Chapter 1

A HISTORY OF COTTON HARVEST AIDS

Stephen H. Crawford
Professor Emeritus
Louisiana State University Agricultural Center
St. Joseph, Louisiana

J. Tom Cothren
Department of Soil and Crop Sciences
Texas A&M University System
College Station, Texas

Donna E. Sohan
Department of Letters, Arts, and Sciences
University of Colorado
Colorado Springs, Colorado

James R. Supak
Department of Soil and Crop Sciences
Texas A&M University System
College Station, Texas

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).

LITERATURE CITED

Anonymous. (1951). *Defoliation guide*. Memphis, TN: National Cotton Council.

Brown, H. B., & J. O. Ware. (1958). *Cotton* (3rd ed.). New York: McGraw Hill.

Colwick. R. F., & Technical Committee Members. (1965). S-2 cotton mechanization project. Mechanized harvesting of cotton. *Southern Cooperative Series Bulletin* (No. 100, March). Mississippi State: Southern Association of Agricultural Experiment Station Directors (SAAESD), Mississippi State University.

Elliott, F. C. (1967). Defoliation with anhydrous ammonia and desiccation with arsenic acid in Texas. *Cotton Defoliation and Physiology Conference Proceedings*, 9-10.

Environmental Protection Agency. (1987). *Paraquat Fact Sheet* (No. 131). Washington, DC: National Service Center for Environmental Publications.

Environmental Protection Agency. (1993). Arsenic acid; receipt of request to cancel; cancellation order. *EPA Publication* (58 FR 26975, May 6). Washington, DC: National Service Center for Environmental Publications.

Ergle, D. R., & A. A. Dunlap. (1949). Responses of cotton to 2,4-D. *Texas Agricultural Experiment Station Bulletin* (No. 713). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Hudspeth, E. B., Jr. (1977). Status of once-over harvest machinery development. Summary *Proceedings Western Cotton Production Conference,* 58-59.

Kirk, I. W., E. B. Hudspeth, Jr., & D. F. Wanjura. (1964). A broadcast and narrow-row cotton harvester. *Texas Agricultural Experiment Station Progress Report* (No. 2311, May 7). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Miller, C. J., & M. M. Aboul-Ela. (1969). Fate of pentachlorophenol in cotton. *Journal of Agricultural and Food Chemistry, 17*, 1244-1246.

Miller, C. J., T. P. Brendel, & P. C. Koska. (1978). Search for a new cotton desiccant. *Proceedings of the Beltwide Cotton Research Conferences,* 60.

Miller, C. J., T. P. Brendel, A. McGinley, & B. Butler. (1980). Cotton variety defoliation tests in Texas - 1978. *Texas Agricultural Experiment Station Miscellaneous Publication* (MP, March, pp.1445-1453). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Miller, C. S., & J. Corbett. (1962). Possible disadvantages of using 2,4-D with pentachlorophenol as a desiccant for cotton. *Texas Agricultural Experiment Station Miscellaneous Publication* (MP-597). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Ray, L. L., & D. L. Jones. (1960). Comparison of cotton harvesting systems on the High Plains. *Texas Agricultural Experiment Station Miscellaneous Publication* (MP-403). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Schroeder, E. W., & J. G. Porterfield. (1954). The development of the Oklahoma brush-type cotton stripper. *Oklahoma Agricultural Experiment Station Bulletin* (B-422, April). Stillwater: Agricultural Communications Services, Division of Agricultural Sciences and Natural Resources, Oklahoma State University.

Smith, H. P., D. T. Killough, D. L. Jones, & M. H. Byrom. (1935). Progress in the study of the mechanical harvesting of cotton. *Texas Agricultural Experiment Station Bulletin* (511, September). College Station: Agricultural Communications, The Texas A&M University System Agriculture Program.

Snipes, C. E., & G. W. Cathey. (1992). Evaluation of defoliant mixtures in cotton. *Field Crops Research,* 28, 327-334.

Sutton, R. M. (1984). The importance of multi-stage lint cleaning in the cotton ginning industry. *Company Handout.* Lubbock, TX: Horn & Gladden Lint Cleaner Co.

Walhood, V. T. (2000). *Personal communication.*

Walhood, V. T., & F. T. Addicott. (1968). Harvest aid programs: Principles and practices. In F. C. Elliot, M. Hoover, & W. K. Porter, Jr. (Eds.), *Advances in production and utilization of quality cotton: Principles and practices* (pp. 407-431). Ames: Iowa State University Press.

Williamson, E. B. & J. A. Riley. (1961). Interrelated effects of defoliation, weather and mechanical picking on cotton quality. *Transactions of the American Society of Agricultural Engineers, 4*(2).

ADDITIONAL REFERENCES

Crawford, S. H. (1979). Study compares cotton defoliants. *Louisiana Agriculture, 22*(4), 8-9.

Crawford, S. H. (1980). Acceleration of cotton boll opening with GAF-7767141. *Proceedings of the Cotton Physiology Conference, 34*, 35.

Crawford, S. H. (1981). Accelerating cotton boll opening with foliar treatments. *Louisiana Agriculture, 25*(1), 12-13.

Crawford, S. H., R. B. Leonard, & K. R. Carroll. (1987). Cotton response to timings of harvest aid treatment. *Proceedings of the Cotton Physiology Conference, 41*, 82.

Defoliation Steering Committee. (1949). *Report of progress from the defoliation steering committee.*

Kasasian, L. (1972). *Cotton Technical Monograph* (No. 3, pp. 64-68). Basel, Switzerland: Ciba-Geigy AG.

McIlrath, W. J. (1955). Effects of 2,4-D on cotton. *The Cotton Gin and Oil Mill Press, November.*

McIlrath, W. J., & D. R. Ergle. (1953). Developmental stages of the cotton plant as related to the effects of 2,4-D. *Botanical Gazette, 114*, 461-467.

Smith, H. P. (1964). *Farm machinery and equipment.* New York: McGraw-Hill.