Chapter 12

HERBICIDE APPLICATION TECHNOLOGY

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INTRODUCTION

Newly introduced herbicides that will be used at less than an ounce per acre increases the importance of the uniform and precise delivery to the target. Even with well calibrated equipment and ideal working conditions, there are wide variations in the amounts of spray particles reaching the soil or plant (Wauchoupe *et al.*, 1977). The hand-pumped knapsack sprayers and spray carts with bicycle wheels have been replaced with tractor-mounted and self-propelled sprayers, and these are evolving to spray systems controlled electronically to include radar and other technologies for ground speed measurement and digital readout of speed, pressure and spray volume. Whatever the degree of sophistication in equipment, the goal is precise and uniform placement of the herbicide on the target at the correct dose and at the proper time. Successful weed control often hinges on the degree to which that is accomplished. Today we may have a better appreciation for the following words than when they were written (Ennis *et al.*, 1963):

> "The rapid advance of weed control technology and the acceptance of chemical weed control practices by farmers will have profound effects on crop production and soil and water management practices."

This chapter briefly traces the evolution of application technology in cotton weed control, describes application methodology, summarizes Cotton Belt application techniques and discusses future needs in cotton weed control application technologies. Because of the extensive use of herbicide sprays, this method of application is emphasized to include hydraulic pressure sprayer components and calibration.

TERMS AND DEFINITIONS

Herbicide applications are usually made in a time frame related to crop development (Chandler, 1984; Holstun and Wooten, 1968). The following six types of herbicide application cover most situations encountered in the production of a cotton crop. The terminology used here will generally follow that established by the Weed Science Society of America (Harger *et al.*, 1985; Beste, 1983).

Preplant Foliage (PPF)— Applied before planting cotton as a foliar application to control existing vegetation.

Preplant Incorporated (PPI)—Applied and blended into the soil before planting.

Preemergence (PRE)—Applied to the soil after planting but before emergence of the cotton to control weeds before or soon after they emerge.

Directed Postemergence (PDS)—Precise application to control existing weeds in a stand of cotton. Usually directed on a band centered over the drill with a minimum of spray contact on the cotton. Cultivation is normally used to control weeds left untreated in the row middles.

Postemergence Over-the-top (POT)—Applied over the top of growing cotton to control weeds in the crop. A broadcast or banded application above the plant canopy requires a herbicide with adequate cotton tolerance.

Late Postemergence (Layby)—Usually a directed spray applied up to the time of last cultivation for the control of existing weeds, and also for preemergence control of late-season weeds depending upon herbicide selection and rate.

Additives are frequently mixed with the herbicide spray solution to obtain more desirable results. That is especially true for postemergence applications. Terms most frequently encountered are: adjuvants, surfactants and crop oil concentrates.

Adjuvants—Any substance in herbicide formulation or added to the spray to modify herbicidal activity or application characteristics. Adjuvant is the most general term and might be used to reduce foam, improve compatibility of an herbicide mixture, or reduce drift as well as increasing herbicide uptake by the weeds for better control.

Surfactant—An adjuvant that improves the emulsifying, dispersing, spreading, wetting or other properties of a liquid by modifying its surface characteristics.

Crop Oil Concentrate (COC)—An adjuvant that contains 80 to 85 percent nonphytotoxic petroleum or vegetable oil plus 15 to 20 percent surfactant and emulsifiers.

APPLICATION TECHNOLOGY EVOLUTION

EARLY DEVELOPMENTS

With the introduction of the liquified petroleum gases in 1945 came "flame cultivation". The burners were frequently attached directly to the cultivator or used in conjunction with conventional sweeps. Two categories of burners were designed for flaming cotton: (a) those for flaming the drill-rows, and (b) those for flaming the row-middles. These flame-cultivators were effective in controlling the vine-complex after cotton stems were at least 3/16 of an inch in diameter at the ground level (Baker, 1966). A water-shielded flame cultivator was subsequently developed which provided lower temperatures on the exposed cotton stem, thus permitting flaming of younger cotton (Matthews and Smith, 1969).

Herbicidal naphtha was applied postemergence as a lateral directed spray (Talley, 1950). Excellent control of small annual weeds was obtained plus good suppression of some perennials such as nutsedges and vines. Precision application was necessary to get good coverage on the weeds without spraying too high on the young cotton seedlings and causing injury. Equipment (oiling shoes or slides) was designed with parallel action mounting so that nozzles were positioned at a constant height and angle (Holstun and Wooten, 1968). These oiling shoes typically had two opposing nozzles mounted to spray into and across the cotton drill, and two nozzles mounted to spray a 4- to 5-inch band on either side of the drill.

Herbicides appeared on the farm scene following World War II, which increased research and development efforts on hydraulic pressure nozzle sprayers. The phenoxy herbicides were a breakthrough in technology, but they lacked selectivity for use in cotton. By the early 1950s, herbicides were being used to control weeds in cotton and reduce the strong dependence on hand labor (Porter *et al.*, 1957; Denver, 1984). Chlorpropham (Chloro-IPC®), dinoseb (Premerge®), and diuron (Karmex®) were applied preemergence in treated bands centered over the drill. Planter-mounted hydraulic drop nozzles with even spray-pattern tips evolved with the use of these herbicides.

Lever-operated knapsack and compression hand sprayers were used to treat small areas (spot-spray) in cotton fields in the early 1950s with herbicidal oil. This application method is still used, but the herbicides have evolved from non-selective herbicidal oil to the selective grass herbicides sethoxydim (Poast®) and fluazifop-P (Fusilade-2000®) (See Chapter 7). The compression and, to a lesser extent, the knapsack sprayers are still in use, but it is now common to see all-terrain vehicles (ATV) equipped with hydraulic pressure sprayer systems, and hand-operated spring-loaded plunger spray guns in use for spot spraying.

As herbicide treatments such as diuron plus surfactant applied as a PDS (directed postemergence) (McWhorter and Sheets, 1961) were introduced, a flurry of activity in PDS applicators followed. Front and rear mounted slide units equipped with two to four nozzles per row became available, and the parallel-action oiling shoes were modified for this purpose. Cultivators were modified that included two to four nozzles per row for PDS application in conjunction with cultivation. Half-wing sweeps were used to leave a 10- to 20-inch band centered on the drill-row undisturbed to which the PDS were applied. Cultivators were later equipped with nozzles for PDS mounted on the rear of fender shields. Directed sprays increased the demand for tapered flat-fan nozzle tips, and helped spur development of off-center tips.

Layby application of cotton herbicides paralleled the PDS concept. With the practice came the use of flooding or deflector spray nozzles which permitted broadcast directed layby spray application using one nozzle per row. Williford (1981) described the array of postemergence equipment available to growers.

SOIL INCORPORATION

Research during the early 1960s with trifluralin (Treflan®) led to a new approach for herbicide application in cotton. Because trifluralin was volatile and photodegraded, significant loss occurred with surface preemergence sprays; thus, it was applied preplant and incorporated into the soil. The new application method resulted in consistently higher weed control levels with less dependence upon rainfall as compared to the conventional preemergence treatments. A burst of activity followed with the development of all kinds of equipment for soil incorporation. The conventional disk harrow was readily available but new equipment ranged from many types of ground-driven incorporators to power tillers. Tapered flat-fan, flooding or deflector, raindrop and wide angle cone nozzles became common components of broadcast soil incorporation devices as they became available.

AERIAL APPLICATION

The first widespread use of aerial application for herbicides in cotton came about with the broadcast preplant use of dinitroanilines (Figure 1). Wide tandem-disk harrows or field cultivators followed closely behind the herbicide application, and large acreages were treated quickly. Aerial application using spray volumes of 3 to 5 gallons per acre are now usual, but ultra-low volumes (ULV) of 1 quart per acre or less are possible (Shankland and Tucker, 1980).

Figure 1. A Cessna Ag-Wagon equipped with disc-core combination nozzles spaced 10 inches apart applying a dinitroanaline herbicide in water at 5 gallons per acre for subsequent soil incorporation.

HERBICIDE FORMULATIONS AND ADDITIVES

Application techniques may vary somewhat according to how the herbicide is formulated. Historically, herbicides were formulated primarily as a wettable powder (WP) or emulsifiable concentrate (EC) for mixing with water and applying as a spray. The wettable powders require agitation in the spray tank to prevent the insoluble powder from settling to the bottom of the tank. Resuspending the settled-out powder and active ingredient is often difficult following an overnight work stoppage or for a breakdown or rain shower during the day.

Granular herbicide formulations have been available with the active ingredient attached to clay particles for distribution as a solid such as many fertilizers are applied. Granules have not been used extensively in cotton because of the difficulties in handling the considerable weight and bulk of solid material and lack of precision placement equipment. Sprays have been more readily accepted because several thousand gallons of a sprayable formulation can be premixed and transported to the field in trailer- or truck-mounted nurse tanks. A hydraulic pump mounted on the nurse tanks is used to refill the sprayer tank. Also, the use of nozzles for precision placement of the spray has advantages for efficacy and selectivity.

More recently, water dispersible granular formulations have become available. These are free flowing particles which avoid dust and container rinsing problems, yet readily mix in water for easy spraying. Another approach to using water dispersible granules may be the ultimate low volume application—no water at all. A metering system using pneumatic applicators can distribute these granules fairly uniformly at the rate of one pound per acre (Gandrud and Skoglund, 1986).

Other formulations such as encapsulation and controlled-release of soil applied herbicides such as trifluralin and cyanazine (Bladex®) offer longer residual weed control.

Adjuvants added to the spray solution are often helpful in one way or another (McWhorter, 1982). Specific materials can be chosen to decrease foaming action while spraying, to improve compatibility of herbicides in a mixture, or to reduce drift. Diuron (Karmex®) was considered effective only as a soil applied herbicide until McWhorter (1963) showed that the addition of surfactant made it active as a foliar spray.

SPECIALIZED APPLICATION TECHNIQUES

Wiese (1986) has described the vast array of herbicide application equipment available, particularly for research purposes. Further discussion here will introduce special techniques which have been used in the field with a more detailed discussion later.

Recirculating Sprayer—This sprayer was first developed in 1964 for spraying in row crops where weeds are taller than the crop (Wills and McWhorter, 1981). The sprayer is mounted on a tractor and the height adjusted hydraulically so that the nozzles are positioned above the crop. The spray solution is directed horizontally across the crop row. Any spray not intercepted by the weeds is trapped in a catch basin and returned to the tank for reuse. The spray volume used depends upon the degree of weed infestation, but recovery of 70 to 90 percent of the solution passing through the nozzles is common. The recirculating sprayer has been used to spray glyphosate (Roundup®) for johnsongrass control in cotton. Some crop injury can occur from the splatter of spray particles on cotton or inadvertent dripping caused by uneven terrain. The practice is nearly abandoned now that more selective herbicides like sethoxydim (Poast®) and fluazifop-P (Fusilade-2000®) are available.

Shielded Sprayer—The herbicide glyphosate stimulated a lot of research effort in designing application equipment to utilize its great herbicidal activity despite its lack of selectivity. The shielded sprayer was developed as one method of using glyphosate (Roundup®) to control weeds in cotton without crop injury. The shields were designed to prevent spray contact on the crop stems or foliage (Jordan, 1978). Some commercial units are available and many have been built in farm shops that are useful for controlling weeds such as perennial vines, bermudagrass and nutsedge in cotton.

Wiper Applicators—Several types of wiper applicators have been used commercially. Some use a spray system and some do not, but the common objective is to get the herbicide on the weeds without hurting the crop. The designs vary from rope-wicks to carpets and rollers.

The one used most widely was the rope-wick applicator (RWA) because of its simplicity and no need for a spray system. J. E. Dale invented the RWA and did the initial research in 1976 and 1977 (Dale, 1978). Most RWAs were made of polyvinyl chloride pipe which served as a reservoir for the herbicide solution. Braided nylon rope served as a wick to carry the herbicide solution by capillary action. As the applicator traveled over the field, the herbicide solution was wiped from the rope onto the weeds. Crop injury was avoided by adjusting the height of the applicator above a crop canopy. Only those weeds sufficiently taller than the crop were treated. Later models were designed to operate between the rows and thus treat smaller weeds.

Many of the applicators were built by farmers in their own shops. The demand was so great that the proper nylon ropes, grommets and sealing compounds were sometimes difficult to obtain. The wicking action of the rope varied considerably with the nature of the materials and physical construction of the nylon rope. This led to some standardization and measurement of rope-wicking properties (Derting, 1981b).

Chemigation—Irrigation has not been widely used for herbicide application. However, with more cotton acreage being irrigated in recent years, there is considerable interest especially in utilizing the sprinkler and drip systems to apply herbicides. In general, weed control using chemigation has been successful although uniform distribution of water and herbicide has been difficult to obtain (King *et al.*, 1980; Banks and Dowler, 1984). Satisfactory weed control has been obtained using as little water as 0.25 inch per acre for preemergence and 0.1 inch per acre for postemergence applications (Dowler, 1987).

Controlled Droplet Applications—Controlled spray droplet size is usually obtained with a spinning disc or rotary atomizer. Interest in this technique surged during the 1970s with the introduction of the Span Sprayer and the desire to reduce spray volumes (Patrick, 1970). Conventional hydraulic nozzles can be used to reduce spray volumes to about five gallons by using smaller orifices, lower pressures or faster ground speeds. However, such practices may increase the percentage of small droplets in the spray pattern and increase problems associated with drift (Taylor, 1981). The alternative method of using a spinning disk to deliver low spray volumes (LV) produces fewer small droplets of a size subject to drifting. The design and speed of the spinning disk can be changed to get the desired droplet size. Most herbicide application has been done at spray volumes around four gallons per acre with low velocity droplets of about 250 microns in diameter.

Air-assist Nozzles—The introduction of low pressure air into a hydraulic nozzle was done to permit application of low spray volumes. Research has shown the air-assist nozzles compare favorably with controlled droplet applicators and flat-fan nozzles at four gallons per acre (McKinnon *et al.*, 1985).

Electrically Charged Spray Particles—Creating an electric field in a spray pattern to propel charged spray particles onto target weeds has shown excellent uniformity of distribution on both upper and lower surfaces of leaves (Law, 1977). The atomization of the spray solution can be accomplished with a spinning disk or by electrostatic principles. Much of this research has been done in England by ICI Plant Protection Division and has resulted in the Electrodyn Sprayer (Coffee, 1981). These sprayer units may be hand carried or mounted on tractors. The hand-held units offer a great advantage to farmers in third world countries because of their efficiency and uniform application of ultra-low volumes (0.4 to 4 pints per acre). However, charged-particle sprayers are highly technical, and except for hand-held units are not yet commercially available.

Sensing Devices—Various sensing devices have been used to activate a spray system to spray weeds extending above the crop or outside the crop row. Such an automated system mounted on a tractor allows fast and economical spot treatment. The herbicide is conserved and applied only where needed.

Although demand was not great enough for commercial production, researchers built directed spray equipment to apply herbicides in a continuous band or only on the hills of cross-plowed cotton. A plant sensor and solenoid valve powered from the tractor battery was used to automate the spot spraying. Spraying only the cotton hills reduced herbicide rates 60 percent (Fulgham and Wooten, 1972).

Electronic Control Systems—Sprayer monitors have evolved along with the development of better herbicides. The need for precise chemical application has been recognized even more with rising herbicide and application costs along with environmental concerns. Over 30,000 spraying monitoring systems are now sold annually (Mueller, 1985). At the heart of some systems is a radar device which measures true ground speed. With electronic controls and a constant measure of true ground speed, the sprayer can be programmed to deliver a given herbicide rate and spray volume. Delivery is automatically adjusted to compensate for changes in ground speed (Weaver, 1984). Tractor manufacturers are now offering performance monitoring packages that will monitor spray applications.

APPLICATION METHODOLOGY

Herbicides are applied by four basic methods: sprays, granules, direct contact and irrigation (Matthews, 1982). The technology associated with these methods and time of application; preplanting, preemergence and postemergence include ground and aerial equipment designed to deliver the herbicide to the target. This section will describe the basic components of some of the equipment used in the four methods of application.

SPRAYS

By far the most common method of herbicide application in cotton management systems is liquid sprays. Most herbicides are applied with low-pressure sprayers. Sprayers range in size from small engine-driven pump units to large self-propelled sprayers. Spray pressures can range up to 145 pounds per square inch (Bode, 1987). Regardless, all low-pressure sprayers have several basic components; a pump, a tank, an agitation system, a flow-control assembly and a distribution system (Bode and Butler, 1981).

Pumps—The heart of the low-pressure sprayer is the pump which may be positive or non-positive types. Positive types (the roller pump, Figure 2A) displace a specific volume of liquid with each stroke or revolution of the pump. Some form of pressure relief or pressure control device must be used so that the spray solution not used in the application is bypassed back to the source tank. Unlike non-positive types (the centrifugal pump, Figure 2B) which are not self-priming, the positive displacement pumps do not require mounting below the tank level. However, non-positive pumps do not require bypass relief (Figure 2B), and they generally last longer (Bode, 1987).

Pumps used for applying herbicides include piston, diaphragm, centrifugal, roller, flex impeller, gear and vane. The most commonly used are the roller, centrifugal and diaphragm. Regardless, the pump should provide enough spray solution to supply the flow required by the nozzles and the tank agitator, and have a reserve capacity of 10 to 20 percent (Bode, 1987).

Centrifugal pumps are the most popular type used because of their durability, simple construction, and ability to handle wettable powder herbicide formulations. Their high output (40 to 130 gallons per minute at pressures up to 75 pounds per square inch) provides sufficient agitation for high-volume spray solution tanks. Though somewhat more expensive than a roller pump, its long life and low maintenance make it an economical choice.

Because of the need to operate at high impeller speeds (3,000 to 4,500 rpm), some type of step-up mechanism is required when operating from power-take-off (PTO) shafts. The simplest and least expensive is a belt-and-sheave assembly. Other step-up mechanisms include planetary gears completely enclosed and mounted directly to the PTO shaft, and a close-coupled, high-speed hydraulic motor. Use of a hydraulic motor to drive the pump keeps the PTO shaft free for other uses. To eliminate the need for a step-up mechanism, turbine pumps are available that operate similar to centrifugal pumps except they can provide the normal flow rate at pressures up to 75 pounds per square inch when mounted directly to the PTO shaft.

Roller pumps are also popular for low-pressure sprayers because of low initial cost, compact size, ease of repair and efficient operation from PTO shafts. A wide assortment of roller pumps are available with outputs ranging from 5 to 40

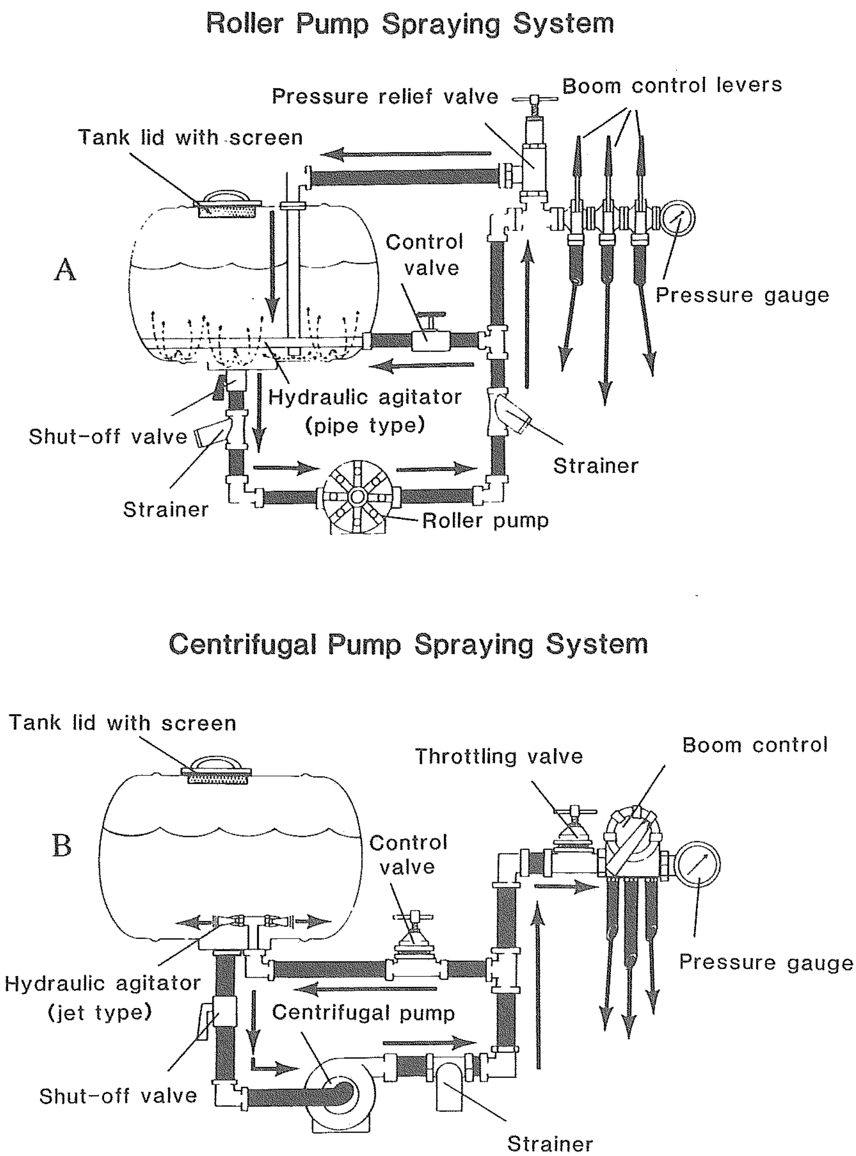


Figure 2. Components of low-pressure sprayers. Positive-displacement roller pump (A), and non-positive centrifugal pump (B).

gallons per minute and maximum pressures ranging from 145 to 290 pounds per square inch (Bode, 1987).

Nylon or polypropylene rollers have proven to be the most resistant to herbicides and are recommended for multipurpose sprayers (Bode, 1987). When the pump is used only for water solutions and wettable powder suspensions at pressures under 100 pounds per square inch, rubber rollers are preferred.

Diaphragm pumps are available in medium to high pressure (145 to 725 pounds per square inch) models with flow rates ranging from 15 to 50 gallons per minute. Diaphragm pumps are self-priming, positive displacement pumps, and require less horsepower than other pump types with similar flow and pressure ratings.

Tanks—Spray tanks should be selected that are large enough not to require frequent refilling. They should also be resistant to corrosion, easy to fill and clean, shaped suitable for mounting and effective agitation, have adequate openings for pump and hydraulic or mechanical agitation connections, and should have a clearly marked sight gauge or other external means of determining spray solution level (Bode, 1987). Tank openings should be large enough for unrestricted tank filling and cleaning, and be equipped with a cover to avoid spillage. A drain that opens through the bottom should be provided so that the tank can be completely drained of its contents. Tanks are constructed of several materials, and their features are listed in Table 1.

Table 1. Features of low-pressure sprayer tank construction materials. (Adapted from Bode, 1987.)

Material	Advantages	Disadvantages
Fiberglass	Strong, durable Repair kits available Equal to aluminum in cost Safe for most herbicides	Break or crack on impact Affected by some solvents Extra mounting support required
Aluminum	Strong, durable Equal to fiberglass cost Repairable	Subject to corrosion from some herbicides Tank volume not visible Cannot use liquid nitrogen solutions with phosphoric base
Galvanized steel	Strong Inexpensive	Easily corroded Corrosion results in strainer, screen, and nozzle tip clogging Tank volume not visible
Polyethylene	Tough, durable Relatively inexpensive Several sizes and shapes Safe for herbicides	Break or crack on impact Cannot be repaired Subject to ultraviolet light—inhibitors reduce damage Extra mounting support required
Stainless steel	Strong, durable Resistant to corrosion from any crop chemical	Expensive compared to other materials Tank volume not visible

Agitation—Agitation requirements depend largely upon the formulation of the herbicide being applied. Soluble liquids and powders do not require special agitation once they are in solution, but emulsions, wettable powders, and liquid and dry flowables will usually separate if they are not agitated by some means. Separation causes the concentration of the herbicide spray to vary greatly as the tank empties. Thus, thorough agitation is essential. Either mechanical paddles or hydraulic jets can be used to agitate the spray solution (Bode, 1987).

Hydraulic agitation is most commonly used on low-pressure sprayers (Bode, 1987). The fluid is circulated by returning a portion of the pump output to the tank and discharging it under pressure through holes drilled in a pipe running the entire length of the tank (Figure 2A) or through special (jet) agitator nozzles

(Figure 2B). Agitator orifices should receive fluid from a separate line on the discharge side of the pump and not just from the bypass line, although the bypass line does provide some agitation.

Flow Control—A roller or other positive-displacement pump usually has a flow-control assembly consisting of a bypass-type pressure regulator or relief valve, a control valve, a pressure gauge and a boom shut-off valve (Figure 2A). The bypass pressure relief valve is needed to prevent damage to the pump and other components when the boom is shut off (Bode, 1987).

To properly adjust the roller pump or other positive-displacement pump system: (a) close the control valve in the agitation line and open the boom shut-off valve; (b) start the sprayer and run the pump at operating speed, and adjust the pressure relief valve until the pressure gauge reads about 10 pounds per square inch above the desired spraying pressure; and (c) slowly open the agitation line control valve until the spraying pressure is at the desired level.

A pressure relief valve and bypass line are not needed with a flow-control assembly for a centrifugal pump, but throttling valves to accurately control the spraying pressure are preferred (Figure 2B). Two control valves (one in the agitation line and one in the spray boom line) are used to control the spray pressure. This permits independent flow control of the agitation line and nozzle output. Especially useful for enclosed cabs of tractor-mounted sprayers are electric-controlled throttling valves (Bode, 1987).

To adjust the centrifugal pump system: (a) prime the pump with all valves open; (b) close both valves and, with the pump running, open the boom control valve until the pressure gauge indicates the desired spraying pressure; and (c) open the agitation line control valve for sufficient agitation. Restore the boom pressure if opening the agitation line control valve caused a pressure change.

As a group, sprayers use one of four types of atomizing nozzles: hydraulic pressure, pneumatic, rotary and electrostatic. Atomizing nozzles regulate the flow rate of the spray solution, form individual droplets, and disperse the droplets into an acceptable distribution pattern (Bode, 1987).

Hydraulic pressure nozzle is the most common atomizing nozzle. These are available as fan-spray, flooding or deflector spray, cone spray and straight stream nozzles. As a group, these hydraulic pressure nozzles produce a wide range of droplet sizes.

Flat-fan spray nozzles are designed to produce a thin sheet of spray with a spray angle ranging from 15 to 110 degrees when pressure forces the liquid solution through the nozzle orifice. Tapered flat-fan nozzles are usually mounted on 20-inch centers and operated at pressures of 25 to 40 pounds per square inch to provide 25 to 30 percent pattern overlap for optimum distribution (Figure 3). Nozzle distance to target (spray height) is 10 to 24 inches depending upon nozzle spray angle and pressure (Table 2). As spray angle increases (while holding pressure constant), the spray height required to maintain 25 to 30 percent spray pat-

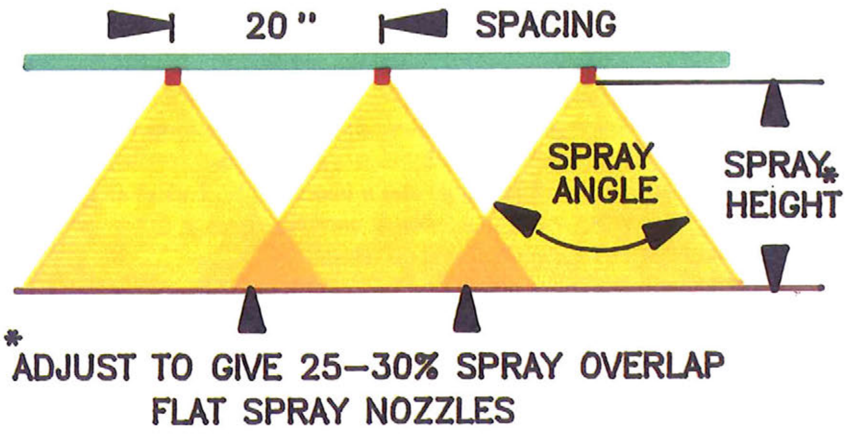


Figure 3. The relationship of nozzle spray angle, spacing, and tip height for tapered flat-fan spray nozzles to result in proper spray pattern overlap.

Table 2. Nozzle height in inches above target surface needed to provide 25 to 30 percent spray pattern overlap. (Adapted from Bode, 1985.)

	Nozzle spacing	
Tip spray angle	20 inches	30 inches
	—Nozzle height—	
(degrees)	(inches)	
65	21 to 23	32 to 34
73	20 to 22	27 to 29
80	17 to 19	24 to 26
110	10 to 12	14 to 18

tern overlap is decreased. Thus, the 95 to 110 degree nozzles can be operated close to the spray target which is often needed when wind speeds increase. Flat-fan nozzles that will produce a normal fan angle and distribution pattern at low pressures (15 pounds per square inch) are also available. These low pressure fan nozzles produce larger drops at lower pressures than regular fan nozzles, but also produce smaller droplet sprays at higher pressures (30 to 60 pounds per square inch) (Spraying Systems Co., 1985).

For band preemergence application of herbicides, the even flat-fan nozzle is available. Unlike the tapered flat-fan nozzles, these nozzles provide uniform coverage across the spray pattern width. Band width is determined by adjusting spray height (Figure 4, Table 3). Again, as spray angle increases, the nozzle can be mounted nearer to the target for a given band width. Band width for preemergence applications is usually two inches greater than the planned width of the first cultivation.

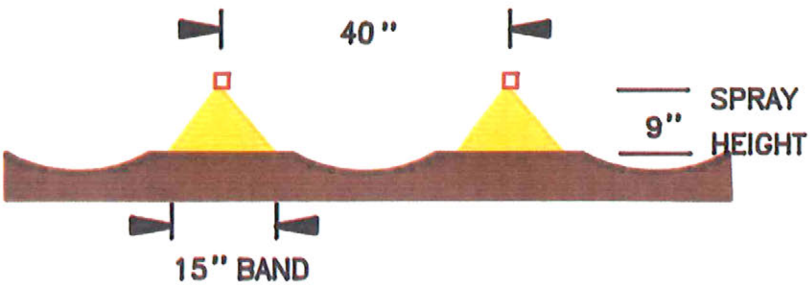


Figure 4. Eighty degree even flat-fan nozzles positioned 9 inches above target to result in a band width of 15 inches.

Table 3. Nozzle height in inches above target surface needed to provide a given band width using even flat-fan spray nozzle tips. (Adapted from Spraying Systems Co., 1985.)

	Nozzle tip spray angle (degrees)		
Band width	40	80	95
		—Nozzle height—	
(inches)		(inches)	
8	11	5	4
10	14	6	5
12	17	7	6
14	19	8	7
16	22	10	8

Tapered flat-fan nozzles also can be used effectively on directed postemergence spray rigs. Each nozzle may be set down and back (in relation to travel direction) to overlap 25 to 30 percent across the drill while maintaining the desired band width (Figure 5A). Nozzle height adjustment needs to provide spray coverage of weeds, but with minimum contact of the cotton foliage. The off-center tapered flat spray nozzle (Figure 5B) also is an alternative in constructing a down-and-back direct spray system. Where spray overlap on successive passes is not desired, an off-center nozzle can be used on the boom as the outside nozzles. Applying herbicides to the skip of a skip-row cotton planting pattern is one example where such an arrangement could be utilized.

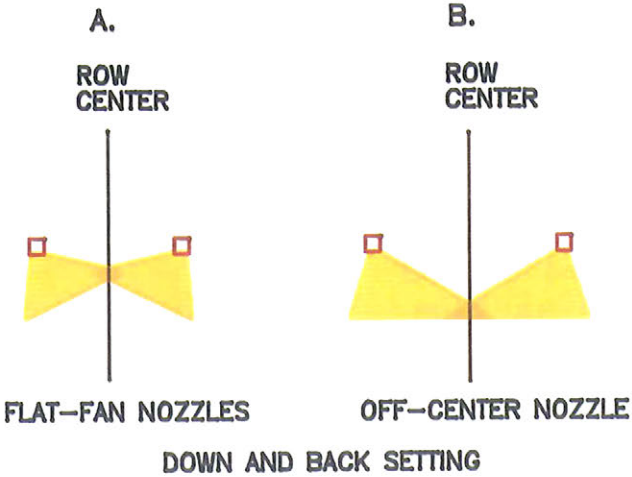


Figure 5. Overhead view of tapered flat-fan nozzles (A) and tapered off-center flat-fan nozzles (B) set to apply a directed spray in a down and back (in relation to direction of travel) pattern.

Flat-fan nozzles are sometimes used in fixed-wing aerial ULV application of certain cotton insecticides. Similar applications of the selective grass herbicides could be made where small but concentrated spray droplets are desired (Barrentine and McWhorter, 1988).

Twin orifice flat-fan nozzles have been developed to provide greater flexibility in boom sprayer use. One nozzle has two orifices side-by-side to produce a wide spray angle pattern. They can be mounted on a drop-pipe from the boom in the row middle to provide directed spray coverage. A nozzle with two orifices front and back is also available that produces two flat-fan spray patterns 60 degrees apart.

Flooding or deflector spray nozzles produce a wide-angle flat spray pattern of 70 to 145 degrees (width depending upon design and pressure) with operating pressures ranging from 10 to 40 pounds per square inch. These nozzles are usually mounted on 40-inch centers, and can be mounted so that the spray pattern is straight down or at any angle as long as 100 percent spray overlap is achieved. To provide 100 percent overlap with flooding nozzles mounted on a disk harrow (Figure 6A), a spray height of about 18 inches with the nozzles tilted up 45 degrees (0 = straight down) is required. For any incorporation device, pattern overlap should be adjusted with the device set at the depth of operation. Flooding nozzles are used in the application of preplant herbicide and liquid fertilizer mixtures. The spray boom can be raised or lowered and the nozzles (or boom and nozzles) rotated to provide 100 percent spray pattern overlap forming an umbrella like spray pattern as illustrated in Figure 7.

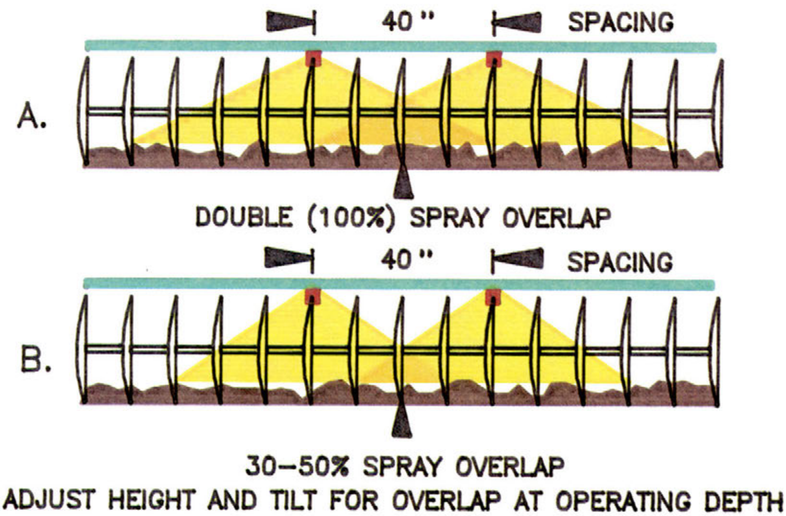


Figure 6. Flooding or deflector nozzles (A) and full-cone wide-angle nozzles (B) mounted on a disk harrow illustrating proper spray pattern overlap.

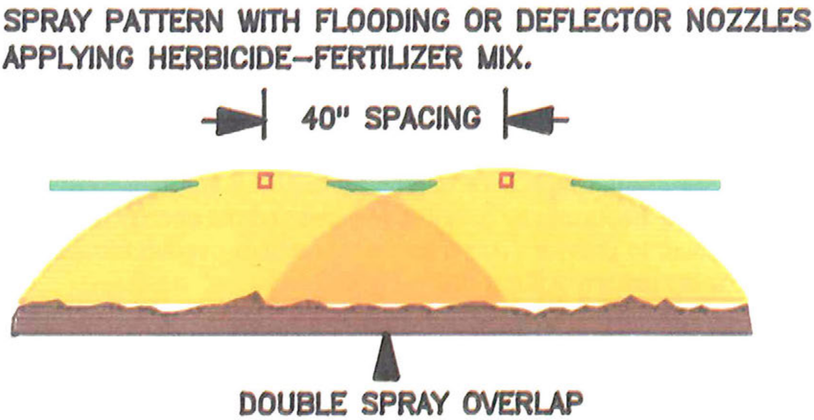


Figure 7. Illustration of a boom equipped with flooding or deflector nozzles tilted up to form an umbrella like spray pattern with double (100 percent) overlap.

Cone spray nozzles are designed to produce a full or hollow cone spray pattern of various angles. Bode (1987) describes the production of a cone spray pattern in detail. The wide-angle (up to 120 degrees) cone nozzle is the most commonly used full cone nozzle in cotton production. These are often mounted to a soil incorporator on 40-inch centers to provide 30 to 50 percent spray pattern overlap at 15 to 30 pounds per square inch (Figure 6B). To improve spray distribution and compensate for restricted height adjustment, nozzles may be tilted 30 to 45 degrees. Hollow cone nozzles have limited use in cotton weed control, but the selective grass herbicides could be band-applied using the two nozzle per row arrangement shown in Figure 8. When cotton exceeds the 8-inch stage, the two-nozzle spacing may be increased from 22 inches to 24 inches and their height from 11 inches to 15 inches, and a third nozzle centered 23 to 24 inches above the cotton drill may be added (Baldwin *et al.*, 1988). The three-nozzle arrangement would be suitable for application of foliar applied selective herbicide and fertilizer mixtures as it is for defoliants.

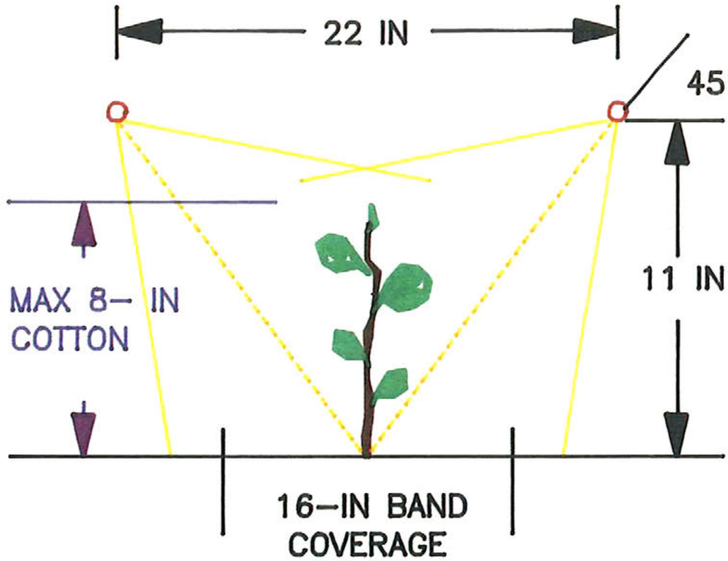


Figure 8. Positioning hollow-cone nozzles when applying over-the-top sprays to a band from two nozzles per row. (Adapted from Baldwin *et al.*, 1988.)

The straight-stream cone nozzle produces a straight but somewhat unstable spray pattern. This nozzle has limited use except for recirculating sprayers (Wills and McWhorter, 1981) and spray guns used for spot-spraying. Straight-stream disc-core nozzles are more often used to meter herbicide solutions that are injected into the soil. This nozzle consists of the usual nozzle body, cap and filter (screen) but the orifice is a flat disc to provide varying flow rates at various pressures.

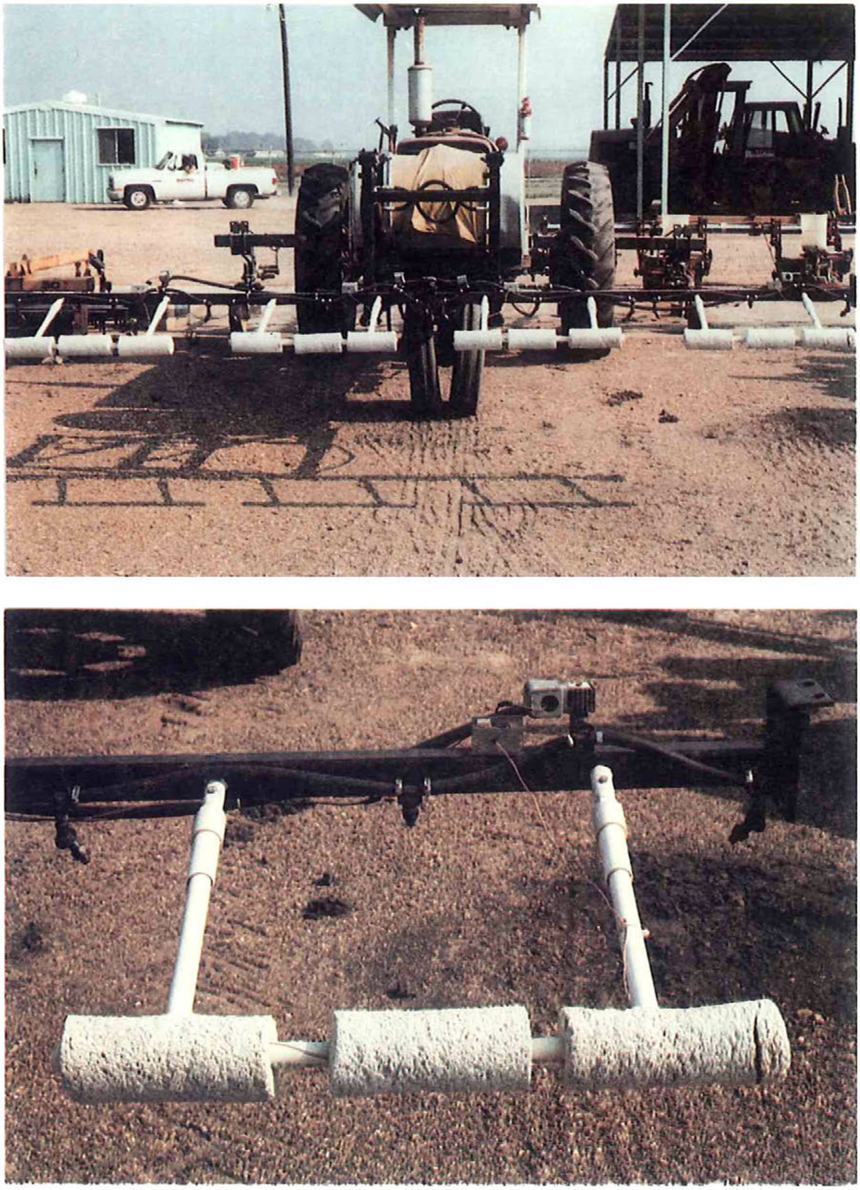
Spot-spraying equipment used in cotton weed control varies from the traditional hand-operated (compressed air, knapsack, etc.) sprayers (Figure 9) to those which are tractor-mounted with the spray nozzles turned on-off via a solenoid valve activated when weeds taller than the cotton plants interrupt an infrared light beam.[1] A tractor-mounted unit which utilizes a moisture sensing system and solenoid valve for spray on-off is under evaluation[2] (Figure 10A). As the weeds which are taller than the cotton contact the moisture laden sponge, the three-nozzles-per-row arrangement (Figure 10B) delivers a momentary spray. It is not uncommon to see all-terrain vehicles (ATV) equipped with hand operated sprayers (Figure 11) applying spot sprays early in the growing season.[3] Spot gun applicators (Figure 12A,B) which apply known volumes of known concentrations of glyphosate (Roundup®), sethoxydim (Poast®), or fluazifop-P (Fusilade-

[1]HEC Sprayer. Town Country Airpark, Lubbock, TX 79404.
[2]Private communication. J. R. Williford, USDA, ARS, Stoneville, MS.
[3]Spraymate 26, Ag Enterprises, Route 1, Box 69, Grainfield, KS 67737.

2000®) to spots of rhizome johnsongrass in cotton are also in use. Figure 12C illustrates a 0.67 ounce (20 milliliters) "shot" which was applied mid-way up the culms of a "spot" of rhizome johnsongrass.

Figure 9. Spot-spraying rhizome johnsongrass with a hand-held compressed air sprayer.

A



B

Figure 10. A front-mounted boom (A) with 3 nozzles per row which applies a momentary spray to weeds growing taller than the crop plants when the moisture sensitive pad (B) interrupts the weeds and activates on on-off solenoid valve.

Figure 11. One of several types of all terrain vehicles equipped with a sprayer which can be used for spot-spraying.

A

B

C

Figure 12. A back-pack (A), spot-gun (B) applicator applying a 2/3 oz "shot" to a spot of rhizome johnsongrass. The blue dye (C) illustrates coverage.

Disc-core-hollow-cone and whirl nozzles are also used on aerial spray booms. They are mounted to the rear and down no more than 45 degrees. Selection of wide angle disc-core or whirl nozzles are to be avoided (Bouse, 1987). Multiple jet or combination nozzles (Figure 13) are common on fixed wing aircraft.

The raindrop cone nozzle, as the name implies, produces larger droplets than other cone types, and is often used in the aerial application of preplant herbicides where drift may be a problem. Its use for contact herbicides may result in unsatisfactory weed control (Bouse, 1987). Spinning atomizers as depicted in Figure 14A, B also are used for LV application. Figures 15 to 23 provide examples of aircraft and nozzle arrangements that may be used to apply herbicides.

Figure 13. A combination pressure nozzle used on aircraft.

A

B

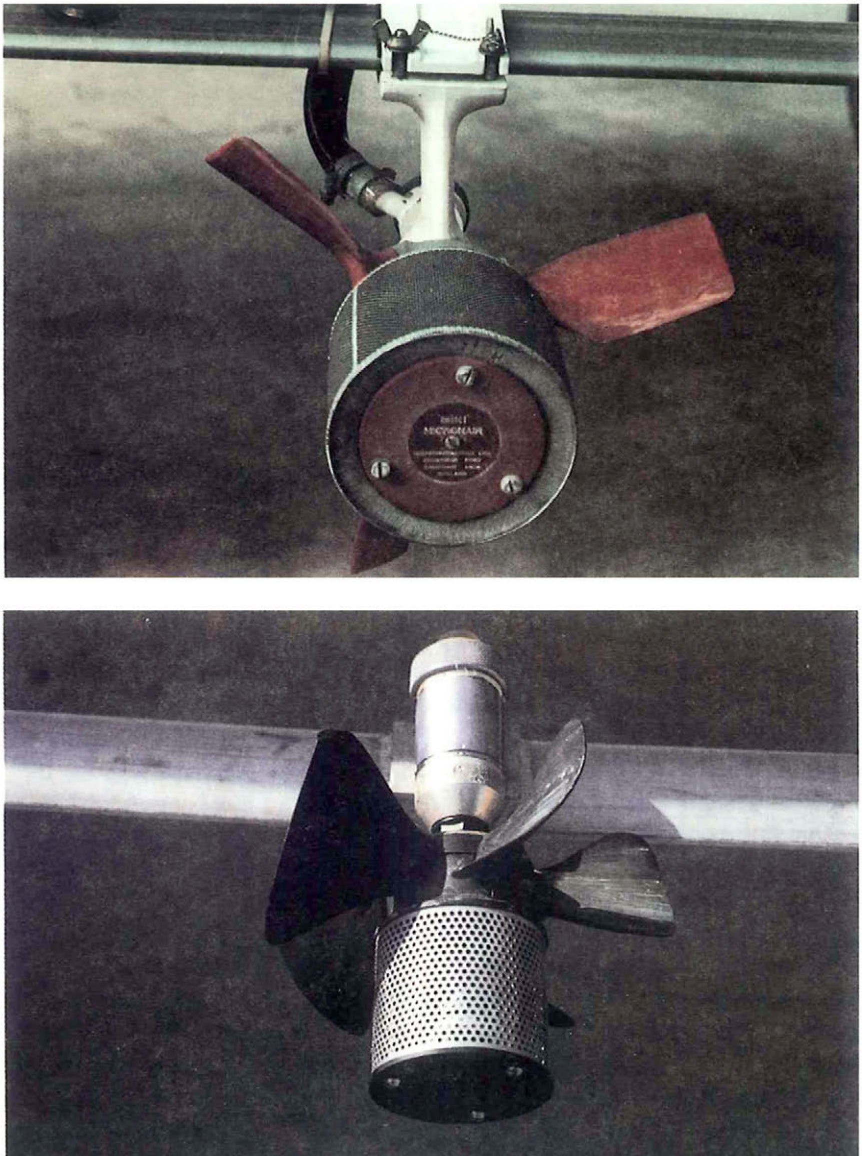


Figure 14. Spinning atomizer nozzles used on aircraft: Micronair (A) and Unimizer (B).

Liquid sprays are the primary methods of applying herbicides in cotton weed management systems, and pressure or hydraulic nozzles the primary means of metering and dispersing the spray. Yet, no single aspect of applying herbicides in cotton weed management is as important, and more often given improper attention to, as sprayer calibration and determining the herbicide-water spray mix. Methods of calibrating low-pressure hydraulic nozzle sprayers are described and accompanied with examples in the Appendix at the end of this chapter.

Pneumatic nozzles atomize the liquid solution by impacting the metered solution with air. Air impaction of the liquid may be outside (external), as in the common paint spray nozzle, or inside (internal) the nozzle. The internal-mixing nozzle is actually a combination pressure-pneumatic nozzle. The metered liquid under pressure is impacted against a pin protruding from the base of the internal mixing chamber which partially atomizes the liquid. Atomization is completed by low volume air introduced into the mixing chamber under low pressures—hence, the name air-assist nozzle. A modified flooding or deflector nozzle tip is used to regulate the air flow into and out of the liquid-air mixing chamber and to produce the spray distribution pattern. The nozzle is designed to apply liquid solutions at 2 to 10 gallons per acre using liquid pressures from 30 to 60 pounds per square inch, and air pressure ranging from 4 to 12 pounds per square inch (Reed, 1985). These nozzles could be used to apply the selective grass herbicides in cotton.

Rotary nozzles were produced as an alternative to the pressure or pneumatic atomization nozzles to provide a spray pattern with a narrow range of droplet sizes. Droplets are formed by introducing the liquid onto a rotating cup, disk or cone. Centrifugal force moves the metered liquid to the outer periphery. Droplet formation and final size is a function of flow-rate, disk diameter and design and rotational speed (Gebhart and Kapusta, 1987).

Several designs of rotary atomizers are available, but most commonly seen is the spinning cone or control droplet applicator (CDA) which utilizes a cone-shaped cup with grooves on the inside and serrations (teeth) on the periphery of the cup lip. These are available with either a direct current electrical motor or a hydraulic motor.[4] A second unit uses an electrically driven horizontally spinning disc with grooves on the inside surface.[5] A third unit utilizes a shielded, smooth-surface disc with outer edge serrations mounted vertically.[6] One other unit uses an inverted cup as a rotary atomizing device.[7] These rotary atomizers could be used for LV or ULV selective herbicide application, but weed control has generally been inconsistent because of inadequate spray coverage (Gebhart and Kapusta, 1987).

Electrostatic nozzles are not used in cotton weed control; however, three different types of electrostatic sprayers have received considerable research effort (Gebhart and Kapusta, 1987). The basic principle is to create a charged spray

[4]Micron Corporation, P. O. Box 19698, Houston, TX 77024 and Sprayright Manufacturing Company, P. O. Box K, West Helena, AR 72390.

[5]Spraying Systems Co., North Avenue, Wheaton, IL 60188.

[6]Techoma S.A., Epernay, France.

[7]J & J Guy Systems, Inc., P. O. Box 241, San Born, MN 56083.

droplet that will adhere to the target (plant part and/or soil). The droplet must be of appropriate mass and charged so that the electric field created between the spray droplets and target surface is sufficient to overcome wind, gravitational and inertial forces that will otherwise cause the droplets to miss the target.

Law (1978) developed an internal-atomizing pneumatic spray nozzle to produce droplets. The charging electrode imbedded in dielectric material for protection, is located within the atomizing chamber and the upper operating voltage was about 2,000 volts. His unit successfully applied water sprays at LV and ULV.

Coffee (1981) designed the only known commercially available electrostatic sprayer for ULV applications. Electrostatic principles not only charge but generate the droplets. Degree of atomization can be varied by changing the charging voltage. This allows for some control over droplet size and charge. Voltage requirements were so low that standard 1.5 volt flashlight batteries would power the commercialized hand-held units.

Others have utilized the rotary atomizer principles in the design of spinning disk electrostatic atomizers for ground (Arnold and Pye, 1980; Marchant, 1986) and aerial (Carlton and Bouse, 1980) equipment. Coffee's design remains the sole commercial unit. The principles are very sound, but the major problem is getting the droplets to the desired target (Gebhart and Kapusta, 1987).

Figure 15. Cessna A188B Ag-Wagon equipped with combination nozzles.

Figure 16. Cessna A188B Ag-Husky-Turbo equipped with combination nozzles.

Figure 17. Cessna A188B Ag-Truck equipped with combination nozzles.

Figure 18. Rockwell Thrush Commander 600 equipped with combination nozzles.

Figure 19. Gruman G-164A Ag-Cat equipped with combination nozzles.

Figure 20. Gruman G-164B Ag-Cat equipped with combination nozzles.

Figure 21. Air Tractor AT-301, 600, equipped with Model 10 Unimizer spinning atomizers.

Figure 22. Air Tractor AT-301, Turbo 680, equipped with Micronair spinning atomizers.

Figure 23. Continental Copter, Mark 5 Tom Cat, equipped with Warner spray system nozzles.

GRANULES

Granular formulated cotton herbicides are not used to any great extent in the Cotton Belt. The preplant incorporated herbicides could be easily applied in granular form, but the continuing need for weed control with postemergence sprays probably accounts for the lack of any trend toward granular application.

Early problems with calibration and granular distribution were encountered. This was due to the adoption and modification of granular fertilizer and seeding equipment for use in applying granular herbicides. Because of the poor distribution obtained with this equipment, weed control was often less than satisfactory.

Herbicides with a relatively high water solubility such as cyanazine (Bladex®) can provide better weed control when applied preemergence in granular form than in a liquid spray (Feeny and Coble, 1964). Those which volatilize and/or photodegrade after application were also more effective in granular form than in liquid sprays. Thus, the weed control from trifluralin (Treflan®) and pendimethalin (Prowl®) applications could be more effective when applied in granular form as compared to liquid sprays.

The concept of controlled release herbicides (Schreiber *et al.*, 1987) may also spur an increase in applying herbicides in granular form. The object of controlled release is to deliver the herbicide to the target site at a constant but effective concentration over a specified period of time (Lewis and Cowsar, 1977). The herbicide is chemically attached or physically entrapped (encapsulated) within another substance.

Because of its volatility and photodegradation properties, trifluralin should be immediately incorporated. Encapsulated trifluralin granules permitted incorporation to be delayed for up to 8 days after application while maintaining weed control (Foley and Wax, 1980). Fall, winter or early spring applications of encapsulated trifluralin gave season-long control without incorporation at planting time and opens the possibility for its use in minimum-till systems (White and Schreiber, 1984).

Other herbicides used in cotton which have been encapsulated are linuron (Lorox®), cyanazine (Bladex®) and metolachlor (Dual®). Most of the herbicides used in preemergence and/or layby applications in cotton could be encapsulated and applied with granular applicators.

The state-of-the-art ground granular applicator uses a pneumatic system. This development permits the use of one application system for ground application of granular fertilizers and/or herbicides. The Gandy Company's[8] pneumatic granule delivery system is capable of applying granules from 1.0 to 270 pounds per acre. The application equipment may be mounted on a combination tool to apply herbicides broadcast preplanting (Figure 24A) or in conjunction with a planter for band preemergence application (Figure 24B) of herbicides. The minimum dry fertilizer-herbicide granular rate suggested to ensure uniform application is

[8]The Gandy Company, Owatonna, MN 55060.

200 pounds per acre (Lowery, 1987); thus, this unit could be used for their application.

A

B

Figure 24. A pneumatic granule applicator for applying granular or dry flowable formulations mounted on a combination tool for secondary tillage and herbicide incorporation (A) or planter attached for band preemergence applications (B). (Courtesy The Gandy Co., Owatonna, MN 55060.)

Dry flowable herbicide formulations have also been applied and evaluated with this device (Haugen and Ganrud, 1983a). Weed control compared favorably with the granular and liquid formulations (Haugen and Ganrud, 1983b).

Many aircraft are equipped with the venturi type spreader for dry herbicide applications. The same hopper used for liquid sprays is used for the granular herbicide. The materials are metered from the hopper into an opening in the top of the venturi-shaped throat of the spreader. Vanes or fins within the spreader deflect the dry particles laterally to increase swath width. Helicopters use on-board spreaders or a self-contained bucket spreader. On-board hoppers are mounted on each side, and the dry granules flow from the hoppers to either centrifugal or pneumatic distributors. The self-contained (including power unit) spreader is suspended on cables beneath the helicopter, and is operated electronically from the cockpit (Bouse, 1987).

A novel, but highly promising, ground granular spreader for the application of dry-herbicide formulations utilizing the rotary principle has been reported by Dale (1987). The device consists of a detachable hopper (Figure 25A) of containerized granules with a preselected circular orifice (Figure 25B) to regulate the flow of granules, and a revolving hollow-cone spreader (Figure 25C) turned by an electric motor. Based on patterns of distribution achieved with commercial trifluralin granules, parallel and perpendicular to a linear path, the device could be used to apply herbicide granules in row crops. When trifluralin granules were applied preplant incorporated, seedling johnsongrass control was 80 to 95 percent.

A

B

C

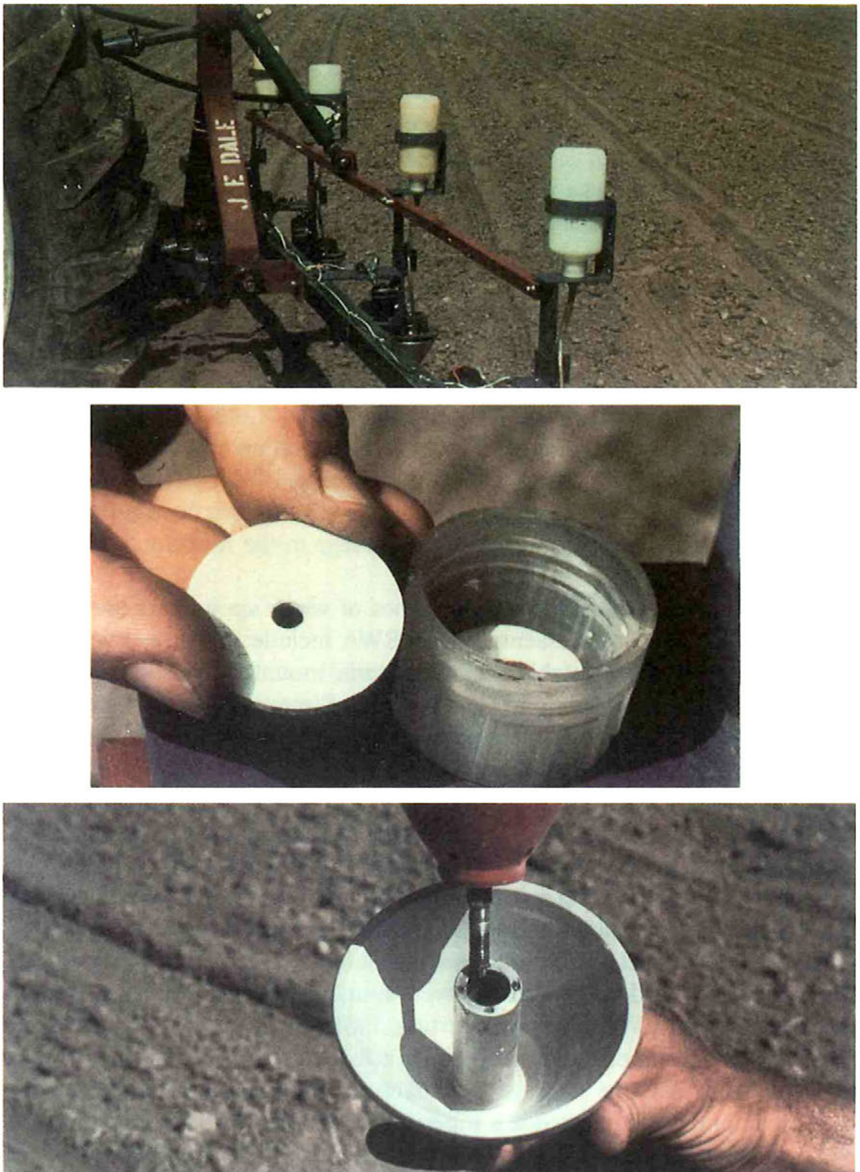


Figure 25. An experimental ground granule spreader for application of dry-herbicide formulations; consisting of containerized granules in a detachable hopper (A) with a preselected circular orifice (B) to regulate flow and a revolving hollow-cone spreader (C). (Courtesy J. E. Dale, USDA, ARS, Stoneville, MS 38776.)

CONTACT

This mode of herbicide application includes equipment-herbicide technologies that were more rapidly evaluated and adopted by growers than any other single advance in herbicide application. This mode of contact application is wiper technology or better known in general as rope-wick application.

Wiping a herbicide onto weeds was not a new concept as producers for a number of years used a boom wrapped with burlap or other material and saturated it with 2,4-D to selectively control hemp sesbania in soybeans. This was followed by the initial research (McWhorter, 1966) and commercialization of the 2,4-D wax bar. The discovery and development of glyphosate (Roundup®) is credited with renewing the interest in wiper application of herbicides and in advancing wiper technology (McWhorter and Derting, 1985).

The rope-wick applicator (RWA), invented by Dale (1978), is credited with initiating research and development in both public and private sectors that led to sale of selected herbicide wiper applicators. The use of RWAs for johnsongrass treatment growing above cotton plants in the early 1980s was common across the Cotton Belt and at least 50 percent of the acreage in the Mid-South region was treated.

Detailed descriptions of the various types of wiper applicators are given by Derting (1987). The basic essentials of a RWA include: (a) a reservoir for the herbicide solution, (b) a suitable wicking material mounted to draw the herbicide solutions from the reservoir, and (c) a method of transporting through the field. The most widely used RWAs were passive; the herbicide solution was fed to the wick by gravity and capillary action. The reservoir pipe of the RWA developed by Dale (1978) also served as the structure for mounting the wick in place.

Active wicking systems use similar reservoir-wick mounting, but they use a closed-system with pressure on the reservoir. This is accomplished either by air in the head above the reservoir or an in-line pump between the reservoir and wick. These systems allow better movement of solution through the ropes, particularly in arid and semi-arid climates typical of the western United States.

The fiber and braid characteristics were found to significantly affect johnsongrass control with RWAs (Wu and Derting, 1981; Derting, 1981A). This facet of RWAs was of such importance in obtaining effective weed control and increasing the wear time that one cordage manufacturer developed the polyester over acrylic diamond braid to provide a superior wick (Revelle, 1982). This cordage is produced on a diamond braider with polyester cords on all ribbons which is braided over a core of acrylic yarn. It has a tough wearing exterior and a high wicking capacity interior.

The passive Stoneville RWA usually required two passes over the johnsongrass for effective (≥85 percent) control using a 1:3 parts solution of glyphosate to water and, because of dripping, caused cotton injury. A newer RWA design that provided excellent johnsongrass control in a single pass with only slight visible cotton injury was the recirculating double pipe wick (McWhorter and

Derting, 1985). This unit consists of two parallel pipes, one mounted above and forward of the other, connected by the rope-wicks. This RWA not only increased the wiping surface area, but the herbicide solution is continuously aspirated from the bottom pipe to the top to maintain fully saturated ropes without drip loss. Once the solution flow through the wicks is adjusted, no other field adjustment is needed regardless of weed infestation level. Solution not wiped onto johnsongrass is recovered for continuous use. In comparative studies, its performance was superior to that from all other active and passive wiper designs evaluated on sloping terrains. The double pipe wick was also the most efficient as measured by the maximum number of acres treated per unit of glyphosate (Roundup®) (McWhorter and Derting, 1985).

Rowcrop carpet wiper applicators of several design modifications have been constructed and evaluated, but commercial sales were limited compared to the RWAs. The first carpet roller applicator was a tractor-mounted aluminum cylinder covered with nylon carpet (Wyse and Habstritt, 1977). A hydraulic motor rotated the cylinder counter clockwise to the direction of travel. A PVC pipe with one-inch holes drilled two inches apart was mounted directly above the carpet roller sumps. Herbicide solution was pumped from a reservoir through tubing to the PVC pipe from which the solution dribbled onto the carpet roller sumps. Optimum cylinder rotation was 20 rpm to prevent dripping. Solution saturation of the carpet was maintained with an electrical sensing device.

A recirculating carpet applicator was designed possessing the elements of a passive wiper, recirculating sprayer and hydraulic sprayer (Chandler, 1981). Called the "Ultimate Stoneville Applicator," carpet was mounted to expanded metal and fit into an opening cut in front of an eight-inch diameter by 80-inch long aluminum pipe which was closed off at each end. Herbicide solution was sprayed onto the back of the carpet through cone nozzles spaced 10 inches apart. Excess spray solution drained from the pipe to a sump and was filtered and recirculated. The commercial unit with some improvements was called the "Carpetbagger" (Roach and Chandler, 1982).

The recirculating sprayer (McWhorter, 1970) was superseded by the rope-wick applicator (RWA) and the RWA is being replaced by over-the-top sprays of the selective grass herbicides. Sethoxydim (Poast®) and fluazifop-P (Fusilade-2000®) are very effective when applied as sprays postemergence to cotton and seedling and/or rhizome johnsongrass and bermudagrass. Regardless, wiper application will continue to be a weapon in the cotton producers arsenal for johnsongrass and other tall weed escapes, because of its simplicity of design and operation, and because numerous units are currently owned by cotton producers.

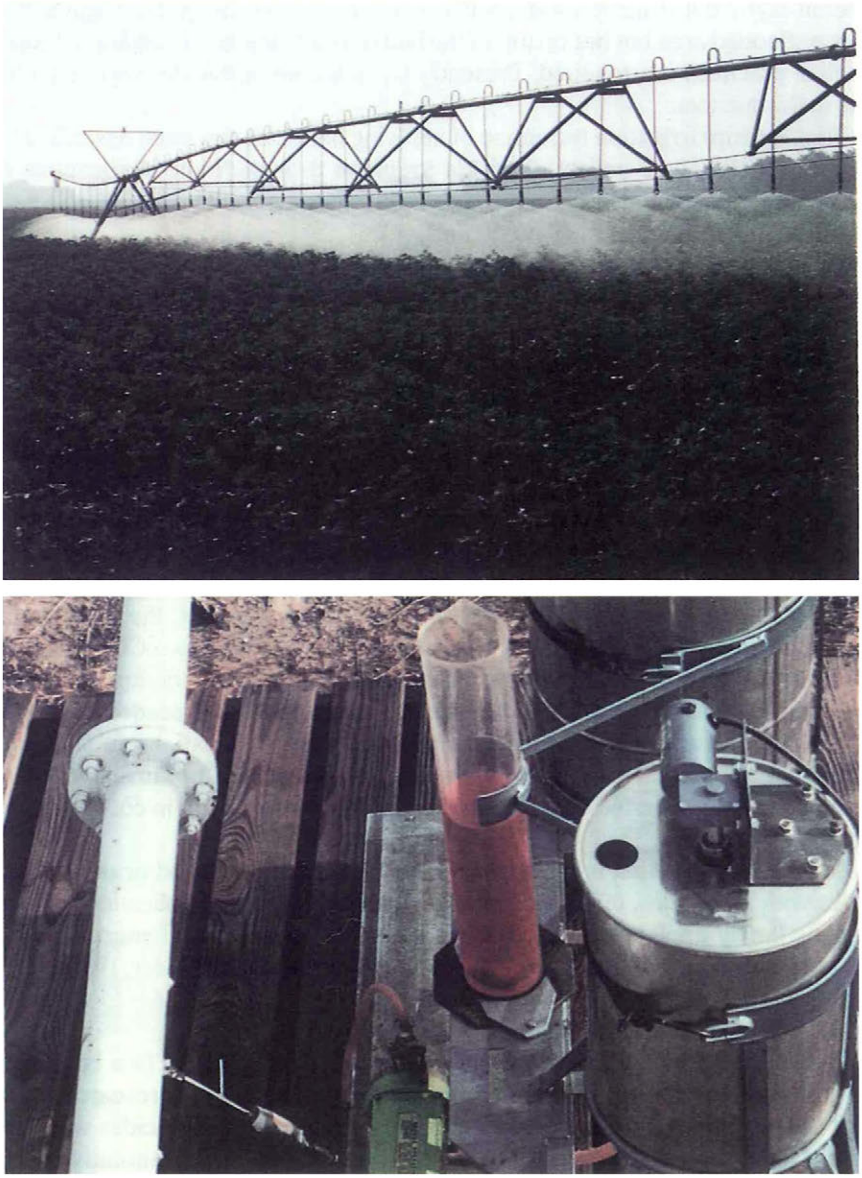
CHEMIGATION

Herbicide application in irrigation water to selectively control weeds is a recent development in weed technology which can increase crop production efficiency by reducing cost for equipment, labor and fuel (Threadgill, 1981). Nitrogen fertilizers have been applied for several years in irrigation systems, particularly sprinkler systems (Bryan and Thomas, 1958). Advances in irrigation systems and associated injection equipment design have stimulated research which resulted in expansion of this technology to include herbicides (Threadgill, 1985a). Herbicide application in irrigation water is known as Herbigation,® a trademark of ICI Americas, but the application of pesticides and/or fertilizers in general fall under the collective term, chemigation.

Several advantages in applying herbicides through a properly designed irrigation system have been reported (Threadgill, 1985abc). These include: (a) excellent uniformity of herbicide application is possible with sprinkler irrigation systems to include center-pivot and linear-move units when compared to aircraft or ground sprayer applications, (b) application of herbicides can be applied on a timely basis even when fields are too wet for tractors or when weather conditions preclude aircraft application, (c) chemigation precludes the requirement for moisture for precise depth of incorporation because the appropriate amount of water can be applied through irrigation which will incorporate the herbicide to the depth desired and be in place to control the germinating and emerging weeds, (d) in soils where soil compaction is a problem, chemigation can reduce compaction caused by tractors and other tillage implements, (e) mechanical damage to the crop caused by tractors or other spray application equipment which can increase disease problems is avoided, (f) exposure to operators of herbicide application equipment is reduced, and (g) with an adequate irrigation system already in place, economic data has shown chemigation to be cost effective.

Conversely, several disadvantages should be considered in chemigation systems. The most obvious is the additional capital outlay required, particularly where no irrigation system is in place. Safety factors to prevent water supply contamination is of utmost importance. This problem is well recognized by the industry and regulatory agencies and practical safety components are commercially available (Ogg and Dowler, 1987). Chemigation requires very good management and a well designed system that applies water uniformly and permits accurate calibration. A thorough knowledge and understanding of the concept is a necessity. Application of herbicides to control weeds via sprinkler irrigation postemergence has produced inconsistent results because the herbicide is lost from the plant surface by runoff due to the high volume of water usually applied ($\geq$2700 gallons per acre). Another possible disadvantage is that chemigation requires considerably more time to apply the herbicide to a large field as compared to aircraft or ground equipment.

The components of a basic system for delivering the herbicide into an irrigation system (Figure 26A) includes a chemical supply tank, an injection pump, and the appropriate safety and anti-siphon devices that prevent potential contamination of the water source (Figure 26B) (Ogg *et al.*, 1983). Some essentials for a chemigation system, including design and safety features, equipment construction materials, supply tanks, injection pumps and equipment calibration, are discussed by Ogg and Dowler (1987). An injection system used on a sprinkler center-pivot research system is shown in Figure 26B.



A

B

Figure 26. A center-pivot irrigation system (A) equipped for experimental (B) use in applying herbicides and/or liquid fertilizers using irrigation water as the diluent.

In nonpressurized or gravity flow systems (flood or furrow irrigation), a constant head siphon can be used instead of an injection pump to meter the herbicide into the irrigation water. Herbicides can be applied immediately after planting or later at layby but irrigation water will control weeds usually in the irrigated furrow or flooded area but not on top of the bed or ridge; therefore, additional weed control practices are required. Presently there are no herbicides registered for use in this manner.

Trickle (drip) irrigation technique of applying herbicide has been described by Ogg *et al.* (1983). A review of trickle irrigation to include the applications of herbicides is presented in a two volume series published by the American Society of Agricultural Engineers (Anonymous, 1985). The application of herbicides through trickle irrigation systems is not widely used because of problems associated with uneven herbicide application, rapid degradation of the herbicide near the emitters and potential health hazards to workers who might drink treated water from delivery lines. Currently there are no herbicides specifically labeled for application through trickle irrigation systems.

Research in Arizona (Anonymous, 1985) has indicated that weed control in cotton has been inconsistent where trickle irrigation is the exclusive method of applying herbicides. A preplant soil incorporated treatment for grass control followed by effective post-directed foliar and/or preemergence herbicide treatments are essential. A particular problem in cotton fields was the nutsedge species that thrive under the wet conditions provided by trickle irrigation.

In stationery, center-pivot or lateral move sprinkler systems, the grass herbicides fluazifop-P (Fusilade-2000®) and sethoxydim (Poast®) plus a COC (crop oil concentrate) have been applied postemergence with excellent control of annual grasses. Acceptable control of the annual grasses and small-seeded broadleaf weeds have also been reported from preemergence applications of trifluralin (Treflan®), pendimethalin (Prowl®) and metolachlor (Dual®). Currently, metolachlor is the only herbicide registered for sprinkler application in cotton (Anonymous, 1985).

Co-chemigation, that is the application of liquid fertilizers and/or other pesticides with herbicides, offers a distinct advantage in reduced application costs as well as timely application of fertilizers and other agricultural chemicals. However, co-chemigation at the present is in its infancy (Ogg and Dowler, 1987).

SOIL INCORPORATION

Delivering herbicide to the soil does not insure performance. This is particularly true of herbicides which require soil incorporation. Initial research found that the performance of the equipment used to incorporate herbicides was variable. Considerable research, utilizing both qualitative and quantitative techniques, has been conducted to determine the soil incorporation characteristics, including depth and uniformity, of numerous devices. A detailed discussion of this subject is reported elsewhere (Barrentine, 1987).

A soil incorporator is defined as any device used to mix or blend a herbicide into the soil (Harger *et al.*, 1985). When the dinitroanaline herbicides were introduced in the early 1960s, soil incorporation was accomplished with various tillage tools already in use; namely, the four-gang tandem disk harrow, rotary hoes, spike-tooth harrows and, to a less extent, power tillers. A description of these devices and others follow.

Four-gang tandem disk harrows may be in-line, front gang off-set or double-gang off-set (Figure 27A, B and C). The disk blades may be spherical or conical in shape with or without notches (Figures 27 D, E, F, and G). Spacings between disk blades may vary from 6.5 to 12 inches and blade diameters from 18 to 30 inches. The finishing disk, combination disk and cutting disk are classified based on their use for primary or secondary tillage and blade spacing, diameter, shape and weight (Table 4). Because it can be used for primary and secondary tillage, the combination disk harrow is the most prevalent.

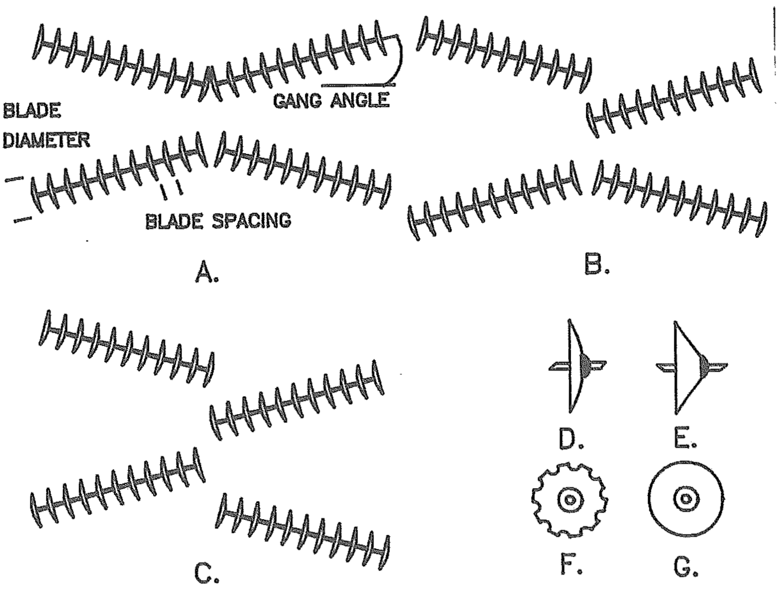


Figure 27. Four-gang tandem disk harrows may be in-line (A), one-gang offset (B), or two-gangs offset (C). Disk blades may be spherical (D) or conical (E) with notches (F) or without notches (G).

Drag harrows are secondary tillage tools used for seedbed preparation and herbicide soil incorporation. Drag harrows are of two basic types, the spike-tooth and the coil-tine harrow. The coil-tine harrow is often referred to as a spring-tooth, coil-tooth, tine-tooth, flex-tine, flexible spring harrow or a flexible tine drag. These harrows have two to five bars with the spikes or tines staggered to have a working spike every 1.5 to 2 inches or a working tine every 4 inches.

Table 4. Descriptive features of four-gang tandem disk harrows.

Disk descriptive name	Tillage use	Disk blade Shape	Spacing	Diameter
			(inches)	
Finishing	Secondary	Spherical	$\leqslant 8$	$\leqslant 20$
Combination	Primary and secondary	Spherical or conical	8 to 9	20 to 24
Cutting	Primary	Spherical or conical	$\geqslant 9$	$\geqslant 24$

Field cultivators are equipped with two or more rows of spring steel shanks spaced 6 to 9 inches apart in a staggered pattern. The shanks may have a forged point or mounting holes for replaceable chisel or shovel sweeps. The shanks referred to as "C" shanks are rigid or spring mounted. Sweeps are usually 110 percent as wide as the shank spacings.

The flexible shank cultivator, often called the Danish or S-tine harrow or Danish or S-tine cultivator, is similar in basic construction to the field cultivator. The coiled-S or S-tine shanks normally are placed in two to four rows with an effective spacing of 6 inches. The tines may be equipped with small 0.75 inch chisel point or 2.5-inch 'goose-foot' (or duck-foot) sweeps.

Power-driven (PTO) tillers may be primary or secondary tillage implements equipped with blades or tines of various types which are forced into and through the soil by transfer of tractor engine power via the PTO. Three basic types of power tillers are available: (a) vertical-action tiller, often called rotary tillers or power-driven rotary hoes, in which the L-, C-, or straight-knife type blades of various lengths rotate about a transverse axis to the direction of tractor travel; (b) horizontal-action tillers are equipped with tapered spikes which rotate and stir the soil in complete circles or oscillate; and (c) combination tillers are equipped with straight tapered spikes and engage the soil with both vertical and horizontal motion.

Ground-driven tillers are of several types, but three major devices are available. The rolling cultivator consists of gangs of ground-driven tine wheels with curved, twisted, partially flat tines which radiate from the center as spokes on a wheel. This unit may be used for broadcast or band incorporation on flat or bedded seedbeds. The rotary hoe consists of one or more gangs of ground-driven tine wheels with round, tapered, curved tines radiating from the center. This device has long been used to uproot seedling weeds pre- or postemergence to various crops, but is used for shallow herbicide incorporation. The open-steel mesh wheel is primarily used for shallow incorporation of a herbicide in a band over the row drill. Often, the mesh wheel replaces the planter press wheel.

Combination tools (seedbed conditioners) are basically two or more tillage tools mounted in series. For example, a ground-driven rotary spiral-cutter reel followed by a spike-tooth harrow and a drag board or plank. Others are constructed using various combinations of secondary tillage tools. Examples of combination tools available include: (a) disk harrow gangs plus two rows of spring mounted C-shanks with chisel points; (b) disk harrow gangs plus four rows of flexible shanks with shovel sweeps plus spike-tooth harrow or spiral-cutter reel; (c) disk harrow gangs plus three rows of spring-mounted C-shanks with shovel sweeps plus five rows of coil-tine harrow; (d) two rows of spring-mounted C-shanks with shovel sweeps plus spiral-cutter reel plus three bars of spike-tooth drag harrow plus drag board or rolling basket; (e) four rows of spring-mounted C-shanks or coiled-S-tine shanks with chisel point or shovel sweeps plus a three-bar coil-tine drag harrow; and (f) disk gangs plus spring-mounted C-shanks with shovel or chisel sweeps plus a spiral-cutter reel plus three rows of S-tined flexible shanks with chisel or goosefoot sweeps plus two rolling baskets.

Attachments to secondary tillage tools used for herbicide soil incorporation are commonly used. These include the coil-tine harrows, spike-tooth harrow and rolling baskets. The rolling baskets are often called reels, rolling harrows, rolling reels, packer reels and rotary basket crumplers. These are particularly popular on combination tools. L-shaped tines are also vertically stagger-mounted on two or more bars as a drag attachment. These are commonly used in conjunction with the flexible shank (Danish) cultivator.

Table 5 lists what is considered to be the optimum operating parameters for equipment used to soil incorporate herbicides. These parameters were based partially on qualitative and quantitative evaluation studies, herbicide labels and equipment manufacturer instructions. However, the specific manufacturer's operating procedures and labels for the specific herbicide should be consulted.

Table 5. Operating parameters for equipment used to incorporate herbicides into the soil. (Adapted from Barrentine, 1987.)

Equipment	Description of operating parameters
Disk harrow, finishing	Set angle to move soil a distance equal to blade diam., operate 6 to 7 mph to cut 3 to 5 inches; 2 passes perpendicular. Higher ground speeds require less gang angle, lower speeds and a single pass usually results in streaking. Mixing can be improved by attaching a spike-tooth or coil-tine drag harrow.
Disk harrow, combination	Same as finishing disk. Use spherical rather than conical blades.
Field cultivator	Shank spacing with shovel sweeps should leave no soil unturned; set tilt angle so cultivator shanks are all operating at the same soil depth, 3 to 4 inches; operate at 5 to 7 mph 2 passes, preferably perpendicular. Drag harrows attached improves horizontal distribution.
Flexible-shank cultivator (Danish or S-tine)	Same as field cultivator; ground-driven reel attachments slightly improve horizontal distribution and reduce ridging. 'Goosefoot' sweeps are usually used.
Combination tool-Field cultivator shanks + spiral-cutter reel + spike tooth drag harrow	Set all components level with soil. Operate shanks 3 to 5 inches deep at least 5 mph. Shank spacing with shovel sweeps should leave no soil unturned. One pass is usually adequate on coarse or medium textured soils.
Combination tool-spiral—cutter reel + spike-tooth harrow + drag board or ground-driven reel attached	Set all components level with soil. Operate 2 to 4 inches deep at 4 to 6 mph. Work best on coarse and medium textured soils. Under bedded culture strike-off beds to planting height and incorporate with a single pass. Two passes are needed for flat-planting culture.

Table 5. Continued.

Rolling cultivator	Under bedded culture on coarse and medium textured soil. Strike-off beds to planting height. 4-gangs/bed usually suggested. Two, three-tined gangs on the bed top trailed by a four- or five-tine gang on each side of the bed. Set front gangs flat, slightly angled toward the center, and trailing gangs at a 15-20 degree angle to the direction of travel and tilted to match bed slope. On flat-planted land, set all gangs level with soil surface. Space gangs in tandem to work entire soil surface. Operate 2 to 4 inches deep at 5 to 7 mph.
Power-driven (PTO) tiller Horizontal-action Roterra	Operate 3 to 6 inches deep at 4 mph. Set tine rpm at 200 to 400. (See operators manual for specifics.) Direct spray pattern into the rear of the spinning tines. Single pass, but use some primary tillage first. Check for uniform working depth prior to incorporation.
Power-driven (PTO) tiller Vertical-action L-shaped blades	Operate to depth of desired incorporation at 6 mph. Set rotor blade rpm at ca 300 (See operators manual for specifics.) Operate so blade bites overlap but not excessively (blade rpm too fast in relation to forward ground speed). No overlap results in poor incorporation and tillage.

COTTON BELT APPLICATION TECHNIQUES

To provide a valid opinion of application techniques, a state-by-state survey was conducted. Survey forms were sent to state weed scientists, county extension personnel and cotton producers in 13 of the cotton producing states: (a) Alabama, Georgia, South Carolina and North Carolina in the Southeast region; (b) Missouri, Louisiana, Arkansas, Mississippi and Tennessee in the Mid-South region; (c) California and Arizona in the West region; and (d) Texas and Oklahoma in the Southwest region. Texas was divided into four areas: Coastal Bend, South, Plains and Blackland (Figure 28).

One hundred and nine surveys were returned. Although the results varied from state to state and within states, they were of such consistency that producer use of herbicide application types and devices could be determined. Results of the survey are presented on a regional and Cotton Belt basis.

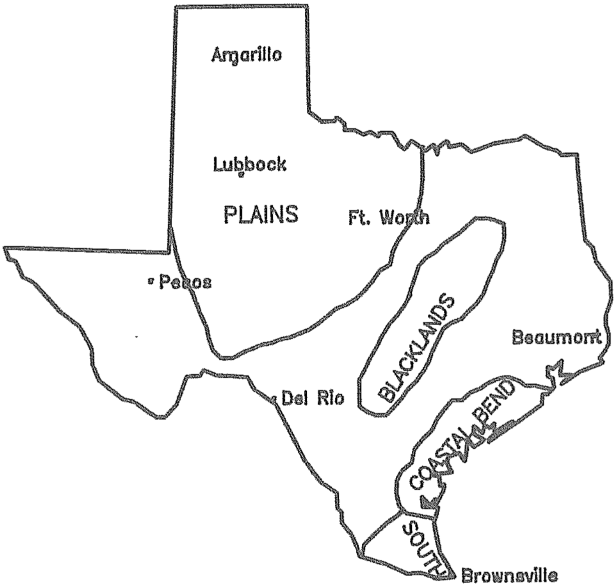


Figure 28. Four major cotton growing areas of Texas (Plains, Blackland, Coastal Bend, and South) used in the opinion poll of application techniques.

SOUTHEAST

Only 2 percent of the acreage in the Southeast receives a preplant foliar (PPF) application, while 97 percent receives some type of preplant incorporated (PPI) material (Table 6). Of the 97 percent that receives PPI applications, only 2 percent is to a band and the remaining 98 percent is broadcast. Approximately 80 percent of these PPI applications are applied with tractor-mounted spray equipment (Table 7). Producers in Alabama apply 30 percent of their PPI herbicides in liquid fertilizer. The remaining portion of PPI applications is applied by air or with high-clearance ground rigs. Incorporation devices vary, but within the region, 71 percent of the incorporation is conducted with four-gang tandem-disk harrows (Table 8) and 14 percent with combination devices. The remaining portion is done with some type of field cultivator or power-driven tiller. Except for minor use in Georgia, Alabama accounts for all the incorporation with combination devices. Power driven tillers are not used often with a 10 percent use-rate being the highest indicated in Georgia and North Carolina.

Preemergence (PRE) treatments are applied to 94 percent of the acreage in the Southeast. Eighty-three percent is to a band and 17 percent is broadcast (Table 6). Producers in Georgia and North Carolina apply a larger portion of their materials broadcast as compared to other states in the region. Nearly the entire acreage (97 percent) is treated with ground equipment (Table 7). A large portion of this (68 percent) is applied with a planter attachment which accounts for band application as the preferred choice.

Table 6. Percentage of cotton acreage treated by various types of herbicide application.

	Southeast					Mid-South						West			Southwest							Cotton Belt
	AL	GA	SC	NC		MO	LA	AR	MS	TN		AZ	CA		TX					OK		
Type of Application					Mean						Mean			Mean	Coastal Bend	South	Blackland	Plains	Mean		Mean	Mean
	(Percent)																					
PPF	2	1	2	0	2	1	1	1	3	2	2	2	28	15	1	0	0	15	4	1	3	6
PPI	92	99	100	98	97	95	95	79	98	95	92	89	95	92	94	96	92	81	91	94	93	93
Band	4	1	3	0	2	79	3	12	33	1	26	28	18	23	2	20	0	10	8	5	7	16
Broadcast	94	99	97	100	98	21	97	88	67	99	74	72	82	77	98	80	100	90	92	95	93	84
PRE	98	86	97	95	94	94	98	99	100	99	98	21	0	10	78	22	50	64	54	12	33	47
Band	94	80	93	65	83	94	99	98	99	89	96	100	—[1]	50	82	33	100	80	74	86	80	88
Broadcast	6	20	7	35	17	6	1	2	1	11	4	0	—	0	18	67	0	20	26	14	20	12
POT	46	66	47	20	45	10	26	39	31	75	36	6	30	18	6	10	25	20	15	7	11	23
Band	50	59	78	50	59	39	28	42	18	18	29	42	65	53	30	24	100	31	46	30	38	45
Broadcast	28	34	22	50	34	20	15	20	18	66	28	5	7	6	60	17	0	11	22	32	27	21
Spot	20	7	0	0	7	41	57	38	64	16	43	52	28	40	10	59	0	58	32	38	35	35
PDS	83	58	55	50	62	96	98	95	81	11	76	16	12	14	5	22	10	9	12	3	7	31
Band	90	91	96	100	94	99	100	98	99	91	97	75	90	82	—	67	100	25	64	67	66	82
Broadcast	5	9	4	0	5	1	0	2	1	8	2	25	10	17	—	33	0	75	36	33	34	18
LAYBY	57	35	32	2	32	47	48	52	79	8	47	69	10	39	0	38	5	16	15	3	9	30
Band	9	42	6	0	14	97	20	24	20	0	41	20	58	39	—	100	100	33	78	100	89	51
Broadcast	88	58	93	100	85	3	80	76	80	100	68	80	42	61	—	0	0	67	22	0	11	49

[1]Not indicated.

Table 7. Percentage of specific methods for making preplant incorporated (PPI), preplant foliar (PPF), preemergence (PRE) or postemergence over-the-top (POT) herbicide applications.

Type of Application	Southeast					Mid-South						West			Southwest							Cotton Belt
	AL	GA	SC	NC		MO	LA	AR	MS	TN		AZ	CA		TX					OK		
					Mean						Mean			Mean	Coastal Bend	South	Blackland	Plains	Mean		Mean	Mean
	(Percent)																					
PPF + PPI																						
Ground	95	98	100	100	98	99	98	93	97	99	97	91	60	75	94	99	90	95	94	96	95	89
Tractor-mt	63	72	97	85	79	69	98	75	89	92	85	85	95	90	51	59	88	98	74	99	86	85
Hi-clearance	5	13	0	10	7	3	2	21	2	6	7	13	5	9	2	41	12	2	14	1	7	8
Planter	1	12	0	5	5	0	0	4	5	0	2	2	0	1	18	0	0	0	4	1	3	2
Air	5	1	0	0	2	1	2	4	2	1	2	9	40	25	5	1	10	5	5	4	5	10
Other[1]	30	0	3	0	8	29	0	3	5	2	8	0	0	0	26	0	0	0	6	0	3	5
PRE																						
Ground	98	96	93	100	97	99	99	99	99	100	99	85	—[2]	—	96	100	—	97	98	78	88	91
Tractor-mt	18	26	23	20	22	1	54	7	39	6	21	78	—	—	28	56	—	40	41	51	46	43
Hi-clearance	2	16	3	20	10	1	0	13	1	5	4	15	—	—	19	38	—	12	23	12	18	13
Planter	79	58	73	60	68	98	48	80	60	90	75	8	—	—	53	6	—	48	36	36	36	45
Air	2	3	3	0	2	1	1	1	1	0	1	15	—	—	4	0	—	3	2	22	11	8
POT																						
Ground	92	95	96	100	96	91	94	95	90	99	94	99	95	97	73	92	—	94	86	74	80	90
Tractor-mt	40	56	48	55	50	61	38	62	57	53	54	64	62	64	34	70	—	67	57	30	44	53
Hi-clearance	45	40	48	40	43	35	28	28	4	46	28	2	12	7	42	26	—	19	29	10	20	20
Spot	18	3	2	0	6	3	32	4	35	4	16	33	25	28	6	1	—	5	4	42	23	21
RWA	1	1	2	5	2	1	1	6	4	0	2	0	0	0	12	3	—	8	8	15	12	5
Air (Fixed-wing)	8	5	4	0	4	9	6	5	10	1	6	0	5	3	22	8	—	6	14	26	20	9
Other[3]	0	1	0	0	1	0	0	1	0	0	<1	0	0	0	5	0	—	0	2	0	1	1

[1]Flotation applicators along with liquid or dry fertilizer, treatments along with custom application of fertilizer, Hi flotation N-Sol spreaders.

[2]Not indicated.

[3]Rotary wing aircraft.

Table 8. Producer preference for general types of soil incorporation devices when applying preplant incorporated PPI herbicides.

	Southeast					Mid-South						West			Southwest							Cotton Belt
	AL	GA	SC	NC		MO	LA	AR	MS	TN		AZ	CA		TX					OK		
Type of Application					Mean						Mean			Mean	Coastal Bend	South	Blackland	Plains	Mean		Mean	Mean
											(Percent)											
Tandem-disk harrow	33	83	75	93	71	26	38	10	20	20	23	57	46	46	46	49	54	52	55	62	58	51
Field cultivator	6	3	10	3	6	41	54	3	28	13	28	23	10	22	31	22	18	20	5	0	3	14
Flexible shank cultivator	4	4	0	0	2	7	4	3	6	0	4	>1	1	12	0	3	2	2	3	2	3	3
Power driven tiller	2	10	10	3	6	1	0	0	1	0	<1	>1	8	0	0	2	2	2	7	26	16	7
Spike/spring tooth harrow	0	>1	0	0	<1	2	2	16	13	0	7	>1	0	8	0	2	>1	2	3	1	2	3
Ground-driven devices	2	>1	5	0	2	17	0	3	18	>1	8	19	27	2	6	13	25	19	8	5	6	10
Combination devices	53	>1	0	0	14	6	2	63	16	67	31	0	8	11	17	9	0	4	20	5	12	13

Postemergence over-the-top (POT) applications are applied to 45 percent of the acreage in the Southeast (Table 6). Georgia producers reported 66 percent of their acreage receives some type of POT treatment while North Carolina producers reported 20 percent. For the region, 59 percent is applied to a band, 34 percent is applied broadcast and 7 percent as a spot treatment. Of the POT applications applied in the Southeast, 94 percent are applied with ground rigs with less than 5 percent going out by air (Table 7). Fifty percent of the ground applications are applied with tractor-mounted sprayers and 43 percent with high-clearance spray applicators. Only 2 percent of the POT treatments in the Southeast are with rope-wick applicators.

In the Southeast, 62 percent of the acreage is treated with a postemergence-directed spray (PDS) with 94 percent of these applications on a band. North Carolina producers use these treatments the least while Alabama producers use them the most (Table 6).

Layby treatments are applied to 32 percent of the acreage with 85 percent applied broadcast. North Carolina producers utilize layby treatments on less than 5 percent of their acreage while Alabama producers treat nearly 60 percent of their acreage with some type of layby treatment (Table 6).

MID-SOUTH

Very little (<2 percent) of the cotton acreage in the Mid-South region receives a preplant foliar (PPF) application. But, 92 percent of the acreage is treated with a preplant incorporated (PPI) treatment, with 26 percent of these applications applied to a band. Missouri reported that nearly 80 percent of its PPI applications are to a band which accounts for most of the high regional response (Table 6).

Nearly all soil incorporated materials are applied by ground equipment with 85 percent applied with tractor-mounted sprayers (Table 7). Missouri reported that 'Do-Alls' with boom attachments were used nearly 30 percent of the time. The Mid-South region reported a wider variation in general methods of incorporating than did the Southeast (Table 8). The four-gang tandem disk harrow is used 23 percent of the time, while combination devices and field cultivators are used 31 and 28 percent of the time, respectively. Louisiana producers use field cultivators over half the time while Missouri and Tennessee producers prefer combination devices two-thirds of the time. Arkansas and Mississippi producers use ground driven devices (mostly rolling cultivators) nearly 20 percent of the time.

Acreage treated preemergence in the Mid-South and Southeast regions was about equal, but 96 percent of the acreage in the Mid-South was to a band as compared to 83 percent for the Southeast (Table 6). Nearly all the acreage treated PRE was applied with a ground rig, and 75 percent was applied with a planter attachment (Table 7).

Thirty-six percent of the acreage in the Mid-South region receives a POT treatment with producers in Tennessee utilizing this type of application most often (Table 6). More than 40 percent of the acreage treated postemergence over-the-top (POT) is applied as spot treatments. Ninety-four percent is applied by ground application with tractor-mounted sprayers accounting for over 50 percent of this (Table 7). Sixteen percent use certain types of spot sprayers designed specifically for spot treatment with Louisiana and Mississippi producers the most frequent users.

Post-directed sprays were utilized on 76 percent of the acreage in the Mid-South. Nearly all of this applied to a band with cultivator attachments (Table 6).

Slightly less than 50 percent of the acreage in the Mid-South region received some type of layby application. Nearly 70 percent of the acreage was treated broadcast using slide units or modified cultivators (Table 6).

SOUTHWEST

Due to the diversity of cotton culture, Texas was divided into four areas in order to highlight any contrast of interest within the state. Fifteen percent of the acreage in the Plains area of Texas is treated PPF (Table 6). This rather high percentage is a result of one respondent that produced no-till cotton and required this treatment for seedbed preparation on his entire acreage. This may also account for the somewhat low percentage (81) treated PPI in the Plains. However, more than 90 percent of the cotton acreage in Texas is treated with a PPI material of which 92 percent is broadcast, and, with the exception mentioned above, is quite consistent from area to area. Five percent is applied aerially with the remaining portion applied by ground rig, mainly tractor-mounted sprayers (Table 7). Nearly half of these applications are incorporated with the four-gang tandem disc harrow and slightly more than 20 percent use the field cultivator (Table 8).

In contrast to the Southeast and Delta regions, producers in Texas treat only 54 percent of their acreage with a PRE treatment (Table 6). South Texas producers use this type of application less than 25 percent of the time, while those in the Coastal Bend area utilize it 78 percent of the time. Nearly 75 percent is applied to a band statewide; however, this type of application varies widely within Texas. South Texas producers apply two-thirds of their PRE treatments broadcast and are the only Texas producers to apply a majority of their PRE applications as broadcast treatments. Producers in all other areas of Texas utilize band treatments at least 80 percent of the time.

Nearly all of the preemergence treatments are applied with ground equipment (Table 7). Methods of these applications are fairly evenly distributed between tractor-mounted sprayers, high-clearance ground rigs and planter attachments. However, due to the rather large acreage treated broadcast, very few planter attachments are used in South Texas. The Coastal Bend and Plains producers use this method approximately one-half of the time, while South Texas producers use tractor-mounted sprayers a majority of the time.

Postemergence over-the-top applications are used on only 15 percent of the acreage in Texas with a range of 6 percent in the Coastal Bend area to 25 percent in the Blackland area (Table 6). Eighty-six percent of these applications are applied with ground rigs, and the remaining portion is applied with fixed- or rotary-wing aircraft (Table 7). About one-third of this acreage receives spot sprays. Nearly 50 percent of the over-the-top applications are to a band.The Coastal Bend area accounts for a large portion of the aerial applications in Texas.

Only 12 percent of the acreage in Texas is treated with a PDS application (Table 6). South Texas producers treat 22 percent of their acreage in this manner—the largest of all areas in Texas. Statewide, the majority of these applications are to a band but this varies for each specific area in Texas. Very little of the acreage in South Texas or the Plains is treated with post-directed sprays.

Fifteen percent of the acreage in Texas receives a layby treatment with a majority of this acreage in South Texas (Table 6). The Coastal Bend area reported no acreage treated with a layby application. The South Texas and Blackland areas reported that 100 percent of these applications are to a band which is in sharp contrast to treatments in the Delta and Southeast.

Farmers in Oklahoma use PPI treatments on 94 percent of their acreage with 95 percent of this applied broadcast (Table 6). Of these PPI applications, 96 percent is by ground rig, with tractor-mounted sprayers used 99 percent of the time (Table 7). Four-gang tandem disk harrows are used to incorporate PPI applications over 50 percent of the time in Oklahoma (Table 8). Field cultivators are used 18 percent of the time, and ground-driven devices 25 percent of the time.

Only 12 percent of the acreage receives a PRE treatment which is mostly (86%) to a band (Table 6). The remaining 14 percent are applied broadcast and 22 percent of these treatments are applied aerially. POT, PDS and layby treatments are used on a very limited amount of acreage in Oklahoma, with less than 8 percent of the acreage treated by any of these methods.

WEST

Of those producers responding from California, 28 percent of their acreage is treated with a PPF treatment, usually to fallow beds during the winter (Table 6). Except for minimum-tillage operations, this was the highest percentage beltwide. Producers in Arizona and California treat more than 90 percent of their acreage with a PPI treatment with less than 25 percent of this to a band.

More than 90 percent of the PPI applications are applied with ground rigs in Arizona, while California producers use aircraft 40 percent of the time (Table 7). Tractor-mounted sprayers are the preference for ground applications in both states.

Four-gang tandem disk harrows are used 55 percent and 62 percent of the time for incorporation in California and Arizona, respectively (Table 7). Arizona producers reported that power-driven tillers were used 26 percent of the time and this was the highest percentage for any of the 13 states. Combination devices are used 20 percent of the time in California.

In Arizona, only 21 percent of the acreage is treated PRE but all applications were to a band. California producers reported no acreage treated in this manner

(Table 6). Ground rigs were utilized 85 percent of the time and aircraft 15 percent of the time to apply PRE treatments in Arizona.

Arizona producers treat only 6 percent of their cotton acreage with a POT treatment (Table 6). California producers use this same type of treatment on 30 percent of their acreage. Sixty-five percent of the acreage treated POT in California is on a band with 28 percent spot-treated. Over 50 percent of the acreage treated POT in Arizona is with spot-treatments. Nearly all of the POT applications in both states are applied with ground rigs with two-thirds of these applied with tractor-mounted sprayers (Table 7).

Sixteen percent of the acreage in Arizona is treated PDS while 12 percent is treated PDS in California (Table 6). The majority of this acreage is treated to a band.

Arizona producers tend to rely on layby applications more than on PDS sprays. Sixty-nine percent of the acreage in Arizona is treated with a layby application while only 10 percent is treated layby in California. Eighty and 42 percent of the acreage treated layby is broadcast applied in Arizona and California, respectively.

COTTON BELT

Procedures and methods of applying herbicides are fairly consistent across the Cotton Belt except for preplant foliar (PPF) treatments. California producers treat 28 percent of their acreage, while the remaining areas treat from 2 to 15 percent. Because of higher than average rainfall and price reductions on the herbicides, paraquat (Gramoxone Extra®) and glyphosate (Roundup®, D-Pak®), the authors estimate that 45 percent of the Mid-South acreage received a PPF treatment in 1990.

On the average, 93 percent of the acreage receives some sort of preplant incorporated (PPI) treatment with 84 percent applied broadcast (Table 5). An average of 89 percent of these applications are applied with ground applicators, primarily tractor-mounted sprayers (Table 7). These Cotton Belt averages are fairly representative of each individual region for PPI applications with only a few exceptions.

Cotton producers use four-gang tandem disk harrows 51 percent of the time (Table 7). Field cultivators, combination devices and ground-driven devices are used in some fashion 10 to 15 percent of the time.

Combination devices are used extensively in certain regions and represent about 13 percent of the total (Table 8). There are numerous types and combinations of these implements. However, the ones mentioned most frequently involve the use of a rotary spiral cutter-reel followed with a spike-tooth harrow. A dragboard or plank was the most common third component of these implements. A fourth component commonly referred to was a field cultivator or flexible-shank cultivator mounted just behind the cutter reel and in front of a spike-tooth harrow.

Power-driven tillers are used in small areas of the Cotton Belt. Producers in Georgia, North Carolina and Arizona were the most frequent users of these implements.

An average of 47 percent of the cotton acreage is treated preemergence (PRE) and nearly 90 percent is to a band (Table 6). Acreage treated PRE varies from 98 percent in the Mid-South to 10 percent in the West. Forty-five percent of the ground PRE applications are with planter attachments (Table 7). This is because most of the acreage is treated on a band basis in a once-over planting-spraying operation.

About one-fourth of the acreage in the Cotton Belt is treated postemergence over-the-top (POT) (Table 5). This low acreage figure is due, in large part, to the lack of selective herbicides. Thus, most of these POT applications are with the selective grass herbicides. Nearly 50 percent of these applications are to a band and 35 percent of the acreage is spot-treated.

Another type of POT treatment for cotton is rope-wick aplicators (RWAs), although only 5 percent of the POT applications are applied with RWAs (Table 7). About 21 percent of all acreage receive spot sprays. The Coastal Bend area in Texas and Oklahoma account for the major portion of the RWA use.

To increase the selectivity of currently available cotton herbicides, producers have turned to post-directed sprays. These applications are mostly to a band on the 31 percent of the acreage treated in this manner (Table 6). The majority of these applications are made in conjunction with mechanical cultivation using shielded cultivators with specialized sprayer attachments designed to treat a 12- to 18-inch band and cultivate the untreated portion of each row. Over half of the acreage treated in this manner is treated two or more times.

Typically, the last herbicide application in cotton is a layby treatment which usually occurs just prior to bloom. Thirty percent of the Cotton Belt acreage is treated with some type of layby treatment with about half of this on a band and half applied broadcast (Table 6). Layby applications are commonly applied with slide units or oiling shoes designed to position one flooding or deflector nozzle or 2 flat-fan nozzles under the crop to control late emerging weeds. These layby herbicides also provide residual control from time of application until harvest. The Mid-South and Southeast producers are the predominant users of layby applications in the Cotton Belt.

FUTURE NEEDS

Weed scientists as a group have long recognized the need for improved application methodology. There are problems with sprayer calibration and with obtaining optimum equipment operation parameters that result in distributing and getting the herbicide to the target at the proper dose and time. In a recent survey of research needs, the WSSA (Weed Science Society of America) membership gave the broadly defined research need; "develop new methods for controlling the movement of herbicides and their metabolites into ground water, surface water, and air", its highest priority ranking. The membership agreed that this need would most likely be satisfied by expanding research in the area of development of new application techniques (McWhorter and Barrentine, 1988).

The industry in general also recognizes the need for such research. At a 1984 Agricultural Research Institute Conference, the need for a conference on pesticide application technology emerged as a predominant conclusion (Hall, 1985). Such a conference followed in 1985 and the specific needs identified were: (a) new and improved agricultural chemical application technology with an emphasis on basic concepts and (b) movement of chemicals from target sites in drift through aerial transport, water transport and other mechanisms. The major conclusions of the attendees at this conference were: (a) critical lack of interdisciplinary research in agrochemical application technology; (b) application technology research has a low priority for funding in spite of public concern of environmental contamination and the need for precision application; (c) application technology is not keeping pace with chemical technological advancements; and (d) innovative technology and engineering concepts from other sciences and industries are not being adapted.

Cotton producers' needs are obviously the ultimate objective of research. Thus, their opinions are sought by most all weed scientists involved in application technology. The most often voiced need in cotton weed control is a selective over-the-top herbicide for broadleaf weeds, particularly the morningglory complex. Without such a herbicide at present, application technology looms as the greatest need. At a recent meeting of Mid-South cotton producers with federal, state, and private research representatives, panel Chairman, Robroy Fisher of Glen Allan, Mississippi, said "We're using the same chemical application technology used 30 years ago". He further commented that "we need technology that's sensitive to the interaction of the chemical and the way its applied—something that will help us cut down on chemical use, but give us more effective control" (Gordon, 1987). It is still not uncommon to use hand-hoeing to rid cotton fields of weeds for which there are no selective herbicides or other effective means of control (Figure 29).

Reduced spray volume and diluents other than water need to be evaluated in cotton weed management systems. In soybeans, application of the selective grass herbicides in paraffinic oil or once-refined soybean oil at one gallon per acre effectively controlled seedling johnsongrass at reduced rates (Barrentine and McWhorter, 1988). Would oil-soluble or miscible formulations of currently available herbicides applied as directed postemergence (PDS) for broadleaf weed control respond similarly? Would such herbicide treatments applied at ULVs in oil increase control of the morningglory complex without significantly increasing cotton injury? If so, research to develop a practical and economical ground applicator for such treatments would be invaluable.

Rotary atomizers have provided a means of producing droplets of a more uni-

Figure 29. Hand-hoeing weeds in cotton for which there are no selective herbicides or other effective control techniques. (Marks, Mississippi, July 1987.)

form size, but the major deficiency resulting in inconsistent weed control has been coverage (Gebhart and Kapusta, 1987). Models have been developed to supplement droplet distribution with an air source, but their performance evaluation is limited. Such evaluations require large plots which few researchers have, but they are needed.

Based on the research of Haugen and Ganrud (1983b) and Dale (1987), efforts on evaluation of concentrated dry formulations of herbicides should be expanded. Performance has been equivalent to liquid sprays, and the concept offers a means of avoiding spray drift and possibly reducing surface and groundwater contamination.

Until such time that more effective and selective herbicides are developed, extension educational efforts should be increased to more effectively utilize current practices. Calibration clinics are needed to stress the need for accurate calibration and proper equipment operating parameters under field conditions. A survey testing of over 100 farm sprayers in North Dakota found that 60 percent were operated with a calibration error greater than 10 percent (Hoffman *et al.*, 1986). Forty-three percent of the sprayers were equipped with nozzle tips which varied more than 10 percent from the proper discharge volume. Travel speeds were inaccurate in 32 percent of the sprayers and 27 percent were operated at an improper boom height for the nozzle spacing and recommended spray height to provide optimum spray pattern overlap. Pressure gauge reading indicated that most application pressures were too low, and 13 percent were inaccurate.

Finally, research efforts should be expanded to include the direct-injection-closed system sprayers now coming on the market. Spray equipment distributors indicate that there is little or no demand for these sprayers at present.[9] What effect the emerging good laboratory practices, endangered species and ground water regulations will have on this demand is yet to come.

SUMMARY

Liquid sprays are the major method of applying herbicides in cotton weed management systems, with the hydraulic pressure atomizing nozzles the primary means of metering and dispersing the spray. Rotary atomizers are not used to any extent in cotton primarily because of a lack of selective herbicides to control broadleaf weeds and inadequate coverage which results in poor control of target weeds (Gebhart and Kapusta, 1987). A selective herbicide to control broadleaf weeds is required before use of air-assist nozzles and chemigation methods for delivering herbicides to the target can be expanded. The effects of chemigation on potential groundwater contamination must also be accessed. Only metolachlor (Dual®) is currently registered in cotton for use with sprinkler irrigation. Expansion in use of granular cotton herbicides will require efficacy and economic evaluations. Recent research in this area indicates there may be a place for the application of concentrated dry formulations. Such formulations will reduce the need for large hoppers and/or frequent refilling. The greatest need is increased research with adequate funding to develop new application techniques.

Procedures and time of applying herbicides–preplanting, preemergence and postemergence–are fairly consistent across the Cotton Belt. Ninety-three percent of the acreage is treated preplant incorporated and 47 percent is treated preemergence. The most frequently used implement for soil incorporation is the four-gang tandem-disk harrow. In certain regions, combination incorporation devices are popular and are used 13 percent of the time. Ninety percent of the acreage treated preemergence is on a band. The acreage treated preemergence varied from 95 percent in the Mid-South to 10 percent in the West. Lack of selective herbicides accounts for the low (<25 percent) percentage of the acreage treated postemergence over-the-top. Contact application (rope wick) is used on only 5 percent of the acreage with the Southwest Plains area accounting for most usage. However, 21 percent of the cotton acreage receive spot sprays. Layby applications are more commonly used in the Mid-South and Southeast regions.

[9]Private communication. R. A. Norris, Vice-President, S & N Sprayer Co., Inc., Greenwood, MS.

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Chapter 12

APPENDIX

CALIBRATION OF LOW-PRESSURE HYDRAULIC SPRAYERS

Low-pressure sprayers equipped with hydraulic pressure nozzles are the primary means of metering and dispersing herbicide spray solutions to the target in cotton weed management programs. Proper sprayer calibration and calculation of the herbicide-water spray mix are the two most important aspects of delivering the herbicide spray solution to the target at the correct dose. Presented below are calibration methods, with examples, that will insure accurate sprayer calibration and herbicide-water spray mix determination. The first method is a commonly used, easy and practical method of calibrating low-pressure sprayers, and this is followed by methods utilizing mathmatical formulas which can be used in widely varying situations.

128th METHOD

There are several methods of calibration, but one commonly used calibration procedure is the 128th method. This procedure is based on the fact that there are 128 ounces in one gallon and the number of ounces applied to 1/128 acre equals gallons per acre. The steps in using this method, adapted from Anonymous (1988) and Baldwin *et al.* (1988), with examples, are presented below. Spray volumes determined with this method are <u>always gallons per land acre</u>, regardless of whether the application is broadcast over the field or to a specified band width on rows of a specified spacing.

<u>Step 1.</u> From Table 1, determine the calibration distance in relation to the row or nozzle spacing for the sprayer and application situation. For broadcast applications such as preplant soil incorporation with a pulverizing disk or field cultivator, use nozzle spacing. If application is to a band surface preemergence behind the planter press wheel or a directed postemergence spray application, use row spacing. Mark off this distance in the actual field to be sprayed.

<u>Step 2.</u> With the application tool attached (field cultivator, directed spray rig, etc.), select the desired operating gear and throttle setting, and perform the operation down and back over the marked out calibration distance and note the time in seconds required for each pass. Two or more runs are suggested from which the average time in seconds is calculated.

Table 1. Travel distance in feet required to spray 1/128 acre at a given row or nozzle spacing in inches.

Row or nozzle spacing	Calibration distance
(inches)	(feet)
40	102
38	107
36	113
34	120
32	127
30	136
28	146
26	157
24	170
22	185
20	204
18	227
16	255
14	292
12	340
10	408

Step 3. Using the same throttle setting of Step 2, turn on the sprayer and adjust and note spray pressure. If using a broadcast boom with nozzles evenly spaced, catch the spray output from one nozzle for the time measured in Step 2 in a container graduated in ounces. Ounces caught from one nozzle is equal to gallons per acre. When row spacing was used in Step 1 and more than one nozzle per row is used, such as a directed spray application, catch the output from each nozzle for the time noted in Step 2, and combine the spray output of all nozzles spraying on a single row. Combined output in ounces from all nozzles per row equals gallons per acre.

Step 4. Check the output from each nozzle across the broadcast boom or the combined output from all nozzles spraying on each single row to assure equal spray output across the width of the spray boom or for each row of the sprayer, by repeating Step 3. Change-out and recheck any nozzle tip which varies more than 10 percent from the desired output. More than 10 percent variation indicates excessive nozzle wear which affects output and(or) spray pattern distribution. Adjust boom or nozzle height, position, etc. according to the type of application, and check the quantity remaining in the spray tank after spraying 1 to 3 acres to verify that the intended spray application rate (gallons per acre) is being applied.

Example 1—Apply a 4-pound-per-gallon emulsified concentrate of Treflan® at 0.75 pound active ingredient per acre (1.5 pints per acre) using a broadcast boom, with tapered flat-fan nozzles spaced 20 inches apart, mounted underneath the front tractor frame (belly-mounted). A four-gang pulverizing tandem disk harrow set to cut 4-inches deep will be used for incorporation. The tractor-sprayer is equipped with two, 200-gallon saddle tanks.

A. Calibration:

Step 1. From Table 1, the distance to travel for 20-inch nozzle spacing is 204 feet. Measure off this distance in the field to be sprayed.

Step 2. Select the desired operating gear, throttle setting and cutting depth of the disk harrow and operate the disk down and back over the 204-foot course, recording the time in seconds for each pass. Assume it required an average of 25 seconds.

Step 3. Set the throttle at the setting used in Step 2 and adjust and note spray pressure. Catch the output from one nozzle for 25 seconds. Output in ounces equals gallons per acre. Assume 15 ounces were caught in 25 seconds, then the sprayer is applying 15 gallons per acre.

Step 4. Repeat for each nozzle and check for uniformity between nozzles, replacing tips varying more than 10 percent. Adjust boom height for proper spray overlap, and verify application rate is 15 gallons per acre.

B. Tank mix calculation:

Acres per 200-gallon tank.

$$\frac{\text{200 gallons per tank}}{\text{15 gallons per acre}} = \text{13.3 acres per tank or 26.6 acres per 400 gallons}$$

The desired rate of Treflan® per acre was 1.5 pints, thus 13.3 acres x 1.5 pints per acre = 20 pints per 200-gallon tank or 40 pints per 400 gallons.

NOTE: When refilling, mix only the amount of solution required to refill the tanks, not for the total tank capacities. If, for example, there were 50 gallons of solution remaining in each tank, mix 300 gallons refill per 15 gallons per acre = 20 acres per refill = 30 pints Treflan® or 15 pints per tank.

Example 2—Apply a tank mix of Bladex® 90 DF plus Zorial® 80 DF at 0.9 + 1.0 pound active ingredient per acre (1.0 + 1.25 pounds product per acre) to a 16-inch band on 40-inch rows surface preemergence behind the planter. A single flat-fan even spray drop-nozzle is planter-mounted behind each press wheel. The tractor-sprayer is equipped with two, 200-gallon saddle tanks.

A. Calibration:

Step 1. From Table 1 the distance to travel for 40-inch row spacing is 102 feet. Measure off this distance in the field to be sprayed.

Step 2. Select the desired operating gear, throttle setting and, with the planter mounted and set to proper planting depth, operate the tractor-planter down and back over the 102-foot course, recording the time in seconds for each pass. Assume it required an average of 15 seconds.

Step 3. Set the throttle at the setting used in Step 2 and adjust and note spray pressure. Catch the output from the nozzle of one row for 15 seconds. Output in ounces equals gallons per acre. Assume 8 ounces were caught in 15 seconds, then the sprayer is applying 8 gallons per acre.

Step 4. Repeat for each nozzle and check for uniformity between nozzles for each row, replacing tips varying more than 10 percent. Adjust nozzle height to spray a 16-inch band. Verify application rate is 8 gallons per acre.

B. Tank mix calculation:

Reduce the broadcast rates to a 16-inch band:

16-inch band ÷ 40-inch row = 0.4 x 1.0 pound Bladex® 90DF = 0.4 pound; and 0.4 x 1.25 pound Zorial® 80DF = 0.5 pound per acre on a 16-inch band.

$$\frac{\text{200 gallons per tank}}{\text{8 gallons per acre}} = \text{25 acres per tank or 50 acres per 400 gallons}$$

25 acres x 0.4 pound Bladex® 90DF = 10 pounds per 200-gallon tank, and 25 acres x 0.5 pound Zorial® 80DF = 12.5 pounds per 200-gallon tank or 20 pounds Bladex® 90DF and 25 pounds Zorial® 80DF per 400 gallons. See **NOTE** for **Example 1** on refills.

Example 3—Apply a 4-pound-per-gallon flowable formulation of fluometuron (Cotoran® 4L) plus nonionic surfactant at 0.4 pound active ingredient per acre (0.8 pint product per acre) plus 0.25 percent volume per volume to a 14-inch band on 38-inch rows as a postemergence directed spray using two tapered flat-fan nozzles per row. Nozzles are mounted on the rear of a shielded cultivator to spray a down-and-back pattern to each row. Tractor-sprayer is equipped with two, 200-gallon saddle tanks.

A. Calibration:

Step 1. From Table 1 the distance to travel for 38-inch row spacing is 107 feet. Measure off this distance in the field to be sprayed.

Step 2. Select the desired operating gear, throttle setting, and operate the directed spray-equipped cultivator down and back over the 107-foot course, recording the time in seconds for each pass. Assume it required an average of 18 seconds.

Step 3. Set the throttle at the setting used in Step 2 and adjust and note spray pressure. Catch the output from both nozzles of one row for 18 seconds. The output from both nozzles in ounces equals gallons per acre. Assume a total of 10 ounces were caught in 18 seconds, then the sprayer is applying 10 gallons per acre.

Step 4. Repeat for each nozzle of each row and check for uniformity between nozzles for each row, replacing tips varying more than 10 percent. Adjust both nozzles for each row to spray a 14-inch band with 25 to 30 percent spray pattern overlap between the two nozzles centered over the drill. Verify application rate is 10 gallons per acre.

B. Tank mix calculation:

Reduce the broadcast rate to a 14-inch band:

14-inch band ÷ 38-inch row = 0.368 x 0.8 pint Cotoran® 4L = 0.3 pint per acre for a 14-inch band.

$$\frac{\text{200 gallons per tank}}{\text{10 gallons per acre}} = \text{20 acres per tank or 40 acres per 400 gallons}$$

20 acres x 0.3 pint Cotoran® 4L = 6 pints per 200-gallon tank. Total per 400 gallons mix = 12 pints. Add 0.25 percent nonionic surfactant per 200-gallon tank = 0.0025 x 200 = 0.5 gallon (4 pints). Total per 400 gallon mix = 1 gallon (8 pints). See **NOTE** for **Example 1** on refills, which would also apply to the surfactant.

Often times in calibration, the first selected nozzle tip size may not provide the desired output. Assume that in **Example 1**, the sprayer was equipped with 80015 flat-fan tips, the pressure was 32 pounds per square inch and 7 ounces per nozzle were collected in 25 seconds, or about half that desired. Doubling the spray pressure will not double the flow rate. To double the flow through the nozzle, the pressure must be increased four fold, or in this case to 128 pounds per square inch. Such a high pressure would be unacceptable as would doubling the ground speed; so, the obvious solution is to double the nozzle tip size (rated flow). The desired 15 ounces in 25 seconds should result from 8003 tips with a slight pressure adjustment. Changing spray pressure should only be used to make minor adjustments in flow rate.

Tip size is stamped on the nozzle tip, and has been made easy to understand. Spraying Systems Company utilizes a four to six digit number stamped on the tip. Reading from left to right, the first two or three numbers are the tip spray pattern angle: 60, 73, 80, 95, 110. The remaining numbers are the flow rate in gallons per minute. For example, a nozzle tip marked 8002 indicates that the tip is a tapered flat-fan rated to deliver 0.2 (02) gallons per minute at a spray angle of 80 degrees (80). For tips designed to produce an even spray distribution pattern (such as used in **Example 2**), the four to six digits are followed by the letter E. An alpha numeric code is used by Delavan Corporation. A tip marked LF2-80 indicates a tapered flat-fan tip (LF) rated to deliver 0.2 gallons per minute (2) at a spray angle of 80 degrees (80). Even spray flat-fan tips are marked with the alpha code E in lieu of the F. The number sequence and meaning remain the same. Refer to the manufacturer's catalogs for codes of other types of nozzle tips.

The gallons per minute ratings for flat-fan tips are usually based on a standard pressure of 40 pounds per square inch. Exceptions are the low pressure tips which are rated at 15 pounds per square inch. Spray pattern angle, thus effective sprayed swath width, will decrease as pressure is reduced below the standard rated pressure.

In situations where the solution is not as obvious as doubling the nozzle size (as stamped on the tip in gallons per minute), the following procedure will permit calculation of the nozzle tip size needed when using the 128th method:

$$\text{Nozzle size in gallons per minute desired} = \frac{0.46875 \text{ (a constant)}}{\text{travel time in seconds}} \times \text{gallons per acre}$$

Therefore, in **Example 2**:

$$\frac{0.46875}{15 \text{ seconds}} \times 8 \text{ gallons per acre} = 0.25 \text{ gallons per minute}$$

This is nearest to 0.3 gallons per minute. Thus, 8003E or LE3-80 even spray nozzle tips are needed. In situations where there is more than one nozzle per row as in **Example 3**, divide the result by the number of nozzles per row. From **Example 3:**

$$\frac{0.46875}{18 \text{ seconds}} \times 10 \text{ gallons per acre} = 0.26 \text{ gallons per minute from two nozzles}$$

0.26 gallons per minute from two nozzles per row = 0.13 gallons per minute per nozzle which is nearest to 0.15 gallons per minute. Thus, two 80015 or LF1.5-80 tips per row are needed.

FORMULA METHODS

No single method of calibration is best for everyone, and the methods described below use mathematical equations or formulas. A knowledge of nozzle types and sizes and the recommended operating pressure ranges for each type of nozzle and desired spray volume per treated acre is required. The first method described calculates nozzle flow rate (nozzle tip size) in gallons per minute which is then converted to ounces per minute for calibration. The second calibration method results in the number of seconds required to catch a quart of spray solution, which is then used to calculate nozzle tip size (gallons per minute). Except for rounding errors, these two methods result in the same answers.

The formula methods are suitable for calibrating broadcast boom, band, direct spray rigs or row crop spray applications. Application rate (spray volume) is always gallons per treated acre, and there is no need to know what the application rate is to a band. Tank mix calculation also does not require reducing herbicide rates to a band basis. However, calculations are needed to determine land acres covered per tank mix capacity if desired.

Rate of application in gallons per treated acre is affected by the sprayer ground speed (miles per hour), nozzle output or flow rate (nozzle tip size, gallons per minute) and effective spray width of the nozzle (nozzle spacing or band width in inches).

Equations Needed:

Ground speed is a common variable in the equations needed to calculate nozzle tip flow rate and gallons per acre spray volume. Speedometers or tachometers are usually not an accurate measure of speed. Errors of 20 to 30 percent in speedometer reading can result from wheel slippage. However, there are kits available that do not use drive wheels for speed measurements.

Ground speed can be calculated from **Equation [1]:**

$$\text{miles per hour} = \frac{\text{course distance in feet x 3600 seconds per hour}}{\text{course time in seconds x 5280 feet per mile}} \qquad [1]$$

In laying out a field course to determine travel time, suggested distances are 100 feet for speeds up to 5 miles per hour, 200 feet for speeds from 5 to 8 miles per hour, and 300 feet for speeds greater than 8 miles per hour. Table 2 lists the travel time in seconds required to traverse courses of 100, 200 and 300 feet at speeds from 3 to 9 miles per hour.

Ground speed may also be calculated based on the fact that 1 mile per hour = 88 feet per minute. Time the sprayer over the field course for one minute and measure the distance traveled in feet and divide by 88 to give miles per hour:

$$\text{miles per hour} = \frac{\text{travel distance in feet per minute}}{\text{88 feet per minute}}$$

Another variable affecting the rate of spray applied per acre is nozzle tip flow rate or output (gallons per minute) and is used to indicate nozzle tip size. As discussed above, flow rate varies with the size of the tip and pressure. To minimize drift hazard, keep the operating pressure within the recommended range for each nozzle tip type.

Nozzle output or flow rate is calculated from **Equation [2]**:

$$\text{gallons per minute} = \frac{\text{gallons per acre x miles per hour x W*}}{\text{5940 (a constant)}} \qquad [2]$$

*For broadcast spraying W = nozzle spacing in inches

*For band spraying W = band width in inches

*For directed sprays or row crop applications $W = \dfrac{\text{row spacing or band width}}{\text{number of nozzles per row or band}}$

Table 2. Ground speed determination. (Adapted from Spraying Systems Company, 1988.)

	Time in seconds required to travel a distance of:		
Ground speed	100 feet	200 feet	300 feet
(miles per hour)		(seconds)	
3.0	23	45	68
3.5	20	39	58
4.0	17	34	51
4.5	15	30	45
5.0	14	27	41
5.5	—	25	38
6.0	—	23	34
6.5	—	21	31
7.0	—	19	29
7.5	—	18	27
8.0	—	17	26
9.0	—	15	23

Equation [3] is to convert gallons per minute to ounces per minute:

$$\text{gallons per minute x 128 ounces per gallon} = \text{ounces per minute.} \qquad [3]$$

The seconds per quart method utilizes **Equation [4]** to calculate the number of seconds required to catch a quart (32 ounces) of spray solution from one nozzle.

$$\text{seconds per quart} = \frac{\text{89,100 (a constant)}}{\text{W* x miles per hour x gallons per acre}} \qquad [4]$$

This method, however does require the use of **Equation [5]** to calculate nozzle tip size (gallons per minute) unless the nozzle tip size is already known.

$$\text{gallons per minute} = \frac{\text{15 (a constant)}}{\text{seconds per quart}} \qquad [5]$$

Manufacturer's catalogs often list ounces per minute along with gallons per minute, and they can be used once the flow rate in gallons per minute is calculated.

Gallons per treated acre when using the gallons per minute method is calculated from **Equation [6]**:

$$\text{gallons per acre} = \frac{\text{gallons per minute x 5940 (a constant)}}{\text{W* x miles per hour}} \qquad [6]$$

To calculate spray volume per treated acre (gallons per acre) with the seconds per quart method use **Equation [7]**:

$$\text{gallons per acre} = \frac{\text{89,100 (a constant)}}{\text{W* x miles per hour x seconds per quart}} \qquad [7]$$

Spray volume (gallons per acre) from **Equations [6]** and **[7]** is always gallons per treated acre when spraying broadcast or to a band. If the spray volume in gallons per land acre applied to a band of known width on rows of known spacing is desired, use **Equation [8]**:

$$\text{gallons per land acre} = \frac{\text{band width (inches)}}{\text{row spacing (inches)}} \text{ x gallons per treated acre} \qquad [8]$$

To calculate spray volume per treated acre when the spray volume on a band is known, use **Equation [9]**:

$$\text{gallons per treated acre} = \frac{\text{gallons per acre on band}}{\text{band width} \div \text{row spacing}} \qquad [9]$$

Equation [10] is needed to calculate the land acres covered by the spray operation when applications are to a band.

$$\text{acres covered} = \frac{\text{row spacing}}{\text{band width}} \text{ x } \frac{\text{tank(s) capacity (gallons)}}{\text{gallons per treated acre}} \qquad [10]$$

The three examples in the 128th method above are used to demonstrate calibration using the formula methods.

GALLONS PER MINUTE METHOD.

Example 1.

A.Calibration

Step 1. Calculation of ground speed. It was assumed that it required an average of 25 seconds to traverse the 204-foot course with the disk-harrow. From **Equation [1]** the speed is calculated to be 5.6 miles per hour:

$$\frac{\text{204 feet x 3600 seconds per hour}}{\text{25 seconds x 5280 feet per mile}} = 734{,}400 \div 132{,}000 = 5.6$$

Step 2. The spray application rate per treated acre was 15 gallons per acre, and nozzle spacing was 20 inches; thus, the nozzle flow rate is calculated to be about 0.3 gallons per minute from **Equation [2]**:

$$\frac{\text{15 gallons per acre x 5.6 miles per hour x 20 inches}}{5940} = 1680 \div 5940 = 0.283$$

As a check, calculate application rate (gallons per acre) using **Equation [6]**.

$$\frac{0.283 \text{ gallons per minute x } 5940}{20 \text{ inches x } 5.6 \text{ miles per hour}} = 1681 \div 112 = 15$$

Step 3. Convert gallons per minute to ounces per minute using **Equation [3]** to give: 0.283 gallons per minute x 128 ounces per gallon = 36 ounces per minute.

Step 4. Install 8003 or LF3-80 tapered flat-fan tips in the boom, set throttle to that used in determining travel speed, and adjust pressure to 40 pounds per square inch. Catch the output from one nozzle for one minute. Adjust pressure to result in a flow rate of 36 ounces per minute. Check remaining nozzles for consistency in output.

B. Tank mix calculation. Same as **Example 1** of the 128th method.

Example 2.

A. Calibration

Step 1. Calculation of ground speed. It was assumed that it required an average of 15 seconds to traverse the 102-foot-course with the planter attached. From **Equation [1]** the speed is calculated to be 4.6 miles per hour:

$$\frac{102 \text{ feet x } 3600 \text{ seconds per hour}}{15 \text{ seconds x } 5280 \text{ feet per mile}} = 367{,}200 \div 79{,}200 = 4.6$$

Step 2. The desired spray application rate was 8 gallons on a 16-inch band (W) or, from **Equation [9]**, 8 ÷ (16 ÷ 40) = 20 gallons per treated acre using one nozzle per row; thus, flow rate in gallons per minute is calculated to be 0.248 gallons per minute (**Equation [2]**) which is nearest to 0.3 gallons per minute.

$$\frac{20 \text{ gallons per acre x } 4.6 \text{ miles per hour x } 16\text{-inch band}}{5940} = 1472 \div 5940 = 0.248$$

As a check, calculate application rate (gallons per acre) using **Equation [6]**.

$$\frac{0.248 \text{ gallons per minute x } 5940}{16\text{-inch band x } 4.6 \text{ miles per hour}} = 1473 \div 74 = 20$$

Step 3. Convert gallons per minute to ounces per minute using **Equation [3]** to give: 0.248 gallons per minute x 128 ounces per gallon = 32 ounces per minute.

Step 4. Install 8003E or LE3-80 even spray flat-fan tips in each nozzle, set throttle to that used in determining travel speed, and adjust pressure to 40 pounds per square inch. Catch the output from one nozzle for one minute. Adjust pressure to result in a flow rate of 32 ounces per minute. Adjust nozzle height for an effective sprayed swath of 16 inches. Repeat for each nozzle checking for consistency in output.

B. Tank mix calculation.

$$\frac{\text{200 gallons per tank}}{\text{20 gallons per acre}} = \text{10 acres per tank or 20 acres per 400 gallons}$$

10 x 1.0 pounds Bladex® 90DF = 10 pounds per 200-gallon tank and 10 x 1.25 pounds Zorial® 80DF = 12.5 pounds per 200-gallon tank. Total per 400 gallons mix = 20 pounds Bladex® 90DF and 25 pounds Zorial® 80DF. See NOTE on refills.

Land acres covered per 400 gallons of mix is 50, as calculated from **Equation [10]**:

$$\text{acres covered} = \frac{\text{40-inch rows}}{\text{16-inch band}} \times \frac{\text{400 gallons}}{\text{20 gallons per acre}} = 50$$

Example 3.

A. Calibration

Step 1. Calculation of ground speed. It was assumed that it required an average of 18 seconds to traverse the 107-foot course with the cultivator attached. From **Equation [1]** the speed is calculated to be 4.1 miles per hour:

$$\frac{\text{107 feet x 3600 seconds per hour}}{\text{18 seconds x 5280 feet per mile}} = 385{,}200 \div 95{,}040 = 4.1$$

Step 2. The desired spray application rate was 10 gallons on a 14-inch band or, from **Equation [9]**, 10 ÷ (14 ÷ 38) = 27 gallons per treated acre using two nozzles per row; thus, flow rate in gallons per minute per nozzle is calculated to be 0.13 gallons per minute per nozzle (**Equation [2]** where W = band width number of nozzles per row) which is nearest to 0.15 gallons per minute per nozzle.

$$\frac{\text{27 gallons per acre x 4.1 miles per hour x (14-inch band} \div \text{2 nozzles)}}{5940} = 775 \div 5940 = 0.13$$

As a check, calculate application rate (gallons per acre) using **Equation [6]**.

$$\frac{\text{0.13 gallons per minute x 5940 gallons per acre}}{\text{(14-inch band} \div \text{2 nozzles) x 4.1 miles per hour}} = 772 \div 28.7 = 27$$

Step 3. Convert gallons per minute to ounces per minute with **Equation [3]** to give: 0.13 gallons per minute x 128 ounces per gallon = 17 ounces per minute per nozzle.

Step 4. Install 80015 or LF1.5-80 tapered flat-fan tips in each nozzle, set throttle to that used in determining travel speed, and adjust pressure to 40 pounds per square inch. Catch the output from one nozzle for one minute. Adjust pressure to result in a flow rate of 17 ounces per nozzle. Adjust both nozzles of each row for an effective sprayed swath of 14 inches with 25 to 30 percent overlap centered over the drill. Repeat for each row checking for consistency in nozzle output.

B. Tank mix calculation

$$\frac{\text{200 gallons per tank}}{\text{27 gallons per acre}} = \text{7.4 acres per tank or 14.8 acres per 400 gallons}$$

7.4 acres x 0.8 pint Cotoran® 4L = 6 pints per 200-gallon tank. Total per 400 gallons mix = 12 pints. Add 0.25 percent = 0.0025 x 200 gallons = 0.5 gallon (4 pints) nonionic surfactant per 200-gallon tank. Total per 400 gallons = 1 gallon. See **NOTE** on refills.

Land acres covered per 400 gallons of mix is 40, as calculated from **Equation [10]**:

$$\text{acres covered} = \frac{\text{38-inch rows}}{\text{14-inch band}} \times \frac{\text{400 gallons}}{\text{27 gal per acre}} = 40$$

SECONDS PER QUART METHOD.

This method is often preferred because seconds to catch a quart of spray solution precludes the need to convert gallons per minute to ounces per minute before catching the nozzle output. **Equation [4]** is used to calculate the number of seconds to catch a quart.

Example 1.

A. Calibration

Step 1. Same as **Example 1** for the gallon per minute method.

Step 2. The spray application rate per treated acre was 15 gallons, and nozzle spacing (W) was 20-inches; thus, the seconds to catch a quart equals 53 from **Equation [4]**.

$$\text{Seconds per quart} = \frac{89{,}100}{\text{20 inches x 5.6 miles per hour x 15 gallons per acre}} = 53$$

Step 3. Calculate nozzle tip size (gallons per minute) from **Equation [5]**

$$\frac{15}{\text{53 seconds per quart}} = \text{0.283 (nearest to 0.3 gallons per minute per tip)}$$

Step 4. Install 8003 or LF3-80 tapered flat-fan tips in the boom, set throttle to that used in determining travel speed, and adjust pressure to 40 pound per square inch. Catch the output from one nozzle for 53 seconds. If not 1 quart, adjust pressure to result in a flow rate of 1 quart (32 ounces) per 53 seconds. Check remaining nozzles for consistency in output.

B. Tank mix calculation. Same as for **Example 1** for the gallon per minute method.

Example 2.

A. Calibration

Step 1. Same as **Example 2** for the gallon per minute method.

Step 2. The desired spray application rate was 8 gallons on a 16-inch band (W) or, from **Equation [9]**, 8 ÷ (16 ÷ 40) = 20 gallons per treated acre using one nozzle per row; thus, the seconds to catch a quart equals 61 from **Equation [4]**.

$$\frac{89{,}100}{16 \text{ inches x } 4.6 \text{ miles per hour x } 20 \text{ gallons per acre}} = 61$$

Step 3. Calculate nozzle tip size (gallons per minute) from **Equation [5]**

$$\frac{15}{61 \text{ seconds per quart}} = 0.246 \text{ (nearest 0.3 gallons per minute per tip)}$$

Step 4. Install 8003E or LE3-80 even spray flat-fan tips in each nozzle, set throttle to that used in determining travel speed, and adjust pressure to 40 pounds per square inch. Catch the output from one nozzle for 61 seconds. If not 1 quart, adjust pressure to result in a flow rate of 1 quart (32 ounces) per second. Adjust nozzle height for an effective sprayed swath of 16 inches. Repeat for each nozzle checking for consistency in output.

B. Tank mix calculation. Same as **Example 2** for the gallons per minute method.

Example 3.

A. Calibration

Step 1. Same as **Example 3** for the gallon per minute method.

Step 2. The desired spray application rate was 10 gallons on a 14-inch band or, from **Equation [9]**, 10 ÷ (14 ÷ 38) = 27 gallons per treated acre using two nozzles per row; thus, the seconds to catch a quart equals 115 from **Equation [4]** where W = band width ÷ number of nozzles per row.

$$\frac{89{,}100}{(14 \text{ inches} \div 2 \text{ nozzles}) \text{ x } 4.1 \text{ miles per hour x } 27 \text{ gallons per acre}} = 115$$

Step 3. Calculate nozzle tip size (gallons per minute) from **Equation [5]**

$$\frac{15}{115 \text{ seconds per quart}} = 0.13 \text{ (nearest to 0.15 gallons per minute per tip)}$$

Step 4. Install 80015 or LF1.5-80 tapered flat-fan tips in each nozzle, set throttle to that used in determining travel speed, and adjust pressure to 40 pounds per square inch. Catch the output from one nozzle for 115 seconds. If not 1 quart, adjust pressure to result in a flow rate of 1 quart (32 ounces) per 115 seconds. Adjust both nozzles of each row for an effective sprayed swath of 14 inches with 25 to 30 percent overlap centered on the drill. Repeat for each row checking for consistency in nozzle output.

B. Tank mix calculation. Same as **Example** 3 for the gallons per minute method.