Longleaf Note: 2

Applications to Restoration Ecology

*This Longleaf Note is an excerpt from **A Guide to Silvicultural Herbicide Use in the Southern United States** edited by Rick L. Cantrell, School of Forestry, Auburn University and published in 1985.*

As longleaf pine has been extirpated from much of its natural range, considerable effort is underway to maintain existing longleaf ecosystems and reestablish longleaf and its associated forest community. Because longleaf seedlings have a grass stage, they do not compete well with other plants for light, water, and nutrients. Thus, seedling survival can be poor and emergence from the grass stage may take several years. In natural stands, fire exclusion results in dense competition from hardwoods. This note provides important information on vegetation control that can be applied to longleaf pine systems. We encourage prudent use of vegetation control methods to minimize impacts on diversity and wildlife. This is particularly true where native plant communities exist.

CHAPTER THREE

APPLICATION TECHNIQUES

Rick L. Cantrell, Auburn University School of Forestry and
James R. Hyland, Alabama Forestry Commission

"Never promise more than you can perform."—Publilius Syrus

There are three general types of application techniques—broadcast, banding and spot treatments. Broadcast treatments are applied to an entire area, whereas band treatments are applied in strips on or along a row of crop trees. Spot treatments involve treating individual stems or applying herbicides to small areas on the soil surface (Figure 3.1).

Ideally, an applicator or landowner would purchase or construct an application device that would be suitable for all types of applications. In reality, however, several different types of equipment are usually required. Equipment selection is dependent on costs, objective, tract size, herbicide characteristics and label requirements, site and vegetation characteristics, concerns for the safety of the operator, and protection of the environment (Griswold 1984).

Broadcast Application Techniques—Machine Mounted

Dispersal Equipment

Liquid Application Systems

Basically, all spraying systems are composed of three units: a supply unit, a control unit, and a delivery unit (Figure 3.2). All three units and their components must be selected or designed to operate reliably over long periods and be capable of applying the prescribed rate to the target area.

Supply Unit

Tank—Specifications include: 1) a size and shape that the prime mover can carry conveniently and safely (low center of gravity); 2) adequate size to minimize refills which are costly to production; 3) corrosion-proof to minimize nozzle clogging which is also costly to production and influences rate and coverage; 4) of a shape (or have a sump) to ensure positive and continuous uptake of solution even when moving over rough terrain; 5) filler hatch should have a water tight cover; and 6) should contain a gauge visible from the operator's position.

Tanks that provide reliable service are constructed of stainless steel, polyethylene, and fiberglass. Mild-steel tanks should be avoided due to rapid corrosion which results in frequent malfunctions.

Agitation—Some herbicide formulations (i.e. wettable powders, nonsoluble liquids and dry flowables) require agitation to ensure thorough mixing and uniform spray solutions. In many instances, bypass agitation is not adequate. Agitation can be accomplished by a hydraulic jet, mechanical stirring, or air sparging (bubbling). Agitation systems are located in the bottom of tanks to mix settled herbicide particles.

Pump—The pump is the heart of a spraying system since it moves the spray solution to the nozzle(s) and supplies pressure. Uniform pressure is needed for uniform nozzle performance and thus, uniform coverage. The pump system must be able to withstand frequently used herbicides and mixtures without excessive wear or corrosion, operate at speeds compatible with the power supply, and agitate the system without interfering with the flow to the boom. Always select a pump with a capacity of at least 20 percent greater than the sum of the requirements for the largest volume to be sprayed. To determine the size of pump needed to apply a given number of gallons per acre, use the following formula:

Pump Capacity (gal/min) =[(Gal/A x boom width (ft) x mph) / 495] (remember to add at least 20 percent).

If the pump is powered by the tractor, the rpm of the pump may vary with the rpm of the tractor which can influence pressure and coverage. The different types of pumps and some features of each are listed below.

centrifugal—suitable for low pressure deliveries common to forestry applications. These pumps are very durable and are a good choice for inexperienced operators. Commercial models come with PTO, hydraulic and gasoline drives.

diaphragm—used for both high and low pressure applications and are very durable with all types of formulations. Small volume diaphragm pumps are normally electrically powered while larger volume pumps have gasoline drives.

piston—suitable for high and (with some modifications) medium pressure applications. These pumps are often powered by gasoline engines and are subject to wear when using wettable powders.

roller and vane—useful for medium pressure and medium volume applications. These pumps are susceptible to wear by wettable powders, but rollers and vanes are replaceable and new type rollers are inexpensive.

Piping and Fittings—Main piping and fittings should have a large diameter (approximately 2 inches - inside) in order to apply high volumes of liquids, and a smaller diameter (approximately 1 inch) for low volume applications. They should be resistant to corrosion and wear.

Strainers (Screens)—Correctly-sized line and nozzle strainers will prevent nozzle clogging and reduce wear by grit on the sprayer components. Generally, strainers are used at four locations in a spray system: (1) basket strainers or tank filler screens, (2) suction strainers, (3) line strainers, and (4) nozzle strainers. Nozzle screen sizes range from 24-200 mesh (mesh = number of openings per linear inch, therefore a mesh of 50 has fewer but larger openings than a mesh of 100) and are chosen according to the size of the nozzle opening and the type of formulation being used. The aperture of the screen mesh should be smaller than the tip orifice (opening). Also, 16-50 mesh screens (larger apertures) should be used when applying abrasive materials (e.g. wettable powders). All screens should be readily accessible, easily dismantled and cleaned, and readily available for replacement when necessary. Frequent cleaning of strainers (once or twice daily) is important to continued production, especially in forestry applications when using high-grit water sources.

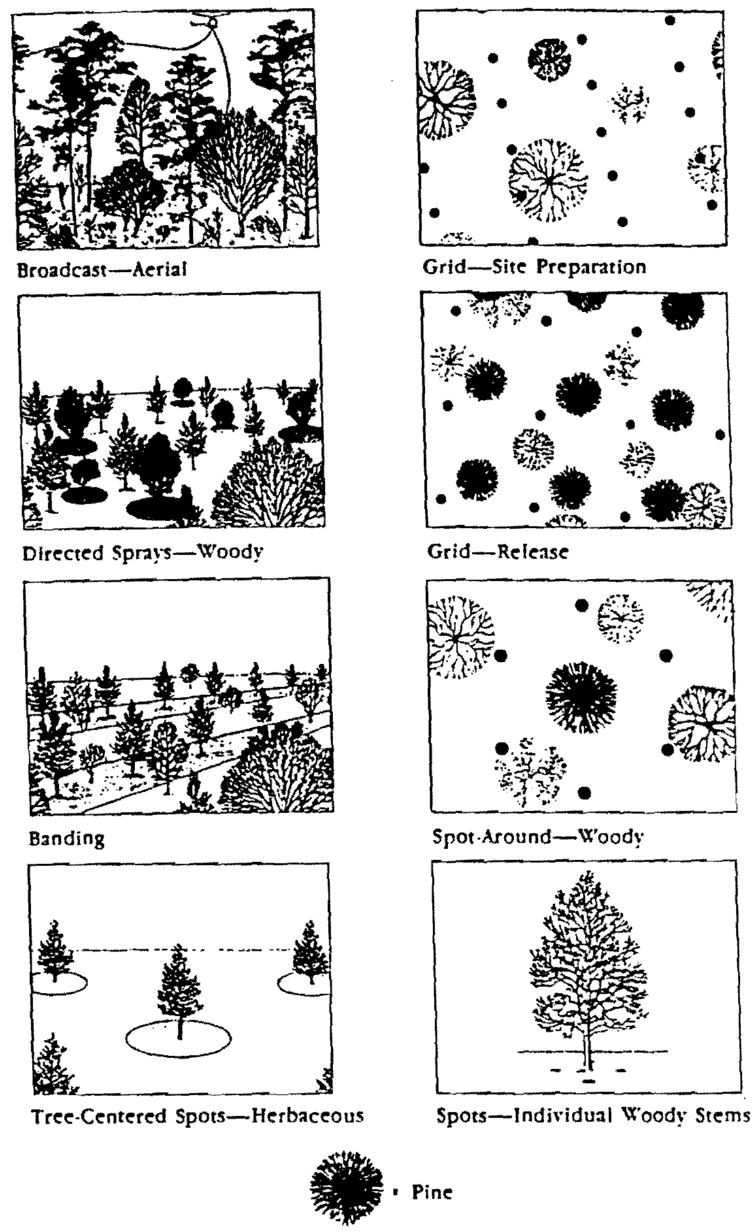

FIGURE 3.1. HERBICIDE APPLICATION TECHNIQUES: BROADCAST AND SPOT TREATMENTS.

The Control Unit

In order to spray a specified number of gallons per acre, the delivery system must be regulated or controlled. This is done by changing application speed, nozzles and or spacings, boom height, and through the use of flow control devices.

Flow Control Devices—Pressure relief and regulating valves bypass excess spray solution thereby preventing pump damage by keeping pressure within operating limits of the pump. These valves are available as manual or electrical (for remote operation) devices.

Directional or control valves may also be manual or electrical and are of two types: directo and ball valves. Directo valves allow the operator to control flow to different sections of the boom. Ball valves control flow from full to positive shutoff.

Check valves in nozzles allow for drip free shutoff and help to prevent leakage from the nozzles.

Pressure Gauges and Monitors—Pressure gauges and monitors are extremely important components of spraying systems because pressure directly affects the flow rate and nozzle spray angle. Select a pressure gauge with a range at least twice the expected operating pressure. Make sure gauges are readily visible to the operator. Pressure drops between control valves and nozzles. If the pressure gauge is mounted next to the pressure relief/regulating valve, either mount a pressure gauge on the boom as well, or frequently check the pressure at the nozzles to determine the amount of pressure drop.

Modern technology has provided the herbicide applicator with electronic monitors, herbicide injection systems, and flow rate control devices. There are two basic types of monitors: whole system and nozzle only monitors. Whole system monitors can observe and record the operating conditions of the total sprayer (speed, pressure, flow rate, gallons per acre, gallons applied, gallons remaining in tank and acres treated). Nozzle only monitors are designed to alert the sprayer operator to interruptions in flow rate at the nozzle (plugging, loss of pressure).

Herbicide injection systems regulate application rate relative to ground speed by injecting herbicide into the water pumping system at a flow rate according to the tractor ground speed. Ground speed can be sensed by a radar unit or a magnetic sensor. It is input into the microprocessor and the swath width and prescribed rate are set on this unit. These factors then regulate the speed of a small capacity herbicide pump which delivers the herbicide to the water flow system. The operator can read ground speed, gallons per minute, and acres per hour.

Application rate can also be adjusted according to ground speed by using a flow rate control system. These systems regulate rate by regulating the pressure of the herbicide-water mixture after the pump. A microprocessor console takes a ground speed signal, along with input of swath width and prescribed rate. When ground speed is slowed the electric pressure valve closes, decreasing flow; the opposite occurs with increasing speed. One problem with this approach is that at very slow speeds (< 2 mph) the swath width will decrease on boomless nozzle assemblies. Thus, coverage is decreased at times in the operation. The console displays ground speed, acres per hour, and gallons per minute.

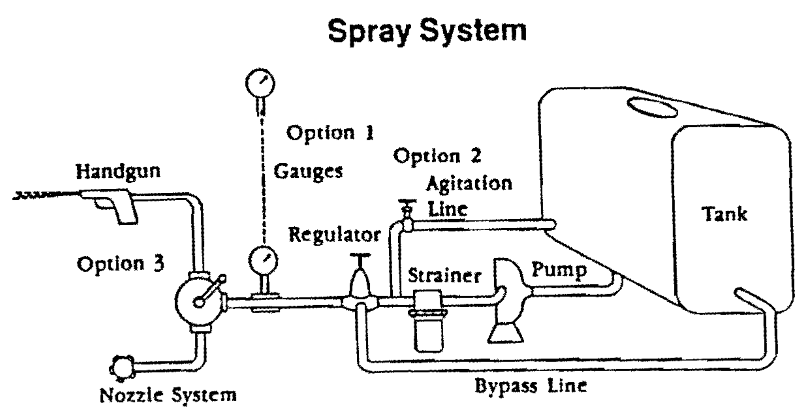

FIGURE 3.2. SCHEMATIC DIAGRAM OF A SIMPLE GROUND BROADCAST SPRAYING SYSTEM (DRAWING COURTESY OF J. H. MILLER).

The Delivery Unit

Delivery of the herbicide to the target area can be accomplished by the boom and spray tips. A growing number of control droplet application (CDA) units are being used in forestry. CDA units usually produce large droplets from spinning or revolving orifices.

Booms—Aerial

Booms support and supply the nozzles. When the boom is located near the trailing edge of the wing of an aircraft, clearance between control surfaces of the wing and boom is essential. End caps on the boom make it easier to flush the boom and nozzles. The boom must have a positive shutoff valve. Four types of booms are now used for aerial applications in forestry situations: (1) a conventional boom, (2) the Microfoil® Boom, (3) the Thru Valve Boom (TVB), and (4) the Warnell® Boom. Each boom has advantages and disadvantages. Selection of a particular one will depend on the landowner's objectives and constraints. Technology in this area has expanded rapidly in recent years and will probably continue to do so in coming years. Consultation with a competent professional applicator, extension specialist, or manufacturer can greatly aid the landowner in specifying or selecting the proper boom. The Microfoil®, TVB, and Warnell® Booms were developed to reduce drift.

Currently, the Microfoil® Boom is used more frequently in forest situations, especially when drift prevention to nearby sensitive areas is essential. The Microfoil® Boom reduces drift by producing very uniform droplet sizes with a minimum of small droplets (or "fines"). It accomplishes this by using airfoil-shaped nozzles that help to reduce air turbulence in the area behind the nozzles where droplets are formed and by regulating pressure at the nozzles to approximately 2 pounds per square inch (psi). The boom is intended for use with conventional water, oil in water, and straight oil sprays. Do not use thickened particulated or inverted sprays when using the Microfoil® Boom.

The Microfoil® Boom can be adjusted from 10 to 30 feet in length and can apply swaths of 10 to 70 feet. Application speeds in the range of 25-60 mph, boom pressure from 15 to 45 psi and flying heights of 125 feet are common when using this boom.

Although several different nozzles are available for use on the Microfoil® Boom, the .013" orifice triple-row nozzle and the .028" single-row nozzle are generally used for forestry work. Another nozzle used occasionally in forestry applications, the .060" orifice nozzle (commonly referred to as the "hayrake nozzle"), is especially suitable when high application altitudes are necessary (300-400 ft) or when the site contains dense brush or multistoried canopies. When using the .060" nozzle, application speeds must be kept below 25 mph (preferred is 22-23 mph), operating pressures should be in the range of 20-40 psi, and wind speed must not exceed 5 mph (2 mph for heights of 300-500 ft). Wind and application speeds and pressures outside these ranges will break up the large droplets produced by the .060" nozzle resulting in increased drift risk and less than optimum vegetation coverage and control.

The primary advantage of the Microfoil® Boom is the reduction of drift risk due to precise placement of the spray material on the target area. Disadvantages include the expense of acquiring and maintaining the boom, "skips" created by imprecise flight line flagging and flying, and frequent nozzle clogging with some materials. Despite these disadvantages, many foresters and landowners specifically require the use of a Microfoil® Boom when developing spray contracts.

The recently-developed TVB® Boom is undergoing extensive testing in many areas. The TVB® Boom, like the Microfoil®, reduces spray pressure at the nozzles to 2 psi. This low pressure, coupled with fairly large nozzle orifices and air-foil design, enables the boom to produce large droplets with a minimum of fines or aerosols. The TVB® Boom is commonly equipped with 0.045″ diameter "burr" nozzles for forestry work, although several other sizes are being tested for forestry applications (i.e., .032). Trials to-date have not experienced any maintenance difficulties with the TVB® Boom, and vegetation control has been comparable to that of other booms.

The TVB® Boom is normally flown at a height of 75 feet and will produce droplets with a minimum of fines at speeds of 100 to 150 mph and greater. At normal application speeds (approximately 50 mph) droplets tend to flatten out as they fall, forming "donuts" which separate into smaller droplets with practically no fines. Swath width is approximately two times the boom length. An advantage the TVB® Boom has demonstrated over the Microfoil® is that swath width is not as narrowly defined and streaks due to improper flight line flagging and or flying are not as common (Kidd and Kline 1985).

The Warnell® Boom is very similar to the Microfoil® Boom but is easier to maintain. The boom length varies from 21 to 30 feet and it is capable of applying up to 30 gallons of spray solution per acre. Normally, operations are made at speeds between 25 and 100 mph, at heights of 50 feet above the target and with a pressure of 35 psi (minimum of 30 psi).

Booms—Ground

Improved technology has provided the applicator with an array of booms and spray systems including "boomless" sprayers. Several systems have been developed to convert skidders, crawlers or farm tractors to sprayers (Figure 3.3). Most ground sprayers used in forestry situations are of the boomless type. Boom sprayers have been used with limited success in forestry applications.

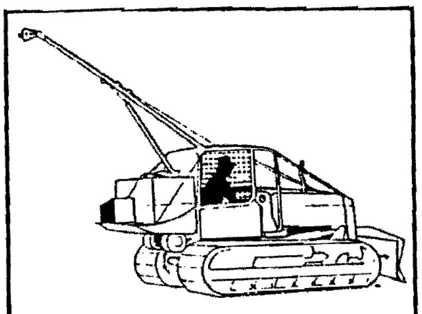

FIGURE 3.3. U. S. FOREST SERVICE "BOOMLESS" GROUND SPRAYER.

Nozzles: Tips, Orientation, Overlap and Maintenance

Nozzles are composed of 4 parts: body, strainer, tip and cap. Nozzle tips, spacings, orientation, and boom height directly affect spray patterns and when all are arranged properly, provide for uniform coverage. These factors are all related and must be considered as such when preparing equipment. For ground applications, nozzle tips with different spray angles require different boom heights for uniform coverage (Table 3.1). The angle of the nozzle in relation to the direction of travel also greatly affects droplet size in aerial applications (Figure 3.4). Flight speed also will have a large effect on the size of droplets produced. Spray equipment manufacturers supply equipment catalogs and provide information on recommended boom heights and nozzle flow rates for various nozzle spacings, pressures and tips. Two of the major manufacturers servicing the South are listed below. Addresses of other manufacturers and dealers of sprayer components are listed in Appendix CC.

Spraying Systems Co.
North Avenue & Schmale Road
Wheaton, IL 60187
(312) 665-5000

Delavan Agricultural
Products Operation
20 Delavan Drive
Lexington, TN 38351
(901) 968-8152

Nozzle tips should be selected for specific spraying jobs and should be based on anticipated spacings, speed, pressure, and desired gallons per acre. Avoid spray tips that require high pressures due

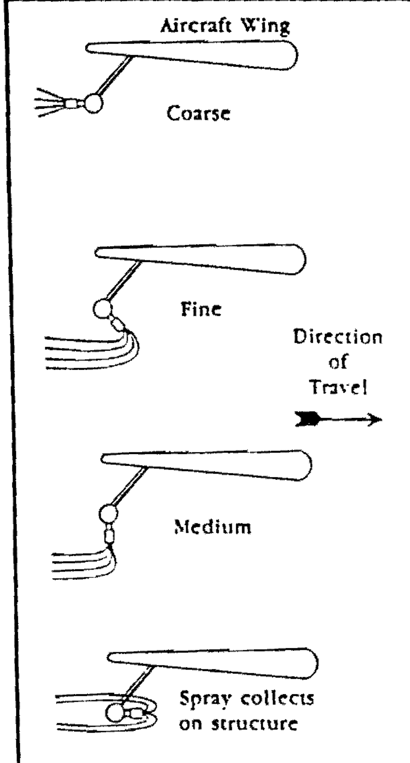

FIGURE 3.4. SPRAY DROPLETS PRODUCED BY VARIOUS NOZZLE ORIENTATIONS FOR AERIAL APPLICATIONS.

TABLE 3.1. BOOM HEIGHTS NECESSARY FOR UNIFORM SPRAY COVERAGE WHEN USING TIPS WITH VARYING SPRAY ANGLES.[1]

a. Even Flat Fan Nozzle Tips—For Banded Applications

Band Width (inches)	Spray Height (inches) 80° Series[2]	90° Series[2]
24	14	12
36	22	18
48	29	24
60	36	30

b. Tapered Edge Flat Fan Nozzle Tips (with overlap)

Spray Tip Angles (degrees)	Spraying Height (inches) for Different Spacing (inches) 20	30
65	21-23	32-34
73	20-22	27-29
80	17-19	24-26

[1]Developed from Spray Systems, Inc. and Delavan's spray products catalogs.
[2]Calculated by the authors.

to the possibility of increasing drift. Nozzles are classified by capacity, type (material and spray pattern), and the angle of the spray pattern. Normally, all nozzle tips on a spray boom should be constructed of the same material and have the same spray angles and flow rates. It is advisable to purchase nozzles with special strainers equipped with check valves. A diaphragm check valve will prevent drippage when the sprayer is not in use and also allows nozzle tips to be changed without spray material leaking from the boom.

Nozzle flow rates depend on the size of the nozzle tip orifice and the pressure. A series of nozzle tips consists of many tips with progressively larger orifices (therefore, larger flow rates) at a specified pressure. It is imperative that recommended pressure and flow rate guidelines be followed when using a selected nozzle tip. Operating outside the pressure range can drastically change flow rates and spray patterns. Manufacturers will supply tables of nozzle flow rates for various pressures and nozzle tips.

Nozzle Tip Wear and Care

Nozzle tips are made from brass, aluminum, nylon, stainless steel, hardened stainless steel, plastic, and ceramic (Table 3.2). All of these materials have different wear rates (Table 3.3). **All nozzles must be checked periodically to detect changes in flow rates due to wear.** Tests with 2,4-D have shown that wear can increase flow rates in some nozzle tips by as much as 8 percent after only 50 hours of use. If 500 acres are treated using a herbicide that costs $65 per acre, an 8 percent increase in the flow rate would increase the herbicide cost per acre to $70.20. The total extra cost for 500 acres would be $2600. In addition, if this were a release treatment, the increased rate might severely injure or kill the crop species.

Clogged nozzle tips should only be cleaned with a nozzle tip brush or soft toothbrush. Researchers have demonstrated that even a toothpick can damage the tips of some nozzles. If nozzles clog while spraying, clean or repair while in an untreated area.

TABLE 3.2. MATERIALS COMMONLY USED IN THE MANUFACTURE OF NOZZLE TIPS.

Material	COMMENTS
Brass	commonly used; relatively inexpensive; subject to rapid wear when used with abrasive materials, such as wettable powders; susceptible to corrosion by some liquid fertilizers (esp. liquid nitrogen).
Aluminum	only moderately resistant to wear; generally not recommended.
Stainless Steel and Tungsten Carbide	most resistant to wear than all other materials; very expensive.
Nylon/Plastic	more resistant than brass or aluminum; threads may be easily damaged; subject to swelling when exposed to some solvents.
Ceramic	very resistant to abrasion; fairly expensive; subject to breakage (newer ones are encased in plastic to avoid breakage).

TABLE 3.3. WEAR RATES OF NOZZLE TIPS MADE OF VARIOUS MATERIALS AS COMPARED TO BRASS.[1]

Nozzle Material[2]	Life Compared to Brass
Aluminum	less than brass
Plastic/Nylon	more than brass
Stainless Steel	3-3.5X
Hardened Stainless Steel	10-15X
Tungsten Carbide	150-200X

[1]Adapted from Hofman and Kucera 1977; and Ozkan 1983d.
[2]In order of increasing resistance to wear.

Understanding Nozzle Tip Numbers and Coding

Nozzle tip numbers and designations vary according to the manufacturer (Table 3.4). Spraying Systems flat fan tips are designated by a 4-6 digit number. The first 2 numbers (reading from the left) indicate the spray angle, while the remaining numbers are the flow rate (gallons per minute) at a pressure of 40 psi. For example, a Teejet® 8002 nozzle tip has an 80° spray angle and will deliver 0.2 gpm at 40 psi. Spraying Systems stainless steel flat fan tips are color coded and are designated with a 4-6 digit number followed by an "S".

Delavan flat fan nozzles are designated by the letters "LF" followed by a 4-5 digit number. From left to right, the first 1-3 numbers followed by a hyphen represent the flow rate (gpm) at 40 psi and the remaining digits represent the spray angle. For example, a LF 1.5-80 tip will deliver 0.15 gpm with an 80° spray pattern at 40 psi. Other spray tips are designated using similar codes and are presented in Table 3.4. Consult manufacturers' catalogs and or representatives when selecting spray nozzles, tips, and accessories.

Forestry Applications

A wide variety of nozzles and tips can be used in forestry operations. Selection of a particular type and size depends entirely on the objective and application equipment (Table 3.5). A discussion of the nozzles and tips most commonly used in forestry situations follows.

Flat Fan Tips

These nozzle tips are most commonly used on boom type sprayers for ground broadcast treatments. These tips produce spray patterns with "tapered edges" resulting in reduced volume at both ends (Figure 3.5). Consequently, they must be aligned so that their spray patterns overlap 30-50 percent (Figure 3.6). For forestry applications, nozzles are normally spaced 20 to 30 inches apart and spray patterns aligned to overlap approximately 30 percent. These tips also should be set at a slight angle (10-15°) to the boom so spray patterns of adjacent nozzles bypass each other. Boom height is dependent on the spraying tip angles and nozzle spacings. It is usually desirable to position the nozzle bodies slightly forward so that they spray forward instead of vertically (Figure 3.7). Spray angles of 65, 73, 80 and 110 degrees are available, but tips with 80° angles are most commonly used.

Even Flat Fan Tips

These tips produce a similar pattern to tapered edge flat fan tips, but differ in that spray coverage is uniform across the spray width (Figure 3.5). Even flat fan nozzles are used exclusively for banding treatments and are sometimes used

TABLE 3.4. NOZZLE TIP NUMBERING AND CODING USED BY 2 MAJOR MANUFACTURERS.

	Designation	Example	Available Angles (degrees)
SPRAYING SYSTEMS			
Tapered Edge Flat Fan	4, 5, or 6 digit number	650067	65
		730077	73
		95015	95
		8002	80
		150015	150
Tapered Edge Flat Fan	4, 5, or 6 digit number followed by an "S"	8001 S	80
		11001 S	110
Low Pressure Flat Fan	4 or 5 digit number followed by "LP"	8001 LP	80
		11015 LP	110
Even Flat Fan	4 or 5 digit number followed by an "E"		40
		8001 E	80
		95015 E	95
Flooding Flat Fan	**Floodjet®** "TK" followed by a 1 or 2 digit number	TK.50	—
		TK	—
Hollow Cone	"TX" or "TY" followed by a 1 or 2 digit number	TX 3	80 (at 100 psi)
		TY 26	65 (at 100 psi)
Full Cone	**Regular** "TG" followed by a 1 digit number	TG 1	—
	Wide (larger drops) "TG- ——W"	TG-2.8W	—
		TG-12W	—
Solid Stream	a 4 or 5 digit number	0001	—
DELAVAN			
Tapered Edge Flat Fan	"LF" followed by a 4 or 5 digit number (color coded)	LF 2-65	65
		LF 20-80	73
		LF 1.16-73	80
			110
Even Flat Fan	"LE" followed by a 4 digit number	LE 1-80	
		LE 15-80	80
Flooding Flat Fan	"D" followed by a 1 to 2 digit number (color coded)	D 1	
		D 20	100-145
Hollow Cone	"HB" followed by 1 to 3 digit number (HC for stainless steel)	HB 1	70
		HB 1.25	(45 & 70 for HC)
Full Cone	"CE" followed by a 1 digit number	CE-4	
			70
Solid Stream	"*1505" followed by a 1 to 2 digit number	*1505-45	
		*1505-8	
Disc-Core	**Regular** "DC—— · ——"	DC 2-13	—
		DC 12-25	—
	Raindrop® (Disc-Core) "RD" followed by 1 or 2 digit number and the spray angle.	RD 1-90°	80
		RD 10-100°	85
			90
			100
	"RA" followed by a 1 to 3 digit number	RA 2	120
		RA 4	

with planting equipment (Figure 3.14). They should **not** be used for broadcast applications and nozzles should **not** be aligned for spray overlap (Figure 3.8). Band widths are controlled by boom height and spray angle (80 or 95°). Operating pressures for these nozzles should be in the range of 15-30 psi and never greater than 40 psi.

Flood Tips

These tips are commonly used for ground broadcast applications of herbicides, fertilizers, and combinations of herbicides and fertilizers and are not recommended for applying contact herbicides at low spray volumes. They are characterized by wide spray angles, up to 160°, and large droplets which

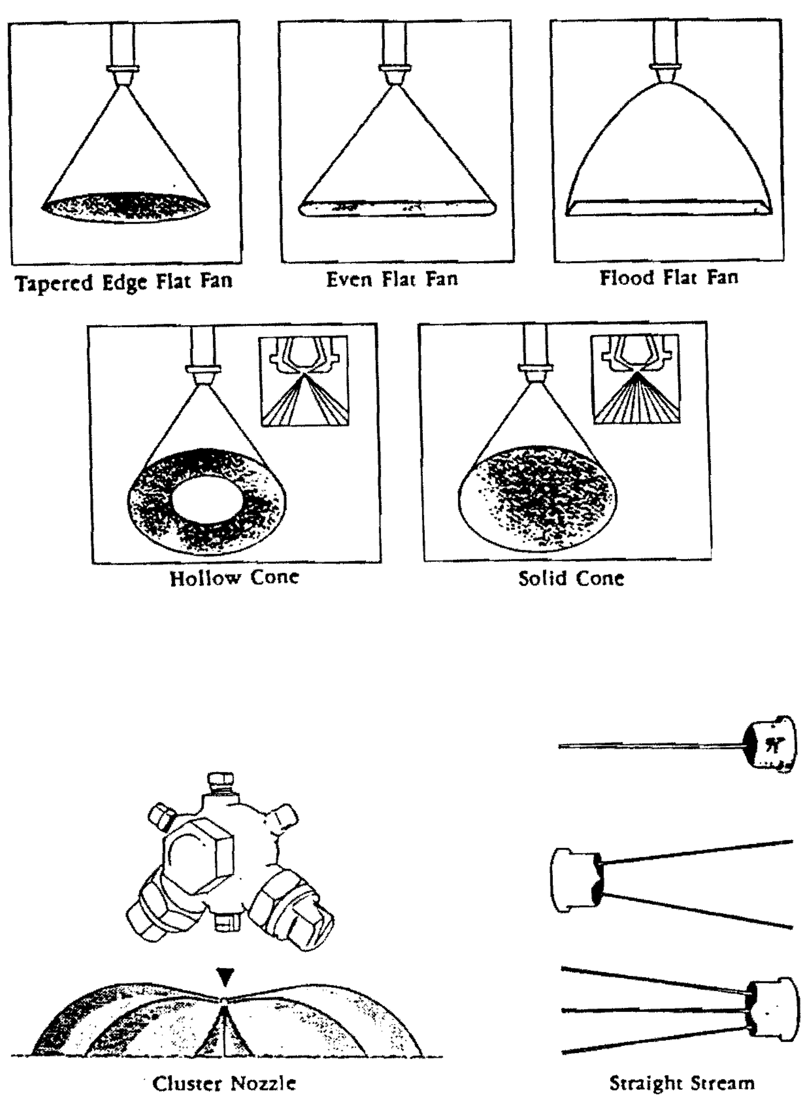

FIGURE 3.5. SPRAY PATTERNS PRODUCED BY VARIOUS SPRAY NOZZLES AND TIPS.

TABLE 3.5. FORESTRY APPLICATIONS: NOZZLES AND TIPS.

Objective	Nozzle tips	Example(s)
Broadcast Aerial	Specialty	Microfoil Triple Row .016"
	Specialty	TVB®-45 Boom with 0.045" "burr" nozzles
	Hollow Cone (disc core)	Raindrop® RD
Ground Broadcast	Flat Fan	Teejet® 650067
	Flooding Flat Fan	D.75 SS
	Straight Stream	®1505-45
	Specialty Cluster Nozzle	Boomjet 5880
Banding	Even Flat Fan	Teejet® 9503 E
Basal Bark		
To-Wet	Even Flat Fan	Teejet® 8003 E
Thinline	Straight Stream	TP 0001
Tree-Centered Spots (for herbaceous)	Hollow Cone	DC 3-25
	Solid Cone	TG-1
	Specialty (hollow cone)	Forestry Nozzle Assembly[1]
Spot (individual stem or grid pattern for woody vegetation control)	Straight Stream	TP 0001
		TP 0002
		TP 0003

[1]Forestry Suppliers, Inc., 205 West Rankin Street, P.O. Box 8397, Jackson, MS 39204-0397.

allow for wider nozzle spacings (60 in. or less for herbicides) and lower boom heights. Lower pressures (8-25 psi) are used than with regular flat fan nozzles. An extremely important consideration with these nozzle tips is spray overlap. These tips produce spray patterns which are not as uniform as those obtained with other flat fan tips (Figure 3.5). Flood fan tips produce spray patterns which have a high application rate at the edges and require an overlap of 100 percent of the nozzle spacing (Figure 3.9). They may also be mounted on a boom in several different positions to vary the spray pattern (Figure 3.10). The position is not very important as long as double coverage is achieved. Normally, the most uniform spray pattern is achieved when the tips are oriented 45° above horizontal.

Cone Tips

There are three types of cone nozzles: hollow cone, full (solid) cone, and whirl chamber nozzle tips. Full cone nozzle tips are used primarily for herbaceous tree-centered spot treatments and spray over an entire circular area. Hollow cone nozzle tips are also used for tree-centered spot treatments but produce a circular spray pattern with concentrations at the outer edge (Figure 3.5). These two nozzle tips are used with operating pressures of 40-100 psi and must be tilted forward or backward (with respect to the boom) for uniform broadcast applications.

A whirl-chamber hollow cone nozzle produces a hollow cone spray pattern with spray angles up to 130° and is used under pressures of 5 to 20 psi. The large orifice on these type nozzles minimizes clogging and produces larger droplets, thereby reducing drift.

A relatively new low-drift hollow cone spray tip, the Raindrop® nozzle, has a conventional disc-core hollow cone nozzle tip to which a cap has been added. This cap functions similarly to a whirl-chamber hollow cone nozzle and removes many of the smaller drift-prone droplets. These tips are used for foliar sprays at pressures of 15 to 45 psi at spraying heights of 50

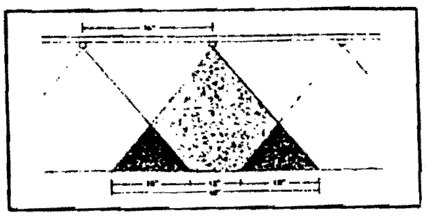

FIGURE 3.6. NOZZLE ORIENTATION AND OVERLAP (APPROXIMATELY 40 PERCENT IN THIS EXAMPLE) FOR TAPERED EDGE FLAT FAN NOZZLE TIPS.

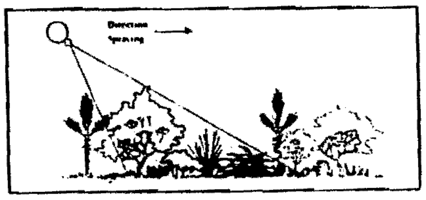

FIGURE 3.7. RECOMMENDED NOZZLE POSITIONING WHEN USING TAPERED EDGE FLAT FAN NOZZLE TIPS.

feet and airspeeds of 25-70 mph. They should also be rotated upward 30 to 45 degrees from the horizontal to produce uniform spray patterns. These nozzles are commonly used on conventional booms for aerial applications to reduce the risk of drift.

Boomless Nozzle Assemblies

Cluster nozzles are used in place of a boom and are capable of applying swaths 30-55 feet wide (Figure 3.5). The Boomjet® 5880 cluster nozzle manufactured by Spraying Systems consists of five nozzles and is commonly used for ground application in forestry situations. A variety of tips are available to change flow rates.

Boomless nozzle assemblies have the distinct advantage over boom units of the protection of the delivery unit. Assemblies are normally positioned behind the tractor and tank to prevent limbs and snags from hitting the delicate tips and to prevent spray from drifting onto the operator. Boomless assemblies can be easily raised for applications to tall brush or small hardwoods using foliar sprays.

Off-center (OC) swivel nozzles yield a 30 to 45 foot swath without a boom. Similar to the cluster nozzle, this nozzle uses two OC tips and the spray angle can be changed by adjusting the swivel. This nozzle is used with the Forest Service Sprayer shown in Figure 3.3.

Manifold nozzles are commonly used on tractor sprayers. Straight stream, narrow stream (15 and 25 degrees), and flat fan nozzles are fitted to short sections of pipe and each nozzle is directed to a section of the spray swath (Figure 3.11). As with the cluster and OC swivel nozzles, the spray swath can be up to 70 feet wide (when the prime mover is stationary). The spray swath does decrease with and varies by speed with a reduction of as much as 25% at a speed of four mph.

Specialty Nozzles

Straight stream nozzles are used primarily for spot (individual stem and grid pattern) and thinline basal bark treatments. They emit a solid stream of liquid at varying rates and distances depending on the pressure used (Figure 3.5).

A forestry nozzle assembly available from Forestry Suppliers, Inc. can be attached to a spotgun and used for spot-around herbaceous weed control (see Figure 3.17). The assembly consists of an 8, 12 or 18" curved extension and a solid cone spray nozzle.

Dry Application Systems

These systems are commonly used for applying dry formulations such as granules or pellets. The application equipment and the size, shape, density, and flowability of the materials affect swath width and pattern. Generally, dry material system components should meet or exceed the following minimum requirements.

Hopper—Walls should be steep enough to ensure uninterrupted flow of the entire system; a slope of 40 degrees from horizontal is usually sufficient. The hopper must be free of leaks and the loading gate must close tightly. The discharge tube gates must provide a tight seal when closed. An agitator will keep fine materials from bridging. An adjustable gate is frequently used to regulate flow rate.

Two devices commonly used for aerial applications are the Simplex® Airblown Seeder and the Isolair® Bucket. The Simplex® Airblown Seeder disperses granules in swath widths up to 90 feet, while the Isolair® Bucket has an effective swath width up to 140 feet. These devices are commonly flown on one-half swath width centers with continuously overlapping swaths (double coverage concept, Figure 3.12). The Isolair® Bucket, due to a larger swath width, is slightly more productive

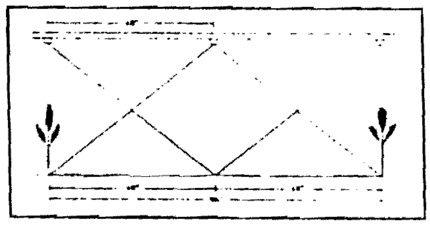

FIGURE 3.9. SPRAY PATTERN PRODUCED BY FLOOD FAN TIPS.

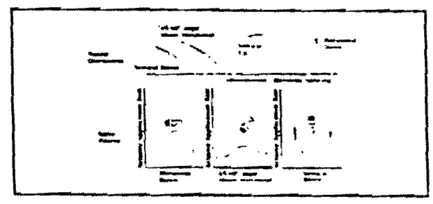

FIGURE 3.10. NOZZLE LOCATION AND ORIENTATION ON BOOMS, AND SPRAY PATTERN WHEN USING FLOOD FAN TIPS.

(150-200 acres/hr) than the Simplex® Airblown Seeder (100-150 acres/hr).

The Omni Spray® is a very durable ground application device for granular and pelletized materials. The system is designed to fit various prime movers and can apply a swath of 90 feet (or 45 ft. to one side if only 1/2 swath or application to only one side is desired). It is capable of maintaining a uniform swath on side slopes up to 20°. Application rate is related to ground speed by use of a speed sensor and microprocessor in control unit. The stainless steel hopper has a capacity of 18 cubic feet and can hold 650 to 1000 pounds of dry material. The Omni Spray pellet applicator is manufactured by Omni Spray, P.O. Box 516, Prattville, AL 36067.

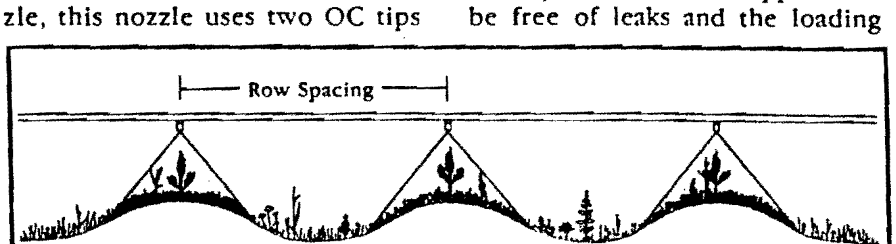

FIGURE 3.8. NOZZLE ORIENTATION AND SPRAY PATTERN WHEN USING EVEN FLAT FAN NOZZLE TIPS.

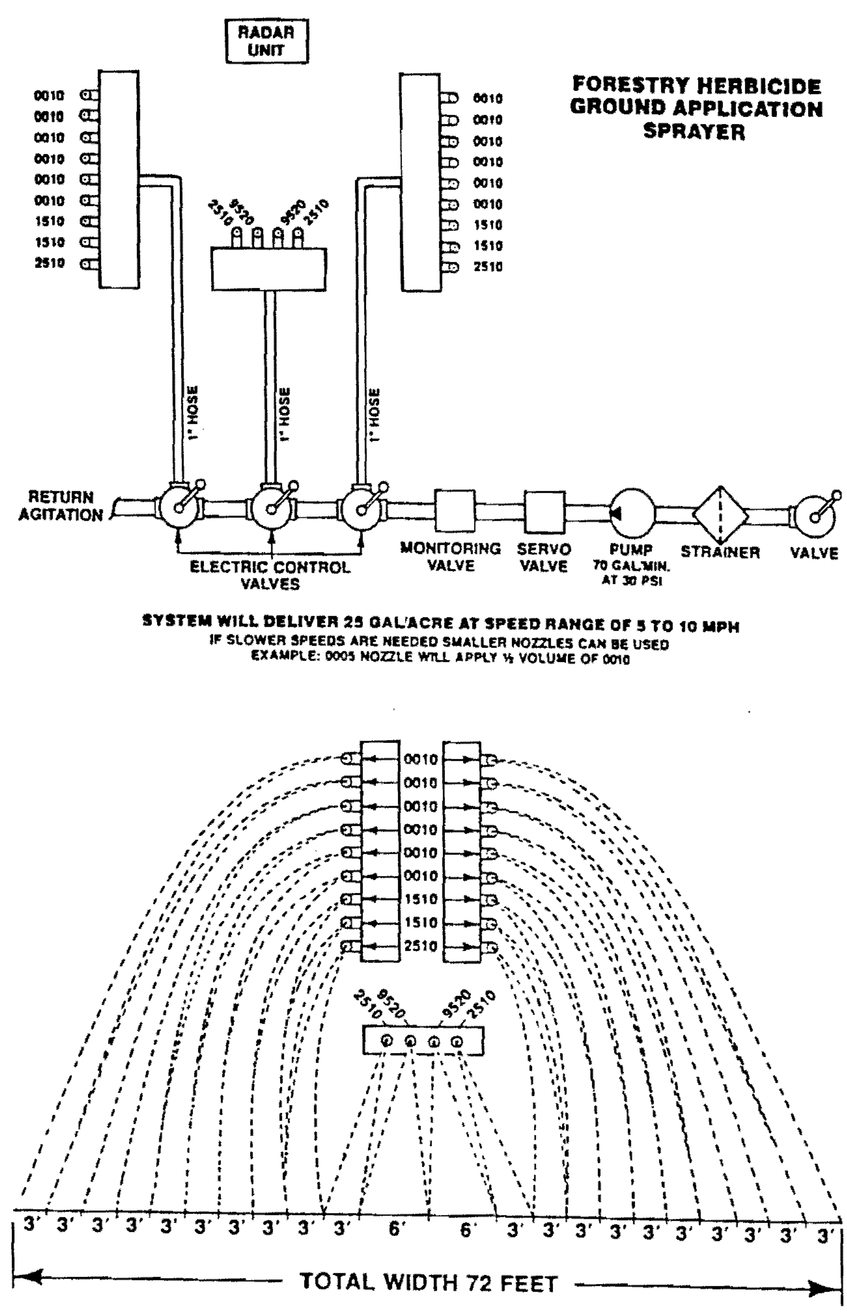

FIGURE 3.11. MANIFOLD NOZZLE GROUND SPRAYING SYSTEM (FROM SAGE ET AL. 1984; USED WITH PERMISSION).

An electrically powered spinning-disc applicator for pelleted and granule herbicides is available for mounting on ground equipment (Herd Cedar Co., P.O. Box 448, Logansport, IN 46947). The inexpensive price and 50 foot swath width makes this application device particularly suitable for small tracts. The hopper has a limited capacity of about 150 pounds.

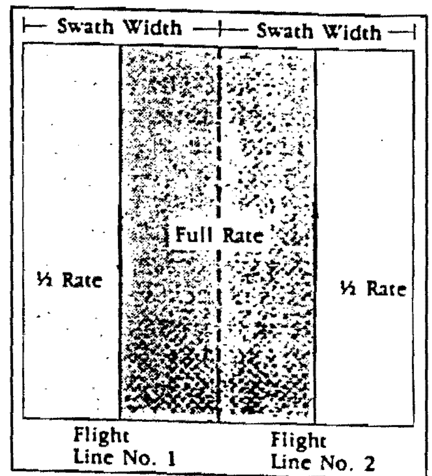

FIGURE 3.12. DOUBLE COVERAGE WHEN FLYING ON ONE-HALF SWATH WIDTH CENTERS.

Calibration

Accurate and efficient delivery of herbicides to the target area cannot be achieved unless spray equipment is properly calibrated. There are a number of methods for accurately calibrating the output of nozzles, booms, sprayers, and dry application systems. If you are already using a reliable procedure, continue using it. If available, consult the owner's manual when adjusting or calibrating sprayers. Equipment must be recalibrated periodically to compensate for wear in nozzle tips, pumps, etc. Herbicides applied in a careless or reckless manner will result in poor weed control, loss of herbicide, crop tree injury, and possible off-site damage. The following sections will discuss the factors controlling calibration and provide specific examples for calibrating ground and aerial broadcast spray equipment.

Calibration Factors

Calibration is primarily affected by 4 factors: (1) sprayer speed, (2) nozzle capacity, (3) pump pressure, and (4) swath width. Each of these factors can be manipulated to varying degrees to change application rates.

Application Speed

Sprayer speed has a tremendous impact on application rates and calibration. Sprayers must be calibrated based on the anticipated application speed. Application speed is one of the easiest factors to adjust when changing application rates. Doubling application speed will decrease the application rate by one-half. Likewise, decreasing the application speed by 1/2 will double the application rate. This direct speed-to-application rate relationship makes it extremely important to maintain the application speeds used in calibration. This is especially critical when operating at lower speeds (ground spray - tractors, backpack sprayers, etc.) when a minor (1 mph) variation in speed represents a significant reduction in application speed. For example, a 1 mph variation in the speed of an individual who is walking and spraying herbicides at the rate of 3 mph is of much greater significance (33%) than a 1 mph variation in the speed of a helicopter that is flying at 50 mph (2%).

Nozzles

Nozzle output (measured in gallons per minute—GPM) at a given pressure can be determined by collecting and measuring the flow from a nozzle at a given pressure for a set period of time. The size and shape of each orifice determine the volume of liquid dispensed and the spray pattern. Normally, nozzle capacities are calculated and reported based on use with water. When spraying materials lighter or heavier than water, flow rates may be different than specified by the manufacturer in spray catalogs. Later sections in this chapter will detail procedures for checking nozzle uniformity and for calibrating sprayers.

Pressure

Pressure performs as a square root function of nozzle output. Therefore, to double output, pump pressure must be increased fourfold. Adjusting application rates by manipulating pump pressure should only be done for very small changes. Nozzles are designed to operate within a recommended pressure range. Operation outside these ranges greatly alters the spray pattern produced by the nozzle (Table 3.6). Spray equipment should always be calibrated using the pressure that will be used during application.

Swath Width

The effective swath width, simply defined, is the width of the treated area that receives a uniform distribution of spray material. Swath width is regulated by boom length, boom height or spray altitude, and the type of nozzles used. Swath width is easily determined by spraying several swaths over a smooth surface (airport runway, water sensitive paper, etc.) and observing the spray pattern.

Calibration of Liquid Systems

The key to efficient and effective applications is properly maintained equipment that can produce a consistently uniform spray pattern. Generally, to obtain even spray patterns, output from all the nozzles on a boom must be within 5-10 percent of one another. Five percent variation is the ultimate goal. However, in practice a 10 percent or less variation is generally acceptable. Follow the steps and example problem outlined below to check for nozzle uniformity.

Procedure for Checking Nozzle Uniformity

1. Catch the flow from all nozzles individually for a set length of time (depending on the sprayer output—generally 1 minute); operate sprayer at normal pressure.
2. Measure output and record by nozzle.
3. Determine the total output of all nozzles.
4. Calculate the average nozzle output.
5. Multiply the average nozzle output by 5% to obtain the nozzle uniformity allowable range factor (NUARF).
6. Average nozzle output—NUARF=low side of allowable variation.
7. Average nozzle output + NUARF=high side of allowable variation.
8. The allowable range of variation lies between these two endpoints (calculated in #7 and #8).

Compare the output of each nozzle to these high and low values. If a nozzle output is lower, disassemble tip and clean the filter or screen and nozzle. Clean nozzle tips with a nozzle tip brush or tooth brush only; even toothpicks can damage some nozzles. If a nozzle output is larger, the orifice has widened through use and the nozzles should be replaced. Always repeat this process after cleaning and or replacing nozzles. Even new nozzles can vary in output by 10 percent or more. An example follows:

Nozzle Output Uniformity Sample Problem

Assume: 6 nozzle boom

ounces of water collected per nozzle

#1	#2	#3	#4	#5	#6
55	45	50	53	68	53

Total ounces=324
Average=54
Average X 5%=2.7=NUARF
Average + NUARF=56.7—high side
Average − NUARF=51.3—low side

TABLE 3.6. RELATIONSHIP BETWEEN PRESSURE AND NOZZLE PERFORMANCE.

	Operating Pressure Above Recommended Range for Nozzles	Operating Pressure Below Recommended Range for Nozzles
PROBLEMS	more fine droplets produced drift hazard greatly increased poor coverage	larger droplets produced weak spray pattern poor coverage
SOLUTIONS	decrease pressure use larger nozzles	increase pressure use smaller nozzles

Results: Clean nozzles #2 and #3. Replace nozzle #5. Repeat process.

The next step in this process is checking for proper nozzle orientation and spray overlap. The reader is referred to the section in this chapter entitled "The Delivery System" for a detailed discussion on nozzle orientation and spray overlap.

The final step in this process is sprayer calibration. As stated earlier, there are numerous methods available. Choose a method that is accurate and easy to use and stick with it. Several calibration techniques for aerial and ground broadcast systems (liquid and dry) are presented in the following sections.

Aerial Sprayer Calibration—Tank Refill Method

Method #1—Basic Steps:

- Determine the acres your aircraft's system treats per minute at the speed and swath width you plan to use (Table 3.7).
- Figure the gallons you must spray per minute to apply the recommended rate.
- Select the size and number of nozzle tips which will deliver the correct number of gallons per minute at the operating pressure of your system (use the nozzle manufacturer's specifications as a guide).
- Make a trial run.
- Determine the amount of herbicide to add to the tank.

The following example will illustrate these basic steps. Your aircraft has a 120 gallon tank. The effective swath width is 50 feet. You plan to spray at 45 mph at a height of 150 feet. The herbicide is to be applied at the rate of 1 gallon of product per 10 gallons of spray per acre. The operating pressure will be 30 psi.

1. Determine acres per minute covered.
   A/min = [2 × swath width (ft.) x speed (mph)]/1000
   In our example, [2 x 50 x 45]/1000 = 4.5 acres per minute.

TABLE 3.7. ACRES COVERED PER MINUTE WHEN SWATH WIDTH AND AIRCRAFT SPEED ARE KNOWN.

Speed (mph)	Acres Per Minute for Various Speeds and Swath Widths							
	Swath Width (Feet)							
	30	35	40	45	50	75	100	200
40	2.4	2.8	3.2	3.6	4.0	6.0	8.0	16.0
50	3.0	3.5	4.0	4.5	5.0	7.5	10.0	20.0
60	3.6	4.2	4.8	5.4	6.0	9.0	12.0	24.0
70	4.2	4.9	5.6	6.3	7.0	10.5	14.0	28.0
80	4.8	5.6	6.4	7.2	8.0	12.0	16.0	32.0
90	5.4	6.3	7.2	8.1	9.0	13.5	18.0	36.0
100	6.0	7.0	8.0	9.0	10.0	15.0	20.0	40.0
110	6.6	7.7	8.8	9.9	11.0	16.5	22.0	44.0
120	7.2	8.4	9.6	10.8	12.0	18.0	24.0	48.0

Formula: Acres per minute = [2 x swath width (ft) x MPH]/1000*

*The technically correct formula is: Acres per minute = [swath width (ft) x MPH]/495; or as in the form above: [2 x swath width (ft) x MPH]/990. The slight difference in divisor is commonly ignored due to the simplicity in working with a multiple of 10, therefore 1000 is used as the divisor.

Table 3.7 contains information for determining the acres covered per minute for aerial applications when swath width and aircraft speed are known. Table 3.8 contains information necessary for determining ground speed for ground broadcast treatments.

2. Determine gallons per minute (gpm) required. In our example, 10 gals/A x 4.5 ac/min = 45 gallons per minute. Be sure your pump can deliver this volume.
3. Select the nozzles. Determine the gpm for each nozzle that would deliver the required 45 gpm flow. Let's assume the boom you are using contains 26 nozzles. The gpm per nozzle is determined this way:
   gpm per nozzle = gpm required/number of nozzles
   In our example, 45/26 = 1.73 gpm per nozzle.

   You choose a pressure of 30 psi. Using the manufacturer's catalog, select a nozzle delivering 1.73 gpm at 30 psi. You may find that the nozzle closest to your needs delivers 1.80 gpm. This small difference can be adjusted by decreasing the pressure. NOTE: only minor changes in delivery rate can be made by changing pressure.
4. Make a trial run to check the system. After installing 26 of the selected nozzles, make a trial calibration test flight to be sure you are spraying at the correct rate. Fill the tanks with water to a known level on a level apron or strip. Fly the aircraft at the selected 45 mph air speed and at the selected pressure for a timed period (60 seconds in this example). Measure the amount of water needed to refill the tank to the original mark. Divide the number of gallons used by the number of acres (4.5 in this example) treated (in 60 seconds) to determine the gallons you are spraying per acre.
5. Determine the amount of herbicide to add to the tank. Herbicide per tank = acres per tank x herbicide recommended per acre. Acres per tank = gallons per tank/gallons per acre.
   In our example, 120 gallons per tank/10 gallons per acre = 12 acres per tank;
   12 acres per tank x 1 gal herbicide per acre = 12 gals herbicide per tank + 108 gals carrier for a total of 120 gallons of spray solution per tank.

Ground Boomjet Sprayer Calibration—Distance and Nozzle Method

Method #2

1. Determine swath width by adjusting pressure and boom height to the desired settings and spraying a swath on the ground or other smooth surface. Measure swath width on the ground (ft).

TABLE 3.8. DETERMINATION OF GROUND SPEED: FEET PER MINUTE CONVERTED TO MILES PER HOUR.

Feet/min	MPH	Formula
88	1.0	a) MPH = Feet traveled in 1 min/88
132	1.5	or
176	2.0	b) MPH = [Distance (ft) × 60]/[Time (sec) × 88]
220	2.5	
264	3.0	
308	3.5	Procedures for Determining Ground Speed
352	4.0	
396	4.5	1. Mark off course length (ft) in the same type terrain or site conditions that application will be made in.
440	5.0	
484	5.5	
528	6.0	2. Measure the time (sec) it takes to drive or walk the course. Use the same gear and throttle settings as will be used when applying the herbicide. Also make sure that as you begin the course, that you are already at application speed (i.e., "running start").
572	6.5	
616	7.0	
660	7.5	
704	8.0	
748	8.5	
792	9.0	3. Use formulae above to determine mph.
836	9.5	or
880	10.0	Quick & Easy Method #2: mark a course that is exactly 88 feet in length (1/60 mile) and divide 60 by the time it takes to drive or walk the course to obtain MPM.
924	10.5	60/time (sec) to drive 88 ft = MPH

2. Using Table 3.9 find the swath width which is closest to your swath width and the corresponding calibration distance.
3. Mark off a course in the same terrain as you will be spraying the length of the calibration distance and operate the equipment you will be using (at the same gear and throttle settings) over the course. Note the time in seconds it takes to drive the course. This should be repeated in order to assure accuracy.
4. Catch and measure the spray material from the nozzle(s) while operating the sprayer "in-place" for the same amount of time (sec) as it took to drive the course length (see step #3 above).
5. The number of pints collected is equivalent to the spray rate in gallons per acre.

TABLE 3.9. DETERMINATION OF CALIBRATION DISTANCE WHEN SWATH WIDTH IS KNOWN.

swath width (ft)	calibration distance (ft)
36	151
38	143
40	136
42	130
44	124
46	118
48	113
50	109
52	105
54	101

To determine calibration distances other than those shown here, use the following formula: calibration distance (ft) = 5445/swath width (ft).

Aerial or Ground Broadcast Sprayer Calibration—Tank Refill Method

Method #3—(Kelpsas and Wagner 1984)

This method and method number 4 are useful for checking the output of spray systems in which the nozzle type and number, swath width, etc. has been predetermined. Output is modified by adjusting application speed and for very small changes, pressure.

1. Determine nozzle type and number, pump pressure, application speed and swath width.
2. Fill sprayer tank with water and operate in place to fill up lines.
3. Refill tank.
4. Spray a measured area (ft^2) at the same pressure and speed as will be used during actual application. Use at least 10 percent of the tank volume.
5. Measure the amount of water needed to refill the tank.
6. Application rate is determined by: Application Rate (gal/A) = [Amount Sprayed (gal) x 43,560 ft^2/A]/[# of swaths x swath width (ft) x distance traveled per swath (ft)].

Aerial or Ground Broadcast Sprayer Calibration—Tank Refill Method

"Quick and Easy" Method #4—(Kelpsas and Wagner 1984)

This method differs from method number 3 in that the sprayer is operated in place for a length of time. The application rate is determined by measuring the amount of water necessary to refill the tank and by using the anticipated sprayer speed in the following equation:

Application Rate (gal/A) = [Amount Sprayed (gal) x 43,560 ft^2A]/[swath width (ft) x Time elapsed during spraying (min) x Anticipated speed (MPH) x 88 ft/min*].

(*derived from 1 mph = 88 ft/min)

Aerial or Ground Broadcast Sprayer Calibration—Nozzle Method

Method #5

This method of calibration is not as accurate as other methods and may need "fine-tuning" when the sprayer is actually in the field, but it can be useful for calibrating indoors when inclement weather persists or if off-site calibration is necessary.

1. Catch water from a single nozzle for one minute while operating spray equipment at the same pressure as is to be used in the field. Record this value in gallons.
2. Multiply the amount collected (gals) by the total number of nozzles on the boom to determine the amount of material sprayed by the boom in one minute. Multiply this value by 495.
3. Multiply the forward speed of the sprayer (that will be used in the field in mph) by the swath width (ft).
4. Divide #2 (above) by #3 (above). This is the gallons of spray material the sprayer is delivering per acre.

These four steps are summarized in the following formula:

Gals/A = [(Amount (gal) collected in 1 min) x (# of nozzles) x 495]/[speed (mph) x swath width (ft)].

Calibration of Dry Systems

Generally, granule and pellet applicators are calibrated in a manner similar to liquid systems. The amount of material dispersed by the applicator is dependent on the size of the metering device opening, application speed, "shaking" of the equipment due to field roughness or air turbulence, and the flow rate of the material. The flow rate of the material, in turn is dependent on the pellet or granule size, temperature, and relative humidity. Nonetheless, these systems can be easily calibrated by following a few basic steps. The basic steps in calibrating dry application systems are:

1) determination of swath width and distribution pattern (see procedure described for calibration of liquid systems);
2) determination of application speed (MPH) (see procedure described for calibration of liquid systems);
3) determination of the flow rate necessary for the desired rate of product per acre; and
4) calibration of metering device.

Flow Rate

The flow rate necessary to apply the desired rate of product per acre can be easily calculated using the formula: Flow Rate (lbs/min) = [lbs product/A x swath width (ft) x speed (MPH)]/500.

Example: What is the flow rate necessary for applying 35 lbs of product per acre in a 90 feet wide swath at 10 MPH?

Flow Rate (lbs/min) = [35 lbs/A x 90 ft x 10 MPH]/500 = 63 lbs/min.

A. For systems that apply herbicides from "two sides", such as the Omni® Spray or Simplex® Airblown Seeder, this flow rate corresponds to: 31.5 lbs/side/min; further 15.75 lbs/side/30 sec. Therefore, with double coverage, a 35 lbs/A rate could be accomplished with a flow rate of 7.88 lbs/side/30 sec (see Figure 3.12 for illustration of double coverage concept).

B. For other systems "without sides", such as the Isolair® Bucket, this flow rate corresponds to: 63 lbs/min; further 31.5 lbs/30 sec. Therefore, with double coverage, a 35 lbs/A rate could be accomplished with a flow rate of 15.75 lbs/30 sec.

Calibration or fine tuning the system can be accomplished by operating the equipment in-place at anticipated application speeds (drive shaft revolutions, etc.) or by actually flying or driving over the area to be treated. In either method, the herbicide or "blank" material is collected for 30 seconds for ground applicators or one minute for aerial applicators in mesh bags which are attached over discharge openings. The material is then weighed and metering gates or devices are then adjusted to deliver the proper amount per side (in our example, 7.88 lbs/side/30 sec). Usually, more material will feed through the metering gates when driving over rough terrain or flying due to "shaking" of the material. Therefore, it is usually easier to adjust the metering gates to deliver 80-90% of the desired amount when calibrating "in-place". Then, when fine-tuning rates after making trial runs, fewer adjustments will have to be made. Also, always remember to prime system before calibrating to fill up discharge tubes.

Broadcast Applications—Handheld

Both liquid and granular herbicides are applied by handheld equipment. Handheld application techniques can be extremely advantageous when treating areas which are too small for efficient aerial or machine-mounted broadcast treatments. They also can be used effectively for treating areas which were missed by other methods, for selective release treatments, to treat buffers near sensitive areas where drift hazard is of major concern and by landowners who have the time and manpower to apply the herbicide themselves.

Application Equipment

Liquid Application Systems

The most common equipment for liquid sprays are lever-operated knapsack sprayers, commonly referred to as "backpack sprayers" (Figure 3.13). Pressure to the system is maintained by operating a hand powered pump using a lever. Tank capacity is normally 2-4 gallons. The user can add a regulator and pressure gauge to the sprayer in order to maintain and monitor pressure and obtain a constant output. For detailed information on the various sprayers available, the reader is referred to the excellent publication by Fisher and Deutsch (1985) in which they evaluate and rate the features, components and operation of 37 backpack sprayers.

Dry Application Systems

Several systems are available for applying granular or pelletized materials. Many of these are commonly referred to as "seeders". Usually, few adaptations are necessary to use seeders or hand-cranked fertilizer distributors for herbicide application. Most of these systems are powered by a hand-crank which turns rotary distributor blades. Swath width and application rate are determined by gate settings, application speed, hand-crank speed, and the size and characteristics of the material being applied. Distribution is frequently "heavy" on the outside edges of a swath when using these spreaders.

Calibration

Liquid Systems

The method for calibrating a multi-nozzle handheld boom spray system is identical to the technique described by Minogue (1984) in Appendix V (Problem #1). The method described below may be used for calibrating single nozzle, as well as multi-nozzle boom systems.

Backpack Sprayer Calibration—Distance Method

1. Fill the tank with water and spray a swath on the ground. Do this at the same pressure and at the same boom height that will be used when applying the herbicide. The system should be equipped with a pressure regulator. Measure the swath width (feet).
2. Reference Table 3.10 to determine the appropriate distance for calibration based on the swath width.
3. Determine the time required to walk the calibration distance at the same pace as will be used when applying the herbicide.
4. Operate the sprayer in place and measure the amount of material collected (in ounces) for the time established in #3. The number of ounces collected will equal the gallons per acre the sprayer is applying.

Table 3.10. Calibration Distances for Various Swath Widths When Calibrating Regulator-Equipped Backpack Sprayers.

swath width (ft)	calibration distance (ft)
6.0	57.0
5.0	68.0
4.0	85.0
3.0	113.0

Backpack Sprayer Calibration—Area Method (Portman 1984)

1. Mark off and spray an area measuring 16 1/2 square feet. Record the amount of time required for spraying.
2. Catch and measure (in pints) the amount of spray solution dispersed by the system for the same period of time (#1).

Figure 3.13. Backpack sprayer.

3. Gallons per acre = No. pints x 20.

The key to proper calibration and application is maintaining a constant pressure, walking speed and boom height.

Dry Application Systems

Calibration of granular or pelletized systems is more system dependent. Normally, the manufacturer will include information on how to adjust and properly calibrate the specific system. General guidelines for calibrating these systems are listed below.

1. While maintaining a constant crank speed (e.g. 1 revolution per second), determine the effective swath width (i.e. measure on the ground).
2. Determine the ground speed you will be using for application (reference Table 3.8).
3. Collect and measure the amount of material dispersed by the system for a length of time (1 minute minimum).
4. Application rate (lbs/A) = [lbs material collected x 43560 ft²/A]/[swath width (ft) x Time elapsed (min) x application speed (MPH) x 88 ft/min].

The application rate is most easily varied with these systems by changing application speed, adjusting dispersal gates, and or hand-crank speed (Note: changing hand-crank speed will also change swath width).

Banded Applications

Research has demonstrated that banded treatments for herbaceous weed control can be as effective as broadcast treatments for weed control and crop tree growth response (Nelson et al. 1983). Band treatments are normally applied over-the-top of the crop species in widths up to six feet. Band widths are dictated by the crop species, herbicide, weed species and site conditions. A band that is too wide will unnecessarily increase the cost per acre, while a band that is too narrow may allow encroachment of the weed species.

A considerable amount of equipment is available for banding applications. Farm tractors, skidders and backpack sprayers may all be equipped with booms and nozzles for banded applications. Normally, even flat fan nozzles are used for applying herbicides in bands.

The application of herbicides in bands in combination with planting can greatly reduce application costs. Several different systems have been developed for this purpose (Miller et al. 1985, Garner and Olinger 1982, Gilbert 1972, and White 1962). The system developed by Miller et al. (1985) attaches to a wildland planting machine and has had few operational problems (Figure 3.14). The system performed reasonably well in initial trials that involved the planting and treatment of 108 acres.

Calibration

Method *1. Tank Refill Method

1. Fill the sprayer tank to a known level with water.
2. Operate the sprayer over a predetermined course (200-400 feet) at the same speed and pressure that will be used for application.
3. Refill the tank to the known mark and measure the amount of water used.

Gallons per Acre = [(43560 ft²/A)(gals sprayed)/(Distance traveled (ft) x Band Width (ft) x No. Bands)].

Example: 3/4 gals of water sprayed on a 275 foot strip using a 2 nozzle boom to spray 6 feet wide bands. The gallons of water sprayed per acre would equal: [(43560) x (.75)/(275 x 6 x 2)] = 10.

A key point in banding operations is distinguishing between field acres and row or band acres. A field acre includes the areas between the bands. A band acre refers only to the area in the bands. Herbicide application rates are specified on a treated acre basis. Therefore, band applications only use a fraction of the amount of herbicide that is recommended for broadcast applications (field acres). However, the concentration of the spray would be mixed exactly the same as if a broadcast application were used. For example: rate recommended for a broadcast (field acre) application is 20 gallons per acre; row width is 10 feet and band width is 6 feet. The band application rate is the

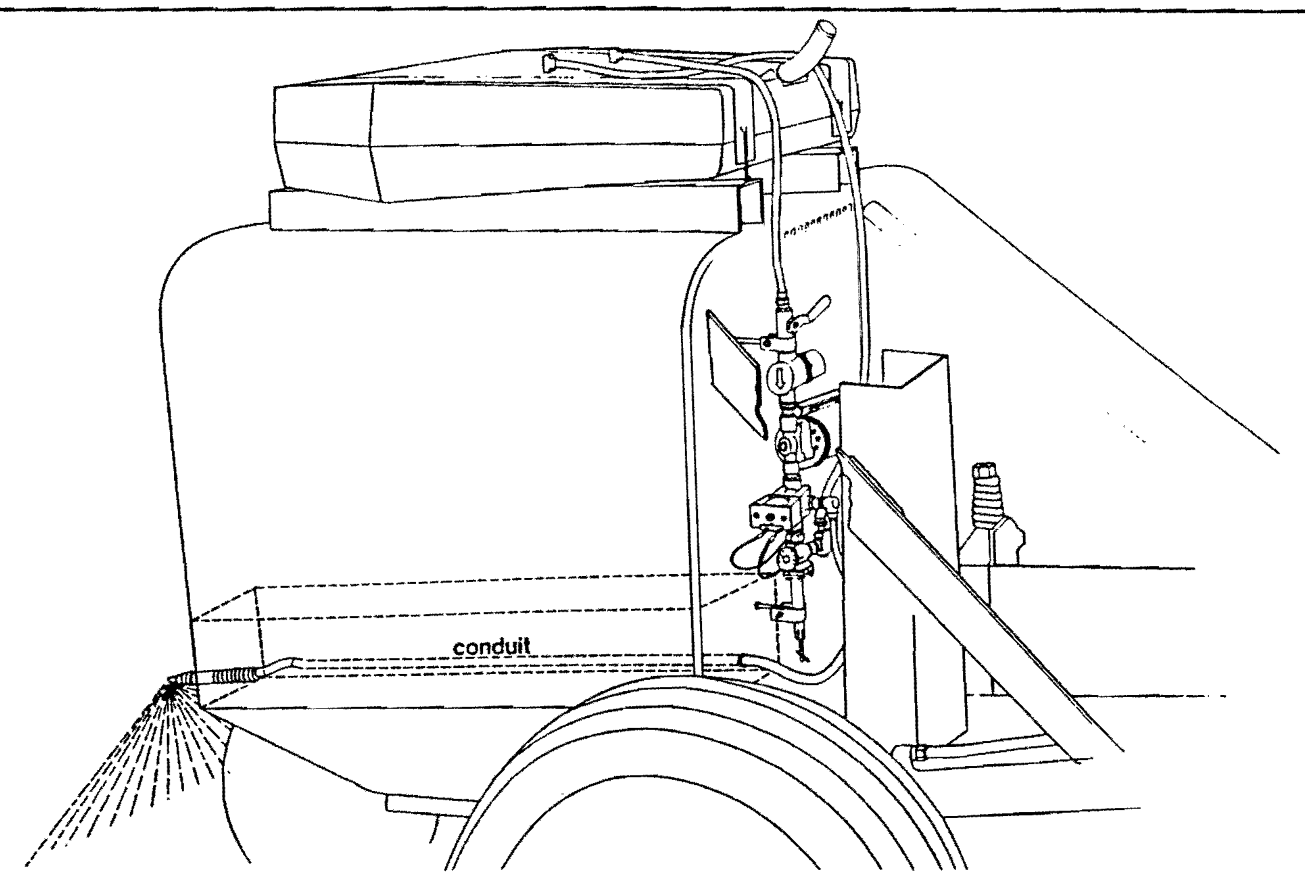

Figure 3.14. Tree planter with spraying system for applying herbicides in bands at the time of planting (from Miller, et al. 1985; used with permission).

ratio of the band width to the row width.

Band width (ft)/row width (ft) = 6 ft/10 ft = 0.6;

0.6 x 20 gal/A broadcast = 12 gals/field acre (when applied in bands).

The acres in the band will receive a treatment at the 20 gallon per acre rate, but the application rate for the entire field is only 12 gallons per acre.

Non-Broadcast Treatments

Often herbicides can be applied in spots, around individual stems, in a grid pattern, or to individual stems for effective weed control. These "spot" treatments are as efficacious as broadcast treatments and can offer substantial savings in herbicide costs. The major disadvantage of spot treatments is that they are usually very labor intensive.

Injection

Injection treatments consist of injecting herbicides through the bark of cull trees into the vascular system at various spacings and rates. Two types of injection devices are commonly used and are equally effective. Long tubular models such as the Cranco®, Jim-Gem®, or Reuel® Little Tree Injector are used to inject herbicides into the base of the tree near the root collar. The ax-like Hypo-Hatchet® (Figure 3.15) is used for injections placed at any convenient height on the stem (usually near waist high). These tubular devices are calibrated by filling their reservoirs with water and operating the release mechanisms so that the water can be collected and measured (do this several times to ensure accuracy). Depending on the device, adjustments can then be made by turning an adjustment screw. An application rate of 1 ml per incision is specified on the labeling of most herbicides used for injection. At a minimum, these devices should be recalibrated at the beginning of each work day and preferably once or twice during the day. For effective and efficient operations, the cutting edge of these tools should be kept sharp

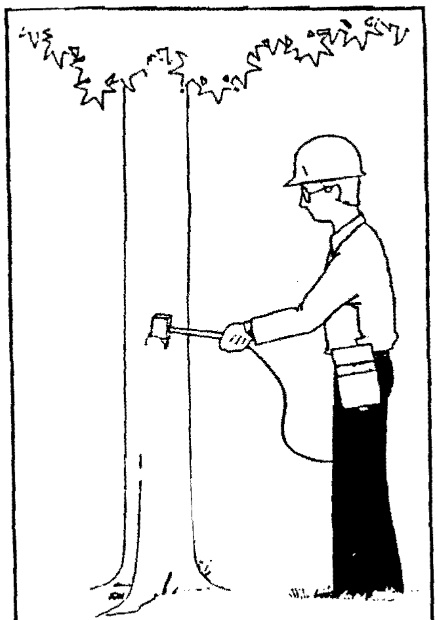

FIGURE 3.15. HYPO-HATCHET

and all working parts lubricated. This type of equipment is exposed to more abrasive conditions than other application equipment and will need more care and maintenance.

Frill Girdle or Hack 'n' Squirt

Frill girdle treatments involve cutting through the bark of a tree into the sapwood with an ax, hatchet, or similar device. Herbicides are applied to these cuts by any convenient method, such as squirt bottles or utility spray bottles. These systems can be "calibrated" to an extent by spraying or squirting water from them into a container and measuring the amount dispersed. An average "per pull" or "per 10 seconds" can then be determined. Although only estimates (at best), these values will aid in applying the herbicides so that excess (costly) or insufficient (poor results) amounts will not be used. Most spray bottles tested to-date disperse approximately 1 milliliter per pull, which is the rate recommended for most injection treatments.

Cut Stump

Cut stump treatments are normally applied undiluted to the outside rim of freshly cut stumps to prevent sprouting. They are most commonly applied using utility-type spray bottles and, as such, are not calibrated. These treatments may also be applied using backpack sprayers equipped with straight stream or cone nozzles. Again, with these applications, sprayers are not normally calibrated.

A method for applying herbicides to stumps with the operation of a feller-buncher was recently developed and has been used with good results (Vidrine 1984). The system utilizes a 60° full cone spray pattern and was consistent in thoroughly wetting the sheared stump. No problems have been encountered with this system during initial trials. Spraying the stumps after shearing requires an additional harvest time of approximately 5 seconds per tree (Vidrine 1984).

Basal Sprays

Spray-To-Wet

These treatments use oil-soluble herbicides applied as diluted sprays using an oil carrier or penetrant to individual stems or clumps of stems using backpack sprayers. The lower 18 inches of the target vegetation is sprayed to the point of runoff. Besides minor adjustments in the equipment to produce an acceptable spray volume, there are no calibration techniques employed for these applications. Even flat fan nozzle tips are commonly used for these treatments.

Thinline

A herbicide handgun applicator attached to a backpack sprayer system is used to apply thinline treatments (Figure 3.16). A 0001 nozzle tip will usually disperse enough herbicide for these treatments. Besides minor adjustments in the equipment to produce an acceptable spray volume, there are no calibration techniques employed for these applications.

Directed Sprays

Woody and herbaceous competing vegetation may be selectively controlled using backpack sprayers. The spray is directed to the foliage of the weed species using spray wands equipped with flat fan or cone nozzles.

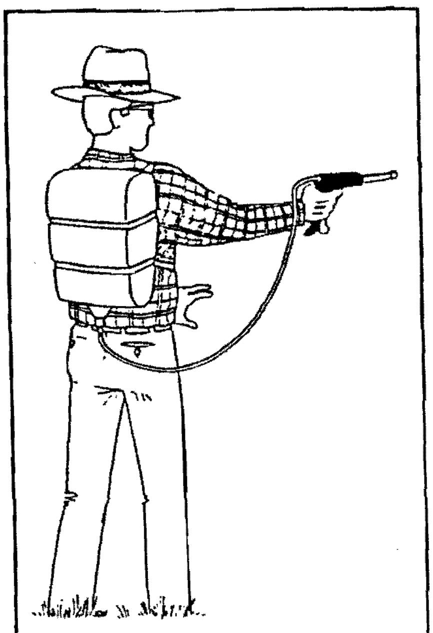

FIGURE 3.16. THINLINE BASAL BARK APPLICATION EQUIPMENT.

Herbicides are usually mixed with water and applied using a backpack type sprayer. Rates are normally specified on a percent solution basis. The foliage of target vegetation is sprayed up to the point of runoff (dependent on the herbicide and weed species). Besides minor adjustments to produce acceptable spray patterns and volume, equipment is not calibrated.

Soil-Applied Liquids and Solids

Individual Stem and Grid Treatments

Liquids, pellets and granule herbicides may be applied to individual stems or to an entire area using a grid pattern (Figures 2.1 and 3.1). These treatments may be applied by hand (i.e. placing pellets near individual stems) or by using a spotgun forestry applicator (for liquids). The spotgun may be attached directly to a container of herbicide (such as Velpar® L) or attached to a backpack sprayer. Hand treatments with pellets or granules are "calibrated" by varying the number of pellets per tree based on dbh and weed species. Calibration of the spotgun depends on the type of handgun being used. Some models have a built-in device for precisely metering spray volume (e.g. Spotgun® and Herbicator®). Adjustments in the rate (1-20 ml in 1 ml increments) are made by turning an adjustment screw. Calibration of handguns without this feature (Gunjet® and Herbicide Spot Applicator®) is described below (Williamson 1985). Spray tips commonly used with these applicators include the 0001, 0002 and 0003 (Figure 3.5). Sprayers used with these applicators must be capable of maintaining pressures between 20 and 40 psi.

Spotgun Calibration

1. Install desired spray tip and fill sprayer with water (1/3 full).
2. Pump the system to application pressure and maintain. If sprayer does not have a regulator, try to keep the pressure at the same level by noting the resistance to the lever when system is "pumped up".
3. Operate the spotgun while directing the spray into a container. Measure (in ml) the amount of water dispersed after pulling the handle 10 times. Depending on the spray tip (see below) vary the timing of your pull and release until the desired amount is achieved.

   Spray Systems Tips

   TP-0001—10 pulls—10 ml = 1 ml/spot
   TP-0002—10 pulls—20 ml = 2 ml/spot
   TP-0003—10 pulls—30 ml = 3 ml/spot
4. As with other equipment, calibration should be done at the beginning of each work day and preferably once or twice during the day.

Tree-Centered Spot Treatments for Herbaceous Weed Control

Herbaceous weed control in young pine plantations can be accomplished using spot-around treatments. Backpack sprayers with cone or flat fan nozzles are commonly used. A spotgun equipped with a forestry nozzle assembly may also be used. This nozzle assembly is frequently used on the Spotgun®, Gunjet® and Herbicide Spot Applicator® (Figure 3.17). The spotgun is calibrated in the same manner as described in the previous section. The backpack sprayer is calibrated by collecting and measuring the amount of solution dispensed for a measured length of time. For example, assume a 20 ml spot is desired and 30 ml were dispensed while spraying for 10 seconds. Either the pressure or the length of time for spraying would then be adjusted to produce a 20 ml spot. These treatments are normally applied over-the-top of seedlings in tree-centered spots from 2-4 feet in diameter (1-2 feet from base of seedling on all sides). The spot size required is dependent on the crop tree size and the type and density of competing vegetation present. Spot size can be varied by changing nozzles and or the height at which the nozzle is held when applying (lower-smaller spot; higher-larger spot).

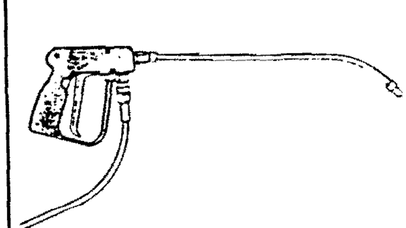

FIGURE 3.17. SPOTGUN EQUIPPED WITH A FORESTRY NOZZLE ASSEMBLY.

Spot-Around Treatments for Woody Vegetation Control

Woody vegetation control in first-year pine plantations can be accomplished using Velpar® L in spot-around treatments similar to the grid-pattern approach. Up to six 1-3 ml spots (diluted or undiluted—see Appendix U) are applied around desirable seedlings using any of the spotgun applicators previously described. In this instance, however, it is imperative to place the spots at least 36" from the desirable seedlings and never directly up slope. Calibration of the equipment is accomplished in the same manner as previously described.

Environmental Conditions and Limitations

Aerial Applications

The use of aircraft for applying herbicides to control competing vegetation in forests represents an important mode of operation in the manangement of forest natural resources. Both fixed-wing (airplane) and rotary-wing (helicopter) aircraft are utilized in the application of herbicides, but the majority of aerial application is done by helicopters. Helicopters offer several advantages over fixed-wing aircraft in forest situations. They are particularly useful for spraying in rough terrain and small irregular areas that are common to forestry applications. Also, heliports can normally be located on-site, reducing long ferrying distances and eliminating the need for airports. Finally, helicopters, due to their slower application speeds and lower operating heights, can more precisely deposit the herbicide on the target area, thereby reducing drift. Fixed-wing aircraft are more useful on larger areas with gently sloping to level topography that are in close proximity to airports.

In aerial applications liquid herbicides are typically applied through high volume spray nozzles on a header boom which, in the case of a fixed-wing aircraft, is mounted along the trailing edge of the wing. The aircraft is flown repeatedly over the target area until the entire area is treated. Safe, effective aerial application requires:

- Close cooperation between the applicator, spray coordinator, and all individuals involved in the spray program when planning a job.
- Careful consideration of the effects on the environment.
- Consideration for the safety of people, animals, and risk to non-target organisms.
- Correctly used and well-maintained equipment that is precisely calibrated.
- Accurate and uniform application.
- A competent, conscientious pilot.
- Strict adherence to the planned procedure.

Recently, aerial application of pellets or granules has increased in popularity due to concerns for adverse public reactions and drift. Pellets or granules applied properly have the following advantages over liquid applications:

- less drift and off-site movement (assuming that very little "fine" or dust is in the material);
- little or no problems with volatility;
- wider window of application (weather restrictions less severe, therefore more days and longer times during the day for application); and
- less restrictive weather conditions;

Disadvantages of dry application systems include:

- need for rainfall to activate herbicides or effectiveness is lost; and
- fewer herbicides available for use, therefore the spectrum of weeds controlled is less than with liquid formulations.
- application only in the spring.

Aerial applications of aqueous solutions of herbicides are not without disadvantages. Limitations include:

- narrow window of application (number of days in spray season and the length of time available per day);
- need for appropriate weather conditions;
- difficulty in treating areas with obstructions;
- difficulty in treating small or irregularly shaped areas;
- long ferrying distances (fixed-wing); and
- problems with crew morale due to the short spray season. Spraying operations are nor-

mally possible for only a few hours in the early morning and before sunset. It is not uncommon for spray crews to spend 16 hours or more per day in preparing for treatment, applying the herbicide, and waiting for appropriate weather conditions. A solution to long work days and accompanying morale problems may be to allow the spray crews to return home and rest during times of the day when spraying cannot be accomplished. Another solution may be to use 2 spray crews. One crew could be responsible for morning spray operations, while the second crew would handle all evening jobs.

Herbicide applicators are primarily concerned with the weather in the immediate area of application and less than 1,000 feet from the ground. The weather in this small area has a major effect on the herbicide application, including the chance for drift problems. Wind is an extremely important factor affecting drift. Stop the application at once if wind speed increases excessively during application. Some general guidelines for appropriate weather conditions for aerial applications include:

1. Wind speed of 5 mph or less.
2. Air temperature and relative humidity is appropriate for the herbicide being used. Temperatures higher than 90°F during times of low humidity, when plant transpiration exceeds water absorption, may reduce herbicide movement and will rapidly evaporate water carriers. Also, temperatures above 90°F increase volatization and the chance for damage to desirable crops. Some herbicide labels may restrict applications to temperatures below 90°F. Always consult the label before applying.
3. Adequate daylight for safe flying.
4. No fog.
5. Little probability of rain within 2 hours (6 hours for Roundup®).
6. Reasonably dry vegetation; normal dew or wetness from an overnight rain is acceptable, provided the addition of the spray does not overload the leaf surfaces to the point of runoff.
7. No inversion layers or lapses present. An **inversion layer** exists in still air that is coolest at ground level, gradually warms to a certain height then is cooler from that point on up. Herbicide particles released into the cool air layer at ground level during an inversion have a minimum upward movement. The slightest air movement can cause this mass of particles to drift for great distances before they fall. A lapse exists when the air is warmest at ground level and gradually cooler at higher elevations. During a strong lapse, the warm air near the ground rises, carrying very small herbicide particles with it. An applicator should at least be aware of these two conditions because they can be severe enough to cause serious drift problems. A simple way to check for and monitor these two factors is to create a smoke column at the site and observe the smoke. During an inversion, the smoke would rise to a certain level then "mushroom" out. Applications can be made below the level the smoke flattens out, but should never be made from a higher altitude. (Note: rubber tires are easily ignited and produce large quantities of smoke while burning).
8. If pelleted materials are used, wind speeds up to 12 mph are acceptable and restrictions 2, 5, 6 and 7 are not of major concern.

Production Rates

Production rates will vary tremendously depending on the terrain, objective, block size, distances between blocks, applicator, spray crew, residual species density, weather and spray equipment. Table 3.11 contains approximate production rates for various application techniques.

TABLE 3.11. PRODUCTION RATES FOR VARIOUS APPLICATION TECHNIQUES.[1]

Application Technique	Estimated Number of Acres Treated
Aerial	
—Helicopter	
—Liquid Spray	50-100 acres/hour
—Dry Formulations	100-200 acres/hour
Ground-Machine Mounted	
—Liquid Spray	20-40 + acres/hour
—Dry Formulations	20-40 acres/hour
Ground-Handheld	
—Backpack Release	3 + acres/man/day
—Backpack Site Prep	5 + acres/man/day
—Dry Formulations	
—machine (seeders)	13 + acres/man/day
—hand	10 acres/man/day
—Spotgun (site prep/release)	10-15 acres/man/day

[1]Estimates; production rates will vary tremendously depending on the terrain, objective, applicator, crew, support vehicles, weed densities, weather and spray equipment.

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