Chapter 3

TRENDS IN WEED CONTROL METHODS

Gale A. Buchanan
University of Georgia
Coastal Plain Experiment Station
Tifton, Georgia

INTRODUCTION

Weeds are a major problem in the production of cotton (*Gossypium hirsutum* L.). Their control requires considerable crop managerial skills and represents major expenditures in the production of the crop. It is not surprising that weeds are such a significant problem in the production of cotton. First, cotton emerges and grows slowly during the first few weeks after planting, particularly during cool weather or under other adverse growing conditions. There are numerous insects and diseases of cotton that may also inhibit its competitiveness with weeds during the early growth period. It is only after the cotton plant has become well established and soil temperature is greater than 75F (24C) that the plant becomes competitive. During this entire early period of establishment, usually the first 9 to 10 weeks after planting, control of weeds is a necessity for orderly development of cotton (Buchanan and Burns, 1970).

Weeds are those plants that seriously interfere with other plants that humans grow for food, feed, fiber or for asthetic reasons (lawns, flowers, etc.). Only a very few—probably less than 30,000 of the more than 300,000 species of plants found throughout the world—are weeds in any crop. Indeed, Holm *et al.* (1977) suggest that probably no more than 200 species account for approximately 95 percent of the weed problems in food and fiber production.

While there are few definitive data regarding the specific weeds of cotton, over 100 plant species are considered troublesome in cotton (Holm *et al.*, 1977). Several weed species are serious pests in cotton in different countries around the world. These include species in the genera *Portulaca*, *Cynodon*, *Cyperus*, *Eleusine*, *Sorghum*, *Echinochloa* and *Dactyloctenium*.

Observations by cotton weed scientists and reported by Whitwell *et al.* (1981) indicate over 30 genera of plants include important species of weeds in United States cotton. These include both annual and perennial as well as grass, sedge, and broadleaf species of plants. In 1980 it was estimated by these scientists that approximately 8.7 million acres of United States cotton was infected with pigweed (*Amaranthus* spp.); 4.0 million acres with sorghum (*Sorghum* spp.); 3.5 million acres with thistle (*Salsola* spp.); 3.0 million acres with nightshade (*Solanum* spp.); and 1.9 million acres with morningglory (*Ipomoea* spp.). There were some changes in the 1986 estimates where infestation was estimated as 4.9 million acres with *Amaranthus* spp.; 3.5 million acres with *Sorghum* spp; 3.9 million acres with *Proboscidea* spp.; 2.9 million acres with *Solanum* spp; and 2.4 million acres with *Ipomoea* spp. (Patterson and Monks, 1986). Estimated reduction in percentage of cotton yields in 1986 was as high as 8.0 percent for nutsedge (*Cyperus* spp.); 7.6 percent for *Sorghum* spp.; 7.8 percent for *Amaranthus*; 12.0 percent for cocklebur (*Xanthium* spp.); and 18.4 percent for *Ipomoea* spp. The widely divergent population of weeds that affect cotton ensures continuous competition pressure to the cotton crop.

The specific nature of the cotton plant and its culture have influenced the evolution of weed control procedures. In much of the United States, cotton is planted during the early spring when soil temperatures are too low for optimum growth (Buchanan, 1981). Unfortunately, there are many weed species that germinate and thrive under such conditions that are unfavorable for cotton. Casual observations in the spring reveal that many species in the genera *Cassia*, *Cyperus*, *Ipomoea* and *Xanthium* germinate and initiate growth at temperatures that are too cold for cotton.

Another complicating factor is that cotton is often produced continuously on the same land, resulting in an intensification in the populations of certain species of weeds, particularly perennials. Weeds in the genera *Cynodon*, *Sorghum*, *Cyperus* and *Solanum* are among those that increase rapidly in continuous cotton. Less common, but occasionally serious weeds that often increase dramatically in continuous cotton include trumpet creeper (*Campsis radicans* L.), and passion flower (*Passiflora incarnata* L.). The result is usually an increase in weed species that are more difficult to control with the procedures available and suitable for the crop.

METHODS OF WEED CONTROL

Methods of controlling weeds in cotton include five general categories: cultural, mechanical, biological, radiant energy or flaming and chemical. The development of these methods of managing weeds has evolved slowly and illustrates the changes that have occurred in agriculture. If there is to be an understanding of trends in weed control in cotton, the nature of the methods available for controlling weeds must be appreciated from a historical perspective.

CULTURAL METHODS

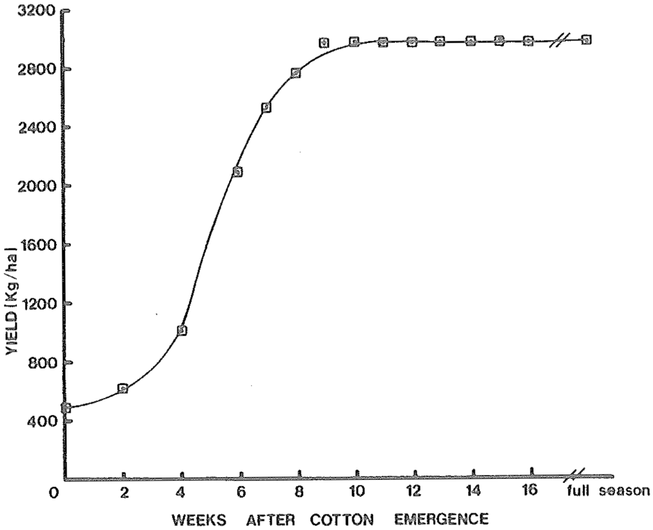
The importance of cultural methods of controlling weeds is often overlooked. This method of weed management is simply the direction of all production practices towards the creation of the most favorable environment for the cotton plant and, at the same time, the least favorable environment for weeds. Unfortunately, this often results in the creation of conditions just as suitable for certain weed species as they are for cotton growth.

Management decisions such as selection of variety, seedbed preparation, time of planting, use of clean seed, soil fertility and pH, planting pattern and moisture can be manipulated so that the cotton is favored to the detriment of the weed flora. Control of limited populations of recently introduced weed species in the "skip" of skip-row cotton, in row-ends, and in turn-rows is an important component of cultural weed control. Rotation with other crops, particularly with crops that permit widely differing weed control procedures and practices, aids in long-term weed management (McWhorter and Hartwig, 1965). Finally, use of fallow or cover crops is an integral part of the cultural approach to weed control.

An extensive series of experiments conducted over several years confirm that if cotton is kept free of weeds for 8 to 10 weeks after planting, it is sufficiently competitive to suppress further weed growth (Figure 1). This is contingent upon a good, uniform stand of cotton under acceptable growing conditions and a mixed population of annual grass and broadleaf weeds. On the other hand, cotton yields may be reduced if weeds are allowed to compete for as little as five weeks after cotton emergence even though cotton is maintained free of weeds for the remainder of the season.

Cotton planted in 21-inch row spacing required a shorter weedfree maintenance period before becoming competitive with weed flora than did cotton planted in more conventional (42-inch) row spacing (Rogers *et al.*, 1976). In further studies, it was noted that nitrogen application up to 90 pounds per acre did not alter this competitive relationship (Buchanan and McLaughlin, 1975). As one would expect, these relationships may be altered when competing with a single species. It was noted that cotton has a substantially shorter weed-free requirement when competing with prickly sida (*Sida spinosa* L.) as compared to competing with a mixed population of annual grass and broadleaf weeds (Buchanan *et al.*, 1977).

Crop rotation, along with associated weed control programs, can, and often does, have a dramatic impact on specific weed problems. Frans (1969) noted increases in *Cyperus*, *Sida*, *Xanthium*, *Cassia*, *Sorghum* and *Ipomoea* spp. in cotton in a survey conducted in 1969. Increasingly widespread use of trifluralin (Treflan®) has been credited, to a great extent, for increases in weeds of these particular genera. On the other hand, Dowler and Hauser (1974) reported that three years' application with fluometuron (Cotoran®, Lanex®) decreased the population of several broadleaf species with an accompanying increase in populations of yellow nutsedge (*Cyperus esculentus* L.) and several annual grass weed species. Dowler *et al.* (1974) noted that several cropping sequences involving intensive cultural or herbicidal weed control programs drastically reduced weed populations. They further reported that none of the treatments altered the composition of the weed populations. Higher populations of weeds were generally



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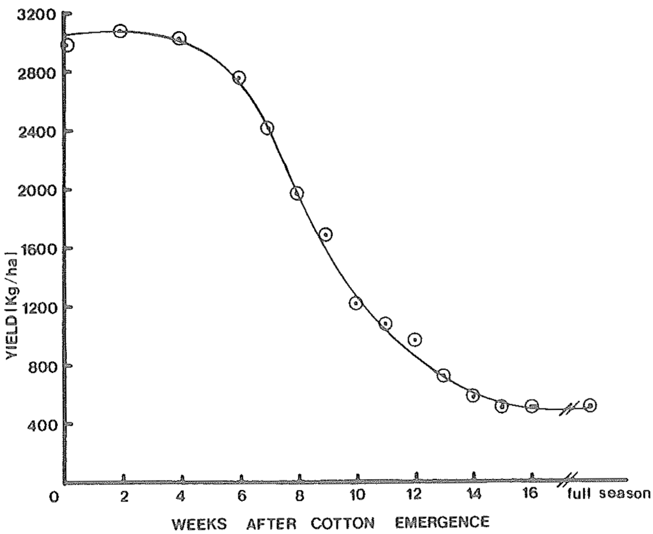

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Figure l. Yield of seed cotton as affected by periods of weed-free maintenance or weed competition. Data are averages of three experiments at two different locations: (a) Weeks of weed-free maintenance, (b) Weeks of weed competition. (From Buchanan and Burns, 1970.)

associated with corn rather than with cotton, peanuts (*Arachis hypogaea* L.), or soybeans (*Glycine max* L.).

Just as crop plants respond differently to soil pH and fertility, weeds are greatly influenced by these growth factors. Indeed, experiments have shown soil pH and fertility to be involved in causing shifts or changes in weed populations in cotton fields (Buchanan *et al.*, 1975; Hoveland *et al.*, 1976).

Cultural weed control procedures are characterized by modest or no additional production cost, while they favor growth of cotton. Also, there is no problem from herbicide residues or adverse growth effects on the cotton. Such procedures do, however, require a high level of managerial skills to implement effectively. Cultural means of controlling weeds in cotton only enhance primary control methods such as use of chemical or mechanical means. Used in conjunction with chemicals and/or mechanical means, cultural approaches become exceedingly powerful measures of dealing with weed populations.

MECHANICAL METHODS

Control of weeds using various types of mechanical devices dates to man's earliest excursions into agriculture. One can visualize the use of simple hand tools to uproot weeds growing in close proximity to the crop. Use of such tools along with animal powered cultivators comprised the cotton farmer's total arsenal of weapons in his war on weeds around the turn of the century. Cates (1917) gives a colorful description of cotton weed control in the early 1900s in Texas using "buzzard wing" sweeps. He pointed out that the first such cultivation usually occurs only ten days to two weeks after planting with each crop receiving four to five cultivations. He further noted that additional cultivations—up to six or seven—often resulted in greater yields. In the more humid Southeast, as many as ten cultivations in one crop were not uncommon. It is interesting to note that *Amaranthus*, *Panicum*, *Ipomoea* and *Sorghum* spp. were serious weeds then, and are still major problems today.

Hand-hoeing has been an integral part of cotton weed control, especially prior to the introduction of herbicides (Figure 2). The first hoeing, usually referred to as "chopping", is accomplished immediately after the first cultivation. Both grass and broadleaf weeds, along with excessive cotton plants, are removed in this process. Brown (1927) pointed out in his book that, "hoeing is expensive tillage, but apparently there is no way to avoid it."

Prior to the introduction of herbicides, hand-hoeing accounted for well over half of the total labor requirement in the production of cotton. However, as use of herbicides became more widespread in the 1950s and early 1960s, hand-hoeing became more of a secondary or supplementary means of controlling weeds. While hand-hoeing is still employed occasionally to remove low levels of infestation of weeds that escaped primary control measures, it is not envisioned that use of this procedure will be an integral component of cotton weed control programs in the future.

Figure 2. Removal of weeds by hand-hoeing. This is a highly effective but costly means of controlling weeds in cotton and was used extensively prior to the introduction of herbicides. It is still occasionally economically feasible to remove modest populations of weeds in this manner.

During the late 1930s and 1940s, animal power gave way to tractor power. Accompanying this transition was the improvement in conventional cultivators, emergence of rotary weeders (Holstun, 1963), mechanical choppers, and the concept of crossplowing (Brown and Ware, 1958). Each of these devices or concepts was designed to cover, uproot, or cut the weed seedling immediately below the soil surface.[1] Weeds are more successfully controlled with such devices when weeds are relatively small and especially if there is a crust on the soil surface. Weeds are killed by desiccation in the dry soil or by covering them with soil. While this is usually successful with annual weeds, it is far less effective with perennials.

Sweep cultivators are highly effective in controlling weeds growing between the drill-rows, but generally less effective in controlling weeds in the drill-row (Ennis *et al.*, 1963). Indeed, effectively controlling weeds in the drill row is the primary concern. During the period after the introduction of tractor power (late 1930s), and before the introduction of herbicides (1950s), numerous rather ingenious mechanical devices were developed and used for weed control in cotton (Figure 3). While all of these devices were effective to some degree, they were effective only when weeds were relatively small and when used under ideal mois-

[1]Weed control equipment and methods for mechanized cotton production. South. Coop. Serv. Bull. 71 (1960). 48 pp.

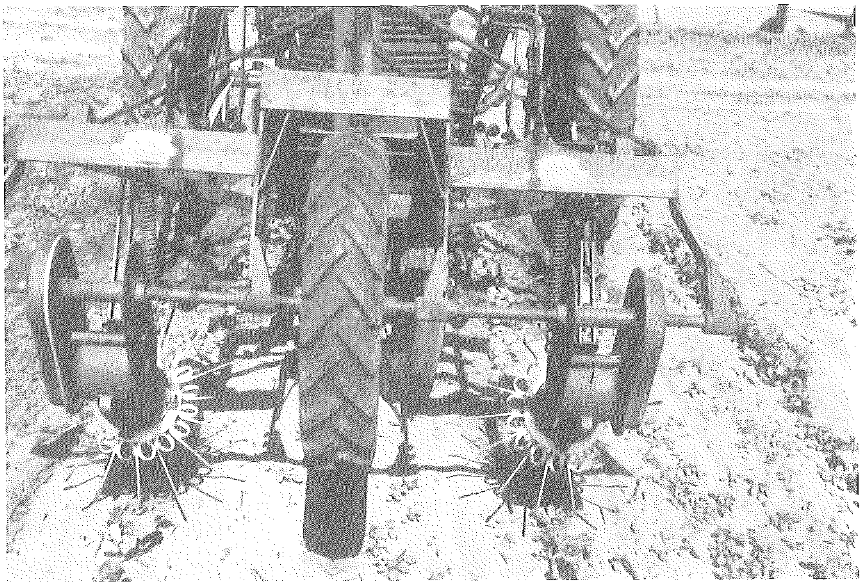

Figure 3. Many tools have been developed over the years for controlling weeds in cotton. Pictured above is a Dixie weeder showing a type of technology that was emerging for weed control and thinning cotton utilizing mechanical devices in semiarid climates of the cotton growing areas. (Photo courtesy Texas Agricultural Experiment Station.)

ture conditions. Of course, since they did not provide any residual control, a new crop of weeds would occur following the next shower.

The concept of cross-cultivation emerged during this period (Figure 4). This procedure can be highly effective in controlling weeds where topography precludes erosion problems. Obviously, good stands of cotton at relatively high seeding rates are required for cross-cultivation to be successful. Usually the first cultivation is in the direction of the row, with subsequent cultivations at 90 degree angles to the direction of the row (Holstun and Wooten, 1968). Subsequent cultivations alternate in direction. Cross-cultivation reduces the amount of hand-hoeing required by as much as 60 percent under certain conditions (Holstun *et al.*, 1960).

While the effectiveness of mechanical cultivation in controlling weeds is unquestioned, other benefits to cotton from cultivation have been highly controversial. To clarify the total benefits accruing from cultivation of cotton, an extensive series of experiments was conducted at two locations over several years in Alabama (Buchanan and Hiltbold, 1977). Results from these experiments showed that the only benefit cotton received from cultivations was from control of weeds. These findings occurred when cotton was planted in a well-prepared seedbed.

Figure 4. Cross-cultivation was used extensively in much of the Mid-South during the late 1940s and throughout the 1950s. A relatively dense, uniform stand of cotton was required to effectively utilize this method of weed control. (Photo courtesy Delta Branch Experiment Station.)

Throughout history, mechanical control of weeds has depended upon human effort, and either animal power or the internal combustion engine. For most of that history, man, and later his animals, were the crucial elements of successful weed control programs. The introduction of the tractor as a power source added a versatile dimension to mechanical control but failed to completely solve the weed problem in cotton.

Mechanical control of weeds is easily implemented and is usually economical, with no possibility of residual chemical problems. Disadvantages are its lack of sustained control with rain resetting or transplanting weeds; the difficulty of controlling weeds growing directly in the drill-row; and its promotion of soil erosion under some conditions. It should be noted, however, that tillage is effective in reducing wind erosion under some conditions. The necessity for the termination of mechanical cultivation with tractors after cotton reaches a certain size is obvious.

BIOLOGICAL METHODS

The concept of biological methods of controlling weeds in cotton has received significant interest over the past several decades. There has been considerable diversity of biological agents employed for weed control, including geese, insects, pathogens, and even nematodes (McWhorter and Chandler, 1982).

To date there have been only a few real successes in controlling specific weeds in agronomic crops, particularly cotton, with biological agents. There have, however, been several rather innovative approaches to employing biological agents. For example, geese will eat seedlings of *Cyperus* spp., *Digitaria* spp., *Sorghum* spp., *Cynodon* spp., and other common weed species, but they will not eat many other weed species often found in cotton (Johnson, 1960; Miller *et al.*, 1962; Mayton *et al.*, 1945). Geese have been used fairly extensively in the Mid-South and Far-West for weed control. Geese require high levels of management for effective utilization as weed control agents. They must be provided supplemental feedings as necessary and clean drinking water at all times (Miller *et al.*, 1962). Geese must be protected from predators such as dogs. Under conditions of extremely high temperature, they must be protected by providing some means of shade. A major problem which enhances the required management is their susceptibility to certain insecticides. Because of this, geese must be relocated prior to insecticide application. Also, it has been shown that while geese would not eat young glanded cotton seedlings they would eat the seedlings of glandless strains.

It was estimated in a California study that it cost $13 per acre to use geese for controlling weeds in cotton. This included the cost of the geese, necessary fencing, supplemental feeding, water and labor. While this was a very reasonable cost, due to the availability of more selective herbicides during the late 1960s, the use of geese for weed control in cotton has decreased in popularity (Danielson *et al.*, 1972; Kempen, 1987).

Silverleaf nightshade (*Solanum elaeagnifolium Cav.*) is an economically important weed in cotton in the southwestern United States. It is naturally parasitized by the parasitic nematode *Orrina phyllobia* (Thorne, Brzeski) (Orr *et al.*, 1975 a, b). Invasion of this host-specific, leaf-feeding nematode either severely stunts or kills the nightshade plant. Unfortunately, this has not resulted in satisfactory control of this weed on a widespread basis. On the other hand, effective control of northern jointvetch (*Aeschynomene virginica L. (B.S.P.)* in rice (*Oryza sativa* L.) and soybeans with the fungus *Colletotrichum gloeosporioides (Penz.)* Sacc. f. sp. *aeschynomenes* is an encouraging indication that biological agents will be developed for major weeds of cotton (Smith *et al.*, 1973; Templeton, 1982). This concept has been referred to as the "mycoherbicide" approach to weed control (Templeton, 1986).

Further support is provided by the more recent successful results of the effectiveness of the fungus *Alternaria cassiae* (Jurair and Kahn) in control of sicklepod (*Cassia obtusifolia*), a major weed problem in cotton in the southeastern United States (Charudattan *et al.*, 1986). These results were based on an extensive series of experiments across much of the South. Probably the most exciting development in the biological control area has been the effectiveness of rust (*Puccinia canaliculata* (Schw.) Lagerh.) (Callaway *et al.*, 1987; Phatak *et al.*, 1983) for control of yellow nutsedge, which is not only a serious weed in cotton, but is among the most devastating weeds in the world (Holm *et al.*, 1977).

Effective use of some biological agents to control weeds provides a remarkably high degree of selectivity at a modest cost. Unfortunately, the cost of development of such agents is often exceedingly high, and for many species of weeds there are few, if any, pathogens or other biotic agents that can be successfully used for weeding cotton. The major drawback, however, is that most cotton fields are infested with several widely differing weed species. Consequently, multiple pathogens or additional weed control measures would be required for effective control.

RADIANT AND UHF ELECTROMAGNETIC ENERGY

Flame for control of undesired vegetation has been used for hundreds of years. The "slash and burn" agriculture that exists, even today, in some parts of the world employs this method. Much of the eastern part of this country was originally cleared by fire.

The use of flame cultivation as early as 1947 was revealed in an unpublished Texas survey (Table 1). However, the first recommendation of flame as a means of controlling weeds occurred in 1959 (Miller *et al.*, 1962; Holstun *et al.*, 1960).

The emergence of flame cultivation was stimulated by development of the flame burner. Inexpensive natural gas, usually butane or propane, that was both cheap and abundant in the 1950s, was the crucial ingredient that stimulated the interest in flame weed control (Figure 5). Early in the development of the concept

Figure 5. An early model of a flame cultivator used to control weeds and cotton. (Photo courtesy Delta Branch Experiment Station.)

Table 1. Flame cultivator used in Texas from 1960 to 1973.[1]

Year	Flame cultivators in use
1960	0
1961	0
1962	3,375
1963	2,164
1964	2,181
1965	3,876
1966	1,502
1967	1,461
1968	762
1969	490
1970	376
1971	282
1972	282
1973	170

[1]Data compiled from county agent annual reports by Cotton Specialist Fred C. Elliott, Texas Agricultural Extension Service, Texas A&M University, College Station, Texas.

of flame cultivation, it was realized that the crop plant must have a relatively tough bark for successful employment of this procedure. Cotton, of course, met this requirement. Use of flame was usually not employed until cotton stems were about 3/16-inch in diameter at ground level and plants were about 8 inches tall. Employed under these conditions and directed under the cotton plant, flame cultivation did not reduce the yield of cotton.

During the 1950s with readily available and inexpensive natural gases, the total cost of flame cultivation was only about $1.30 per acre. It was not unusual to use five to seven flame cultivations in a single season (Miller *et al.*, 1962).

Flame is effective on a wide range of weed species, particularly when weeds are small (less that two inches tall), and flame is used repeatedly over the season (Holstun *et al.*, 1960). Flame is relatively ineffective after broadleaf weeds are four to five inches tall. Improvements in flame cultivators increased the effectiveness of this means of controlling weeds (Figure 6).

From its inception, flame cultivation was considered to be supplementary to other methods of control. It is generally far less effective when employed as the primary means of weed control. Since there is no residual control associated with flaming, repeated treatments are necessary.

Flame cultivation has an advantage in that it can be employed when soils are wet, does not disturb the soil, and leaves no chemical residue. Even so, this technique is rarely used today. The emergence of effective herbicides and the

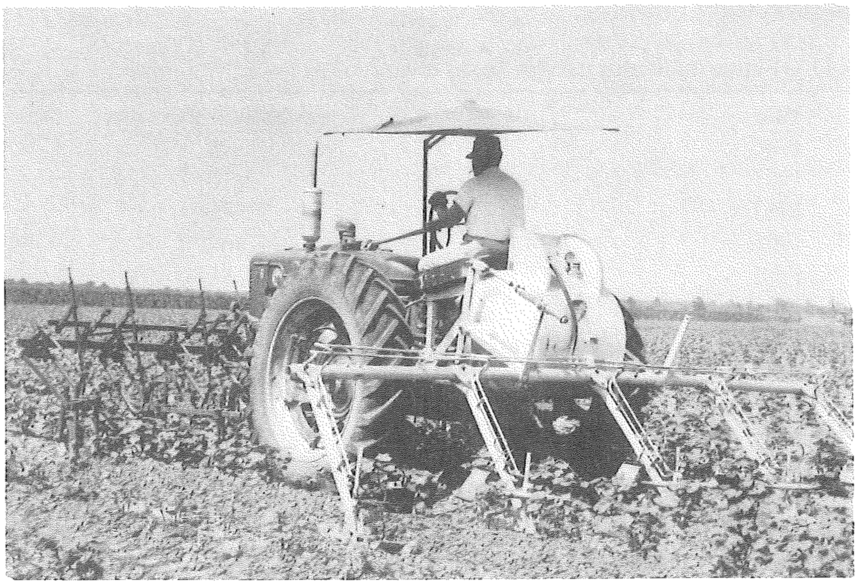

Figure 6. A later model of a flame cultivator used for flaming cotton. Note the simplicity and evolution of this piece of equipment as compared to that shown in Figure 5. (Photo courtesy Delta Branch Experiment Station.)

escalating price of natural gases are primarily responsible for the loss of interest in flame cultivation, and it is quite unlikely that this will be a viable component of weed management systems in cotton in the future.

Use of ultra-high frequency electromagnetic energy as a weed control method received some interest in the early 1970s (Davis *et al.*, 1971, 1973). Investigation showed that *Amaranthus* spp., a major weed of cotton, could be controlled under field conditions with exposure to 360J/cm^2 (Menges and Wayland, 1974). Because of excessive cost of energy generation and other technical difficulties, this method has not evolved beyond the novelty stage.

CHEMICAL METHODS

The emergence of safe, effective, and relatively inexpensive agricultural chemicals, particularly herbicides, remains one of the most significant agricultural developments in the entire history of agriculture. It is difficult to imagine that the era of highly effective, selective herbicides is only as recent as the end of World War II.

Cotton farmers, along with peanut farmers and a few others, were early adopters of the emerging technology of chemical weed control. The increasing scarcity and high cost of hand labor and the necessity for a clean field to ensure acceptable yields and market quality contributed to the rapid acceptance of the chemical method of controlling weeds in cotton. The relatively long (nine to ten weeks) period that weeds must be controlled before cotton becomes competitive further increased the grower's interest in methods of controlling weeds that had residual effects.

In addition to the above factors, farmers were attracted to chemicals and other new methods for controlling weeds in cotton for the simple reason that existing methods were not fully satisfactory. While the problems with labor were extremely difficult to manage, probably the most important factor in the rapid acceptance of the chemical method of controlling weeds was that herbicides were effective and highly versatile with regard to placement, method and time of application.

In the basic agronomy textbook, Principles of Field Crop Production (Martin and Leonard, 1949 edition), not a single mention is made of herbicides. Indeed, only a brief section is devoted to the control of weeds in cotton.

Special non-fortified (phytotoxic) oils were among the first chemicals used for weed control in cotton in the early 1950s (Table 2). Effective and inexpensive petroleum products made the phytotoxic oils a cost effective means of controlling weeds for a number of years.

Petroleum fractions, commonly referred to as naphthas, with a boiling range of 302F (150C) to 392F (200C) containing 18 to 25 percent aromatic compounds are the most satisfactory herbicidal oils for controlling weeds in cotton (Colwick, 1960). The herbicidal naphthas were among the first chemicals available for postemergence weed control in cotton (Talley, 1950). Used properly under appropriate conditions, they were highly effective in controlling a wide range of weed species, especially young grasses and broadleaf weeds (Holstun and McWhorter, 1965).

The herbicidal naphthas were also great educational tools. Because they were highly phytotoxic to cotton foliage, farmers learned the necessity of careful application techniques. Successful use required properly designed and adjusted application equipment and a good, debris-free seedbed (Figure 7). There are also certain environmental conditions required for successful use. Grower experience with the herbicidal naphthas paved the way for successful use of the new generation of herbicides soon to follow.

An interesting and very important part of the development of herbicides for weed control in cotton was provided by the introduction of the dinitro compounds. Davis (1964) noted "The spectacular rise and fall of interest in the dinitro-[2]compounds between 1950 and 1956 represents one of the most valuable lessons that we have learned in weed research in the past 15 years." Various amine salts of dinoseb (Premerge®) applied preemergence had shown generally favorable results for selective weed control in cotton prior to 1952 (Cowart *et al.*, 1950; Harris *et al.*, 1950). Although there had been some scattered evidence of a potential hazard to cotton from dinoseb, considerable acreage was treated in

[2]The most common material in this general group is dinoseb (4,6-dinitro-o-*sec* butylphenol) usually formulated as an amine salt.

Table 2. Herbicides used in cotton in the United States.

Common name	Trade name	Year of introduction
dinoseb	Premerge 3®	1947
herbicinal	Naphthas	1952
chlorphopham	Chloro IPC®	1950
dalapon	Dowpon®	1953
diuron	Karmex®	1954
DCPA	Dacthal®	1956
EPTC	Eptam®	1961
DSMA	(several)	1963
MSMA	(several)	1963
trifluralin	Treflan®	1963
norea	Herban®	1963
monuron	Telvar®	1963
dicryl	Dicryl®	1963
sodium chlorate	(several)	1966
nitralin	Planavin®	1968
linuron	Lorox®	1962
fluometuron	Cotoran®	1964
prometryn	Caparol®	1964
bensulide	Prefar®	1968
paraquat	Paraquat CL	1965
alachlor	Lasso®	1969
dipropetryn	Sancap®	1973
profluralin	Tolban®	1975
dinitramine	Cobex®	1971
norflurazon	Zorial®	1975
fluchloralin	Basalin®	1976
pendimethalin	Prowl®	1976
oryzalin	Surflan®	1976
methazole	Probe®	1976
perfluidone	Destun®	1979
cyanazine	Bladex®	1972
glyphosate	Roundup®	1974
sethoxydim	Poast®	1982
fluazifop	Fusilade®	1982
metolachlor	Dual®	1984
oxfluorfen	Goal®	1984

(Chandler, 1984; Herbicide Handbook, Weed Sci. Soc. Amer. (1974), 430 pp.; Herbicide Handbook, Weed Sci. Soc. Amer. (1979), 479 pp.)

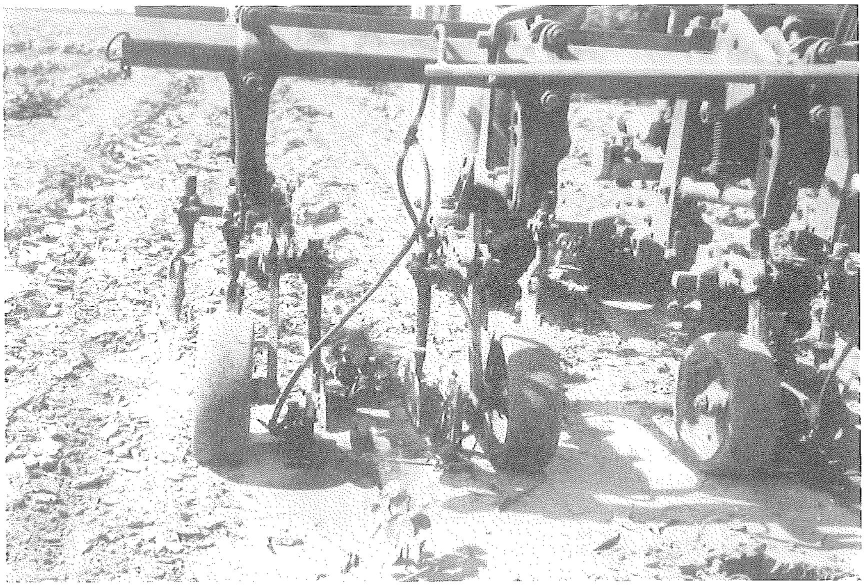

Figure 7. Pictured here is a typical device used for applying herbicidal naphthas to cotton. A relatively smooth debris-free seedbed was an absolute must to effectively utilize this technique for controlling weeds in cotton. (Photo courtesy Delta Branch Experiment Station.)

1952. Unfortunately, several hundred acres of cotton were either killed or severely injured. An intense scientific investigation quickly followed leading to the conclusion that soil type, rainfall, soil pH, and temperature influence the phytotoxicity of dinoseb to cotton (Davis, 1956; Davis and Davis, 1954; Davis *et al.*, 1954; Barrons *et al.*, 1953). Further investigation showed the importance of phytotoxicity of these compounds through vapor action (Hollingsworth and Ennis, 1953) and that cotton is not much more tolerant to dinoseb than are the weeds it is intended to control (Davis, 1964).

While the above incident was quite unfortunate for the cotton farmers and others, it did provide a very real learning experience and valuable lesson that ultimately was helpful in the future development of herbicides for weed control in cotton. It clearly pointed out the potential pitfalls associated with this new weed control technology and revealed the latent need for better and more effective means of controlling weeds in cotton.

The search for more selective herbicides for weed control in cotton continued through the 1950s. Chlorpropham (Chloro IPC®) was introduced about the same time as dinoseb, and monuron (Telvar®) and diuron (Karmex®) somewhat later. These were far more selective herbicides for cotton than was dinoseb, although monuron was occasionally phytotoxic. Each of these herbicides is applied preemergence. Dalapon (Dowpon®), which was introduced during the 1950s, exhibited excellent postemergence activity against johnsongrass, a potentially troublesome perennial grass in cotton. Dalapon proved to be too phytotoxic to apply as an overall spray to cotton, but worked quite nicely when used as a spot-directed treatment (Swezey and Fisher, 1955; Watson, 1955).

Development of selective herbicides continued slowly but steadily throughout the 1950s. However, even by 1963, most cotton producing states recommended only three herbicides—diuron, chlorpropham and dalapon—along with herbicidal naphthas for weed control in cotton (Standifer, 1964).

A number of new herbicides were introduced during the 1960s. The importance of some of these herbicides was exceedingly far-reaching and impacted dramatically on cotton production in the United States.

The introduction and rapid acceptance of trifluralin (Treflan®), a dinitroaniline, added a new herbicide to the cotton farmer's arsenal of weed control agents and also ushered in the new concept of soil incorporation of herbicides. The farmers have employed numerous types of devices to incorporate herbicides into the soil (Figure 8); however, the conventional disk harrow remains the most commonly used device for this purpose (Figure 9).

Trifluralin was followed later in the 1960s by nitralin (Planavin®), another dinitroaniline herbicide that required soil incorporation. This herbicide remained on the market for only a few years.

The severe problem of nutsedge stimulated interest in the thiocarbamates. Use of EPTC (Eptam®), a thiocarbamate, as an injected treatment was developed and used for a few years (Wooten *et al.*, 1966; Holstun *et al.*, 1963). Short residual and the narrow margin of safety contributed to the loss of interest in this weed control treatment for cotton.

While the herbicidal naphthas were used widely during the 1960s, there was still interest in more selective postemergence herbicides. The organic arsenicals, DSMA and MSMA, met this requirement and have been widely used since, often in combination with other herbicides which have residual activity. The excellent activity of the arsenicals, particularly MSMA, on annual grasses and substantial activity on nutsedge (*Cyperus* spp.) and *Sorghum* spp. has resulted in extensive use of these herbicides. These herbicides along with the introduction of paraquat (Gramoxone®) continued to stimulate interest in equipment to apply herbicides as directed sprays. Numerous designs have been conceived and pieces of equipment have been developed for applying herbicides in this manner (Figure 10).

A number of other herbicides, some of which are still in use today, were also introduced during the 1960s. Fluometuron (Cotoran®, Lanex®), introduced during the 1960s, has proven to be one of the most successful preemergence applied herbicides yet for weed control in cotton. Several other herbicides introduced and used during the 1960s have either been discontinued or used very little during recent years. These include norea (Herban®) and dicryl (Dicryl®).

There were few truly major developments in herbicides for cotton weed control during the 1970s. Several dinitroanilines, including pendimethalin (Prowl®),

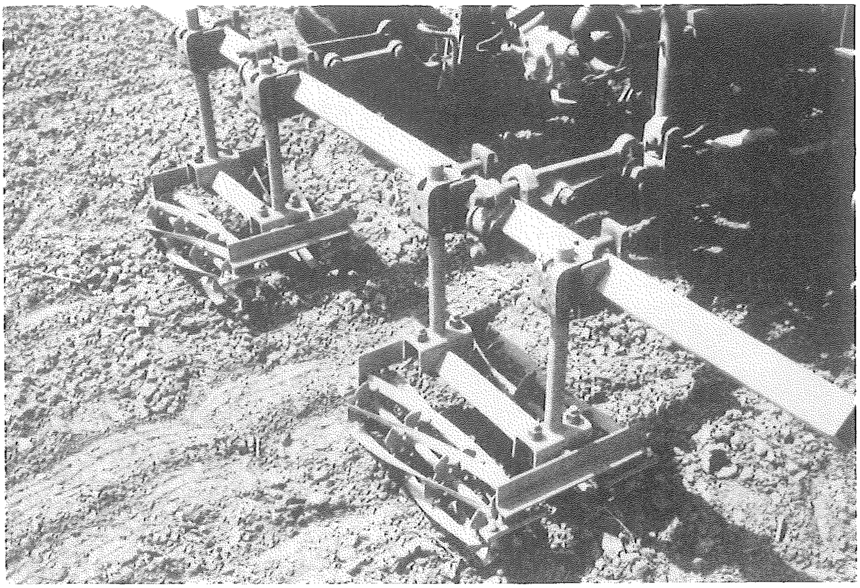

Figure 8. One of many such devices used to incorporate trifluralin in cotton soils. The concept of incorporation was ushered in primarily with the introduction of this herbicide in the mid 1960s. Such devices as pictured above generally have given more uniform incorporation of herbicides than does the conventional disk harrow.

fluchloralin (Basalin®), profluralin (Tolban®), oryzalin (Surflan®) and dinitramine (Cobex®), became available and were developed for cotton. None of these was substantially better than trifluralin, which was developed during the mid-60s.

Glyphosate (Roundup®), introduced in the 1970s, gives excellent control of several particularly difficult to control weeds such as bermudagrass (*Cynodon* spp.) and johnsongrass (*Sorghum* spp.), as well as a number of annual and perennial weeds. Since glyphosate is highly phytotoxic to cotton, special care must be exercised during application. This herbicide was the first material that was truly effective when used in the recirculating sprayer (McWhorter, 1970, 1977). Development of the ropewick applicator (Dale, 1979) and the recirculating wiper (Chandler, 1981) proved to be an even more effective means of applying glyphosate to weeds without causing injury to cotton.

The most significant cotton weed control development during the 1980s was the introduction of herbicides that were highly active against annual and perennial grassweeds, but had little or no activity against broadleaf plants. Sethoxydim (Poast®) and fluazifop (Fusilade®) were introduced during the 1980s and have enjoyed modest success. However, the effectiveness and relatively low cost of the dinitroanilines have provided stiff competition to any new herbicides for grass control in cotton.

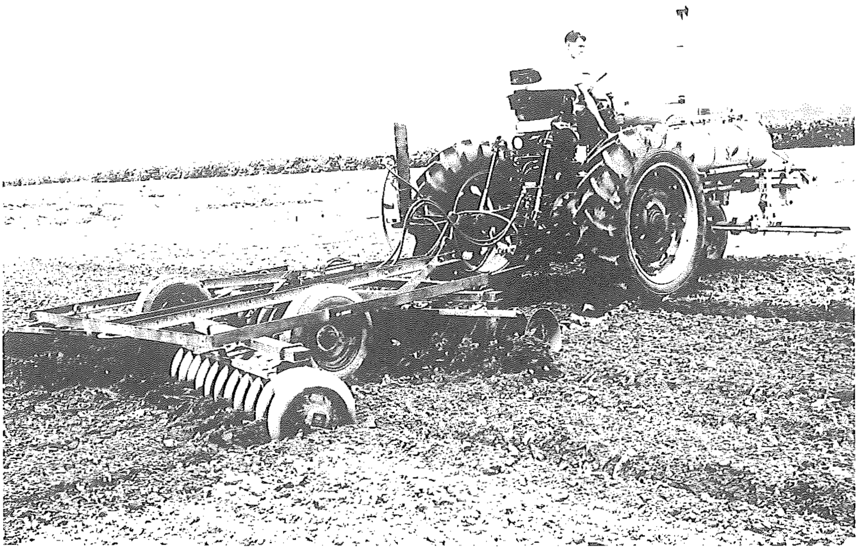

Figure 9. Incorporation of trifluralin with the conventional disk harrow. While not the most effective device for incorporating herbicides, the disk is still the most widely used means of incorporation.

By 1968, 22 herbicides were labeled and used in some areas of the United States in control of weeds in cotton (Holstun and Wooten, 1968). About this same number of chemicals are still available today, although some herbicides have passed into history to be replaced with newer materials (Chandler, 1984).

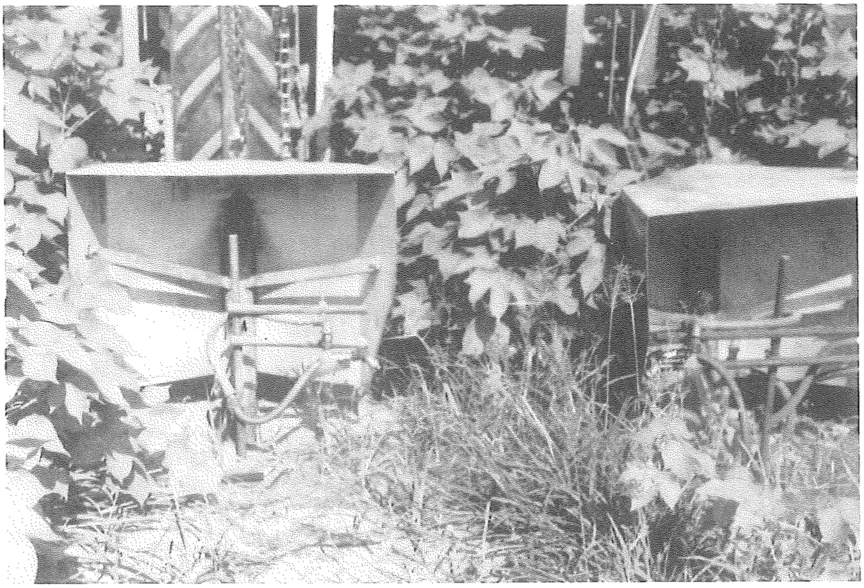

Figure 10. Devices for applying herbicides as directed sprays in cotton have undergone tremendous evolution in equipment since the 1950s. Pictured above is a more recent innovation developed for effectively applying herbicides as directed sprays in cotton. (Photo courtesy Delta Branch Experiment Station.)

Methods of Using Herbicides—Some herbicidal treatment can be used at almost any time during the growth of the cotton plant. Indeed, there are six specific periods in the cotton production cycle that offer an opportunity to use an application of herbicides. These include: applications made preplant to the foliage (PPF); preplant soil incorporated (PPI); preemergence (PRE); postemergence directed (POST/DIR); postemergence over-the-top (POST-OTT); and late postemergence or layby (LP). Herbicides can and often are applied using two or more of these application opportunities in series.

The timing of herbicide applications varies with many factors, and the best cotton growers know that maximum production efficiency demands the minimum number of applications of herbicides that will provide satisfactory weed control. Of course, there must be consideration given to soil and environmental conditions, weed species to be controlled, efficacy and cost of herbicide, level of control desired and other weed control measures employed.

The use of these treatments varies considerably in the different regions of the country. For example, preemergence and directed postemergence treatments are more frequently used in the eastern United States Cotton Belt than in the West (DeBord, 1977). On the other hand, use of preplant foliar treatments are more common in Texas than in Mississippi.

The chemical method of controlling weeds in cotton has been popular for the simple reason that herbicides work. Herbicides are highly selective and can be employed in several different ways at almost any stage of development of cotton. Major problems associated with the use of herbicides are that some are expensive; some may persist in the soil under some conditions; and some may, under some conditions, stunt or otherwise injure the cotton plant.

Problems with Herbicides—The dinitroaniline herbicides may prevent lateral root development of the cotton seedling under some conditions (Anderson *et al.*, 1967; Arle, 1968; Hacskaylo and Amato, 1968; Orr *et al.*, 1969). Research has shown that high rates of trifluralin reduce plant height, lateral root formation and yield (Baker, 1976; Gordon and Frans, 1977; Banks *et al.*, 1977). Deleterious effects of these herbicides are often influenced by adverse growing conditions, interaction with other pesticides and method and depth of incorporation; also, they are often associated with seedling disease.

A "maximum" herbicide program including the highest recommended rate of trifluralin applied preplant incorporated, fluometuron applied preemergence, fluometuron plus MSMA applied as a directed spray, and fluometuron applied post-directed at layby caused early phytotoxicity, reduced yields in some years and reduced earliness of cotton in all years (Gaylor *et al.*,1983).

In some instances there are deleterious interactions of herbicides with other pesticides employed in cotton production. For a number of years researchers have known that the combined use of a substituted urea herbicide such as diuron (Karmex®) and an organo-phosphate insecticide such as phorate (Thimet®) will increase cotton injury as compared to use of either of these pesticides alone (Hacskaylo *et al.*, 1964; Pires and Hacskaylo, 1963; Ranney, 1964).

Imazaquin (Scepter®) at low concentrations has been shown to affect growth of certain crops such as corn (Basham *et al.*, 1987) and cotton (Barnes *et al.*, 1989). Soil concentrations of imazaquin ranging from 0.007 to 0.024 μg/g reduced cotton yields 7 to 42 percent (Barnes *et al.*, 1989). Such herbicide concentrations have occurred in soil samples taken 12 to 24 months following preplant incorporated applications at rates of 140 g/ha.

SYSTEMS APPROACH

It has long been recognized that the best approach to controlling weeds in cotton is to use two or more methods employed in a systematic fashion. Soon after the introduction of herbicides in the early 1950s, investigators began evaluation of weed control systems by combining chemical methods (Harris, 1960; Snipes *et al.*, 1984). One investigator pointed out that combinations of herbicides with cross-cultivation resulted in greater production efficiency (Holstun, 1963). Other researchers have shown that efficiency in controlling weeds is dependent upon the nature of the weed pressure (Stewart *et al.*, 1983). Some investigators have shown the effectiveness of herbicides applied may vary with different stages of development (Nastasi *et al.*, 1986). Herbicides with excellent activity on a wide range of grass weeds provide greater net return when used as over-the-top sprays following preemergence applications of fluometuron than when following preplant incorporated applications of trifluralin (Nastasi *et al.*, 1986). This research, and other studies using currently available herbicides, clearly show that the employment of chemicals plus mechanical cultivation in a total system that takes into consideration cultural methods, provide the most reliable and economical method of controlling weeds (Nastasi *et al.*, 1986).

A single postemergence application of either fluazifop or sethoxydim following a preemergence application of fluometuron resulted in better control of broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash.] and greater yield and net return than treatment with trifluralin and fluometuron applied preplant incorporated and preemergence, respectively (Byrd and York, 1987). A second application of fluazifop or sethoxydim applied later in the season increased late season control, but did not increase cotton yields or net return.

The systems approach to cotton weed control is sometimes referred to as integrated weed management (IWM). Addressing the problems of weeds in cotton in such a manner is certainly compatible with the integrated pest management (IPM) concept of dealing with cotton insect pests.

EXPECTED TRENDS IN COTTON WEED CONTROL

Of the five basic methods available for controlling weeds in cotton, the cultural method accounts for the greater portion of weed control in the normal cotton growth cycle. While it is difficult to assess the relative importance of field sanitations, planting weed-free seed, and using ideal cotton cultural practices to control weeds in the crop, it is readily observed that cotton grown under these conditions rapidly becomes sufficiently competitive to prevent weed growth. This "critical" period in which weeds must be controlled ranges from six to ten weeks for most cotton grown in the southeastern United States.

Since flame and UHF electromagnetic radiation are essentially discontinued and biological control still is in early developmental stages, weed control during this critical phase must be provided either by mechanical or chemical methods. With prevailing economic conditions, there is little argument that the use of chemical methods to control weeds in the drill row during this six to ten week period is the best alternative. In the row middles and the "skips" of skip-row cotton, the economic relationships are not so clearly defined. Under these conditions mechanical methods would probably be more cost effective. For the foreseeable future, the trend in cotton weed control will be a refinement of these methods into more effective weed management strategies.

FUTURE OUTLOOK OF COTTON WEED CONTROL

It is anticipated that there will be newer and better chemicals as well as improved mechanical devices available for weed control in cotton. The real excitement in controlling weeds in cotton will be more elegant management systems and usage of these methods. It is not unreasonable to expect that a few of our major weeds will be at least partially controlled by utilization of biological agents. Likewise, there are opportunities for the cotton breeder to contribute to better weed control by producing varieties that are better adapted to specific geographical locations and more competitive with weeds.

Utilization of emerging research techniques generally referred to as "biotechnology" will undoubtedly lead to more elegant means for weed control in cotton. It is not unreasonable to expect that such techniques will lead to the development of genetic lines of cotton that have high levels of tolerance to key herbicides. Genetically altered cotton plants would add an important dimension to the greater freedom and effectiveness of the chemical method of controlling weeds in cotton.

The computer will enable the grower to conveniently keep more definitive records about his fields, including weed problems, topography and soil characteristics. This will enable the grower to make early decisions about weed control with greater confidence. A better understanding of the effects of weeds on cotton and the development of more definitive weed action levels or weed response thresholds will contribute to improved economics in the control of weeds in cotton.

Improvements in methods available to the cotton farmer for controlling weeds can be expected. This advantage can be partially offset by newly emerging or changing weed problems. Consequently, the cotton farmer must continue to place emphasis on weed control in order to maximize production efficiency.

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