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 $\mu g/m^3$)[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 $\mu g/m^3$; other samples in ppm.

[3] OSHA PEL: Inorganic As. = 10 $\mu g/m^3$; organic As. = 500 $\mu g/m^3$.

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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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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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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COTTON HARVEST MANAGEMENT:
Use and Influence of Harvest Aids

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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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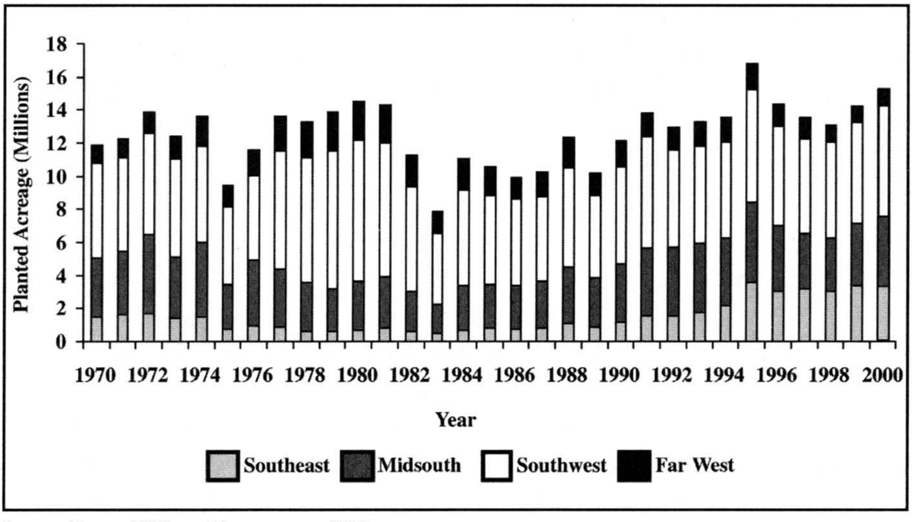
PREFACE

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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