 14 DAT. In contrast, at College Station, all core treatments received defoliation ratings between 82 and 89 percent. In the regional standard treatments, the follow-up desiccant application at five to seven days after the initial treatment resulted in defoliation levels ranging from 84 to 95 percent at both locations.

Overall, tank mixes that included defoliants + Prep did not consistently improve boll opening over that achieved with the defoliant-only treatment at 7 DAT or 14 DAT at either location. None of the treatments had an impact on lint yield or fiber quality at either location.

STRIPPER TRIALS

Of the seven core treatments evaluated, Folex® generally was more effective than Dropp with regard to overall Performance Index and percent defoliation at seven DAT at all locations. At Lubbock and Altus, the PI for the Harvade® treatment was approximately the same as that of Folex, whereas, at Prosper, Harvade and Dropp received lower PI and defoliation ratings than Folex. The Folex + Dropp treatment was consistently more effective than either defoliant used alone at all locations. Applying Prep in combination with defoliants (Dropp, Folex, or Harvade) improved PI and defoliation ratings over those obtained with only the defoliants. The Folex + Prep combination was the best overall core treatment at Prosper and Lubbock, whereas all three defoliant + Prep treatments received similar PI and defoliation ratings in Oklahoma. The use of Prep in combination with the respective defoliants tended to increase boll opening at seven DAT, but the improvements generally were not statistically significant.

At 14 DAT, ratings reflected the effect of the defoliants + boll opener and of the desiccant (Cyclone) that was applied five to seven days after the initial treatment. Among the seven core treatments, the highest PIs and best defoliation ratings at all locations were achieved with the defoliant + Prep combinations. Of the regional standards, Ginstar and Ginstar + Prep received the highest PI and percent defoliation ratings during the 1995-1996 testing period (the only years the treatments were included in the study). Overall, Ginstar tended to be more effective than the other defoliants; Prep combined with Ginstar did not further improve PI ratings, percent defoliation, or percent boll opening. The Folex + Dropp combination treatment provided better defoliation than either product used alone at all locations. At 14 DAT, split applications of Cyclone resulted in 40 percent and 80 percent defoliation, whereas single application (0.5 pound a.i.

per acre) resulted in only 6 percent and 30 percent defoliation at Prosper and Lubbock, respectively. The split application of Cyclone also provided better desiccation than the single (0.5 pound a.i. per acre) application.

Terminal regrowth rarely exceeded 20 percent and was not regarded as a serious problem in most years. In contrast, basal regrowth was an every-year occurrence and ranged from 50 to 100 percent in most test plots by 21 DAT. Plants treated by Prep, defoliant + Prep, and Cyclone followed by Cyclone consistently were among the first to develop new leaves and generally had the most extensive new foliage. A tankmix treatment of defoliant + Roundup followed by Cyclone was the most effective in suppressing both basal and terminal regrowth. Also, treatments that contained Dropp (alone or in combination with Prep or another defoliant) provided some suppression of terminal regrowth. Ginstar was notably less consistent than Dropp in suppressing development of new leaves, but generally was more effective than the other defoliants.

Harvest-aid treatments had little or no effect on yield or lint quality at any location in any given year even though pronounced differences in overall performance, defoliation, and desiccation ratings were noted among treatments. On occasion (usually in conjunction with prolonged wet conditions during the crop termination-harvest period), poor grades and high levels of leaf trash were observed in all lint samples from a given test location. Leaf grade and trash parameters exhibited surprisingly little variation, even though there were pronounced differences in PI and in defoliation and desiccation ratings from treatment to treatment.

Although plots were machine-harvested to simulate farm conditions, the harvested cotton was loosely packed and stored in paper, cotton, or burlap bags; thus, these conditions were not representative of those inside trailers or tightly packed modules. Subsequent ginning and lint cleaning undoubtedly helped normalize variations in trash content (just as occurs at commercial gins). Nevertheless, the failure of the varied harvest treatments to affect leaf grades and trash content in the lint, coupled with little variation in fiber quality parameters at a given location (but often with considerable variation among locations), suggests that environmental conditions have a major influence on how much foreign matter ultimately ends up in the lint.

These observations suggest that good desiccation is by far more critical than defoliation in preparing cotton for stripper harvesting.

SUMMARY

The primary reason for using harvest aids is to increase grower profits. This objective is achieved by enabling growers to harvest their crops in a timely manner, which allows them to better schedule harvest equipment and labor. This also improves harvesting and ginning efficiencies and reduces the risk of heat and microbial damage to fiber and seed during field storage. Producers have a range of harvest-aid options. The most appropriate, cost-effective option for each producer's operation largely will be determined by the production region, environmental conditions, crop yield potential, and harvest method. Additional data are needed to establish how much defoliation is economically justifiable, especially in stripper areas. Results from the Uniform Harvest Aid Performance and Fiber Quality Evaluation trials in the Southwest region (Anonymous, 1999) indicate that defoliation may have a relatively small effect on leaf grades and HVI trash content.

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FAR WEST[1]

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OVERVIEW

The Far West Region of the United States Cotton Belt includes California, Arizona, and portions of New Mexico. In New Mexico, the production of Pima cotton and of the Acala™ varieties developed for that state are concentrated in the El Paso Valley. The predominant portion (70 percent) of Arizona's production is located in Maricopa and Pinal Counties, with additional acreage in the Parker, Yuma, and Safford areas. California's 1995 cotton production – 1.3 million acres – predominately was concentrated in six counties of the southern San Joaquin Valley. This acreage represents 97 percent of California's total production. The other areas of production are Imperial and Riverside Counties and, more recently, acreage planted in the Sacramento Valley (Anonymous, 1995). In addition, a significant percentage of U.S. Pima is produced in this two-state region.

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[1] Members of the Far West team who participated in the Cotton Defoliation Work Group project were from the University of California Cooperative Extension Service, including Gerardo Banuelos, Brett Allen, and Steve Wright, Tulare County; Joe Padilla and Bruce Roberts, Kings County; and Tome Martin-Duvall and Ron Vargas, Madera County.

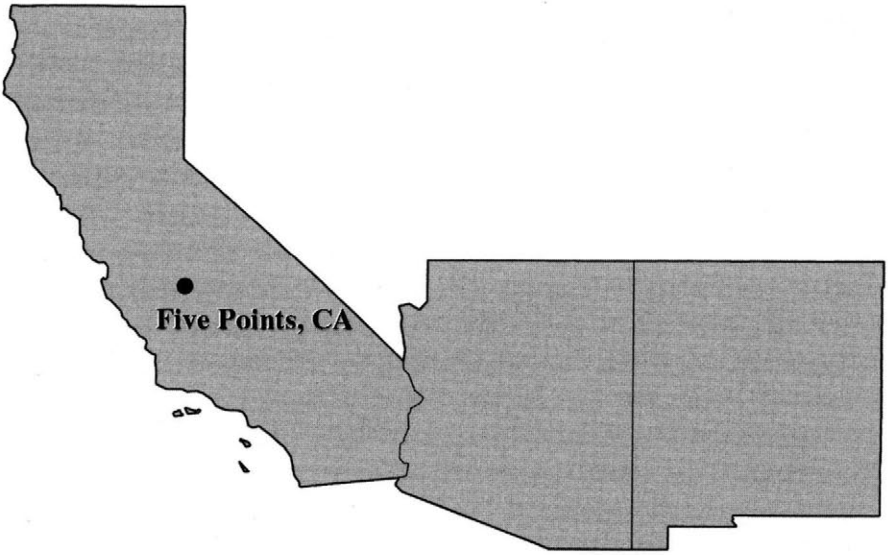

Figure 1. Far West cotton harvest-aid study location.

The Far West's cotton production is characterized by a hot, arid growing season; the entire acreage is irrigated. This lends some advantage in preparing the crop for defoliation because of greater control of soil moisture and nitrogen by terminating irrigation. The low desert areas of both Arizona and California experience a monsoon period with elevated humidity during late July, extending through August. Following this humid period, weather in both states is ideal for defoliation. Temperatures usually are above 80 F well into October.

Harvest of the Far West crop is performed with spindle-type harvesters (Roberts *et al.*, 1996). Therefore, defoliation practices play an important pre-harvest role. Although similar materials are used in both Arizona and California, recommended rates differ in each area. Combinations of materials and application methods vary from farm to farm.

Normal defoliation usually requires two applications: The first may be a treatment of ethephon or ethephon in combination with a phosphate defoliant (Folex®/Def®). Sodium chlorate is used extensively for cleanup applications. Additives like paraquat and cacodylic acid are included to enhance the desiccation of remaining leaves. Ginstar® provided the highest percent defoliation from a single application. (Wright *et al.*, 2000; Hutmacher *et al.*, 2001).

The trends in harvesting, storage, and ginning of seed cotton described in other regions are very evident in the Far West. The shift to using modules for field storage and seed cotton handling has increased. More than 80 percent of the entire region's harvested cotton is moduled (Glade *et al.*, 1995). The convenience and economics of this handling system also have led to many changes at the processing level.

The number of active gins in both Arizona and California has decreased by 40 percent during the past 10 years. Although acreage has remained relatively constant, the decreasing number of active gins has been offset by a 40-percent increase in ginning capacity during this same period (Glade *et al.*, 1995).

The current harvesting and handling system using modules has allowed cotton growers to take advantage of other production changes that have led to greater benefits from earliness and helped preserve fiber quality. This system also places greater emphasis on pre-harvest preparation and timely harvest of well-defoliated cotton for safe storage and handling (Curley *et al.*, 1988).

The results of a standard set of treatments in the San Joaquin Valley clearly indicate that rate adjustments are necessary for adequate defoliation. Treatments that produced 80 percent or greater leaf drop in other regions had only minor effect (30 percent or less) in the San Joaquin Valley. These same treatments produced acceptable defoliation in the desert areas of California and Arizona.

One cause of this difference is the *Verticilium* wilt-tolerant Acala varieties grown in the San Joaquin Valley. Results of a "variety by defoliation" trial conducted at the University of California West Side Research and Extension Center are presented in Table 1. In this comparison, the higher-wilt-tolerant Acala varieties were much less affected by two applications of sodium chlorate than less-wilt-tolerant varieties.

ENVIRONMENTAL CONSIDERATIONS

Western pre-harvest and harvest practices have been criticized for their impact on air quality. The production areas of this region are located in fertile valleys that are experiencing significant urban growth. These valleys ("closed air" basins) are becoming more aware of the various activities that affect air quality; environmental and regulatory interest is increasing.

Besides urban encroachment, the cropping rotations within this region offer an additional challenge in managing cotton defoliation. Late-summer and fall vegetables are important alternate crops that are actively growing when cotton is being defoliated. Nontarget drift of cotton defoliants onto an adjacent field of leafy vegetables can be costly.

An important objective for cotton defoliation in the Far West is to continue to emphasize crop monitoring for effective late-season management that enhances defoliation. The crop requires good water and nitrogen management from cutout to termination and defoliation. Producers must continue screening for new materials or combinations that improve crop defoliation and harvestability. From this effort, environmentally acceptable practices will be available to assist western cotton growers to harvest, store, and deliver to the gin the highest-quality seed cotton.

Table 1. Defoliation comparison for Acala™ varieties – 1992.[1]

Variety	*Verticillium* wilt rating	% Defoliation (14 DAT)
Maxxa	High	43
GC-510	High	25
DP6166	High	38
SJ-2	Mod	60
DP6100	Low	78
DP90[2]	Low	90

Source: Roberts, 1996.

[1] Defoliated with sodium chlorate (4.5 pounds a.i. per acre) on Sept. 28 and Oct. 9.

[2] DP90 is not approved for San Joaquin Valley production.

CALIFORNIA HARVEST-AID PRACTICES AND PERFORMANCE

Defoliation of upland Acalas grown in the California's San Joaquin Valley is accomplished by using two applications of harvest-aid materials. Standard practices include applications of Prep™, combinations of chemical defoliants with Prep, or defoliants alone as first treatments applied at the recommended stage of maturity (i.e., nodes above cracked boll). This initial treatment is followed by a second application of harvest-aid materials to assist the further defoliation and complete desiccation of remaining leaves. Although a single application would be desirable, the norm for this production region of California is two applications of harvest-aid materials.

In 1992, a five-year study was initiated to uniformly assess various defoliation treatments across the U.S. Cotton Belt. An objective of the "Beltwide Harvest Aid Performance and Fiber Quality Evaluation" was to test a set of uniform core treatments across a range of climatic conditions and production practices.

After the first year of this Beltwide study, the efforts were expanded to include a Far West region. California's San Joaquin Valley was selected to represent this region; it was added to the study in 1993. The arid climate and high *Verticillium* wilt-tolerant Acala varieties grown in this area contributed to the diversity of locations for the Beltwide study. Because of these regional differences, California's standard core treatments have not performed as well as treatments in the other regional locations.

MATERIALS AND METHODS

The trials were conducted from 1993 to 1996 at the University of California Research and Extension Center, Five Points, California. The soil type was a Panoche clay loam. Standard regional cultural practices and recommended pest-management procedures were followed to ensure normal crop growth. Yearly planting, treatment, and harvest dates, along with other agronomic information, are shown in Table 2. Plots were four 40-inch rows, 60 to 65 feet long.

Variety selection was based on grower preference and valley-wide acreage. In 1993, Acala GC-510 was the predominant variety planted in the San Joaquin Valley. From 1994 to 1996, Acala Maxxa was used in the study, because this variety was planted in more than 65 percent of the San Joaquin Valley acreage.

Defoliation treatments were applied with a modified Hagie 470 "High Cycle" applicator. The treatments were applied with a broadcast boom (TXV 10, hollow cones) with nozzle spacing of 20 inches. Harvest-aid materials were applied with 20 gallons per acre water at a pressure of 55 psi. One pint of Agri-Dex® per acre was added to all treatments that had a surfactant as part of the manufacturer's recommendation.

Evaluations for performance, defoliation, desiccation, and open bolls were conducted at 7 and 14 days after treatment (DAT). Terminal and basal regrowth was determined as defined in the standardized protocol, between 21 DAT to 28 DAT. Plots were harvested after 14 DAT with a John Deere® 9910 two-row spindle-type picker modified for plot harvest. Seed cotton was harvested from the two center rows of each plot. Plot yields were recorded and samples collected for percent lint and fiber quality (High-Volume Instrumentation) and spun-fabric evaluations.

Table 2. California planting, treatment, and harvest dates, and percent open bolls at treatment, 1993-1996.

Dates	1993	1994	1995	1996
Planting	4/7	4/5	4/10	4/4
Treatment	9/20	9/12	9/27	9/19
Harvest	10/21	10/10	10/18	10/8
Crop Condition at Treatment				
Open bolls (%)	65	55	55	55

Source: Anonymous, 1999.

RESULTS AND DISCUSSION

PERFORMANCE INDEX

Performance Index (PI) is an overall evaluation of the effectiveness of a treatment, including defoliation, boll opening, regrowth, desiccation, and leaf sticking, on a 0 to 100 scale. PI of the standard core treatments varied from year to year. In general, the core treatments were less effective than the recommended "western" application rate of the same materials. Because the differences among core treatments was so subtle, no efforts were made to discriminate between PI and defoliation ratings. Therefore, for the Far West region, defoliation ratings only reflect overall performance of the various treatments.

Evaluation ratings are from the 14 DAT observations if not otherwise noted.

DEFOLIATION

Defoliation ratings were based on visual evaluations of "leaf drop." The values are expressed as a percent of leaves present at time of application that were removed by the treatment. Although ratings were recorded at both 7 DAT and 14 DAT, the only data presented are from 14 DAT. This information is presented in Table 3.

Table 3. Percent defoliation at 14 days after treatment – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	4	0	4	0	2
Folex® @ 1.5 pt	50	38	26	14	32
Dropp® @ 0.2 lb	8	14	11	9	11
Harvade® @ 8.0 pt	32	35	6	3	19
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	17	12	11	4	11
Folex @ 0.75 pt + Prep @ 1.33 pt	42	10	37	17	26
Dropp @ 0.1 lb + Prep @ 1.33 pt	17	21	13	8	15
Folex @ 2.0 pt + Prep @ 2.0 pt		69	54	22	51
LSD ($p<0.05$)	9.934	8.987	8.114	7.577	

Source: Anonymous, 1999.

In 1993, the Folex treatments (Folex alone at 1.5 pints per acre and a combination of Folex and Prep at 0.75 and 1.33 pints per acre, respectively) performed better than the other core treatments. The highest level of defoliation achieved at the 14 DAT evaluation was only 50 percent. The 1993 trial, using Acala GC-510, was the only time the core Folex treatments performed as well as a standard treatment. After shifting to Acala Maxxa in 1994, the core Folex treatments (Folex alone and in combination with Prep) produced, on average, half the leaf drop of the higher "western" rates of Folex and Prep.

Defoliation performance results from 1996 are low – even for the higher regional rates. An extreme heat spell through August is thought to have produced a late-season canopy of leaves with a thicker cuticle layer. This was noticed in the overall lower performance of all harvest-aid treatments throughout the San Joaquin Valley during this season.

The Folex + Prep combination (2 pints per acre of each product) in 1994 was the only treatment during this study that would have received no additional cleanup application prior to harvest under standard grower practices.

DESICCATION

Desiccation values are visual evaluations of percent of total remaining leaves on the plant that are damaged or desiccated as a result of the treatment. The data use a relative scale of 0 to 100, where 0 equals no remaining desiccated leaves and 100 indicates all leaves remaining on the plant are desiccated. This information is presented in Table 4. This parameter is significant for a harvest system, because it relates to the potential amount of green leaf material that could be harvested with the seed cotton. Green leaf trash adds to the overall moisture content of the harvested seed cotton and can result in storage problems once moduled.

Although there were differences among the various treatments, final desiccation values at 14 DAT all were relatively low. When these values are combined with the overall low defoliation at 14 DAT, the results for the standard core treatments reflect poorly defoliated and "green" fields.

Table 4. Percent desiccation at 14 days after treatment – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	2	0	1	0	1
Folex® @ 1.5 pt	30	12	12	16	18
Dropp® @ 0.2 lb	5	8	7	10	7
Harvade® @ 8.0 oz	25	12	2	4	11
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	12	5	5	3	6
Folex @ 0.75 pt + Prep @ 1.33 pt	20	8	9	14	12
Dropp @ 0.1 lb + Prep @ 1.33 pt	8	12	5	10	9
Folex @ 2.0 pt + Prep @ 2.0 pt		11	12	22	15
LSD (p<0.05)	11.461	6.142	4.136	5.805	

Source: Anonymous, 1999.

BOLL OPENING

Boll opening was determined by counting total bolls and open bolls in 1 meter of row. This value is represented as Percent Open Bolls (Table 5). With the exception of the 1996 results and a few treatments in 1995, defoliation treatments resulted in significantly greater boll opening than the untreated control. At 14 DAT, the Harvade® treatments performed as well as the Prep combinations. Dropp® alone was the least effective at opening bolls. Overall, even slight defoliation enhanced boll opening.

Most of the core treatments produced satisfactory boll opening each year of the study, reflecting the seasonal management and climatic conditions of this trial location. Pests were controlled to maintain good top boll retention; the final irrigation was scheduled to allow the top bolls to fully open. However, some leaf drop and leaf desiccation was helpful in allowing more light to penetrate the canopy and aid in boll opening.

Table 5. Percent Open Bolls at 14 days after treatment – California.

TREATMENT	**1993**	**1994**	**1995**	**1996**	**Mean**
Untreated	86	88	89	84	87
Folex® @ 1.5 pt	90	94	92	91	92
Dropp® @ 0.2 lb	89	94	86	85	88
Harvade® @ 8.0 oz	90	97	97	89	93
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	89	94	86	89	90
Folex @ 0.75 pt + Prep @ 1.33 pt	90	92	90	88	90
Dropp @ 0.1 lb + Prep @ 1.33 pt	90	93	94	87	91
Folex @ 2.0 pt + Prep @ 2.0 pt		96	95	93	95
LSD ($p<0.05$)	2.103	3.897	7.546	ns[1]	

Source: Anonymous, 1999.

[1] ns = not significant.

REGROWTH

Terminal regrowth was determined by counting the number of plants in a 1-meter row segment with new leaves larger than 10 millimeters in size on the main stem tips. The values, presented in Table 6, are the percentages of plants with terminal regrowth; they were collected post-harvest between 21 DAT and 28 DAT. Patterns for regrowth are associated with severity of the initial defoliation treatment. An abrupt shock from a strong defoliant or desiccant usually will produce greater and earlier regrowth.

Basal regrowth (Table 7) was determined by the same means as terminal regrowth, except that these values represent the percent of plants with new leaves (larger than 10 millimeters) at the base of the main stem. Basal regrowth was slightly higher than terminal regrowth but followed a similar pattern among treatments. The higher regrowth was from the Folex rates of 1.5 pints and 2 pints per acre, and from the Harvade treatment of 8 ounces per acre.

Regrowth data for 1996 are not available. The overall lower defoliation observed during this year's trial also caused little regrowth.

Table 6. Percent terminal regrowth at 21 to 28 days after treatment – California.

TREATMENT	1993	1994	1995	Mean
Untreated	58	15	40	38
Folex® @ 1.5 pt	58	31	77	55
Dropp® @ 0.2 lb	55	17	49	40
Harvade® @ 8.0 oz	76	42	44	54
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	63	8	56	42
Folex @ 0.75 pt + Prep @ 1.33 pt	57	6	63	42
Dropp @ 0.1 lb + Prep @ 1.33 pt	62	10	41	38
Folex @ 2.0 pt + Prep @ 2.0 pt		34	62	48
LSD ($p<0.05$)	ns[1]	19.047	ns[1]	

Source: Anonymous, 1999.

[1] ns = not significant.

Table 7. Percent basal regrowth at 21 to 28 days after treatment – California.

TREATMENT	1993	1994	1995	Mean
Untreated	10	26	40	25
Folex® @ 1.5 pt	49	61	77	62
Dropp® @ 0.2 lb	20	22	49	30
Harvade® @ 8.0 oz	44	85	44	58
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	20	66	56	47
Folex @ 0.75 pt + Prep @ 1.33 pt	67	16	63	49
Dropp @ 0.1 lb + Prep @ 1.33 pt	22	38	41	34
Folex @ 2.0 pt + Prep @ 2.0 pt		71	62	67
LSD ($p<0.05$)	35	42	37	

Source: Anonymous, 1999.

LINT YIELDS

Lint yields for 1993-1996 are shown in Table 8. Defoliation treatments did not adversely influence final lint yields. The purpose of these defoliation trials was to preserve the yield and quality of the cotton in the field at the time of harvest. The guideline of Nodes Above Cracked Boll (NACB) was used to schedule each year's defoliation to ensure there would be no effect on lint yield or quality because of the treatment itself. Therefore, differences among the various treatments were not expected.

It is important to note, however, that the samples collected for HVI analysis and the larger bulk samples that were to be spun into fabric were not stored in a module prior to ginning. At harvest there was noticeable difference among the defoliation treatments' seed-cotton moisture levels. This is because of handling the harvested seed cotton while collecting the sub-samples.

Preparing a field for efficient machine harvest is only part of today's harvest requirements. The Beltwide use of the module system for field storage, transporting, and handling at the gin make harvesting dry, well-defoliated seed cotton more important in preserving final quality of the lint. Continued reliance on harvest-aid materials to assist in the pre-harvest preparation will be necessary to effectively use these systems.

Table 8. Total lint yield (lb per acre) – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	1794	1949	1517	2046	1826
Folex® @ 1.5 pt	1852	1869	1506	2060	1822
Dropp® @ 0.2 lb	1849	1926	1433	1985	1798
Harvade® @ 8.0 oz	1758	1904	1532	1938	1783
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	1746	1898	1506	2064	1804
Folex @ 0.75 pt + Prep @ 1.33 pt	1762	1870	1462	1994	1772
Dropp @ 0.1 lb + Prep @ 1.33 pt	1798	1886	1477	2073	1809
Folex @ 2.0 pt + Prep @ 2.0 pt		1828	1487	2053	1789
LSD ($p<0.05$)	ns[1]	ns[1]	ns[1]	91.162	

Source: Anonymous, 1999.

[1] ns = not significant.

FIBER QUALITY DATA

HVI fiber data are shown in Tables 9 through 15. The HVI fiber quality analysis was performed by Cotton Incorporated, Raleigh, North Carolina. Overall, the fiber quality data do not show a strong relationship to any effect of the various defoliation treatments.

Scheduling of the defoliation treatments using NACB would have ensured the absence of negative effects on fiber development and quality as measured by length, strength, and micronaire. The differences in color grade and leaf trash were not directly related to defoliation efficacy. As mentioned in the desiccation section (above), these samples were handled differently from field-harvest seed cotton, which would have been stored in a module prior to ginning.

Table 9. Fiber length (in) – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	1.15	1.14	1.14	1.18	1.15
Folex® @ 1.5 pt	1.12	1.13	1.13	1.17	1.14
Dropp® @ 0.2 lb	1.13	1.13	1.15	1.19	1.15
Harvade® @ 8.0 oz	1.12	1.14	1.14	1.19	1.15
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	1.14	1.12	1.14	1.18	1.14
Folex @ 0.75 pt + Prep @ 1.33 pt	1.10	1.12	1.14	1.19	1.14
Dropp @ 0.1 lb + Prep @ 1.33 pt	1.14	1.12	1.13	1.17	1.14
Folex @ 2.0 pt + Prep @ 2.0 pt		1.13	1.14	1.19	1.15
LSD ($p<0.05$)	0.039	ns[1]	0.019	ns[1]	

Source: Anonymous, 1999.
[1] ns = not significant.

Table 10. Fiber strength (g/tex) – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	32.60	30.08	30.77	33.35	31.70
Folex® @ 1.5 pt	30.85	30.42	29.45	32.27	30.75
Dropp® @ 0.2 lb	32.92	30.38	29.63	33.67	31.65
Harvade® @ 8.0 oz	31.43	30.48	30.57	33.67	31.54
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	32.08	29.70	30.52	33.95	31.56
Folex @ 0.75 pt + Prep @ 1.33 pt	30.65	30.45	30.15	33.95	31.30
Dropp @ 0.1 lb + Prep @ 1.33 pt	31.67	29.63	30.40	33.83	31.38
Folex @ 2.0 pt + Prep @ 2.0 pt		29.92	29.97	33.08	30.99
LSD ($p<0.05$)	1.52	ns[1]	0.73	1.29	

Source: Anonymous, 1999.
[1] ns = not significant.

Table 11. Micronaire – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	4.70	3.92	4.18	4.10	4.22
Folex® @ 1.5 pt	4.70	3.90	4.13	4.24	4.24
Dropp® @ 0.2 lb	4.65	3.97	4.14	4.17	4.23
Harvade® @ 8.0 oz	4.65	3.92	4.16	4.16	4.22
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	4.58	3.90	4.02	4.12	4.16
Folex @ 0.75 pt + Prep @ 1.33 pt	4.58	3.88	4.10	4.15	4.18
Dropp @ 0.1 lb + Prep @ 1.33 pt	4.60	3.92	4.07	4.06	4.16
Folex @ 2.0 pt + Prep @ 2.0 pt		3.95	4.12	4.13	4.07
LSD ($p<0.05$)	0.12	ns[1]	ns[1]	ns[1]	

Source: Anonymous, 1999.

[1] ns = not significant.

Table 12. Color grade – reflectance (Rd) – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	75.0	74.88	76.90	74.58	75.34
Folex® @ 1.5 pt	77.0	74.93	77.07	76.93	76.48
Dropp® @ 0.2 lb	74.8	74.42	77.35	76.22	75.70
Harvade® @ 8.0 oz	76.5	74.05	77.28	75.22	75.76
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	74.5	74.30	77.45	74.77	75.26
Folex @ 0.75 pt + Prep @ 1.33 pt	76.5	74.10	77.58	76.04	76.06
Dropp @ 0.1 lb + Prep @ 1.33 pt	75.8	74.57	77.42	74.70	94.30
Folex @ 2.0 pt + Prep @ 2.0 pt		74.47	78.00	76.38	76.28
LSD ($p<0.05$)	1.48	ns[1]	ns[1]	1.29	

Source: Anonymous, 1999.

[1] ns = not significant.

Table 13. Color grade – yellowness (+b) – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	9.20	9.38	8.88	9.02	9.12
Folex® @ 1.5 pt	8.92	8.98	8.67	8.88	8.86
Dropp® @ 0.2 lb	9.40	9.10	8.60	8.85	8.99
Harvade® @ 8.0 oz	8.95	9.30	8.77	8.92	8.99
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	9.23	9.13	8.73	8.98	9.02
Folex @ 0.75 pt + Prep @ 1.33 pt	8.82	8.95	8.58	8.73	8.77
Dropp @ 0.1 lb + Prep @ 1.33 pt	8.95	9.08	8.53	9.02	8.90
Folex @ 2.0 pt + Prep @ 2.0 pt		9.02	8.43	8.70	8.72
LSD ($p<0.05$)	0.23	0.327	0.252	0.27	

Source: Anonymous, 1999.

Table 14. Percent trash – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	0.43	0.29	0.27	0.43	0.33
Folex® @ 1.5 pt	0.25	0.24	0.22	0.24	0.24
Dropp® @ 0.2 lb	0.43	0.38	0.17	0.28	0.33
Harvade® @ 8.0 oz	0.30	0.29	0.22	0.37	0.27
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	0.50	0.30	0.21	0.46	0.36
Folex @ 0.75 pt + Prep @ 1.33 pt	0.25	0.37	0.16	0.38	0.26
Dropp @ 0.1 lb + Prep @ 1.33 pt	0.35	0.30	0.26	0.38	0.30
Folex @ 2.0 pt + Prep @ 2.0 pt		0.31	0.12	0.33	0.21
LSD ($p<0.05$)	0.148	ns[1]	ns[1]	0.188	

Source: Anonymous, 1999.

[1] ns = not significant.

Table 15. Fiber length uniformity – California.

TREATMENT	1993	1994	1995	1996	Mean
Untreated	84.8	81.30	82.85	83.25	83.05
Folex® @ 1.5 pt	83.5	80.78	81.55	83.73	82.39
Dropp® @ 0.2 lb	84.5	80.73	82.53	84.15	82.98
Harvade® @ 8.0 oz	84.0	81.20	82.33	83.00	82.63
Harvade @ 6.5 oz + Prep™ @ 1.33 pt	84.8	81.18	81.57	83.13	82.67
Folex @ 0.75 pt + Prep @ 1.33 pt	84.0	80.63	82.20	82.99	82.46
Dropp @ 0.1 lb + Prep @ 1.33 pt	85.0	80.82	81.45	83.40	82.67
Folex @ 2.0 pt + Prep @ 2.0 pt		80.57	81.47	83.35	81.80
LSD ($p<0.05$)	1.08	ns[1]	1.125	ns[1]	

Source: Anonymous, 1999.

[1] ns = not significant.

SUMMARY

Far West cotton production is characterized by a hot, arid growing season; the entire acreage is irrigated. This lends some advantage in preparing the crop for defoliation, because the season's final crop irrigations can be scheduled to afford greater control of soil moisture and nitrogen. Harvest of this acreage is performed with spindle-type harvesters, so defoliation practices play an important pre-harvest role. Although effective defoliation is the primary goal, a sequential application often is required to fully desiccate the remaining leaves and help open any green bolls. This practice is particularly important in the preparation of Pima cotton for harvest.

Although similar materials are used in Arizona and California, each production area has specific labeled rate differences. Within each production area, material combinations and application methods vary from farm to farm. Initial defoliation treatments include harvest-aid materials such as Folex, Def, or Ginstar in combination with Prep (ethephon). These materials have provided the most consistent results over a range of climatic conditions.

Sodium chlorate is used extensively for cleanup applications. Additives such as paraquat or cacodylic acid are included to enhance the desiccation of remaining leaves.

In cooperation with the Beltwide Harvest-Aid Performance and Fiber Quality Evaluation, California's San Joaquin Valley was selected to represent the Far West production area. Far West conditions represent a unique environment for comparing the effects of pre-harvest practices. As the Far West representative, California participated in the last four years of the five-year study to uniformly assess various defoliation treatments. The "standard" core treatments did not perform as well in the California trials as they did in other regions of the Cotton Belt. The overall lower treatment response is attributed to the San Joaquin Valley's arid climate and the high *Verticillium* wilt-tolerant Acala varieties grown in this region of California. The Far West location provided a more challenging environment to test the performance of the standard treatments, thus providing an important contribution to the final Beltwide database.

Regional objectives for improved cotton defoliation in the Far West continue to emphasize seasonal crop monitoring for effective management that enhances defoliation. This includes good water and nitrogen management from cutout to termination and defoliation. Research must continue screening new materials or combinations that improve crop defoliation and harvestability. The growing environmental concerns, urban encroachment, and crop rotation requirements continue to make cotton pre-harvest preparation one of the most visible and challenging aspects of cotton production in the Far West. Success in this effort will provide western growers with environmentally acceptable practices to harvest and deliver the highest-quality seed cotton.

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APPENDICES

Appendix 1. Standard harvest-aid treatments.[1]

Untreated check
Folex® @ 1.5 pt per acre
Dropp® @ 0.2 lb per acre
Harvade® @ 8 oz per acre + Agri-Dex® @ 1 pt per acre
Harvade @ 6.5 oz per acre + Prep™ @ 1.33 pt per acre + Agri-Dex @ 1 pt per acre
Folex @ 0.75 pt per acre + Prep @ 1.33 pt per acre
Dropp @ 0.1 lb per acre + Prep @ 1.33 pt per acre
Folex @ 2 pt per acre + Prep @ 2 pt per acre[2]

Source: Anonymous, 1999.

[1] Standard treatments varied slightly in different regions. These variations are noted in the summary report (Anonymous, 1999).

[2] Regional standard.

Appendix 2. Harvest-aid performance data collected each year.

Term	Timing[1]	Definition
Defoliation (%)	7 DAT and 14 DAT	Percent of leaves present at time of application that were removed by treatment, on a scale of 0 to 100.
Desiccation (%)	7 DAT and 14 DAT	Percent of total leaf number remaining on the plant that were desiccated as a result of the treatment. Relative scale of 0 to 100, where 0 equals no remaining desiccated leaves and 100 indicates all leaves desiccated and remaining on the plant.
Terminal Regrowth (%)	21 DAT	Determined by counting the number of plants in a 1-meter row segment with new leaves larger than 10 mm in size that had regrowth on stem tips.
Basal Regrowth (%)	21 DAT	Determined by counting the number of plants in a 1-meter row segment with new leaves larger than 10 mm in size that had regrowth from the main stem.
Open Bolls (%)	7 DAT and 14 DAT	Determined by counting total bolls and open bolls in a 1-meter row segment.

Source: Anonymous, 1999.

[1] DAT = Days After Treatment.

Chapter 10

PUBLIC AND ENVIRONMENTAL ISSUES

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INTRODUCTION

Cotton typically is regarded as a labor-intensive, high-input crop that has been grown for centuries because of demand for cotton products. Despite the availability of an array of synthetic and other natural fibers, cotton still accounts for almost 50 percent of all textile fiber consumed (Wakelyn *et al.*, 1998), thus making it the most important textile fiber in the world.

Although the economic value of raw cotton is relatively low, it remains the primary "cash crop" for many farming operations throughout the world. Currently, cotton is grown in about 85 countries, many of which are less-developed agrarian economies with large, unskilled labor forces. Although advancements have been made in cotton production, these have not been adapted universally. For example, as the millennium closed, about 70 percent of the world's cotton still was being hand-harvested (Chaudhry, 1997).

The United States is globally recognized as a highly advanced nation in the forefront of developing, manufacturing, and applying new technologies. The United States continues to produce 15 to 20 percent of the world's cotton, which is a tribute to the willingness of U.S. farmers to embrace new technologies that have helped reduce labor, land requirements, and production costs. Rapid adoption of steadily improving mechanical, chemical, and biological technologies enables individual farmers to expand the size of operational units and to decrease the number of people (producers and laborers) required to grow cotton and other crops. In 1910, 35 percent of the U.S. population lived and worked on farms (Anonymous, 1962), whereas, in 2000, fewer than two percent were involved directly in food and fiber production.

MECHANICAL HARVESTERS

Hand-picking is considered the most labor-intensive operation in cotton farming and has been shown to cause ergonomic problems for harvesters (National Research Council, 2001). Efforts to develop mechanical cotton harvesters (pickers and strippers) began in the mid 1800s (Brown, 1938). As the engineering aspects of mechanical harvesting were being resolved in the 1940s, it was recognized that there was a need to remove or dry unneeded leaves on the plant prior to mechanical harvest. Uniform defoliation or desiccation generally allows earlier harvest and tends to preserve the yield and quality of a given crop by eliminating potential lint contaminants (i.e., leaf trash) and by minimizing losses from field weathering. The rapid acceptance and widespread use of mechanical harvesters in large part was because of the simultaneous development and availability of effective cotton harvest-aid products.

Indirectly, harvest aids also made it practical to further mechanize seed-cotton handling and storage systems with little risk of negative impact on yield and quality. Development of the seed cotton moduling system in the 1970s made it possible for harvesting to become a continuous process, independent of ginning capacity. Because modules could be readily transported over longer distances, gins were consolidated and upgraded with higher-speed, more-efficient equipment to increase utilization. Consolidation generated business volumes that justified additional expenditures for services such as standardized (Universal Density) presses and for on-site warehousing and shipping of cotton.

Other technological advancements that contributed to on-farm profitability of U.S. cotton production included the introduction and improvement of herbicides, increased use of fertilizers, improvements in conventional and transgenic varieties, expanded irrigation, new plant growth regulators, refinements in cultural and tillage practices, and continued improvements in farm machinery. An inevitable result was that farm sizes increased, but the number of operators and laborers decreased. Similar trends occurred in support industries such as farm machinery and merchant suppliers.

CONSUMER CONCERNS

Because of the transition from a rural to an urban society in the United States, the majority of the population has lost direct contact with agriculture. However, many individuals and groups have developed strong concerns about the potential social, economic, and environmental issues modern U.S. agriculture poses to food safety, air and water quality, and solid waste generation and disposal. These concerns have resulted in passage of numerous federal and state regulations that affect crop protection product use, secondary emissions, and disposal of wastes (see Table 2). New issues continue to emerge; they are expected to do so for the foreseeable future.

As consumer concerns increased, governments – especially foreign governments – responded by objecting to shipments of numerous products derived from crops treated with certain crop protection products, as well as to raw materials and products from genetically modified plants. Such issues have affected, and will continue to affect, U.S. farmers and farm economies as well as those of allied industries, particularly since the U.S. agricultural economy has become heavily dependent on exports and foreign consumers.

The farm sector has responded – and continues to respond – not only by challenging the scientific validity and merits of questionable mandates and restrictions, but also by acting as good stewards of the land and the environment. However, this is an era when perception tends to become reality and scientific facts are questioned or discounted. The agricultural sector needs to be visibly and continually proactive in addressing issues related to food and fiber production and to environmental stewardship. Agriculture must make concessions even when profitability and the local farming system and support industry may be negatively affected.

EFFECT OF PUBLIC PERCEPTION - A CASE HISTORY

ARSENIC ACID

The power of public perception and concern is exemplified in the case of arsenic acid, a harvest-aid product introduced in the 1950s, which was used for nearly 40 years as a highly effective and relatively inexpensive cotton desiccant. Arsenic trioxide, from which many arsenic products were derived, largely was a by-product of copper, zinc, and lead smelting (Adams *et al.*, 1994). In comparison to sulfuric and other strong acids, arsenic acid is unique, in that it is an excellent cotton desiccant that does not damage cotton fibers.

This product was suited ideally for use in the Southwest (Texas and Oklahoma), where sparse and erratic rainfall limited yield potentials of large tracts of dryland cotton. The low yields and short plant stature made spindle picking impractical, but such crops were well suited for less-costly stripper harvesting, if the leaves and other plant materials could be dried economically and efficiently. Arsenic acid fit these harvest-aid criteria and was widely used throughout the Southwest from the mid 1950s until it was withdrawn from the market in 1993.

Arsenic is ubiquitous. It occurs naturally in soils, from where it is taken up in small quantities by plants and introduced into foods (Table 1) and other plant-derived products. Arsenic also is an essential element in the diets of some animals (Adams *et al.*, 1994; Anderson, 1983); the Food and Drug Administration has set tolerance limits for residues of arsenic compounds when used as veterinary drugs (21 CFR 556.60; see Glossary, p. 296) (Department of Health and Human Services, 1998).

Even though it is natural, arsenic is recognized universally as a "poison," and inorganic arsenic is a documented carcinogen (Bencko, 1977; Environmental Protection Agency, 1986; Department of Health and Human Services, 1998). Over the years, concerns arose about arsenic accumulation in soils and human exposure risks following long-term use of this cotton desiccant. Monitoring studies showed that, over time, labeled applications of this desiccant added to the inherent levels of arsenic in soils, but not to the extent that long-term sustainability of crop production was at risk. Still, arsenic residues on plant material harvested along with the seed cotton were alleged to constitute a potential risk to workers at gins and to area residents.

Table 1. Concentration of arsenic in nature.

Substance	Concentration (ppm)
Water	0.01 - 1.0[1]
Soil	1.0 - 500.0[1]
Grass	0.1 - 1.6[1]
Fish	2.0 - 9.0[1]
Shrimp	25[2]
Lobsters	50[2]

[1] Source: Peoples, 1975.
[2] Source: Reeves, 1976.

RESIDUES

When the desiccant arsenic acid is applied to cotton, some arsenic (inorganic form) is deposited on the soil, plant materials, and cotton fibers; concerns surfaced about the fate of these residues. For example, textile mills were concerned about arsenic levels in airborne dust, wastewater, and trash (Perkins, 1989; Perkins and Brushwood, 1991; 1993), despite research studies (Perkins and Brushwood, 1991) that showed that 1) airborne arsenic levels were orders of magnitude less than the regulated levels, 2) normal washing operations at mills readily removed arsenic from the fibers, and 3) cotton textiles essentially were free of arsenic residues. Also, means are available at textile mills to remove arsenic from wastewater and to collect and safely dispose of plant trash that contained arsenic residues (Perkins and Brushwood, 1991). Likewise, gin trash could be spread uniformly over fields without significantly contributing to the natural level of arsenic in the soils, while returning beneficial crop residues to the soil (Seiber *et al.*, 1981).

In 1986, the Environmental Protection Agency adopted a rule regulating inorganic arsenic as a hazardous air pollutant (HAP) under the Clean Air Act (Environmental Protection Agency, 1986). The standard covered five industries, but specifically did not cover cotton gins, because the estimated health risks to gin workers and area residents from cotton gins was too small.

In 1991, EPA published a preliminary determination to cancel registration of arsenic acid on cotton (Environmental Protection Agency, 1991). The textile industry had become concerned about the product, because, in some cases, arsenic levels in the cotton textile mill waste had exceeded the EPA level for leachable arsenic (40 CFR 261.24), thereby classifying the mill waste as a hazardous waste (Perkins and Brushwood, 1993). Also, levels of arsenic in textile effluent in some mills exceeded local or state effluent guidelines (Perkins and Brushwood, 1991).

REGISTRATION VOLUNTARILY CANCELED

Because of these concerns and potential EPA actions (Environmental Protection Agency, 1991), registration for arsenic acid was canceled voluntarily (Environmental Protection Agency, 1993), and its use as a cotton desiccant was discontinued after the 1993 season. EPA noted in the proposal to cancel registration (Environmental Protection Agency, 1991) that the risk to applicators was unreasonable, but the risk to area residents and gin workers was considered acceptable even when very conservative risk estimates were applied.

Even though the levels of exposure to gin workers, textile workers, and area residents were at least 100 times less than the U.S. Occupational Safety and Health Administration permissible exposure limit (PEL) for inorganic arsenic of 10 $\mu g/m^3$ (29 CFR 1910.1048), according to all available data (Environmental Protection Agency, 1986; Hughes *et al.*, 1997a; 1997b; Perkins and Brushwood, 1991), suits were filed by residents living within five miles of several gins for alleged health effects. Also, worker compensation claims were filed by gin and textile workers citing acute and chronic health effects from arsenic in the cotton and airborne cotton-related dust in the working environment. These lawsuits ultimately were settled out of court for less than it would have cost to hear the cases, even though there was no evidence to support a conclusion that the exposure levels constituted a clear health risk. Because alleged health effects and environmental concerns continue to be raised, there could be further lawsuits because of past use of arsenic-containing materials on cotton. Current harvest-aid chemicals also could be subject to lawsuits for alleged health effects from their use on cotton.

Overall, arsenic acid was in the marketplace for 37 years as a labeled cotton desiccant. Its record shows that, when used properly, it was a safe, effective product. Yet it was withdrawn from use in large part because of "downstream" processing consequences and textile mill concerns, rather than from in-field application risks. Ultimately, loss of arsenic acid, coupled with the lack of comparable, low-cost replacements, increased production costs, reduced cotton acreage in sections of Texas and Oklahoma, and threatened the economic viability of affected producers, as well as operators of key support industries.

HEALTH AND ENVIRONMENTAL CONCERNS

What, if any, are the lessons to be learned from this experience that can be applied in the future? It is very likely that other harvest-aid products will be challenged on the basis of health and environmental concerns; some even may be discontinued because of the loss or withdrawal of product registrations. Promising new products may never make it to the marketplace because of the difficult and costly processes of discovery, development, and registration.

The future direction of the cotton industry will be guided by how well it controls stewardship of product use, knowledge and awareness of public concerns, careful adherence to use restrictions, refinements of use practices with old – as well as new – products, and continued adoption of viable new technologies. With the use of harvest-aid products (as with other crop protection products), special attention must continue to be directed at limiting off-target movement (drift and volatilization), especially with compounds that have activity on nontarget vegetation (e.g., paraquat on small grains or glyphosate on corn) or that can have adverse effects on people, domestic animals, wildlife, and other organisms.

ADDITIONAL CONCERNS/ENVIRONMENTAL ISSUES

In evaluating harvest practices used for cotton, factors other than cost and the lowest acceptable level of treatment efficacy need to be considered. These include the potential effects on downstream cotton industries including cotton gins, cottonseed oil mills, and textile mills. From an environmental perspective, it is advantageous to leave extraneous (non-lint and seed) plant materials, soil particles, and other foreign materials in the field.

The primary function of gins is to separate lint from seed and to remove as much foreign matter as practical. As foreign-matter content increases, more mechanical cleaning is required, increasing the short fiber content and adversely affecting other lint quality parameters (e.g., length uniformity and color) and gin particulate matter (PM) emissions.

Gins are required to meet EPA air-quality standards for PM (regulated as PM_{10}, particulate matter less than 10 microns; $PM_{2.5}$, PM less than 2.5 microns; and TSP, total suspended particulate) (40 CFR 50) and must obtain and maintain air-quality permits (Table 2). In order to help reduce external gin emissions of PM and other potential air pollutants, it is important to minimize foreign material content in seed cotton and lower the levels of harvest-aid residues on lint and trash.

Table 2. Laws and regulations for chemical residues on plant materials, in air emissions, and in water.

Law or Regulation	Purpose
EPA – Clean Air Act (CAA) (42 U.S. Code 7401 et seq.)	Provides EPA with the authority to set NAAQS (for criteria pollutants[1]) to control emissions from new stationary sources and to control hazardous air pollutants (HAP).
• Federal permits	"Title V" (permits); 40 CFR 70.
• State permits	Each state has own permitting system.
EPA – Federal Water Pollution Control Act (known as the Clean Water Act – CWA) (33 U.S. Code 1251 et seq.)	The major law protecting the "chemical, physical and biological integrity of the nation's water." Allows the EPA to establish federal limits on the amounts of specific pollutants that can be released by municipal and industrial facilities.
• National Permit Program (National Pollution Discharge Elimination System, NPDES)	Permits; 40 CFR 122.
• Textile Effluent Guidelines	Part of NPDES permit requirements; 40 CFR 410, subparts D, E, and G.
EPA – Resource Conservation and Recovery Act (RCRA) (42 U.S. Code 9601 et seq.)	A "cradle-to-grave" system for management and disposal of nonhazardous and hazardous waste; characteristics of leachable wastes (e.g., toxic wastes, 40 CFR 260.24).
EPA – Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (42 U.S. Code 9601 et seq.)	Known as the "Superfund." Gives the EPA power to recover costs for containment, other response actions, and cleanup of hazardous waste disposal sites and other hazardous substance releases. Note: Residues of a chemical like As. can make an area a Superfund site.

(Table continues)

Table 2. (continued)

Law or Regulation	**Purpose**
EPA – Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (7 U.S. Code 135 et seq.)	The major law for pesticide registration and pesticide use. In 1996, FQPA amended pesticide registration/ tolerance-setting requirements.
• Worker Protection Standard	To reduce the risks of illness or injury from workers' and handlers' occupational exposures to pesticides and from accidental exposure of workers and other persons to pesticides; 40 CFR 170.
DOL – Occupational Safety and Health Act of 1970 (OSHA) (29 U.S. Code 651 et seq.)	Provides OSHA with authority to set regulations so that industry will maintain safe and healthful workplaces.
• OSHA Air Contaminants Rule	To reduce the risk of occupational illness for workers by reducing exposure limits for more than 400 chemicals[2] (29 CFR 1910.1000).
• Hazard Communication Standard	Prevention of occupational disease and notification of workers regarding chemical and physical hazards and risks in the workplace (20 CFR 1910.1200).

[1] Criteria Pollutants (40 CFR 50): Includes particulate matter (regulated as PM_{10}, $PM_{2.5}$) and volatile organic chemicals (VOCs) regulated as ozone. Harvest-aid products can be VOCs and HAPs (40 CFR 61).

[2] Examples: Permissible exposure limit (PEL): arsenic compounds (inorganic), 10 $\mu g/m^3$; arsenic compounds (organic), 500 $\mu g/m^3$; paraquat, 500 $\mu g/m^3$; and Def®, no PEL.

The quantity and toxicity of harvest aids and other plant-protection product residues in gin emissions and gin by-products are of concern to some state regulators (Hughs *et al.*, 1997a; 1997b). Depending on the source and concentration of the contaminant, these residues could be classified as hazardous wastes, and more states eventually may require gins to obtain solid-waste permits (Environmental Protection Agency, 1999a; 1999b). Leaving most of the trash in the field at harvest reduces the need for trash disposal, lowers gin external emissions, and reduces the potential for litigation on behalf of nearby residents for alleged health problems.

TRASH

Extraneous materials (trash) in lint and seed affect cottonseed oil mills and textile mills. Trash in cottonseed can increase PM emissions at oil mills. Over-cleaning at gins creates more short fibers and fine trash, which subsequently result in textile mill processing problems (e.g., increased ends-down in spinning – stoppages in spinning because of breaks in yarn), higher workplace and external emissions, and waste disposal problems. Each of these contributes to cotton processing costs.

Textile mills also are concerned about the chemical residues contained in the dust and on the cotton lint. Chemical residues in the unwanted solid materials (textile mill waste) and effluents from dying and finishing operations that exceed residue limits set for discharge (Perkins and Brushwood, 1991; 1993) can be classified as hazardous wastes.

In the European Community and elsewhere, the presence of high levels of heavy metals and chemical residues from crop-protection products could prevent textile products from qualifying for an ecolabel status (EU Ecolabel for Textiles, 1999; The Oko-Tex Initiative, 1998; Global Ecolabeling Network, 1999), reducing their value or even marketability.

AIR QUALITY

In the United States, air quality and other concerns may be grounds for new restrictions and even may threaten continued registration of some products. For example, tribufos (the active ingredient in Folex®/Def®) was added to the list of toxic air contaminants (TAC) in California (Lewis, 1997) and was subject to reviews under the California Birth Defect Prevention Act of 1986 and by Federal EPA under FQPA/FIFRA. These designations have lengthened the re-entry interval after application and have led to other use restrictions for tribufos.

Residues of harvest-aid products have a higher potential for being detected on lint, seed, and trash, because they are applied late in the season, when all or most of the bolls are open. If residues of products exceed established tolerance levels, the feeding of whole cottonseed, cottonseed hulls, cottonseed meal, and gin by-products to animals must be limited or stopped altogether.

The concentrations of tribufos and of arsenic detected on gin by-products and in the external emission from cotton gins are shown in Tables 3 and 4, respectively. Measured concentrations of arsenic on cotton fibers and in airborne dust in gins and textile mills also are reported in Table 4. Other studies have shown that little or no arsenic accumulates on the seed, even when excessive rates of arsenic acid were applied, because of the barrier provided by the lint (Warrick, *et al.*, 1992).

Because arsenic is a stable element (i.e., it does not degrade like most organic compounds), the levels of arsenic reported in Table 4 can be used to approximate the baseline levels of harvest-aid products deposited on the lint and cotton by-products. These have the potential to remain on airborne dust in gin and textile mill workplaces and on gin and cottonseed oil mill external emissions. The similarity in the arsenic and tribufos residue levels reported in Tables 3 and 4 illustrates the potential for contamination with these and other harvest-aid products, demonstrating the importance of using all harvest-aid products strictly in accordance with label stipulations to minimize residues.

Table 3. Summary of residue data, tribufos (Folex®/Def®).

Sample	Concentration	Reference
Cotton gin by-products	5.14-36.39 (ppm) (Tolerance reassessment: 40 ppm)[1]	Law, 1998 Law, 1998; Travaglini, 1999
Cotton gin external emissions (in cyclone exhaust)	Max: 44 ppm Avg: 8.5 ppm	Hughs *et al*, 1997a
Air concentration 100 m from gin	Max: 0.003 $\mu g/m^3$ Avg: 0.0006 $\mu g/m^3$	Hughs *et al*, 1997a

[1] Tolerance for Tribufos, 40 CFR 180.272.

MATERIAL REGISTRATION, REGULATION, AND SAFE, EFFICIENT USE

REGISTRATION OF DEFOLIANT PRODUCTS

FIFRA and FQPA – All crop protection products, including defoliants, are registered for use in the United States under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended in 1996. Approval for use is granted through the EPA, which oversees

Table 4. Summary of residue data, arsenic (As.).

Sample Origin	Sample Type[1]	(ppm or μg/m^3)[2]	Reference
Cotton fiber	Not desiccated	1.5 <1 0.014 - 0.023	Perkins and Brushwood, 1991 Perkins, 1989 Columbus *et al.*, 1984
Cotton fiber	Desiccated	13 – 98 62 – 91	Perkins, 1989 Columbus *et al.*, 1984
Leachable (TCLP) from cotton fiber (max value detected in 50 samples)	Desiccated	0.9	Harry, 1992
Airborne respirable dust (in textile mill)	Desiccated	0.42[3]	Perkins, 1989
Airborne respirable dust (cotton gin at bale press)	Not desiccated	0.020	Columbus *et al.*, 1984
Airborne respirable dust (cotton gin at bale phase)	Desiccated	0.173	Columbus *et al.*, 1984
Cotton gin external emissions (in cotton gin cyclone exhaust)	Desiccated	Max.: 21.9 Avg.: 8.2	Hughs *et al.*, 1997a & 1997b
Air concentration 100 m from gin	Desiccated	Max.: 0.0015 Avg.: 0.0006	Hughs *et al.*, 1997a & 1997b

[1] Samples collected from fields that either were desiccated with arsenic acid or not desiccated with arsenic compounds.

[2] Concentrations of airborne samples are in μg/m^3; other samples in ppm.

[3] OSHA PEL: Inorganic As. = 10 μg/m^3; organic As. = 500 μg/m^3.

the registration process. Recent estimates detail how a candidate chemical product undergoes at least a 10-year process from discovery to registration. The product is submitted to more than 120 tests outlined by the EPA, to develop a complete toxicological profile. Because of these regulations, total costs of bringing a product to market typically exceed $50 million.

FIFRA was amended in 1996 by the Food Quality Protection Act (FQPA). This legislation requires that all existing tolerances be reviewed with the intent of providing greater protection for infants and children. Under FQPA, risk of exposure to each active ingredient is measured for each route of exposure: dietary, drinking water, residential (indoors and outdoors), and other non-occupational situations, such as golf courses.

The most prominent defoliant considered in the early FQPA review process was tribufos, the active ingredient of Folex and Def. Because it is an organophosphate (OP), it was included in the review along with other members of this group, which largely consists of insecticides. The review resulted in greater restrictions of the use of tribufos.

Optimizing Product Efficiency – The primary reason for using cotton harvest aids is to allow the crop to be harvested when yield and quality are at or near their peak. Presently, U.S. producers have a relatively good assortment of cotton harvest-aid products from which to select. However, because of exorbitant discovery, development, and registration costs, fewer new products are being added to the market, and, because of environmental and health concerns, added restrictions continue to be imposed on existing products. Both factors are likely to increase product and application costs during an era when cotton growers are struggling to reduce overall production costs.

In order to better manage costs and obtain the desired results (i.e., defoliation, boll opening, desiccation), growers must strive to use existing harvest-aid products in an agronomically efficient, economically viable, environmentally responsible manner. Getting the crop ready for harvest truly is a season-long process, beginning with preparations that allow for timely planting and result in uniform emergence. Fertilization practices, weed control, insect management, proper use of plant growth regulators, and water management are key factors that promote high fruit retention and lead to early, uniform crop maturity.

Once bolls begin to open, several techniques are available for assessing overall crop maturity and timing of harvest-aid applications (see Chapter 5), but the final decision on when to treat also must be tempered by consideration of individual field conditions, current and projected weather conditions, and harvesting capacity. These factors, plus the method of harvest (stripper or picker), crop conditions, and method of application ultimately influence the selection of products that will be used in conditioning the crop for harvest.

Much has been learned recently about the effectiveness of various harvest-aid treatments in different production regions (environments) over a period of years (seasonal growing conditions) throughout the U.S. Cotton Belt

(Anonymous, 1999). In most states, Extension and research personnel continue to build on this database and use this information by providing growers with annual, area-specific harvest-aid recommendations.

Still, successful crop termination remains as much an art as it is a science. Harvest-aid decisions must take into account both product capabilities and basic plant biological processes and developmental patterns, as well as seasonal growing conditions that influence or possibly alter these processes and patterns.

SELECTING HARVEST AIDS

The main considerations in the selection of harvest aids and application methods are traced to costs, the desired results with the current crop (i.e., accelerated boll opening, defoliation, desiccation, regrowth control), field location (proximity to other crops, residential areas, etc.), and time required to treat. Use of product combinations (either pre-mixed or tank-mixed) is increasing, but the "best" combinations often are specific to the year and crop. Various additives (surfactants, crop oils, fertilizers) can increase efficacy of some products by facilitating uptake of active ingredients by drought-stressed leaves or enhancing absorption of compounds (e.g., thidiazuron) that do not penetrate readily into plant leaves (Snipes and Wills, 1994).

Most harvest-aid compounds are relatively immobile in plants. Consequently, good coverage – resulting from the use of manufacturer-suggested spray volumes, nozzles, nozzle spacing, ground or air speed during application, and, if recommended, spray additives – is essential in obtaining desired results. Typically, best results are achieved when harvest aids are applied under warm, sunny conditions with minimal wind and low probabilities of rainfall or a significant decrease in temperatures within three to five days after treatment. Some products (e.g., thidiazuron, ethephon) respond best when applied during periods with relatively high daytime and nighttime temperature regimens. In most instances, but especially in drought-stressed cotton, paraquat will be more effective when applied late in the day, to avoid a long period of sunshine immediately after application.

Off-target movement caused by physical drift can be a problem with harvest-aid applications. This can result in significant economic damage to nearby sensitive crops, gardens, or ornamental plants. Where practical, only ground application equipment should be used in fields near residents and populated areas. As a standard "good neighbor" policy, products that produce strong odors (e.g., tribufos) should be avoided near towns and residential areas; it can be helpful to notify nearby neighbors when such a product will be applied.

Use of wide-angle, higher-volume nozzles designed to operate at lower spay pressures will allow the boom height of ground applicators to be lower and generate larger droplets, which are less likely to drift off target. Drift-control additives also may be an option with some products or product combinations. Products with low specific gravities (e.g., paraquat) are more prone to remain suspended for longer periods and drift off site than are heavier compounds. Because of their drift potential, growers should use extra precautions or even, if practical, switch to alternative products when treating fields adjacent to sensitive crops or near populated areas.

Off-label practices or use of non-labeled products must be avoided. Several products on the market provide excellent regrowth suppression or other desirable responses at a reasonable cost, but are not labeled for use in cotton. In most instances, no tolerances have been established for residues of these compounds on cotton products or by-products. Detection of residues likely will result in litigation, damages, condemnation of treated fields, or condemnation of contaminated products (lint, seed, or cotton by-products) harvested from treated fields.

Application of harvest-aid products stimulates a series of physical and biological reactions that require time before producing the desired results. The length of time required often is a function of temperature, light, humidity, and other climatological variables. After a crop has been properly treated with harvest aids, it is not necessarily ready for harvest under "all conditions." All too frequently, producers become impatient and initiate harvesting before boll opening (and lint and seed drying), defoliation, or leaf desiccation is complete. The end result may be reduced harvest efficiency and poor grades because of excessive trash and staining of the lint.

Growers also can negate potential benefits of a "perfect" harvest-aid job by harvesting during high-moisture periods when cotton is least likely to pick cleanly or is more apt to contain "bark" if stripped. High moisture during harvest can lead to post-harvest problems (e.g., lower lint turnout and quality and possible mycotoxin formation) from increases in bacteria and fungi during storage in modules and even in trailers (Roberts *et al.*, 1996).

Harvest aids are the "chemical tools" that enable cotton to be efficiently harvested with mechanical pickers and strippers. Like all crop protection products, however, they must be used in accordance with label guidelines and local, research-based recommendations. Anyone using chemicals must remain mindful of the circumstances under which the products are to be used and adjust use practices to be environmentally sound and to accommodate adjacent crops, people in nearby communities, and the processors and end users of the commodity.

PROACTIVE STEWARDSHIP PROGRAMS AND SAFETY REQUIREMENTS

Because of increasing public awareness about use of chemicals, it is becoming increasingly important for the cotton community, including companies, aerial and ground applicators, and producers, to become more proactive in practicing and promoting good stewardship and safe application of all cotton crop-protection products, including harvest-aid products.

The number of regulations will continue to increase and to become more restrictive for the use of crop protection products. Because harvest aids are applied after partial or nearly complete boll opening, there is a higher probability of detectable residues occurring on the cotton fibers, plant residues, and, possibly, even the seed and seed products. The odor and drift potential of some products must be considered, especially if they are to be used near residential areas or in the proximity of sensitive ornamental and crop plants.

Some manufacturers conduct routine chemical residue screening on raw cotton fiber (yarn or greige fabric) to qualify the fiber or fabric shipment for certain ecolabels (EU Ecolabel for Textiles, 1999; The Oko-Tex Initiative, 1998; Global Ecolabeling Network, 1999). Screens often are for older organochlorines and other compounds no longer registered for use on U.S. cotton.

HEAVY-METAL SCREENING

In addition, screens routinely are conducted for selected heavy metals. Although arsenic is a naturally occurring element that normally appears on raw fiber at background levels (Table 4), much higher levels of this element have been detected in some U.S. cotton. These elevated residue levels typically were traced back to the use of registered harvest-aid products containing cacodylic acid (an organic arsenic-based product). The cotton industry is challenged to keep production practices in line with consumer expectations.

PROACTIVE PROGRAMS AND COMMUNICATION

Proactive environmental stewardship programs for harvest aids are very important to ensure safe and wise product use, to provide assurance to the general public, and to temper adverse claims made by environmental groups. The guiding principle should be adoption of efficient harvest-preparation procedures that also ensure worker and public safety and protection of the environment.

Cotton farmers should strive to communicate to the public all the environmentally responsible steps they are taking to help the agricultural and urban communities grow and prosper together. Urban communities should be made aware that most farmers already incorporate such environmental stewardship practices.

In recent years, two programs have been under way to help focus on stewardship and environmentally responsible farming operations: "Cotton Cares," a National Cotton Council prototypical environmental awareness and incentive program, and "Careful By Nature," a multistate public awareness program and user community educational program. These efforts promote agronomically and environmentally sound practices and emphasize communication, harvest preparation, and sensitivity to one's neighbors. Their principles include:

Good Communication – Maintain regular contact with neighbors and community to discuss and provide updates on crop treatment strategies. Items that should be considered include 1) presence of and proximity to schools, parks, playgrounds; 2) proximity of sensitive garden, ornamental, and crop plants, 3) methods of application (i.e. ground or aerial), 4) products to be used, and 5) specific local concerns.

- Communicate with advisers (Extension personnel, crop consultants, industry representatives) and spray operators to ensure all parties understand the requirements, restraints, and concerns associated with the spray management plan.
- Order spray applications in writing and specify precise location of the farm or field to be treated. Identify the crop treated, the location and proximity of neighbors' crops and sensitive areas, and details on how to contact the grower-operator if questions arise.

- Ensure that the grower or a designated representative is on site to observe the application.
- Ensure that the applicator has communication with the grower or grower representative in the event of changes required during the treatment operation.

Harvest Preparation – Base selection and rates of harvest-aid materials on harvest method (picker or stripper), crop status (percent open bolls, nodes above the uppermost cracked boll (NACB), heat-unit accumulation since cutout, etc.), current and projected weather conditions, and harvest capacity.

- Use application technology such as higher-volume, wide-angle nozzles, adjuvants, and, where feasible, drift-control agents to provide good coverage, promote product penetration into the plants, and minimize off-site movement of the active ingredients.
- Read and follow all product-use guidelines and precautions listed on the label.
- Select application method based on local situations, e.g., proximity to residential areas, sensitive plants or crops, streams, etc.
- Be aware and mindful of schools, playgrounds, parks, residential areas, etc., and maintain appropriate buffer zones.
- Respect and respond positively and promptly to public concerns regarding off-target movement of harvest-aid materials.

Minimizing Impact to Adjacent Areas

- Apply all crop protection chemicals, including harvest aids, only when weather conditions are favorable for spraying, to optimize efficacy and minimize off-target movement.
- Use appropriate methods to assess environmental conditions on site (wind speed, temperature, humidity).
- Apply pesticides when the wind is moving away from sensitive areas.
- Use buffer zones on the downwind boundary of fields adjacent to sensitive areas.

STATE AND LOCAL REGULATIONS CONCERNING PESTICIDE APPLICATION

Federal and state laws regulate the application of restricted materials for agricultural use (e.g., Worker Protection Standard), but other state and local restrictions also may apply. For example, in California, counties may elect to impose additional requirements and issue permits that regulate application of restricted-use materials, including cotton harvest aids. Variations in local permitting primarily are aimed at reducing the potential for exposure in the proximity of rural schools and residences.

In addition to the standard permit conditions required in California for application of restricted-use harvest-aid products (e.g., tribufos and paraquat) and buffer zones of one-eighth or one-half mile from designated areas or structures, the grower/operator must: 1) provide a copy of his permit to each pest control advisor in his employ; 2) issue a written request for the application of a specific restricted material to a certified applicator; 3) file a Notice of Intent to treat a specified field or area; and 4) file monthly reports on the identities and quantities of pesticide purchased and used to the County Agriculture Commissioner's office.

Other cotton states generally are not as restrictive as California, but the crop protection products user community needs to be aware of state and local laws and regulations, and of local concerns and sensitivities, then respond in a proactive and neighborly manner. It also is important to know your local regulator.

SUMMARY

Cotton defoliants and desiccants played a major role in the rapid, widespread adoption of mechanical cotton pickers and strippers in the United States during the 1940s and 1950s. Now products that induced uniform boll opening, defoliation, or desiccation enable crops to be mechanically harvested when yield and quality are at or near their peak. This also enables seed cotton to be moduled and stored in fields or gin yards for extended periods with little risk of damage to the lint or seed.

In relation to other crop protection products used in cotton, harvest aids are unique in that they are applied only after some or most of the bolls open. As a consequence, harvest aids are the primary products that make direct contact with, and deposit residues on, the crop components that will be harvested, including lint, seed, and plant by-products.

SAFETY ISSUES

As with other crop protection products, safety issues and environmental concerns have been raised by individuals, public groups, and governmental entities, both in the United States and abroad. Some of these concerns continue to be based more on perception than on sound science and research findings. This is what occurred with the use and subsequent loss of the desiccant, arsenic acid. This product, because of a nearly universal negative perception combined with a few legitimate environmental and safety concerns, rare instances of misuse, and the reluctance on the part of industry to adapt available corrective technologies, ultimately was withdrawn from the market.

The case of arsenic acid clearly illustrates how "downstream" processing consequences that occur in the gin, cottonseed processing, and textile mill industries may have more impact on the viability of a product (or class of products) than the in-field risks associated with its use. Compliance with labeled requirements to attain the least-cost, lowest acceptable level of defoliation or desiccation with a harvest-aid product may suffice to get the crop out of the field but inadvertently may create a multitude of problems for gins and textile mills. These include over-cleaned cotton (high short-fiber content), particulate matter emissions, and solid waste disposal.

Excessive levels – or even the presence – of some chemical residues can disqualify cotton shipments for qualifying for ecolabel status, cause unwanted solid materials to be classified as hazardous wastes, and result in failure of textile mill effluents to meet residue limits for discharge. Because many of these problems are associated with the waste materials, the appropriate harvest aids should be used to leave as much of these materials in the field as is economically practical for the farmer.

INCREASING RESTRICTIONS ON USE

Crop protection products, including harvest aids, are required to undergo periodic EPA reviews that typically result in more use restrictions and even in the loss of product registrations. The discovery, development, and registration costs for new products are exorbitant and typically require 10 years to complete. Consequently, relatively few new products are being brought to market.

PROACTIVE PRACTICES

To counter negative perceptions and protect the harvest-aid products currently on the market, it has become increasingly important for the entire cotton community – producers, producer organizations, consultants, Extension and research personnel, applicators, and manufacturers – to become more proactive in practicing and promoting good stewardship and safe application of all crop protection chemicals, including cotton harvest aids.

Users of these products must remain mindful of the circumstances under which these products are being used. It is vitally important to structure use practices to be environmentally sound and to ensure safety for adjacent crops, people, and their property in nearby communities. Good communication is the key factor in maintaining good relationships with both neighbors and customers.

GLOSSARY

CAA – Clean Air Act, 42 U.S. Code 1251 et seq.

CERCLA (Superfund) – Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S. Code 9601 et seq.

CFR – Code of Federal Regulations. This is where the U.S. federal regulations after promulgation are codified. The preceding number is the Title, the succeeding number (after CFR) is the Part of Section (e.g., 29 CFR 1910 is Title 29 Code of Federal Regulations at Part 1910).

CWA – Clean Water Act (Federal Water Pollution Control Act), 33 U.S. Code 1251 et seq.

EPA – Environmental Protection Agency, 42 U.S. Code 4321 et seq.

FFDCA – Federal Food, Drug and Cosmetic Act, 21 U.S. Code 321 et seq.

FIFRA – Federal Insecticide, Fungicide and Rodenticide Act, 7 U.S. 135 et seq.

FQPA – Food Quality Protection Act of 1996. It amended FIFRA pesticide registration/tolerance-setting requirements and the FFDCA.

FR – Federal Register. This is where regulatory announcements and new rules and their justification are published. The preceding number is the volume, the succeeding number (after FR) is the page, usually followed by the date when it appeared (e.g., 51 FR 27956 is Volume 51 Federal Register, page 27956).

HAP – Hazardous Air Pollutant, 40 CFR 61.

HCS – Hazard Communication Standard, 29 CFR 1910.1200.

NAAQS – National Ambient Air Quality Standard under the CAA (for criteria pollutants), 40 CFR 50.

NESHAP – National Emission Standard for Hazardous Air Pollutants under the CAA.

Nonattainment – Areas that are not meeting NAAQS, 40 CFR 51.100 et seq.

NPDES – National Pollution Discharge Elimination System. The national permit program under the CWA, 40 CFR 122.

OSHA – Occupational Safety and Health Administration (part of the Dept. of Labor), 29 U.S. Code 651 et seq.

Ozone – One of the criteria pollutant NAAQS; denotes chemical that is formed through chemical reaction in the atmosphere involving VOC, NO_x, and sunlight; also a primary constituent of smog.

PEL – Permissible Exposure Limit for an air contaminant under OSHA standards.

PM – Particulate Matter. One of the criteria pollutant NAAQS; denotes the amount of solid or liquid matter suspended in the atmosphere. The EPA regulates PM as PM_{10} (particles 10 mm and less) and $PM_{2.5}$ (fine particulates 2.5 mm or less). Some states also regulate PM as total suspended particulate (TSP).

RCRA – Resource Conservation and Recovery Act, 42 U.S. Code 6901 et seq.

RCRA Characteristic Wastes – Hazardous wastes that are ignitable, corrosive, reactive, or toxic, 40 CFR 260.64.

RCRA Listed Wastes – Specially listed hazardous wastes in 40 CFR 261.30-33.

TAC – Toxic Air Contaminant. Specified in California state regulations.

TCLP – Toxic characteristic leaching potential under RCRA, 40 CFR 261.24.

Title V – The part of the CAA that deals with federal permits, 40 CFR 70.

U.S. Code – The United States Code where legislation, including health, safety, and environmental legislation, is codified once it is passed by Congress (e.g., 42 U.S. Code 7401 is Title 42 U.S. Code at paragraph 7401).

VOC – Volatile Organic Compounds. A group of chemicals that react in the atmosphere with nitrogen oxides (NOx) in the presence of heat and sunlight to form ozone; does not include compounds determined by EPA to have negligible photochemical reactivity.

WPS – Worker Protection Standard under EPA, 40 CFR 170.

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Chapter 11

COTTON HARVEST-AIDS AND BIOTECHNOLOGY: THE POSSIBILITIES

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INTRODUCTION

The success of any crop improvement program relies on sufficient genetic variability to introduce or improve desired traits. Traditionally, when the required variability is not present, it must be induced by mutations or bred with related species for characteristics that are absent in the cultivated species (Bajaj, 1998). Such methods normally take several years to accomplish; however, genetic engineering and other forms of biotechnology can provide an approach that allows hybridization among different species in a shorter time frame, as well as transferring a greater variety of genetic information in a more precise, controlled manner. Biotechnology also may be used to facilitate or enhance traditional breeding programs. This is adventitious for the cotton industry, as many wild species of *Gossypium* are available to provide sources of genetic variability (Prentice, 1972).

Advances in the use of biotechnology for crop improvement have led to dramatic increases in acreage of genetically enhanced cotton over the last few years (Anonymous, 2001b). U.S. cotton farmers planted genetically enhanced seed on more than 11 million acres in the 2000 growing season (Anonymous, 2001c). In that year, genetically enhanced cotton acres compromised 69 percent of total cotton acreage (Anonymous, 2001a).

Transgenic technology – The most successful approach for insect resistance in cotton (and other important agronomic crops) has been through the use of the bacterium, *Bacillus thuringiensis (Bt),* which produces proteins toxic to some of the insects most damaging to cotton. Commercially introduced by Monsanto Company in 1996, Bollgard® cotton varieties are genetically engineered to code for a delta endotoxin of *Bt.* Bollgard varieties provide effective control of tobacco budworm, pink bollworm, and salt marsh caterpillar, and suppression of several other lepidopterous pests, e.g., bollworm, loopers, and beet armyworms. However, *Bt* toxins currently available are ineffective against insects such as whitefly, thrips, boll weevil, and lygus bug; research continues for improving protection of cotton from insect attack. In addition, questions persist about the *Bt* toxin and its insect specificity and development of resistance to the toxin by target insect populations.

Another successful trait introduced into cotton is one that confers resistance to the herbicide glyphosate (Roundup®). Roundup Ready® (Monsanto Company) has demonstrated excellent tolerance to Roundup Ultra® (glyphosate) herbicide up to the four-leaf stage. Approved in 1996 and first commercially grown in 1997, Roundup Ready cotton varieties tolerate both topical and post-directed applications of Roundup herbicide. Some of these transgenic varieties also possess the Bollgard gene for insect protection. Although Roundup Ready cotton has been successful, concerns with fruit abortion and excessive cavitation on these cotton varieties have been voiced (Edmisten and York, 2000).

Bromoxynil-resistant cotton (BXN®) (Stoneville Pedigreed Seed Co.) was the first transgenic cotton variety released, but it has not met with the same initial success as have the Bollgard and Roundup Ready traits. However, as the advantages of transgenic technology become more evident, BXN cottons will gain much greater acceptance in certain production areas of the U.S. Cotton Belt.

BXN varieties contain a gene that produces an enzyme (nitralase) that gives these transgenic varieties the ability to metabolize bromoxynil, a broadleaf herbicide. This allows Buctril® (bromoxynil) herbicide (Aventis Group) to be applied postemergence for topical control of most broadleaf weeds found in cotton fields (e.g., cocklebur, common ragweed, and all species of morningglory) (York and Culpepper, 2000). Cotton varieties with the BXN trait were introduced to farmers in 1995. In 1997, the Environmental Protection Agency announced its decision to deny the company's petition to extend the use of the herbicide Buctril on gene-altered cotton for the 1998 growing season (Kantz, 1998). The decision was based on the company's failure to meet certain risk assessment guidelines for bromoxynil, as prescribed by the Food Quality Protection Act. However, in May, 1998, registration of Buctril on BXN cotton cultivars finally was approved (Byrd, 1998).

In addition to the single-gene transgenic varieties, grower demand for multiple-gene, or "stacked," varieties is increasing. An example is Stoneville Pedigreed Seed Co.'s ST 4892BR™ variety, which stacks the protection of Bollgard and the weed control attributes of Roundup Ready.

Gene Research – New developments in gene identification and transformation technologies will assist in the development of more transgenic applications, such as cotton plants possessing novel genes involved with fiber modifications, parental gene expression, and key physiological pathways. For example, the National Science Foundation awarded a federal grant for a three-year cotton gene research project, focusing on the triggering mechanism of fiber development, to be headed by the University of California-Davis (Geissinger, 1999). The National Science Foundation also is funding a unique study on the expression of parental genes in plant polyploids (where more than one parental genome is present). A research team has been assembled under a grant to study what, if any, impact parental gene expression contributes to the success of important polyploid crops such as canola, cotton, corn, potatoes, and wheat (Fannin, 2000).

Research focusing on plant genomes also is in progress. Independently investigating drought- and freezing-tolerance mechanisms, another University of California-Davis research team is working on manipulating complex pathways through key regulatory genes, as opposed to the typical genetic engineering of single genes or a small number of genes to synthesize a particular compound (Amber, 2000).

Monsanto Company has conducted research on development of a "Technology Protection System" (TPS) or "terminator" gene. Transgenic varieties incorporate the TPS gene, in which – when the plant nearly is mature – the introduced plant gene becomes active, stopping the seed from making the protein required to produce new plants (Nixon, 1999). However, the company has altered the project's goal. Monsanto Company now is working on other "gene-protection technology," which would discourage farmers from planting seeds from a previous crop by inactivating only the specific gene responsible for the value-added biotech trait (Pro Farmer Editors, 1999).

Genetic engineering to confer useful agronomic traits to cotton is likely to lower the cost of production, improve yield and quality, and promote environmentally friendly farm practices (Bajaj, 1998). To date, biotechnology has not been commercially applied to the area of cotton harvest aids. However, this may change as stricter regulations are established regarding chemical use and as costs increase. The potential exists to manipulate physiological processes to enhance harvest-aid efficiency. This chapter explores these possibilities as well as briefly describing some of the technology that could be used to achieve physiological goals.

PHYSIOLOGICAL ASPECTS SUITABLE FOR GENETIC MANIPULATION

Specific combinations of hormones and their relative concentrations are important regulators of plant growth and development. In early studies, genes from *Agrobacterium tumefaciens* were shown to alter the levels of cytokinin and auxin in plants, demonstrating that the ratio of these hormones can control root and shoot production (Klee *et al.*, 1987; Medford *et al.*, 1989). Many physiological processes directly affected by hormonal signals are triggered by environmental circumstances. In these cases, production of the hormone does not involve changes in gene expression. Therefore, genetic manipulation at the level of hormone production is very complex and, in fact, may not be entirely useful. However, development of the receptor (protein) that the hormones bind to usually is genetically regulated and is active only in certain tissue at certain times. Therefore, enhancing the cotton harvesting process by genetically manipulating hormonally regulated physiological aspects of the plant may be a key area for future research.

REGULATION OF ABSCISSION/SENESCENCE BY ETHYLENE AND AUXIN

Regulation of abscission within cotton plants will greatly enhance harvest efficiency and fruit retention. As with many other plant processes, the process of abscission is not simple. Although auxin and ethylene play the major roles in abscission, gibberellin, abscisic acid, and cytokinins also have important effects. The promotion of abscission by gibberellin, abscisic acid, and cytokinin results from stimulating ethylene production, while auxin appears to be mediated, at least in part, by phytochrome. The phytochrome molecule senses changes in day length and produces a signal transduction cascade that causes the plant to start the process of senescence and abscission (leaf drop). The start of the abscission process usually is noted by a marked decrease in auxin levels within the leaf.

In general, ethylene enhances abscission by promoting the formation of an abscission zone. Abscission occurs in specific cells at the base of some petioles, leaves, floral organs, and fruit; however, not all plant parts have abscission layers or exhibit ethylene-enhanced abscission. Such is the case with cotton plants in which abscission zones form in the leaves, but not in mature cotton fruit. This allows ethylene-releasing compounds to be used on mature cotton plants, defoliating them without causing fruit drop.

The abscission zone that forms at the base of fruit, flowers, and leaves consists of one or more layers of thin-walled cells. Just before abscission occurs, certain cells within the abscission layer (the cells farthest from the stem) are digested by cellulases and pectinases. In addition to increases in cell wall-degrading enzymes, there is an unequal pattern of growth within the abscission zone, resulting in leaf, fruit, or flower drop. This process can be delayed by high levels of auxin.

The enzymes responsible for abscission are genetically regulated (Salisbury and Ross, 1992). For example, levels of mRNA molecules coding for cellulase have been found to increase following increases in ethylene production (Ruperti *et al.*, 1998). Ethylene has been shown to increase the steady state level of endopolygalacturonase mRNA in the abscission zone of peach trees (Bonghi *et al.*, 1992) and increases a protein kinase in the abscission zone of some plant species (Sessa *et al.*, 1996).

Abscission-specific genes have been identified in cotton that may be modified through genetic manipulation (Peterson *et al.*, 1996). A study by Del Campillo and Bennett (1996) suggests that abscission in tomatoes is a multistep process involving both activated and repressed cellulase genes, and that the relative importance of each cellulase in the process of abscission depends on the physiological conditions under which abscission takes place. Bean-leaf abscission has been correlated with the *de novo* accumulation of a cellulase and mRNA accumulation (Koehler *et al.*, 1996). In this study by Koehler *et al.*, genes encoding the bean leaf abscission cellulase were isolated and partially sequenced. One study actually has identified three separate polygalacturonases that are expressed in tomato leaf abscission and flower expression, each with a different temporal expression (Kalaitzis *et al.*, 1997). Several other studies have identified genes that are involved in the process of abscission, some of which are promoted by ethylene (Taylor *et al.*, 1991; Tucker *et al.*, 1991; Coupe *et al.*, 1995; Gonzalez-Bosch *et al.*, 1997).

Although the majority of research has been conducted on other crop species, this information may be used by molecular biologists interested in cotton leaf abscission. Knowing that abscission results from many genetically regulated events and that specific genes have been identified, it may be possible to use biotechnology to regulate these events, thus regulating abscission and improving harvest efficiency. Some points of regulation may be genes involved in the production of cellulase, and ethylene and auxin activity. It also is conceivable that a plant could be genetically regulated to prevent formation of an abscission zone in young squares, flowers, or bolls, thereby preventing premature abscission and potential losses in yield. Another possibility is to modify the cotton plant in such a way that zone forms at maturity or from a day-length signal, so natural defoliation could occur without the application of harvest-aid chemicals.

BOLL DEVELOPMENT

Uniform boll development is desirable for proper cotton harvest; however, the indeterminate nature of the cotton plant results in unequal maturation of cotton bolls. At harvest, chemicals can be applied to the plant to cause as many bolls to open as possible.

The process of boll opening is similar to the formation of an abscission zone during the defoliation process. The harvest-aid chemical, ethephon, increases the natural ethylene level in mature closed bolls, causing them to open. Premature use of ethephon may cause the opening of immature bolls containing fiber inferior to that of bolls that were set earlier (Kerby and Ruppenicker, 1989).

Crop uniformity is a management objective influenced by every aspect of production. Weather and insect pests cause the greatest variations in crop maturity, from delayed plantings with poor stands to irregular fruit set during the season. Management options help reduce the impact of these natural factors. A more uniform boll set accomplishes two important management goals. First, it provides more open bolls for a timely once-over harvest. Second, the fiber within the bolls will be of uniform quality (Hake *et al.*, 1996).

Several studies with plant species other than cotton have identified genes related to fruit ripening that may aid in improving uniformity in boll development. In a study by Hadfield *et al.* (2000) on melon fruit, cDNAs corresponding to mRNAs – whose abundance is ripening-regulated and fruit-specific – were identified. One of these mRNAs encodes for a protein corresponding to 1-amino-cyclopropane-1-carboxylic acid (ACC) oxidase, an important enzyme in the ethylene biosynthesis pathway. The other identified mRNAs encode for proteins involved in amino acid biosynthesis and seed storage. Several other studies have identified additional ripening-related genes (Rebers *et al.*, 1999; Sato-Nara *et al.*, 1999; Zegzouti *et al.*, 1999).

REGROWTH

Cotton is a perennial plant grown as an annual. If the cotton plant is exposed to available soil moisture and warm temperatures following defoliation, it will resume growth by sprouting new vegetation. Regrowth vegetation is difficult to defoliate, because the juvenile tissue does not form abscission zones.

Regrowth of foliage after defoliation of a cotton plant is not desirable because of its potential to interfere with harvest and to stain the cotton fiber (Hake *et al.*, 1996). Excessive regrowth vegetation must be desiccated before harvest, requiring additional harvest-aid chemicals. Additional chemical treatments often are insufficient to prevent staining during harvest and storage.

Off-color or stained cotton is marketed at a discounted value. Additional cleaning to remove stained fibers is not practical, because of the reduced quality of the cotton and increased processing costs. Newly formed leaves also will add to the trash content. Excess trash requires that the cotton be passed through multiple gin cleaners, reducing the amount of fiber (i.e., some fiber is lost during each cleaning). Bringing clean cotton to the gin benefits the producer by reducing lint losses and preserving fiber quality.

In the specific case of regrowth in cotton after defoliation, the hormones of most concern are those involved in shoot formation (auxin, gibberellic acid, and ethylene). For example, high levels of auxin present in late-season regrowth will make new foliage less likely to defoliate when subsequent defoliation compounds are applied, because of the lack of abscission-layer formation. One method of controlling regrowth in cotton plants after defoliation may occur at the level of receptor formation. Hormone receptors are proteins that the hormone binds to in order to cause a plant response (e.g., regrowth). Regulation at the level of hormone production would not be practical, as many environmental circumstances also can cause hormone production without gene involvement. Regulation of receptor formation would prevent a particular hormone from causing a response, regardless of hormone concentration.

ENHANCED ABSORPTION OF HARVEST AIDS ON LEAF SURFACES

The cuticle of the leaf protects it from excessive water loss and also serves as a deterrent to chemical entry. Environmental conditions affect the thickness of the cuticle as well as its composition. For example, research has demonstrated that, under hot, dry conditions, cotton leaf cuticle thickness increased by 33 percent, and uptake of defoliant was reduced by 34 percent (Oosterhuis *et al.*, 1991). The general practice of adding surfactants or spreaders to the spray solution can increase the contact of the defoliant with the leaf surface, while, under conditions that favor a thick waxy layer, the addition of crop oils to the spray solution increases chemical entry and improves defoliation.

Although a relatively thick cuticle is desirable throughout most of the life of the plant to reduce water loss, a thinner cuticle at the time of defoliant application would be beneficial. If a cotton plant could be developed that reduces its waxy layer as it reaches full maturity, chemical defoliants could enter the leaf more easily. This would result in the use of smaller quantities of defoliants, surfactants, and oils. Some studies related to pathogen attack on leaf surfaces have identified genes that code for proteins (enzymes) that aid in the degradation of pectic polymers. These enzymes include several pectinolitic enzymes and pectin methylesterase (Gaffe, 1997; Shevchik, 1999). It may be possible to identify these genes in cotton or to introduce them into cotton plants to induce a change in leaf wax composition and thickness as the plant gets closer to the defoliation period.

INCREASED RETENTION OF SQUARES, FLOWERS, AND BOLLS

A greater number of retained squares produces more flowers, which results in more harvestable bolls. Squares, flowers, and young bolls (<10 days post anthesis) will abscise because of many factors. Some of these factors include insect attack, water stress, nutrient stress, and poor weather conditions (Kerby and Hake, 1996). A possible point of regulation for increasing retention is to develop plants that do not form abscission zones in the flowers, squares, and young bolls, or that form them at a slower pace.

Important points of regulation would be to control or to stop the presence of cellulase activity in young flowers, squares, and bolls. Localized regulation in these areas is desired, as foliage still would require abscission zones and cellulase activity for defoliation to occur. The most likely successful point of regulation is in the site-specific control of cellulase production and other enzymes involved in the formation, degradation, and separation of the abscission zone.

The physiological processes mentioned here generally are thought to be closely linked to cotton defoliation practices. However, modifications in water-stress tolerance, insect and herbicide resistance, growth characteristics, and fiber quality are areas that may assist the harvesting process by providing a healthy plant that produces a high-quality cotton crop. The following section discusses possible techniques that may help in improving the physiological processes that have been noted.

USE OF BIOTECHNOLOGY TO ACHIEVE PHYSIOLOGICAL GOALS

Significant progress has been made in biotechnology in general, accompanied by an increase in its uses for the improvement of cotton. "Biotechnology" has been defined as "the collection of industrial processes that involve the use of biological systems" (King and Stansfield, 1990). Some of the most dynamic techniques relating to agriculture are the sequencing of plant genomes, comparative mapping across species with genetic markers, and objective-assisted breeding after the identification of candidate genes or chromosome regions for further manipulations (Ortiz, 1998).

Resources – This section briefly describes some of these techniques and tools that could be applied toward achieving the physiological goals previously discussed. A number of excellent resources are available (see the Literature Cited section at the end of this chapter), if more information is desired. Examples of such resources include:

Bajaj, Y.P.S. 1998. *Biotechnology in Agriculture and Forestry, 42: Cotton.* Springer Verlag, New York.
Bains W. 1998. *Biotechnology from A to Z.* Oxford University Press, New York.
Maniatis T., J. Sambrook, and E.F. Fritsch. 1989. *Molecular Cloning : A Laboratory Manual* (Three-Volume Set). Cold Spring Harbor Laboratory Press, New York.
Mather J.P., and P.E. Roberts. 1998. *Introduction to Cell and Tissue Culture: Theory and Technique (Introductory Cell and Molecular Biology Techniques).* Plenum Publishing Corp., New York.
Paterson, A.H. 1997. *Molecular Dissection of Complex Traits.* CRC Press LLC, Boca Raton, FL.

PLANT GENOMICS/MOLECULAR MARKERS

Plant genomics, the science that seeks to understand how genes enable a plant to carry out its functions as a living organism, is a newly emerging field based on the developing technology of gene sequencing. The information derived from studies of plant genomics will enable scientists to investigate how the diversity of functions in all plants is related to simple changes in individual genomes (Delaney *et al.*, 1998). The field effectively began in 1989 with the initiation of the Multinational *Arabidopsis* Genome Research Project (Clutter, 1999). Ultimately, plant genomics may be applied to modifying plants for optimal performance. For example, more information may be available on why plant-resistant genes are clustered together and how they may be manipulated (Paterson, 1997). Commercial crops from this new research area even may be available within the next few years (Gwynne, 1999).

Linkage is a familiar concept in genetics that dates back to the early studies on *Drosophila* (fruit fly), when it was shown that combinations of genes tended to be inherited as groups, linked together because of proximity to one another on the same chromosome (Watson *et al.*, 1992). As linkage relationships are identified as a result of the increasing number of known genetic markers for plant chromosomes, chromosome maps can be constructed. Markers found to be linked to important agronomic characteristics also can be used to select for those characteristics in breeding programs. Some of the techniques used to manipulate and analyze genomes already are well established, while a great deal of ingenuity and energy is being expended in devising new methods to overcome the technical difficulties inherent in tackling entire genomes (Watson *et al.*, 1992).

GENETIC TRANSFORMATION

Some of the major limitations of genetically transforming agronomically important crops are the extreme difficulty of isolating and maintaining viable protoplasts, the inefficiency of current transformation methods, and, in particular, the inability to regenerate complete fertile plants from transformed cells (Smith, 2000). *Agrobacterium*-mediated transformation and particle bombardment of target tissue, followed by regeneration through somatic embryogenesis, are two techniques commonly used to transform cotton (Peeters and Swennen, 1998). *Agrobacterium*-mediated transformation is useful for introducing single genes, such as those responsible for many insect or herbicide resistances (Umbeck *et al.*, 1987), while particle bombardment allows for the introduction of multiple genes. A third technique involves the direct DNA uptake into protoplast, analogous to plasmid transformation of bacterial cells.

***Agrobacterium*-mediated transformation** is the method most commonly used to genetically alter cells of dicotyledonous plants. *Agrobacterium tumefaciens* is a naturally occurring pathogenic bacteria in the soil that has the ability to transmit a tumor-inducing plasmid into an adjacent living plant cell. Strains of *A. tumefaciens* carrying the plasmid may be genetically engineered artificially (without causing tumor induction) to introduce foreign genes of choice into plant cells (King and Stansfield, 1990). The process of gene transfer from *A. tumefaciens* to plant cells is quite complex and involves a number of procedures, including bacterial colonization, induction of the bacterial virulence system, and T-DNA transfer and integration into the plant genome (de la Riva *et al.*, 1998).

Particle bombardment (or biolistics) is the technique whereby microscopic particles of tungsten or gold, coated with genetically engineered DNA, are explosively accelerated into cells (Forbes *et al.*, 1999). Transformation efficiencies are affected by the attributes of the particles used, surface properties of the bombarded tissue, and turgor pressure of the cell. A variety of particles and acceleration systems are available to introduce genetic material into cells.

CLONAL PROPAGATION

The cotton plant is propagated by seed and is cultivated as an annual crop. Deterioration of varieties occurs because of natural crossing and mechanical mixtures during the ginning process. Clonal techniques could be helpful in maintaining varietal purity. In addition, transgenic plant production, regardless of method, requires the ability to regenerate plants from single (or a small number of), isolated transfected cells (Old and Primrose, 1989). Clonal propagation, a tissue culture technique, allows plant cells and tissue to be regenerated into mature, fertile plants. Two such clonal propagation methods are somatic embryogenesis and protoplast cultures.

Somatic embryogenesis is a complex process of making artificial (cloned) seeds using an asexual means of reproduction. The process has been a significant achievement in plant tissue culture as a target for genetic engineering and for the production of synthetic seeds. This method also has greater potential for inexpensive, large-scale propagation than current methods (e.g., seeds, macropropagation, and micropropagation) (Thompson, 1998). The phenomenon of somatic embryogenesis has been reported in about 300 species of plants (Bajaj, 1998). However, regeneration through somatic embryogenesis is genotype-dependent (Trolinder and Chen, 1989). Somatic embryogenesis in cotton first was observed in suspension cultures of the wild species, *G. klotzschianum* (Price and Smith, 1979), with considerable progress being made since this first observation (Gawel and Robacker, 1995).

Protoplast cultures. Protoplasts – cells whose walls have been removed – have proved suitable for gene transfer in a number of agricultural crops (Bajaj, 1994). With the right combination of the plant hormones, auxins and cytokinins, transformed protoplasts can be induced to regenerate cell wall and callus, as well as whole plants (Smith, 2000).

Applications of protoplast technology are limited, as many species of economic importance fail to regenerate with this method (de Marco and Roubelakis-Angelakis, 1996). In cotton, although protoplasts have been isolated by a number of researchers (Firoozabady and DeBoer, 1986; Chen *et al.*, 1989; Peeters *et al.*, 1994), the regeneration of complete plants is a comparatively recent development (Bajaj, 1998).

SUMMARY

The genetic engineering of plants has facilitated the production of agronomically desirable crops that exhibit increased resistance to pests, herbicides, pathogens, and environmental stress, and enhancement of qualitative and quantitative crop traits (Gasser and Fraley, 1992). Commercially available transgenic cotton varieties include Bollgard, Roundup Ready, and BXN traits. New developments in gene identification and transformation technologies will assist in increasing the number and type of transgenics on the commercial market.

A number of cotton research projects, not yet at the commercial development stage, are investigating novel avenues of genetic engineering. Examples discussed in this chapter include gene research projects focused on improving cotton fiber quality (Geissinger, 1999), the impact of parental gene expression (Fannin, 2000), manipulating complex pathways (Amber, 2000), and a "gene protection" technology (Pro Farmer Editors, 1999).

To date, biotechnology has not been commercially applied to the area of cotton harvest aids. The future may be different, as stricter safety regulations and policies are established, and as costs of chemicals and their application increases. Fortunately, the potential exists to manipulate many physiological processes, resulting in enhanced harvest-aid efficiency. Some of these physiological processes include abscission/senescence, boll development, regrowth of foliage, absorption quality of the leaf surface, and retention properties of squares, flowers, and bolls.

Genetic engineering to confer useful agronomic traits to cotton is likely to lower the cost of production, improve yield and quality, and promote environmentally friendly farm practices (Bajaj, 1998). Along with these many benefits, though, comes the potential for adverse ecological effects, because of the often-sustained expression of the engineered traits in the genetically engineered (transgenic) plant and the persistence of the transgenic plant or plant residue in the environment (Donegan and Seidler, 1998). Other concerns include reduction of genetic diversity, new pest emergence, changes in ecosystem dynamics, chemical contamination, and genetic pollution (Charest and Duchesne, 1995). However, with careful monitoring and responsible handling of the advancements possible from genetic engineering, benefits to society may be achieved with minimal environmental risk.

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INDEX OF TRADE NAMES, PRODUCTS, AND COMPOUNDS[1]

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[1] Some products are sold under several trade names, and this listing may be incomplete. An attempt was made to use the original and the most recognizable trade names. Some of the products listed no longer are available or labeled for use as cotton harvest aids.

SUBJECT INDEX