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Nozzles: Selection and Sizing

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This fact sheet covers nozzle description, recommended use for common nozzle types, and orifice sizing for agricultural and turf sprayers. Proper selection of a nozzle type and size is essential for correct and accurate pesticide application. The nozzle is a major factor in determining the amount of spray applied to an area, uniformity of application, coverage obtained on the target surface, and amount of potential drift.

In spraying systems, nozzles break the liquid into droplets and form the spray pattern. Nozzles determine the application volume at a given operating pressure, travel speed, and spacing. Selecting nozzles that produce the largest droplet size, while providing adequate coverage at the intended application rate and pressure, can minimize drift.

The size of the spray particle is important because it affects both efficacy and spray drift of the application of an herbicide, insecticide, or fungicide. If the size of the spray particle (for example, 250–500 microns) is doubled and the application volume stays the same, you have only one-eighth as many spray droplets (Figure 1). For example, to gain optimum efficacy in weed control, a 10–20 gallons per acre (GPA) spray volume is typically recommended, with a "medium" droplet size suggested for contact nontranslocating herbicides, and a "coarse" droplet size suggested for contact translocating herbicides. Concern for drift may cause you to consider using larger droplet sizes and higher spray volumes.

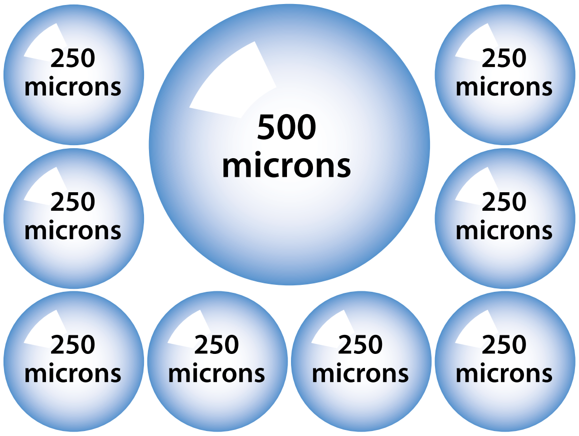

Figure 1. Cutting droplet diameter size in half results in eight times the number of droplets.

Nozzle Description

Nozzle types commonly used in low-pressure agricultural sprayers include: fan, hollow-cone, full-cone, and others. Special features such as air induction (AI) and drift reducing (DG) are available for some nozzles.

Fan Nozzles

The most common type of nozzle used in agriculture is the fan nozzle. A fan nozzle is widely used for spraying pesticides—both banding (over and between rows) and broadcast applications. These nozzles produce a tapered-edge, flat-fan spray pattern (Figure 2). On boom sprayers for broadcast applications, nozzles are positioned so that their output overlaps.

Fan nozzles fall into several categories, such as:

- standard flat-fan;
- even (E) flat-fan;
- low-pressure flat-fan; and
- extended-range (XR) flat-fan;
  and some special types such as
- off-center (OC) flat-fan; and
- twin-orifice (TJ) flat-fan.

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Designs to reduce drift include turbo, flood, “raindrop,” and air-induction nozzles. Some fan nozzles combine several of these design elements. Fan nozzles that produce very large droplets at all pressure ranges include TeeJet’s Turbo TeeJet Induction, Turbo FloodJet, and TurfJet.

The **standard flat-fan** nozzle normally operates between 30 pounds per square inch (psi) and 60 psi, with an ideal range of 30–40 psi. The **even flat-fan nozzles** apply uniform coverage across the entire width of the nozzle’s spray pattern. They are used for banding and should not be used for broadcast applications. The bandwidth can be controlled with the nozzle-release height and the spray angle.

The **extended-range flat-fan nozzle** provides fair drift control when operated at less than 30 psi. This nozzle is ideal for an applicator who likes the uniform distribution of a flat-fan nozzle and wants lower operating pressures for drift control. Because extended-range nozzles have an excellent spray distribution over a wide range of pressures (15–60 psi), they can be used on sprayers equipped with flow controllers.

The special-feature fan nozzles, such as the **off-center fan**, are used for boom-end nozzles so the swath is uniform end-to-end vs. tapered at the edges. The **twin-orifice fan** produces two spray patterns: one angled 30 degrees forward and the other directed 30 degrees backward (Figure 2). The droplets are small due to the atomizing by two smaller orifices. The two spray directions and smaller droplets improve coverage and penetration—a plus when applying post-emergence contact herbicides, insecticides, and fungicides. Because of

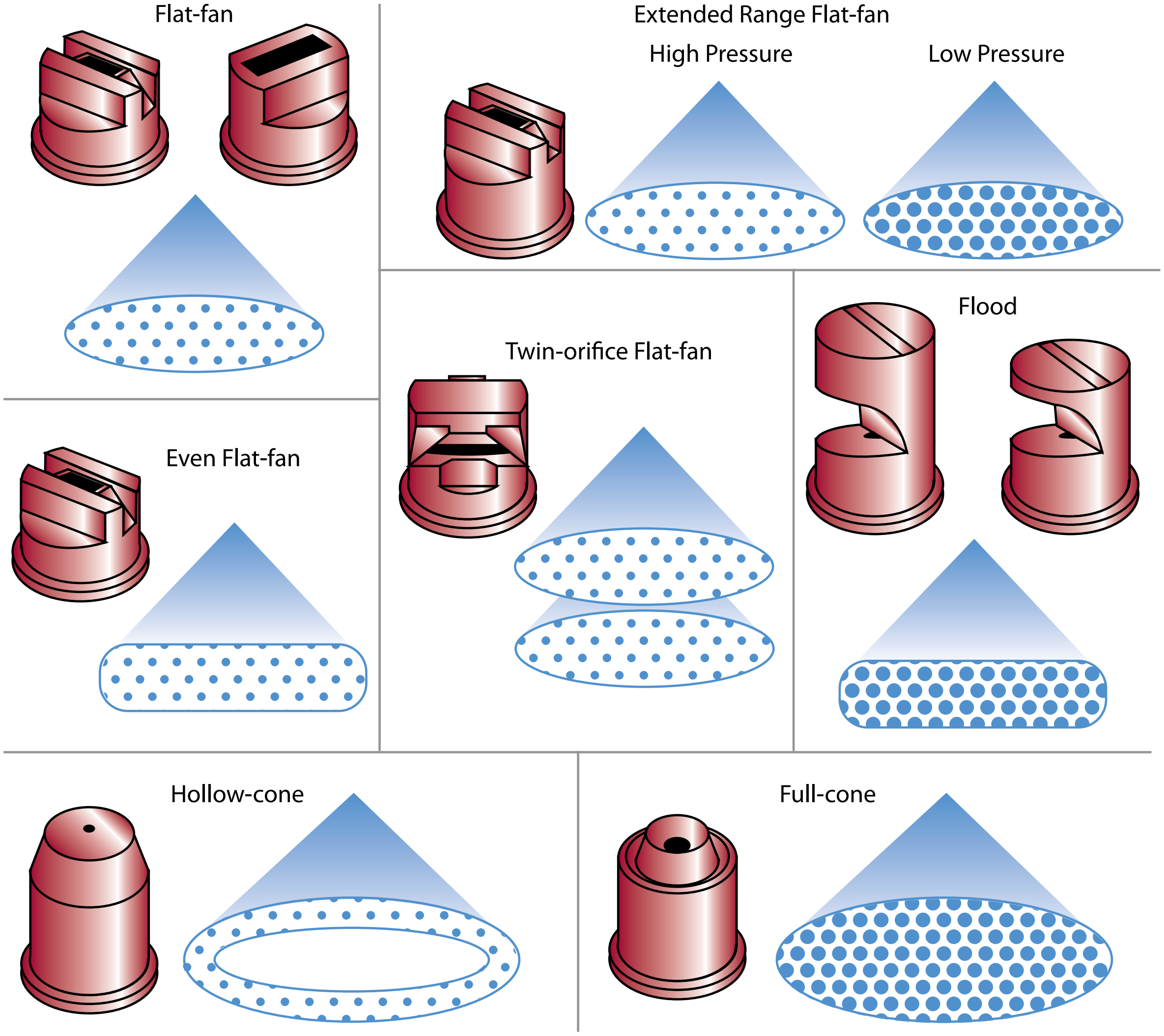


Figure 2. Relative droplet size for nozzles shown in patterns.

the small spray droplets, drift is a concern. To produce "fine" droplets, the twin-orifice usually operates between 30 psi and 60 psi.

Fan nozzles are available in several spray angles. The most common spray angles are 65 degrees, 80 degrees, and 110 degrees. Recommended nozzle heights for flat-fan nozzles during broadcast application are given in Table 1.

Table 1. Suggested minimum spray heights.

Spray Angle (degrees)	Spray Height (inches) 20" Spacing Overlap 50%	20" Spacing Overlap 100%	30" Spacing Overlap 50%	30" Spacing Overlap 100%
65	22–24	NR	NR	NR
80	17–19	26–28	26–28	37–39
110	10–12	15–17	14–18	25–27

NR: Not recommended

The correct nozzle height is measured from the nozzle to the target, which may be the top of the ground, growing canopy, or stubble. Use 110-degree nozzles when booms are less than 30 inches high with 30-inch nozzle spacing; use 80-degree nozzles when the booms are higher.

Although wide-angle nozzles produce smaller droplets, the lower boom height reduces the drift potential more than the corresponding decrease in droplet size. The nozzle spacing and orientation should provide for 100 percent overlap at the target height. Most fan nozzles should not be oriented more than 30 degrees back from vertical.

TeeJet identifies its flat-fan nozzles with a four- or five-digit number designation. The first numbers are the spray angle and the other numbers signify the discharge rate at rated pressure. For example, the "8005 nozzle" has an 80-degree spray angle and will apply 0.5 gallons per minute (GPM) at the rated pressure of 40 psi. The "11002 nozzle" has a 110-degree spray angle and applies 0.2 GPM at the rated pressure of 40 psi. Additional designations are:

BR = brass material
SS = stainless steel
HS = hardened stainless steel
VP = polymer with color coding
VK = ceramic with color coding
VH = hardened stainless steel with color coding
VS = stainless steel with color coding

Some fan nozzles are identified by "LF" or "LF-R," which reflects the standard and extended-range fan nozzles. The first numbers are the spray angle followed by a dash, and then the discharge rate at rated pressure. For example, an LF 80-5R is an extended-range nozzle with an 80-degree spray angle that will apply 0.5 GPM at the rated pressure of 40 psi.

The drift-reducing (DG) fan has a pre-orifice that controls the flow. The spray nozzle is approximately one orifice-size larger than normal, but a round orifice before the outlet controls the flow and, therefore, it produces larger droplets and reduces the number of small, drift-prone droplets.

Other Fan Designs

The turbulence-chamber nozzle is a design that incorporates a pre-orifice concept with an internal-turbulence chamber. These design improvements have resulted in larger, less driftable droplets and improved spray-pattern uniformity. Turbulence-chamber nozzles are available in flat-fan and flood-nozzle designs.

The Turbo TeeJet (TT) and the Turbo TeeJet Induction (TTI) have the widest pressure ranges of the fan nozzles: 15–90 psi for the TT, and 15–100 psi for the TTI. Both nozzles produce large droplets for less drift and are available only in 110-degree spray angles.The Turbo flat-fan nozzle design develops an improved spray pattern compared to the extended-range flat fan and other drift-reducing flat-fan nozzles and is used in the application of postemergence products. Position the nozzle so that the preset spray angle is directed away from the direction of travel. The Turbo flat-fan nozzle is recommended for use with electronic spray controllers, where speed and pressure changes occur regularly.

The air-induction type nozzle produces large drops through the use of a venturi air aspirator for reducing drift. These include:

- Delavan AgSpray's Raindrop Ultra
- Greenleaf Technologies' TurboDrop and AirMix
- Lurmark's Ultra Lo-Drift
- TeeJet's air-induction AI and TTI
- ABJ Agri Products' Air Bubble Jet
- Wilger Industries' Combo-Jet

By incorporating air into the solution, an air-fluid mixture is produced. The air-fluid mixture forms a larger spray droplet because air is entrapped in the spray solution within the nozzle. To accomplish the mixing, an inlet port and venturi are typically used to draw the air into the nozzle under reduced pressure.

Special calibration requirements may be necessary for some venturi nozzles. For example, Greenleaf Technologies—designer of the TurboDrop venturi two-piece nozzle—requires the exit orifice to be two times the size of the venturi orifice. Otherwise, the exit orifice may create a negative pressure-effect in the venturi area, resulting in failure of the nozzle to create the proper spray quality (actually reversing flow from the air inlets). Therefore, you will need to select and calibrate these nozzles based on the venturi orifice, which is color-coded to meet manufacturing specifications. A chart for this purpose is available from the manufacturer.

Flood Nozzles

Flood nozzles are popular for applying suspension fertilizers where clogging is a potential problem. These nozzles produce large droplets at pressures of 10 psi to 25 psi. The nozzles should be spaced closer than 60 inches apart. The nozzle spacing, orientation, and release height should be set for 100 percent overlap.

Nozzle spacing of 30 inches to 40 inches produces the best spray patterns. Pressure influences the spray patterns of flood nozzles more than fan nozzles. However, the spray pattern is not as uniform as with the fan nozzles and special attention to nozzle orientation and correct overlap is critical. Besides fertilizer suspensions, these nozzles are used with soil-incorporated herbicides, preemergence without contact herbicides, and with spray kits mounted on tillage implements.

Flood nozzles are designated “TK” or “TF” by TeeJet and “D” by Delavan AgSpray. The value following the letters is the flow rate divided by 10 at a rated pressure of 10 psi. For example, TK-SS2 and D-2 are flood nozzles that apply 0.2 GPM at 10 psi.

The new Turbo flood nozzles (with preorifice and turbulence chambers) have excellent spray patterns and combine the precision and uniformity of extended-range flat-fan spray nozzles with the plugging resistance and wide-angle pattern of flooding nozzles. The design results in larger droplets and improved distribution uniformity. Turbulence in the chamber portion of the spray nozzle lowers exit pressure, reducing the formation of driftable droplets. Orifice design improves pattern uniformity over older-style flooding nozzles. Turbo flood nozzles are recommended for soil applications, particularly when applying tank-mix combinations of fertilizers and herbicides.

TurfJet Nozzles

The TurfJet is a new nozzle designed for the turf industry. It is modeled after the Turbo flood nozzle, which is used for agricultural field crops. The major difference is that the TurfJet nozzle incorporates a larger orifice to accommodate heavier application volumes, which are common in the turf industry.

Hollow-Cone Nozzles

Hollow-cone nozzles (Figure 2) are generally used to apply insecticides or fungicides to field crops when foliage penetration and complete coverage of leaf surfaces are required. These nozzles operate at pressures ranging from 40 psi to 100 psi. Spray-drift potential is higher from hollow-cone nozzles than from other nozzles due to the small droplets produced.

Full-Cone Nozzles

The wide-angle, full-cone nozzles produce large droplets. Full-cone nozzles, which are recommended for soil-incorporated herbicides, operate at pressures between 15 psi and 40 psi. Optimum uniformity is achieved by angling the nozzles 30 degrees and overlapping the spray coverage by 100 percent.

Nozzle Materials

Nozzles are made from several materials. The most common are brass, nylon, stainless steel, hardened stainless steel, tungsten carbide, thermoplastic, and ceramic. Ceramic and tungsten-carbide nozzles are very longwearing and extremely corrosion-resistant. Stainless-steel nozzles last longer than brass or nylon and generally produce a uniform pattern over an extended time period. Nylon nozzles with stainless steel or hardened stainless-steel inserts offer an alternative to solid stainless-steel nozzles at a reduced cost. Thermoplastic nozzles have good abrasion resistance, but swelling can occur with some chemicals, and they are easily damaged when cleaned. Nozzles made from hard materials cost more initially, but in the end they pay for themselves because of their long-lasting properties.

Nozzle Influence on Droplet Size

Spray-drop size is one of the most important factors affecting drift. Because of the unusually small size of the target, good coverage is essential for those insecticides and fungicides that must come into contact with the pest insect or disease-causing organism. Similarly, in the case of protectant fungicides and nonsystemic stomach poison insecticides, thorough coverage is essential, because untreated surfaces allow infection or crop damage to continue from feeding insects without exposing them to the applied control. "Fine-" to "medium-" size droplets are desirable when applying insecticides and fungicides, because they usually provide better coverage. "Fine" droplets, however, are difficult to deposit on the target, so they may remain airborne and drift long distances because of their small, lightweight size.

Spray-droplet diameters are measured in micrometers. A micrometer is approximately 1/25,000 of an inch and is usually referred to as a "micron." For reference, the thickness of a human hair is approximately 100 microns. Drops smaller than 150 microns in diameter (smaller than the diameter of a sewing thread) usually pose the most serious drift hazard. Drift is far less likely to be a problem when droplets are 200 microns and larger in size. A study indicated that spray particles less than 50 microns in diameter remain suspended in the air indefinitely or until they evaporate. This should be avoided because there is no way to control deposition of very small droplets.

A classification system developed by the British Crop Protection Council (BCPC) and the American Society of Agricultural and Biological Engineers (ASABE) assigns a droplet-size category to a nozzle based on droplet-size spectrum (Table 2). This system allows for comparison of droplet size between various nozzles, operating conditions (pressure), and manufacturers.

Table 2. Droplet-size classification chart.

Droplet Category[1]	Symbol	Color Code	Approximate VMD Range[2] (microns)
Very Fine	VF	Red	< 105
Fine	F	Orange	106–235
Medium	M	Yellow	236–340
Coarse	C	Blue	341–403
Very Coarse	VC	Green	404–502
Extremely Coarse	XC	White	> 503

[1] ASABE (American Society of Agricultural & Biological Engineers) Standard 572.

[2] VMD = Volume median diameter—a value where 50% of the total volume or mass of liquid sprayed is made up of droplets larger than this value, and 50% is made up of droplets smaller than this value. Reported VMD ranges vary widely, based on the type of laser analyzer used.

At a given pressure, a nozzle will produce a range of droplet sizes. However, manufacturers strive to design nozzles with uniform outputs while reducing the number of "fines" a nozzle produces. Nozzles are rated based on the typical droplet-size range they produce. Most—if not all—nozzle manufacturers' catalogs have droplet-class charts, and pesticide labels may include droplet-size category recommendations.

Table 3 provides information on the effect of droplet size on coverage. Table 4 provides information on droplet evaporation and the distance various drop sizes will travel before evaporating. Table 5 shows wind-movement characteristics of various size droplets. Decreasing the droplet size from 200 microns to 20 microns will increase coverage by a 10-fold factor, but Table 4 shows that a 20-micron water drop will travel less than one inch before it completely evaporates in less than one second.

Droplets smaller than 100 microns in size obtain a horizontal trajectory in a very short time and evaporate very rapidly. The pesticides in these droplets become very small aerosols, which will move up into the atmosphere and will not fall out until picked up in falling rain. Droplets larger than 150 microns in size resist evaporation to a much greater degree than smaller

Table 3. Spray droplet size and droplet effects on coverage.

		Application Rate = 1 GPA	
Droplet Diameter (microns)	Type of Droplet	Coverage Droplet (per square inch)	Relative to 1,000 Micron Drop
5 (VF)[1]	Dry fog	9,220,000	200
10 (VF)	Dry fog	1,150,000	100
20 (VF)	Wet fog	144,000	50
50 (VF)	Wet fog	9,222	20
100 (VF)	Fine mist	1,150	10
150 (F)	Fine mist	342	7
200 (F)	Fine drizzle	144	5
300 (M)	Fine rain	61	3
500 (VC)	Light rain	9	2
1,000 (XC)	Heavy rain	1	1

[1] See Table 2 related to droplet-size classification.

droplets due to their larger volume. From these and other research results, we can conclude that there is a rapid decrease in the drift potential of droplets as their diameter increases to about 150 microns.

Table 4. Spray droplets: evaporation and distance traveled.[1]

Droplet Diameter (microns)	Terminal Velocity (feet per second)	Droplet Diameter After Water Evaporates (microns)	Distance Traveled From Nozzle (inches)
20	0.04	7	<1
50	0.25	17	3
100 (VF)[2]	0.91	33	9
150 (F)	1.70	50	16
200 (F)	2.40	67	26

[1] Conditions assumed: temperature = 90°F, relative humidity = 36%, spray pressure = 25 psi, pesticide solution = 3.75%.

[2] See Table 2 related to droplet-size classification.

Table 5. Movement of spray droplets.

Droplet Diameter (microns)	Droplet Size	Time Required to Fall 10 Feet	Lateral Movement in a 3-mph Wind
5	Fog (VF)[1]	66 minutes	3 miles
20	Very fine (VF)	4.2 minutes	1,100 feet
100	Very fine (VF)	10 seconds	22 feet
240	Medium (M)	6 seconds	28 feet
400	Coarse (C)	2 seconds	8.5 feet
1,000	Extremely coarse (XC)	1 second	4.7 feet

[1] See Table 2 related to droplet size classification.

Several factors determine if a spray particle will deposit on the surface of a plant. "Very fine" droplets (especially those smaller than 50 microns) are collected efficiently by insects or by needles on coniferous plants, but tend to remain in the airstream and carried around stems and leaves of weeds. "Medium" droplets applied when there is some air velocity will deposit more efficiently on stems and on narrow, vertical leaves such as grasses, while "coarse" droplets will deposit most efficiently on large, flat surfaces, such as broadleaved plants.

Be sure to review the pesticide label regarding droplet-size requirements because of the reduced coverage associated with large drops. Usually, systemic herbicides work very well with large drops. When applying contact-type fungicides for disease control, a smaller drop may be needed due to the need for better coverage. The same is true for stomach-poison insecticides and insecticides that must come into contact with the pest.

A Range of Sizes

In reality, a range of droplet sizes is needed to effectively deposit pesticides on the variety of plant types, sizes, and shapes encountered. The following describes how different droplet sizes vary in their effectiveness.

To control pests effectively, the actual range of droplet sizes will depend on the specific pesticide being used, the kind and size of the target plant, and weather conditions. Some new nozzles are specifically designed to reduce drift by reducing the amount of small, driftable "fines" in the spray pattern.

Insecticides and fungicides generally require smaller droplets than herbicide applications to obtain adequate target coverage. However, in most cases, applying "medium" droplets (vs. "fine" or "very fine") should provide the coverage needed while reducing the risk of drift.

Experimental results with foliar herbicides suggest that droplet sizes in the range of 150 microns ("fine") to 400 microns ("coarse") do not significantly differ in weed control unless application volumes are extremely high or very low. Exceptions to this guideline may exist for specific herbicides.

Droplet-Size Classification

Droplet-size information is useful for determining the correct nozzle for an application and pesticide (see *Droplet Chart / Selection Guide*, Virginia Cooperative Extension publication 442-031). However, this information is not always readily available to the applicator. Instead, a classification system is used to define nozzle output (Table 2). Nozzle manufacturers use this standardized system to indicate the droplet size of their nozzles for different size and pressure combinations.

Product labels may specify an appropriate droplet classification recommended for the manufacturer's products. For example, an herbicide label recommends using a nozzle producing "medium" size droplets. From a sample nozzle-manufacturer's chart (Table 6), the applicator can select any nozzle and pressure combination with the "M" or yellow classification. This system allows the applicator to use many different combinations of nozzles and pressure settings, achieve the desired droplet size, reduce drift, and provide adequate coverage required for pest control.

Table 6. Droplet size-classification for nozzle size and pressure (example from TeeJet.)**.** PSI

	PSI						
	15	20	25	30	40	50	60
XR8001	F	F	F	F	F	F	F
XR80015	M	F	F	F	F	F	F
XR8002	M	M	F	F	F	F	F
XR8003	M	M	M	F	F	F	F
XR8004	C	M	M	M	M	F	F
XR8005	C	C	M	M	M	M	F
XR8006	C	C	C	M	M	M	M
XR8008	VC	VC	C	C	M	M	M

Spray Volume and Pressure for Foliar Herbicides

Some applicators are reducing the spray volume of foliar herbicides. When you reduce spray volume, the herbicide concentration will increase to maintain the same dose of active ingredient. But as spray volume is reduced, the droplet size may decrease, and if so, this means greater drift potential. Research has also shown that control of some broadleaf weeds with contact herbicides is usually reduced when the spray volume is reduced. However, reduced spray volumes have little effect on weed control with most systemic herbicides, as long as the chemical is applied properly at the recommended rate.

To compensate for the reduced spray volume, some applicators will increase spray pressure from 30–40 psi to 50–60 psi. They believe small droplets will be "driven" into the crop canopy and increase coverage. However, a large number of small droplets will quickly lose their velocity and evaporate before reaching the canopy (as shown in Table 4).

In addition, small droplets have low momentum and insufficient energy to be "driven" into the canopy. Therefore, increasing pressure should not be used as a substitute for spray volume. It is recommended to maintain pressures less than 40 psi, and if you need coverage, increase spray volume.

Boom Sprayer Set-up

Do not mix nozzles of different materials, types, spray angles, or spray volumes on the same spray boom. A mixture of nozzles produces uneven spray distribution. Fan nozzles produce a flat, oval spray pattern with tapered edges (Figure 2). Because the outer edges of the spray patterns of flat-fan nozzles have tapered or reduced volumes, nozzles must be carefully aligned to prevent interference, and at the proper height, so that adjacent patterns along the boom will overlap for uniform coverage. Uniform pattern is achieved when the overlap is 50 percent to 100 percent of the nozzle spacing (Figures 3 and 4). To check spray overlap, spray clean water onto a flat surface (concrete) and observe its drying patterns. Effective application requires avoiding skips and major overlaps in the spray pattern. The fan nozzle is generally the best choice for the broadcast application of pesticides because of its ability to produce a uniform pattern when correctly overlapped.

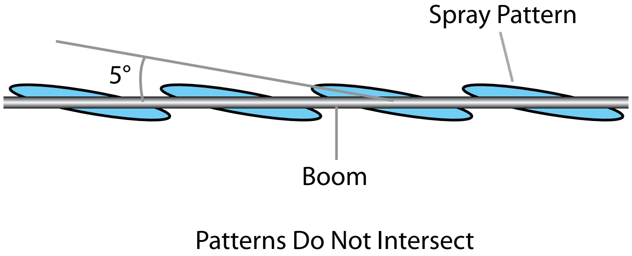


Figure 3. Flat-fan nozzles angled 5 degrees from the boom.

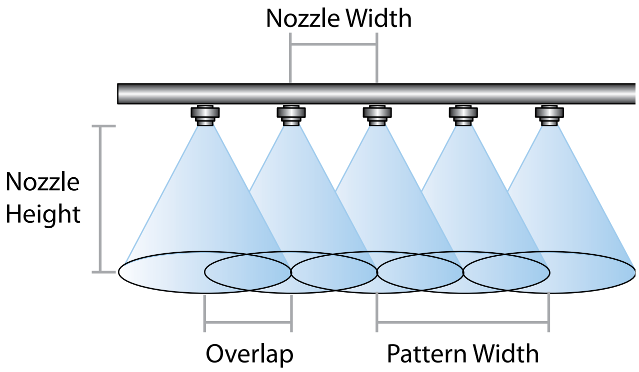


Figure 4. Nozzle overlap of 100 percent.

Worn nozzles increase application rates and change distribution patterns. The result is poor pest control, crop damage, residue problems, and increased costs. A check of the boom sprayer assures that each nozzle is delivering an identical volume of spray in a smooth pattern, with no heavy streams or blank areas. Should a nozzle become clogged, it is best to blow out the dirt with compressed air or use a soft-bristled brush such as a toothbrush. Wear chemical-resistant gloves when handling and cleaning nozzles to reduce pesticide exposure. NEVER use a wire or nail as a cleaner because the orifice can be easily damaged. NEVER put nozzles in the mouth. Remember, improperly functioning or worn nozzles are costly.

Most booms are arranged with 20-inch nozzle spacing. However, 30-inch nozzle spacing may have several advantages. If a boom is configured with nozzles spaced at 20 inches, operators should consider a 30-inch nozzle configuration during a rebuild or retrofit. If an 80-degree nozzle spaced at 20 inches is replaced with a 110-degree nozzle spaced at 30 inches, these advantages maybe seen:

- Boom height remains the same,
- Orifice size is increased by one-third,
- Drift potential is reduced,
- Fewer nozzles to purchase and maintain,
- Potential to increase screen size (less clogging), and
- Nozzle spacing matches 30-inch rows during field spraying.

Nozzle Selection

It is important to select a nozzle that develops the desired spray pattern and spray volume. The nozzle's intended use—whether for broadcast application of herbicides or insecticide spraying on row crops—determines the type of nozzle needed. Examine current and future application requirements and be prepared to have several sets of nozzles for a variety of application needs. In general, do not select a nozzle that requires a nozzle screen less than 50 mesh. Nozzles requiring 80–100 mesh screens clog too easily.

Follow the steps below to determine the correct nozzle type and capacity needed.

Step 1: Consult the label. The most important source of information is the pesticide label. Not only will the label specify the application rates, controllable pests, and conditions needed to apply the pesticide, it often will provide information concerning the GPA, droplet classification, nozzle type, and spacing as well. Follow the instructions outlined on the pesticide label. If nozzle recommendations are not stated on the label, use Table 7 to select a nozzle type best fitted to the application while considering the droplet size.

Step 2: Select operating conditions. Select or measure ground speed in miles per hour (mph). Select the desired nozzle spacing and spray volume. For most broadcast applications, 30-inch spacing is preferred. If the label does not recommend nozzle spacing or spray volume, follow university and chemical-company recommendations. Correct selection of a spray volume is important. It will influence several spray characteristics such as drift potential, coverage, droplet size, acres per tank, and pesticide efficacy.

Step 3: Calculate required nozzle discharge. To select a specific orifice size, the spray volume, nozzle spacing, and travel speed are needed for the following calculation:

Equation 1:

$$\text{Nozzle discharge (GPM)} = \frac{(\text{travel speed} \times \text{nozzle spacing} \times \text{spray volume})}{5940}$$

where: travel speed = miles per hour
nozzle spacing = inches
spray volume = gallons per acre (GPA)

Step 4: Consult a nozzle catalog. Once the nozzle discharge has been determined, consult a nozzle catalog for a specific nozzle number or size. Using the nozzle type selected from the application guide (Table 7), review the specification of these nozzles in the discharge-capacity column. Several consecutive nozzles may meet your needs, but select a nozzle that operates at a low pressure and gives the desired droplet classification that allows a range for "fine-tuning." Remember, most nozzles only perform well over a limited pressure range. Generally, the greater the operating pressure, the smaller the droplets. Smaller droplets increase drift potential. Conversely, larger orifices produce larger droplets.

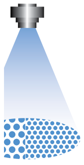
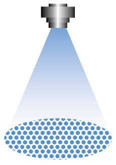
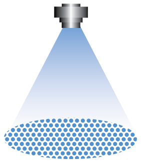
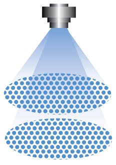
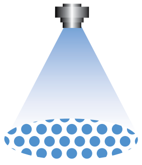
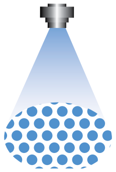
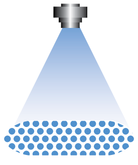
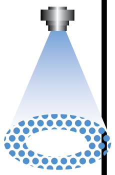
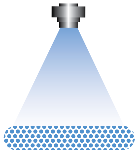
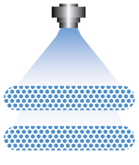
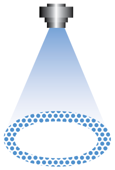
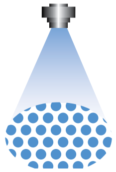
A linear relationship does not exist between nozzle pressure and flow discharge. If the discharge rate is not found in the catalogs, calculate the operating pressure using known catalog conditions:

Equation 2:

$$\text{psi}_1 = \text{psi}_2 \times \left(\frac{\text{GPM}_1}{\text{GPM}_2}\right)^2$$

where: $_1$ = the desired condition
$_2$ = the known catalog specifications

Table 7. Nozzle guide for spraying.

	Broadcast Spraying								Band and Direct Spraying				
													
	Extended Range Flat Fan	**Standard Flat Fan**	**Drift Guard Flat Fan**	**Twin Flat Fan**	**Turbo Flood Wide Angle**	**Full Cone**	**Flood Nozzle Wide Angle**	**Raindrop Hollow Cone**	**Even Flat Fan**	**Twin Even Flat Fan**	**Hollow Cone**	**Full Cone**	**Disc and Core Cone**
Herbicides													
Soil-incorporated	Good		Very Good		Very Good	Very Good	Good	Good					
Pre-emerge	Very Good (on low pressure)	Good	Very Good		Very Good	Very Good		Good	Very Good	Good		Good	
Post-emerge Contact	Good	Good		Very Good					Good	Very Good	Very Good		
Post-emerge Systemic	Very Good (on low pressure)	Good	Very Good		Very Good			Good	Very Good	Good			
Fungicides													
Contact	Very Good	Good							Good		Good		Very Good
Systemic	Very Good (on low pressure)		Very Good		Very Good				Very Good				Good
Insecticides													
Contact	Good	Good		Very Good						Very Good	Very Good		Very Good
Systemic	Very Good (on low pressure)		Very Good		Very Good				Very Good				Good

Avoid high pressures for the nozzle used. Higher pressures increase the drift potential and put strain on the sprayer components. Conversely, avoid pressures less than the recommended minimum pressure, because spray patterns begin to distort and cause poor spray uniformity.

Step 5: Calibrate the sprayer. Once the nozzles are selected, purchased, installed, and flushed, calibrate the spray system. Nozzle catalogs provide tables to show spray volumes for various nozzles, spacing, pressures, and ground speeds. Use these tables initially to set up the sprayer, then use the "ounce" calibration method (below) to evaluate and adjust the sprayer for accurate application.

Table 8. Sprayer Calibration With the "Ounce" Method

Nozzle Spacing or Row Width (inches)	Distance (feet)	Nozzle Spacing or Row Width (inches)	Distance (feet)
48	85	30	136
44	93	28	146
40	102	24	170
36	113	20	204
32	128	16	255

1. Use Table 8 (calibration cards are available at your local Extension office) for distance to drive in the field. Use nozzle spacing for booms. For directed and band rigs, use the row spacing.

2. Set throttle for spraying and operate all equipment. Note seconds required to drive measured distance.

3. Catch spray for the time (noted in Step 2, above) in a container marked in ounces (a calibrated bottle or measuring cup). If using a boom sprayer, catch spray from one nozzle during noted time. On directed rigs, catch spray from all nozzles per row for noted time.

4. Nozzle or nozzle-group output in ounces equals gallons per acre actually applied.

5. Repeat for each nozzle to assure uniform distribution.

Nozzle Selection and Sizing Example

Suppose a postemergence herbicide is to be broadcast at 15 GPA at a speed of 5 mph.

Step 1: Using Table 7 as a guide, the best choice is a Turbo TeeJet. The recommended nozzle spacing is 30 inches.

Step 2: The operating conditions are provided above.

Step 3: Determine the nozzle output in GPM; calculate the required nozzle discharge using Equation 1:

$$\text{Nozzle Discharge (GPM)} = \frac{\text{5 mph X 30 inches X 15 GPA}}{5940} = \text{0.38 GPM}$$

Step 4: Consult a nozzle catalog. The selected nozzle must have a flow discharge of 0.38 GPM when operated within the recommended range for the nozzle. A nozzle-performance table shows the discharge rate at various pressures for several nozzle sizes. Table 9 shows that four nozzles listed in the catalog are possible choices: TT11003, TT11004, TT11005, or TT11006 nozzles may be purchased for this application, but the TT11004 gives the most flexibility with a wide pressure range for fine-tuning.

Table 9. Nozzle data and comparison of pressures and discharge.

	Catalog		Calculated From Eq. 2	
Nozzle	**psi**	**GPM**	**psi**	**GPM**
TT11003	60	0.37	64	0.38
TT11004	30	0.35	36	0.38
TT11005	20	0.35	24	0.38
TT11006	15	0.37	16	0.38

Nozzle Manufacturers[1]

Several principal spray-nozzle manufacturers supply local equipment dealers. Each manufacturer distributes nozzle catalogs that can be obtained from your local dealer or ordered from the following websites (accessed: July 2019):

ABJ Agri Products:
www.abjagri.com/

Albuz:
http://albuz-spray.com/index.php/en

BEX Inc.:
www.bex.com/

Billericay Farm Services Ltd.:
https://www.bfs.uk.com/product/air-bubble-jet/

Transland, LLC (The CP Products Co.):
https://www.translandllc.com/cp-products/

Delavan AgSpray Products:
www.delavanagspray.com/

Greenleaf Technologies:
http://www.greenleaftech.com/

Hypro (PENTAIR):
https://www.pentair.com/en/brands/hypro.html

Hardi North America:
1

Lechler Inc.:
www.lechlerusa.com/

TeeJet Technologies:
www.teejet.com/

Wilger Industries Ltd.:
www.wilger.net/

References (adapted from)

Nozzle-Selection and Sizing. University of Nebraska-Lincoln Extension, Institute of Agricultural and Natural Resources, publication EC141, 2011; http://extensionpublications.unl.edu/assets/pdf/ec141.pdf (accessed: July 2019)

Nozzle Types for Boom Sprayer Applications of Crop Protection Products. Kansas State University, Agricultural Experiment Station and Cooperative Extension Service, publication MF-2541, April 2002; https://www.bookstore.ksre.ksu.edu/pubs/MF2541.pdf (accessed: July 2019)

Resources

Fine Tuning a Sprayer with the "Ounce" Calibration Method. Virginia Cooperative Extension publication 442-453 (BSE-178P), December 2014; https://pubs.ext.vt.edu/442/442-453/442-453.html (accessed: July 2019)

Plumbing System of Agricultural Sprayers. Virginia Cooperative Extension, publication 442-452, October 2014; https://www.pubs.ext.vt.edu/442/442-452/442-452.html (accessed: July 2019)

Sprayer Nozzles Selection and Calibration. University of Kentucky Cooperative Extension Service, PAT-3, March 1996; www.uky.edu/Ag/PAT/pat3/pat3.pdf (accessed: July 2019)

Sprayer Nozzle Selection. University of Georgia Cooperative Extension, bulletin 1158, February 2012; https://secure.caes.uga.edu/extension/publications/files/pdf/B%201158_3.PDF (accessed: July 2019)

Selecting Drift-Reducing Nozzles. North Dakota State University Extension Service, FS-919, July 2008; https://www.ag.ndsu.edu/agmachinery/documents/pdf/selecting-drift-reducing-nozzles (accessed: July 2019)

Strategies to Reduce Spray Drift. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, publication MF-2444, March 2000; https://www.bookstore.ksre.ksu.edu/pubs/MF2444.pdf (accessed: July 2019)

Droplet Chart / Selection Guide. Virginia Cooperative Extension, publication 442-031 (BSE-149P), September 2014; https://www.pubs.ext.vt.edu/442/442-031/442-031.html (accessed: July 2019)

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[1] Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned.

Acknowledgments

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Weight and Measures Conversions

Weight

16 ounces = 1 pound = 453.6 grams
1 gallon water = 8.34 pounds = 3.78 liters

Liquid Measure

1 fluid ounce = 2 tablespoons = 29.57 milliliters
16 fluid ounces = 1 pint = 2 cups
8 pints = 4 quarts = 1 gallon

Length

3 feet = 1 yard = 91.44 centimeters
16.5 feet = 1 rod
5,280 feet = 1 mile = 1.61 kilometers
320 rods = 1 mile

Area

9 square feet = 1 square yard
43,560 square feet = 1 acre = 160 square rods
1 acre = 0.405 hectare
640 acres = 1 square mile

Speed

88 feet per minute = 1 mph
1 mph = 1.61 kilometer per hour

Volume

27 cubic feet = 1 cubic yard
1 cubic foot = 1,728 cubic inches = 7.48 gallons
1 gallon = 231 cubic inches
1 cubic foot = 0.028 cubic meters

Common Abbreviations and Terms

FPM = feet per minute
GPA = gallons per acre
GPH = gallons per hour
GPM = gallons per minute
mph = miles per hour
psi = pounds per square inch
RPM = revolutions per minute