

A User's Guide to Spray Nozzles



TeeJet®



A User's Guide to Spray Nozzles

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How *A User's Guide to Spray Nozzles* is Different

A User's Guide to Spray Nozzles is educational and informative. It provides fact, not opinion.

In this guide, you will only find reference material that will help make you a more knowledgeable buyer and user of spray nozzles. In addition, we hope this material enables you to better evaluate performance claims published by all nozzle manufacturers. Spray nozzles are highly engineered, precision components and consideration should be given to the manufacturer and the manufacturer's capabilities.



Introduction

Your success in any spraying season is dependent on many individual factors. Some of these factors you can control, like the equipment you use, and others you can not, like the weather. The purpose of this guide is to assist you in an area where you have total control: spray nozzle selection and use.

Even though spray nozzles are a physically small component in your overall operation, they are vitally important. Improper application of plant protection products can be extremely costly if re-spraying is required, performance is reduced or legal issues arise as a result of chemical drift. However, many users perceive spray nozzles as fairly simple components, when in fact it is quite the opposite. There are dozens of nozzle types from various manufacturers that offer very different performance.

This guide was developed to help you:

- Learn more about the technical aspects of spray nozzles.
- Select the spray nozzles best suited to your specific application requirements.
- Maintain your spray nozzles for optimal performance.

A poor choice in spray nozzles or the use of under-performing nozzles can lead to re-spraying or reduced performance – two problems no user should face.

The Costly Consequences of Spraying Too Much or Too Little

Making sure you have the proper spray nozzles for your application and that they are performing properly are two things that every user should practice to maximize performance and profitability.

The spray nozzles you select will determine:

- The amount of chemical applied to an area.
- The uniformity of the application.
- The coverage of the chemical on the target surface.
- The amount of potential drift.

Using the wrong spray nozzle or a spray nozzle that isn't performing properly can result in over or under application. Over application can be wasteful and costly; under application can result in a reduction in performance or the need for re-application.

The use of a rate controller can certainly help ensure the proper amount is sprayed. You can also make minor adjustments to sprayer pressure or speed to apply the correct amount of chemical.

Even a spray nozzle that is worn by only 10% may not give you the coverage and performance you expect.

However, the proper application volume doesn't necessarily mean maximum effectiveness. For example, if you're using the wrong nozzle or if the nozzle is worn by as little as 10%, the spray pattern may not be uniform across the boom and you won't get the spray coverage you expect. Coverage may be streaky and some areas may get more or less chemical than intended. You may need to re-apply the product.

No matter the root cause, over and under application both have high price tags – thousands of dollars and in some cases, tens of thousands of dollars. Of course, the actual cost will depend on your operation and the plant protection products you use. See the example to the right.

These problems can be avoided by making sure you've selected the proper spray nozzles for your application and that they are in good working order. If you think there is a nozzle that may better meet your needs or suspect that your nozzles are worn, do not hesitate to replace them. The cost of replacement nozzles is minor compared to the effects of poor spraying. In fact, you'll recoup the cost of the nozzles by applying the proper amount of chemical in just a few acres.

Cost calculator for under or over application:

Under application of chemical causing re-spray* (U.S. dollars):

\$27/acre x 100 acres	\$2,700
\$27/acre x 1000 acres	\$27,000
\$27/acre x 2000 acres	\$54,000

*Does not include time/labor, fuel or machinery expense.

Over application of chemical by 10% (U.S. dollars):

(\$27/acre x 10%) x 100 acres	\$270
(\$27/acre x 10%) x 1000 acres	\$2,700
(\$27/acre x 10%) x 2000 acres	\$5,400

Spray Nozzle Fundamentals →

1. Spray Patterns
2. Spray Pattern Geometry
3. Spray Pressure
4. Droplet Size Basics
5. Defining Spray Drift

1. Spray Patterns

There are many types of nozzles and spray patterns available and your choice will be dependent on your particular operation. The three major types are:

- Flat Fan
- Hollow Cone
- Full Cone

Flat Fan

The flat fan spray nozzle forms a narrow, elliptical, inverted “V” pattern. (FIGURE 1) Deposition is heaviest at the center of the pattern and dissipates toward the outer edge. A uniform distribution pattern across the boom is achieved when the boom height and nozzle spacing are optimized for proper spray pattern overlap of adjacent nozzles. Variations of the flat fan include:

- Extended range flat fan for broadcast spraying. Designed to operate with a wider range of spray pressures. (FIGURE 2)
- Flooding for broadcast spraying. Wide angle flat pattern using larger droplets. (FIGURE 3)
- Even spray for band spraying. Non-tapered spray patterns provide even coverage without overlapping. (FIGURE 4)



FIGURE 1:
Flat fan spray pattern

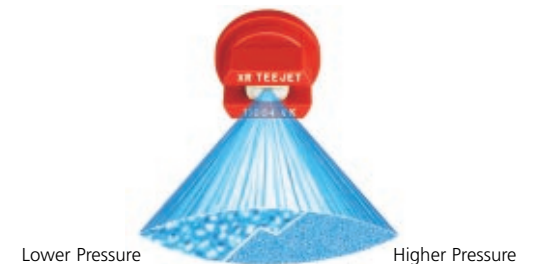


FIGURE 2:
Extended range flat fan
spray pattern

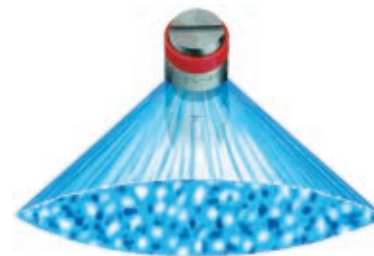
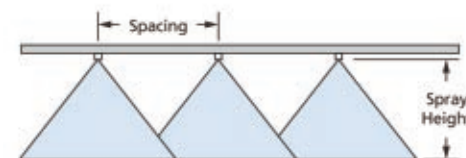


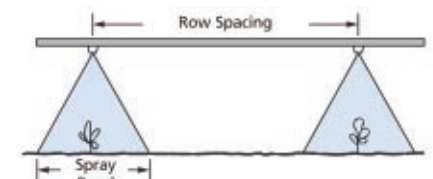
FIGURE 3:
Wide angle flat fan
spray pattern



FIGURE 4:
Even spray pattern



Overlap broadcast pattern



Band spray application

Hollow Cone

The hollow cone spray nozzle forms a round ring pattern for specialty and directed spraying. This unique pattern provides complete coverage by creating a finely atomized spray pattern. (FIGURE 5)

Full Cone

The full cone nozzle creates a round full pattern for specialty applications. (FIGURE 6)

2. Spray Pattern Geometry

The charts to the right provide information on the theoretical spray coverage of the included spray angle at various spray heights. These values are based on the assumption that the spray angle remains the same throughout the entire spray distance. In actual practice, this does not happen. (FIGURE 7)

Always keep in mind that spray coverage will vary based on **operating pressure, spray height and nozzle spacing**. Follow the manufacturer's recommendations to achieve uniform coverage.

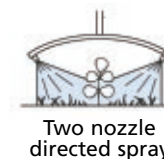
Suggested minimum spray heights can be found in the **table on the next page**. (FIGURE 8) These heights are based on the minimum overlap required to obtain uniform distribution. In many cases, typical height adjustments are based on 1:1 nozzle spacing to height ratio. For example: 110° flat spray nozzles spaced 20" (50 cm) apart are commonly set 20" (50 cm) above the target.



FIGURE 5:
Hollow cone spray pattern



FIGURE 6:
Full cone spray pattern



Two nozzle directed spray



Three nozzle directed spray

Included Spray Angle	Theoretical Coverage at Various Spray Heights (in inches)							
	8"	10"	12"	15"	18"	24"	30"	36"
15°	2.1	2.6	3.2	3.9	4.7	6.3	7.9	9.5
20°	2.8	3.5	4.2	5.3	6.4	8.5	10.6	12.7
25°	3.5	4.4	5.3	6.6	8.0	10.6	13.3	15.9
30°	4.3	5.4	6.4	8.1	9.7	12.8	16.1	19.3
35°	5.0	6.3	7.6	9.5	11.3	15.5	18.9	22.7
40°	5.8	7.3	8.7	10.9	13.1	17.5	21.8	26.2
45°	6.6	8.3	9.9	12.4	14.9	19.9	24.8	29.8
50°	7.5	9.3	11.2	14.0	16.8	22.4	28.0	33.6
55°	8.3	10.3	12.5	15.6	18.7	25.0	31.2	37.5
60°	9.2	11.5	13.8	17.3	20.6	27.7	34.6	41.6
65°	10.2	12.7	15.3	19.2	22.9	30.5	38.2	45.8
73°	11.8	14.8	17.8	22.0	27.0	36.0	44.0	53.0
80°	13.4	16.8	20.2	25.2	30.3	40.3	50.4	60.4
85°	14.7	18.3	22.0	27.5	33.0	44.0	55.4	66.4
90°	16.0	20.0	24.0	30.0	36.0	48.0	60.0	72.0
95°	17.5	21.8	26.2	32.8	40.3	52.4	65.5	78.6
100°	19.1	23.8	28.6	35.8	43.0	57.2	71.6	85.9
110°	22.8	28.5	34.3	42.8	51.4	68.5	85.6	103
120°	27.7	34.6	41.6	52.0	62.4	83.2	104	
130°	34.3	42.9	51.5	64.4	77.3	103		
140°	43.8	54.8	65.7	82.2	98.6			
150°	59.6	74.5	89.5					

Included Spray Angle	Theoretical Coverage at Various Spray Heights (in cm)							
	20 cm	30 cm	40 cm	50 cm	60 cm	70 cm	80 cm	90 cm
15°	5.3	7.9	10.5	13.2	15.8	18.4	21.1	23.7
20°	7.1	10.6	14.1	17.6	21.2	24.7	28.2	31.7
25°	8.9	13.3	17.7	22.2	26.6	31.0	35.5	39.9
30°	10.7	16.1	21.4	26.8	32.2	37.5	42.9	48.2
35°	12.6	18.9	25.2	31.5	37.8	44.1	50.5	56.8
40°	14.6	21.8	29.1	36.4	43.7	51.0	58.2	65.5
45°	16.6	24.9	33.1	41.4	49.7	58.0	66.3	74.6
50°	18.7	28.0	37.3	46.6	56.0	65.3	74.6	83.9
55°	20.8	31.2	41.7	52.1	62.5	72.9	83.3	93.7
60°	23.1	34.6	46.2	57.7	69.3	80.8	92.4	104
65°	25.5	38.2	51.0	63.7	76.5	89.2	102	115
73°	29.6	44.4	59.2	74.0	88.8	104	118	133
80°	33.6	50.4	67.1	83.9	101	118	134	151
85°	36.7	55.0	73.3	91.6	110	128	147	165
90°	40.0	60.0	80.0	100	120	140	160	180
95°	43.7	65.5	87.3	109	131	153	175	196
100°	47.7	71.5	95.3	119	143	167	191	215
110°	57.1	85.7	114	143	171	200	229	257
120°	69.3	104.0	139	173	208	243		
130°	85.8	129	172	215	257			
140°	110	165	220	275				
150°	149	224	299					

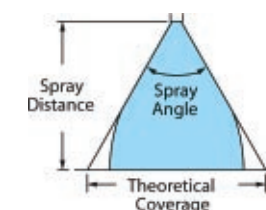


FIGURE 7: Theoretical coverage

	(inches)		
	20"	30"	40"
65°	22-24"	33-35"	NR*
80°	17-19"	26-28"	NR*
110°	16-18"	20-22"	NR*
120°	10-18"	14-18"	14-18"
120°	14-16"	15-17"	18-20"

	(cm)		
	50 cm	75 cm	100 cm
65°	75	100	NR*
80°	60	80	NR*
110°	40	60	NR*
120°	40	60	75
120°	40	60	75

FIGURE 8: Suggested minimum spray heights
*Not recommended

$$\frac{\text{GPM}_1}{\text{GPM}_2} = \frac{\sqrt{\text{PSI}_1}}{\sqrt{\text{PSI}_2}}$$

$$\frac{\text{l/min}_1}{\text{l/min}_2} = \frac{\sqrt{\text{bar}_1}}{\sqrt{\text{bar}_2}}$$

FIGURE 9: Relationship between flow rate (GPM or l/min) and pressure (PSI or bar)

The most commonly used spray angle for various nozzle types are listed below and in FIGURE 8 to the left.

- Flat fan nozzles are available with 65°, 80° or 110° spray angles.
- Extended range flat fan nozzles are available with 80° or 110° spray angles.
- Even flat fan nozzles are available with 40°, 65°, 80°, 95° or 110° spray angles.
- Flooding (wide angle) nozzles typically produce a 120° spray angle.
- Hollow cone nozzles are available with 65° or 80° spray angles.

3. Spray Pressure

Nozzle flow rate varies with spraying pressure. In general, the relationship between flow rate in gallons per minute (GPM) or liters per minute (l/min) and pressure in PSI or bar is shown at the left. (FIGURE 9)

Key facts about pressure:

- Increasing the pressure by four times doubles the flow rate.
- Higher pressure decreases droplet size and increases drift potential.
- Higher pressure increases orifice wear.
- Pressure impacts the spray angle and coverage. Operate your spray nozzles within the proper pressure range.
- Performance data is typically provided in spray nozzle catalogs for spraying water. Liquids more dense or heavier than water, such as 28% liquid nitrogen, form smaller spray angles. Liquids less dense or lighter than water form wider spray angles.

4. Droplet Size Basics

A nozzle's spray pattern is made up of many droplets of varying sizes. Droplet size is the diameter of an individual spray droplet. Droplet sizes are measured in microns (micrometers). One micron equals 0.001 mm (.0000394"). For example, the diameter of a human hair is about 100 microns.

Most nozzles have a wide array of droplet sizes. These droplet sizes are commonly summarized by statistical analysis based on testing from sophisticated droplet size measuring equipment such as laser and imaging systems. Droplets are then classified as shown to the right. (FIGURE 10) These classification categories enable comparisons to be made between nozzles. The most reliable droplet size data will conform to the British Crop Protection Council (BCPC) standard in accordance with the American Society of Agricultural Engineers (ASAE) standard S572. This standard provides strict conditions for spray droplet measurement and is preferred because it uses reference nozzle sets to normalize data. This eliminates interpretation differences when comparing statistical data among different types of laser measuring equipment. (FIGURE 11) Generally speaking, without these classification categories, you can never accurately compare droplet size numbers between nozzles or nozzle types.

Droplet size is a key factor in nozzle selection:

- When coverage is critical, such as in some post-emergence contact applications, nozzles with fine droplets are used because of the excellent coverage on leaf surfaces.
- Nozzles producing medium-size droplets are most commonly used for application of contact and systemic herbicides, pre-emergence surface applied herbicides, insecticides and fungicides.

- Nozzles producing coarse droplets with some systemic herbicides can be used to minimize off-target drift.

Remember, droplet size can vary based on pressure. The same nozzle can produce medium droplets at low pressures and fine droplets at higher pressures.

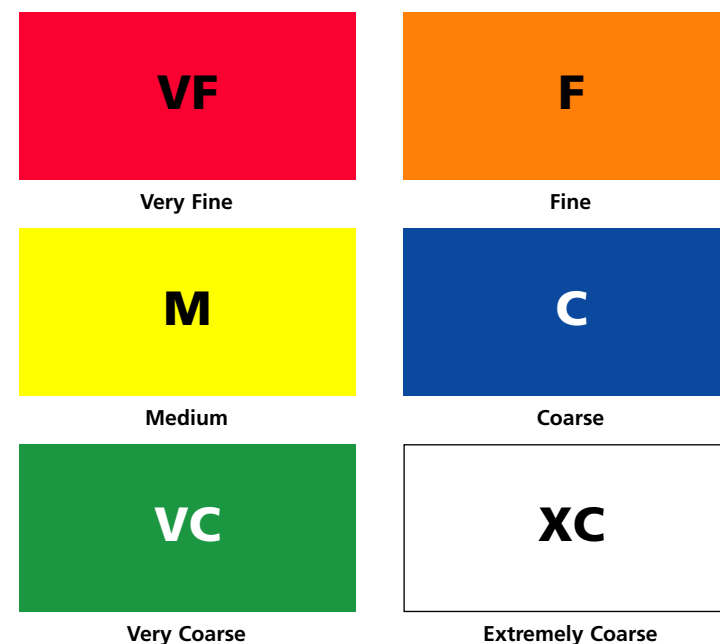


FIGURE 10



FIGURE 11: Laser analyzer

5. Defining Spray Drift

Spray drift is an industry-wide term used to describe the physical movement of pesticide droplets or particles through the air outside of the intended target area. Droplets most prone to drift are those less than 150 microns in diameter.

Factors that determine drift:

- Wind velocity has the greatest impact on spray drift.
- The greater the distance between the spray nozzle tip and the target area, the greater impact wind velocity can have on drift.
- Increased operating speeds can cause the wind to be diverted back into upward wind currents and vortexes behind the sprayer that trap small droplets and can contribute to drift.
- When temperatures are over 77°F (25°C) with low relative humidity, small droplets are more prone to drift because of the effects of evaporation.
- Low application rate usually requires the use of small nozzle sizes, increasing the risk of drift.
- The smaller the nozzle size and the greater the spray pressure, the smaller the droplet size and the greater proportion of driftable droplets.

Various agencies conduct rigorous distribution and drift testing. When evaluating drift data, always inquire about the source of the data. The best data will come from independent testing agencies such as a number of North American research institutions and universities as well as international institutions. The international institutions include the Silsoe Research Institute (SRI) in the United Kingdom, the Central Science Laboratory (CSL) also in the United Kingdom, the Federal

Biological Research Centre for Agriculture and Forestry (BBA) in Germany and the Centre for Pesticide Application and Safety (CPAS) in Australia.

Certain agencies also conduct assessment testing on spray application systems. Some of these agencies have rating systems and accreditation programs. Ask to see these such ratings when evaluating drift potential. The most popular rating system is the Local Environment Risk Assessment for Pesticides (LERAP).

For more information contact:

ASAE (<http://www.asae.org/>)

CSL (<http://www.csl.gov.uk/>)

BBA (<http://www.bba.de/english/mainset.htm>)

SRI (<http://www.sri.bbsrc.ac.uk/>)

Pesticides Safety Directorate (PSD)

(<http://www.pesticides.gov.uk/>)

CPAS (<http://www.aghort.uq.edu.au>)

LERAP (http://www.pesticides.gov.uk/fg_leraps.asp)

HELPFUL TIPS TO CONTROL DRIFT:

- Reduce operating pressure to increase droplet size. Flow rate will be reduced so it may be necessary to go to a larger nozzle size to stay within the labeled application rate.
- Use nozzles that produce larger droplets such as drift reducing nozzles or nozzles of larger capacity.
- Lower boom height to reduce drift but maintain proper overlap for spray coverage.

Know Your Nozzle Types

1. Venturi Air Induction Nozzles
2. Extended Range Flat Fan Nozzles
3. Pre-Orifice Flat Fan Nozzles
4. Flooding Type Nozzles
5. Nozzles for Specialty Applications

1. Venturi Air Induction Nozzles

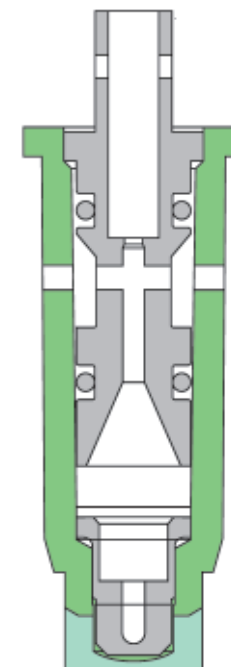
Air induction (AI) nozzles feature two orifices. The first orifice, known as the pre-orifice, meters the liquid flow. The second orifice, known as the exit orifice, is larger than the pre-orifice and forms the spray pattern. There is a venturi or air aspirator between the two orifices. This air venturi draws air into the body of the nozzle where it is mixed with water. This mixing creates an air-entrained spray pattern at a lower pressure. The spray pattern is comprised of large, air-filled, coarse droplets with very few drift-susceptible droplets.

Using AI nozzles:

- Ideal for drift reduction while maintaining good coverage. The air bubbles in the droplets cause the droplets to shatter on impact with the leaf and provide better coverage.
- Be sure to use the proper operating pressures to achieve the proper droplet size. Most AI nozzles require an operating pressure of 30 to 100 PSI (2 to 7 bar) to maximize performance.
- Most AI nozzles produce a wide angle flat fan pattern.
- AI nozzles are typically used for broadcast spraying of post-emergence systemic herbicides, fungicides and insecticides. In banded and directed spraying, AI nozzles

provide excellent performance in application of pre-emergence herbicides, post-emergence systemic herbicides, fungicides and insecticides.

- Carry a few spares. Even though cleaning these nozzles shouldn't require tools, in-field cleaning isn't recommended because of the number of small pieces. If in-field cleaning is necessary, keep a small can of compressed air on board the sprayer.



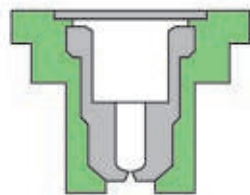
Venturi Air Induction Nozzle

2. Extended Range Flat Fan Nozzles

Extended range flat fan nozzles are widely used because they provide excellent spray distribution over a wide range of pressures. When operated at lower pressures, drift is reduced. Better coverage is achieved at higher operating pressures.

Using extended range flat fan nozzles:

- Frequently used for soil and foliar applications when better coverage is required. For soil applications, the recommended pressure range is 15 to 30 PSI (1 to 2 bar). Foliar applications require smaller droplets to increase coverage and pressures from 30 to 60 PSI (2 to 4 bar) are required.
- Lower pressures and higher flow rates will produce droplets more resistant to drift. Pressures above 30 to 40 PSI (2 to 3 bar) produce finer droplets more prone to drift.
- Nozzles should be placed so patterns overlap a minimum of 30% on each spray pattern edge.



Extended Range Flat Fan Nozzle

3. Pre-Orifice Flat Fan Nozzles

Pre-orifice flat fan nozzles reduce the operating pressure internally and produce a larger droplet than conventional flat fan nozzles. The nozzle's pre-orifice restricts the amount of liquid entering the nozzle and creates a pressure drop through the tip. Fewer droplets prone to drift are produced and spray pattern uniformity is excellent. Pre-orifice nozzles are available in flat fan and plug-resistant flooding versions.

Using pre-orifice nozzles:

- Flat fan versions operate at pressures from 15 to 90 PSI (1 to 6 bar), require a minimum of 30% overlap on the edge of each spray pattern and should be mounted so the preset spray angle is directed away from the direction of travel.
- Flat fan versions are widely used for the application of post-emergence products.
- Compared to extended range flat fan nozzles, drift can be reduced by as much as 50%.
- Carry a few spares. The pre-orifice is more difficult to clean than conventional nozzles and not practical for in-field cleaning. If in-field cleaning is necessary, keep a small can of compressed air on board the sprayer.



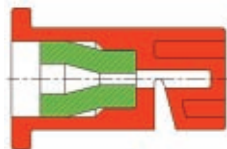
Pre-Orifice Flat Fan Nozzle

4. Flooding Type Nozzles

Flooding type nozzles produce a wide angle flat fan pattern. Pressure changes affect the width of the spray pattern more than with extended range flat fan nozzles.

Using flooding type nozzles:

- Best distribution is achieved with nozzles mounted for 100% (or double) overlap (meaning the edge of one spray pattern extends to the center of the adjacent nozzle) at the lowest possible operating pressure.
- Nozzles can be mounted to spray in any direction but the mounting position will impact the distribution. If spraying downward, rotating the nozzles 30° to 45° up from horizontal will help uniformity at operating pressures in the 10 to 30 PSI (.7 to 2 bar) range.
- At low pressures, flooding type nozzles produce large droplets; at high pressures, smaller droplets are produced – even smaller than flat fan nozzles with an equivalent flow rate.
- Compared to extended range flat fan nozzles, drift can be reduced by as much as 50%.
- Pre-orifice style flooding versions operate at pressures from 10 to 40 PSI (.7 to 2.8 bar), require a minimum of 30% overlap on the edge of each spray pattern and can be mounted in a variety of positions for spraying in any direction.
- Flooding versions are well-suited for soil applications especially when applying a mix of fertilizers and herbicides.

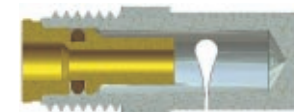


Flooding Type Nozzle

5. Nozzles for Specialty Applications

There are many variations on the basic nozzle types and many other specialty nozzles available as well. Your choice will, of course, depend on your application requirements.

- Variation of standard nozzles includes twin spray, wide angle and extra wide angle sprays, double-outlet flat spray and even flat spray.
- Boomless nozzles are designed for spraying areas not easily accessed with a boom sprayer. Flat spray and extra wide flat spray patterns are typically used to provide a wide swath.
- Hollow cone nozzles are available in disc and core types for spraying pesticides at higher pressures and flow rates. Standard hollow cone nozzles produce a finely atomized spray and are commonly used for spraying post-emergence contact herbicides, fungicides and insecticides. Wide angle versions are also available.
- Full cone nozzles provide a coarse spray pattern and are available in standard and wide angle spray patterns. These nozzles can be used in broadcast spraying and in some banded applications.
- Solid stream nozzles provide from one to seven solid streams. They are commonly used for the application of liquid fertilizer.



Boomless Type Nozzle

Selecting the Right Spray Nozzle

These are the questions you need to ask yourself.

1. What are you spraying?
2. How are you spraying?
3. What is your tolerance to drift?
4. What is the weight of the spray solution?
5. What is the pressure range of the sprayer?
6. What is the nozzle spacing on the boom?
7. What is the boom height?
8. Which nozzle material is best?
9. Who is the nozzle manufacturer and why does it matter?

There is a reason why there are dozens of different nozzle types available in hundreds of different sizes, capacities and materials. Each nozzle is designed to yield very specific performance based on *what* you're spraying, *when* you're spraying and *how* you're spraying.

It may be tempting to overlook the role spray nozzles can have in the overall success of your spraying season simply because they are a small, relatively low-cost component. However, a poor choice in spray nozzles or the use of under-performing nozzles, can lead to re-spraying or reduced performance – two problems no user should face.

Giving serious consideration to your spraying objectives and studying your options shouldn't be shortchanged. It's a small time investment that will help maximize your success. Start by reviewing your spraying requirements and be prepared to have multiple nozzle sets on hand to meet your varying needs.

1. What are you spraying?

Herbicides, fungicides or insecticides — for soil incorporated, pre-emergence or post-emergence? If post-emergence, contact or systemic? Is it a wettable powder, emulsifiable concentrate or flowable? Will two or more chemicals be used in combination?

2. How are you spraying?

- **Broadcast?**
- **Banded?**
- **Directed?**
- **Mechanical air assisted?**

The answers to these basic questions will get you started. Consult the charts on pages 38-41 for recommended nozzle types. Another good source of information on nozzle type is the pesticide label. In addition to information on recommended nozzle types, many chemical labels include information on gallons per acre (GPA) or liters per hectare (l/ha) and nozzle spacing.

3. What is your tolerance to drift?

If you answer yes to any of the following questions, you may want to consider low drift nozzles.

- Will you be applying near any residential areas?
- Do you spray in an area with different, adjacent crops or ornamentals?
- Are you concerned about the impact your spraying may have on the environment?
- Have you had a drift complaint in the past?
- Do time constraints require you to spray under less than ideal conditions?

Selection of a nozzle that reduces drift potential requires an understanding of droplet size.

The Correlation Between Droplet Size and Drift

All nozzles produce a range of droplet sizes within the given spray pattern. To measure the range of droplets produced by a nozzle, three measurements are generally used.

- $D_{V0.1}$, is a value where 10% of the total volume or mass of liquid sprayed is made up of droplets with diameters smaller or equal to this value. For example, if the $D_{V0.1}$ is listed as 100 microns, this means that only 10% of the volume of the spray is contained in droplets smaller than 100 microns. The other 90% of the volume of the spray is contained in droplets larger than 100 microns.
- $D_{V0.5}$, also known as VMD, is a value where 50% of the total volume or mass of liquid sprayed is made up of droplets with diameters larger than the median value and 50% smaller than the median value. For example, if the VMD is listed as 250 microns, this means that 50% of the volume of the spray is in droplets both larger and smaller than 250 microns.
- $D_{V0.9}$, is a value where 90% of the total volume or mass of liquid sprayed is made up of droplets with diameters smaller or equal to this value. For example, if the $D_{V0.9}$ is listed as 500 microns, this means that 90% of the volume of the spray is contained in droplets 500 microns or smaller. Only 10% of the volume is contained in droplets larger than 500 microns.

Be sure to verify which standards are being used when reviewing droplet size classification data. BCPC (formerly known as British Crop Protection Council) specifications and ASAE standard S572 are the leading standards for compliance.

Droplet size classification information is provided by nozzle manufacturers for products at varying pressures. Chemical labels also use this classification system to indicate proper product usage and ensure efficacy.

Drift Studies

Drift has become a topic of great interest in recent years and many studies have been conducted to document drift potential of different types of nozzles at varying operating pressures. However, drift studies can be difficult and costly to conduct and there are several different methodologies in use. The methodology influences the results so it is very important to understand these differences if you are comparing drift data from different manufacturers or studies from different research groups. Direct comparisons should not be made between:

- **Field studies** - They are costly and difficult to conduct, but the data from these studies is considered the most reliable since actual spraying conditions are tested.
- **Lab studies** - They use various collection devices and dye concentrations. This technique uses various sophisticated collection devices in a lab setting that replicates field spraying as precisely as possible.
- **Wind tunnel testing** - Uses water sensitive paper to collect and observe drift. The use of wind tunnels and water sensitive paper is the least accurate and clear guidelines for accuracy and repeatability do not exist.

When evaluating drift data, it is important to read the entire test report. Some companies can selectively extract information to make their spray nozzles look better and/or make invalid comparisons across various nozzle types.

Key Drift Concepts

If you've determined that drift is a concern, keep these concepts in mind:

- Weather conditions, sprayer set-up and nozzle choice are the most important influences on drift.
- Reduce the proportion of small droplets in the spray. This can be achieved by using spray nozzles that produce coarse droplets at the intended operating pressure.
- Protect the spray from wind by adjusting boom height and shrouding. Lower boom heights are usually recommended to reduce drift. Shrouds, cones and other protective shields can also reduce drift but can be costly and may not fit all sprayers.
- Dilute the spray solution if the chemical label allows it. Use of higher carrier volumes reduces drift by necessitating the use of larger nozzles to apply the higher volumes, which results in a less drift-prone spray. Plus, the spray solution is more dilute at the higher volume so the drift will contain less active ingredient and have less potential for damage.
- Select the appropriate nozzle for your travel speed. Higher travel speeds typically require the use of larger flow rate nozzles that generate coarser sprays and reduce drift potential.
- Consider the active ingredients in your herbicides and insecticides and adjust accordingly to minimize vapor and spray drift.
- Larger droplets do reduce drift potential. However, larger droplets can negatively impact product effectiveness. Insecticides, fungicides and contact herbicides with little or no systemic activity usually require small droplets to ensure thorough coverage. Systemic materials that move within plants can use larger droplets.

General guidelines:

- Fine droplets: Use for post-emergence contact applications that require excellent coverage on leaf surfaces.
- Medium droplets: Use for contact and systemic herbicides, pre-emergence surface applied herbicides, insecticides and fungicides.
- Droplet size will vary based on pressure. In general, the smaller the nozzle size and the greater the spray pressure, the smaller the droplets and the greater proportion of driftable droplets.
- A larger capacity nozzle will produce more coarse droplets.
- Wider fan angles have finer droplets.
- Always spray for the situation at hand. Conventional spraying is fine under certain conditions. Low-drift strategies are appropriate for outside perimeters or when the winds are higher than normal.

4. What is the weight of the spray solution?

Tabulations in spray nozzle catalogs are based on spraying water that weighs 8.34 pounds per U.S. gallon or 1 kg per liter. Use conversion factors (FIGURE 12) when using solutions heavier or lighter than water. Multiply the desired GPM or GPA (l/min or l/ha) of solution by the water rate conversion factor. (FIGURE 13) Then use the converted GPM or GPA (l/min or l/ha) to select the proper size nozzle.

Pounds per Gallon	Kilograms per Liter	Conversion Factor
7.0 lbs./gal.	.84	.92
8.0 lbs./gal.	.96	.98
8.34 lbs./gal.	1.00 – WATER	1.00
9.0 lbs./gal.	1.08	1.04
10.0 lbs./gal.	1.20	1.10
10.65 lbs./gal.	1.28 – 28% nitrogen	1.13
11.0 lbs./gal.	1.32	1.15
12.0 lbs./gal.	1.44	1.20
14.0 lbs./gal.	1.68	1.30

FIGURE 12: Density conversion tables

$$\text{GPA (solution)} \times \text{Conversion Factor} = \text{GPA (water)}$$

$$\text{l/ha (solution)} \times \text{Conversion Factor} = \text{l/ha (water)}$$

FIGURE 13: Density conversion formulas

5. What is the pressure range of the sprayer?

Always operate any nozzle in the middle of its recommended operating range for best performance. Sizing nozzles in the middle of the sprayer pressure range offers more flexibility for adjustments in speed or changes in the terrain, especially when using an automatic rate controller. Reducing spray pressures below the rated minimum will result in poor spray patterns.

6. What is the nozzle spacing on the boom?

The nozzle size you need depends on many factors including the desired application rate, ground speed and nozzle spacing. For each nozzle type and spray angle, the manufacturer recommends proper spray heights and nozzle spacing. Nozzle spacing of 20" (50 cm) and 30" (75 cm) are most common. This information may also be available on the chemical label.

7. What is the boom height?

Lower boom heights are usually better as long as proper overlap of spray nozzles is achieved. In general, nozzles with 110° fan angles can be used at lower boom heights than 80° fan angles. Lower boom heights reduce drift and improve coverage. Higher boom heights increase nozzle overlap and can help maintain good pattern uniformity for low drift nozzles.

8. Which nozzle material is best?

To determine the best material for your application, you need to know what chemicals you will be spraying and what you perceive to be an acceptable wear life (spray hours) for your nozzles. It may be advantageous to choose nozzles in wear-resistant materials. The initial cost may be higher, but the longer life will offset the cost in the long run. Also, depending on your application requirements, you may need different types of spray nozzles in different materials. **Note: Do not mix nozzle types or materials on a boom. Always equip a boom with identical nozzles.**

Material selection guidelines:

- Wear-resistant materials such as ceramic maintain a constant flow rate over a longer period of use.
- Brass materials wear quickly. A brass nozzle may have an increase in flow of 10 to 15% after 50 hours of use, depending on what product is being sprayed.
- Plastic material with stainless steel or ceramic inserts cost less than stainless steel and will last longer than brass.
- Plastic can, in some cases, be more fragile than other materials and can be damaged more easily. However, with advancements in manufacturing technique and with proper care, the life expectancy out of plastic nozzles can be quite good. In fact, with some nozzle designs, plastic nozzles can wear as long as, if not longer than, stainless steel.
- Stainless steel will last longer than brass.
- Ceramic will last the longest.

Comparing wear life of nozzle materials:

- Plastic: two to three times longer than brass. Four to six times longer than brass with some plastic nozzle designs.
- Stainless steel: four to six times longer than brass.
- Ceramic: 20 to 50 times longer than brass.

9. Who is the nozzle manufacturer and why does it matter?

Once again, because spray nozzles are so small, it may be easy to think of them as simple components. However, spray nozzles are highly engineered, precision components and consideration should be given to the manufacturer and the manufacturer's capabilities. Here's a list of credentials to look for:

Focus on agricultural and turf spray technology. Is the manufacturer focused on spray nozzles and related equipment? Is spray nozzle manufacturing a core competency or just a "supplemental" offering? Manufacturers committed to the industry will invest more in research and development, quality control and support than those producing spray nozzles as an auxiliary or secondary item.

Experience, expertise and a willingness to share. The manufacturer should have a proven track record in the industry – preferably spanning decades. The company should also demonstrate its understanding of the technology and changing trends by introducing new products on a regular basis.

Does the company share its knowledge and invest in making you a savvy customer? Catalogs, technical publications and company web sites should do more than sell you products – they should help you improve quality and efficiency in application of your crop protection products.

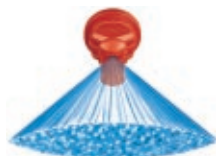
Size. How many spray nozzles does the manufacturer produce annually? How much manufacturing space is dedicated to spray nozzle production? These are often good indicators of quality. Manufacturers producing low quality nozzles won't have the same level of demand as those producing superior products.

Commitment. Is the manufacturer actively involved in the international spray community? Does it participate in conferences and technical committees? Does it conduct research and share the findings with the industry to advance spray technology? All of these items indicate a long-term commitment to the industry and the environment – both of which provide value to you.

	Herbicides				Fungicides		Insecticides	
	Soil Incorporated	Pre-Emergence	Post-Emergence		Contact	Systemic	Contact	Systemic
			Contact	Systemic				
Extended Range Flat Spray			Excellent	Good	Excellent	Good	Excellent	Good
Extended Range Flat Spray <i>at pressures below 30 PSI (2 bar)</i>	Good	Good	Good	Very Good	Good	Very Good	Good	Very Good
Wide Angle Pre-orifice Flat Spray			Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
Wide Angle Pre-orifice Flat Spray <i>at pressures below 30 PSI (2 bar)</i>	Good	Good	Good	Excellent	Good	Excellent	Good	Excellent
Air Induction Flat Spray	Very Good	Very Good	Good	Excellent	Good	Excellent	Good	Excellent
Twin Flat Spray			Excellent		Excellent		Excellent	
Wide Angle Pre-orifice Flood Spray	Excellent	Excellent		Very Good		Very Good		Very Good



Extended Range Flat Spray



Wide Angle Pre-orifice Flat Spray



Air Induction Flat Spray



Twin Flat Spray



Wide Angle Pre-orifice Flood Spray

		Herbicides			Fungicides		Insecticides	
		Pre-Emergence	Post-Emergence		Contact	Systemic	Contact	Systemic
			Contact	Systemic				
Banding	Even Air Induction Flat Spray	Excellent	Good	Excellent	Good	Excellent	Good	Excellent
	Even Flat Spray	Good	Very Good	Good	Very Good	Good	Very Good	Good
	Twin Even Flat Spray		Excellent		Excellent		Excellent	
Directed Spraying	Even Air Induction Flat Spray	Very Good	Good	Excellent	Good	Excellent	Good	Very Good
	Even Flat Spray	Good	Good	Good	Good	Good	Good	Good
	Twin Even Flat Spray		Very Good		Very Good		Very Good	
	Air Induction Flat Spray		Good	Excellent	Good	Excellent	Good	Excellent
	Hollow Cone Spray		Excellent		Excellent		Excellent	
Mechanical Air Assisted	Hollow Cone Spray		Excellent	Good	Excellent	Good	Excellent	Good



Even Flat Spray



Even Air Induction Flat Spray



Twin Even Flat Spray



Hollow Cone Spray

Consult the Experts

This booklet is filled with a tremendous amount of actionable information. Its goal is to educate you and guide you through the spray nozzle selection process so you make the best decision possible. However, the process is complex because there are so many variables. It is recommended you consult with spray nozzle experts for assistance during the selection process to validate your decision.

Local resources: University and county extensions are always willing to help. Tap into their personnel and request recent publications on spraying equipment. These agencies have no manufacturer bias.

Third-party research: Broaden the scope of your knowledge. There are several respected researchers in the field that publish technical data on a regular basis. Ask your local university extension for additional information or consider researching on the Internet. <http://www.asae.org/> has a variety of helpful articles available.

Government sources: State agricultural departments as well national and international departments shouldn't be overlooked. The Spray Drift Task Force (<http://www.agdrift.com/>), the Environmental Protection Agency (<http://www.epa.gov/>) and

the United States Department of Agriculture (<http://www.usda.gov/>) are additional institutions that have information to share.

Chemical and spray nozzle manufacturers: These companies can be a good source of information. However, it is important to remember their goal is to have you purchase their products, so watch for bias. Several companies do invest in customer education for the betterment of the industry, but carefully scrutinize manufacturer-sponsored research. Manufacturers typically don't publish research unless it presents their products in a positive fashion.

Making Maintenance a Priority

Crop protection products can only be effective if applied properly. That means selecting the proper spray nozzle and then ensuring optimal performance. Sounds simple enough, right? But in reality, ensuring proper spray nozzle performance can be challenging. Here's why.

Spray nozzles don't last forever. Yet it is extremely difficult to detect wear because it may not be visible. Spray nozzle wear of 10, 20 or even 30% won't be visible. Special optical equipment would be required to actually see changes in the orifice size. So rather than relying on visual inspection, you should compare the flow rate from a used nozzle with the flow rate from a new nozzle of the same size and type.

- Check the flow rate by using a graduated collection container, a timing device and a pressure gauge mounted at the nozzle tip.
- Compare flow rates. If the flow from the used nozzle is 10% greater or more, replace it.
- A 10% over application of chemical on a twice-sprayed 1000-acre (247-ha) farm could represent a loss of \$2,000 to \$10,000 (U.S.) based on current chemical costs. This number doesn't take into account fuel, machinery wear and tear, time/labor or crop damage.

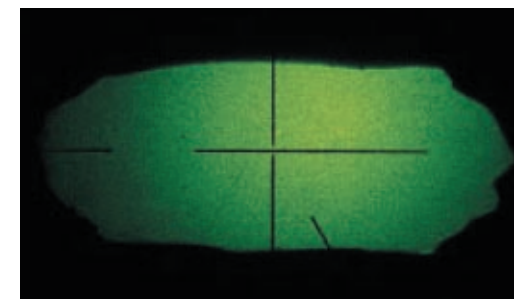
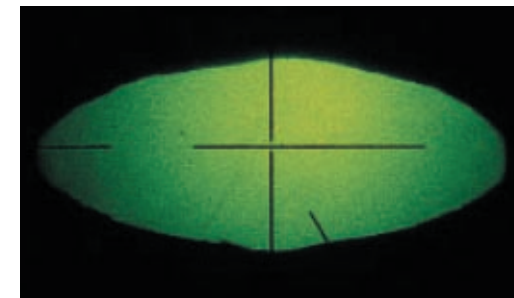
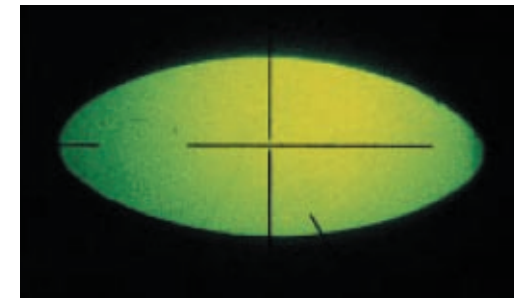


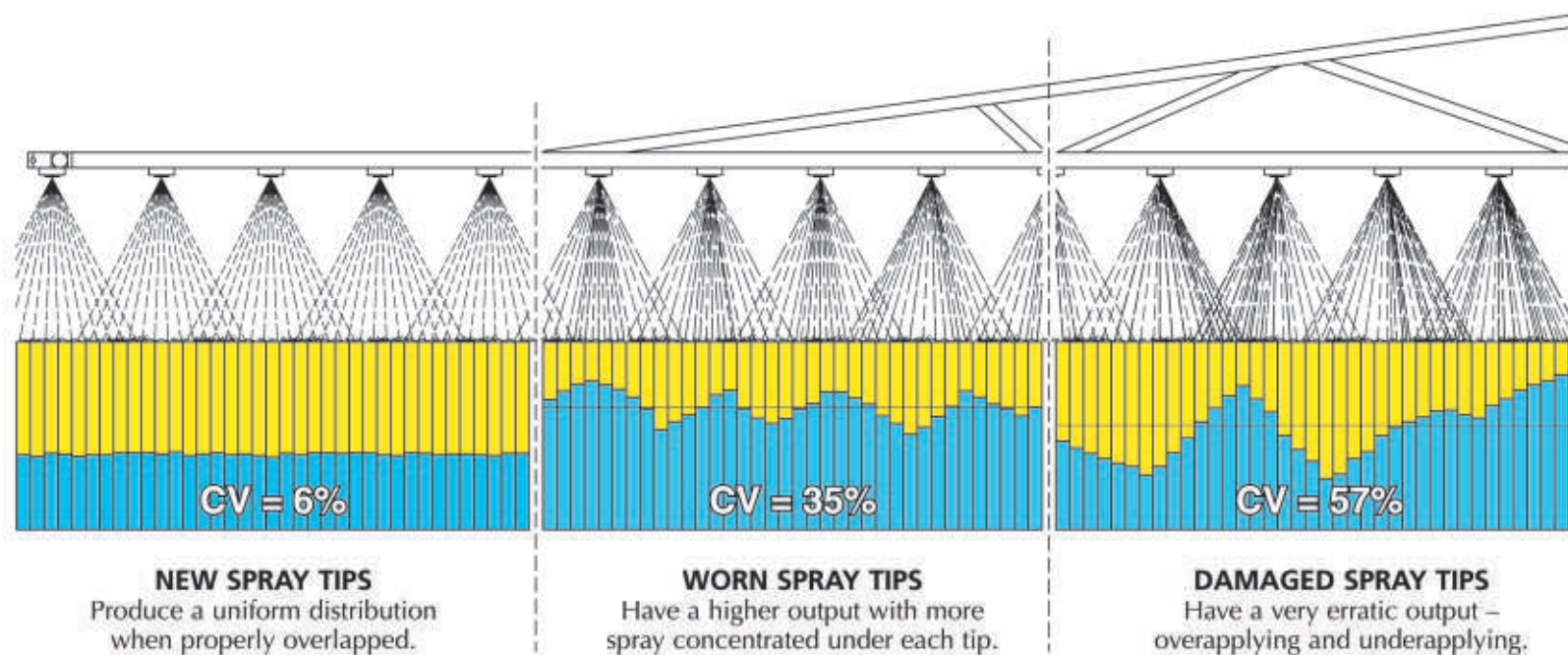
FIGURE 14: An inside look at nozzle orifice wear and damage. New nozzle (top), worn nozzle (middle) and damaged nozzle (bottom).

- If you feel your spray nozzles are wearing quickly, consider upgrading to longer wear materials.

Prior to replacing spray nozzles due to wear, it is critical to keep them in good working order. Variations in spray distribution, droplet size or flow rate can reduce the effectiveness of the application.

- It is important to clean clogged spray nozzles properly. Use a soft-bristled brush or compressed air for cleaning. Do not use metal objects under any circumstances.
- Use extreme care with softer tip materials such as plastic.
- Be sure to use adequate strainers to minimize clogging.

What is Cv? Coefficient of Variation is what it stands for. The Cv is a statistical method that is widely accepted throughout the world for determining spray uniformity of nozzles across a spray boom. The lower the Cv value, the better the distribution quality. For extremely uniform distributions the Cv can be less than or equal to 7%. In some countries, nozzles must conform to very strict Cv specifications, while other countries require annual sprayer distribution testing. These stipulations emphasize the importance of distribution quality and its effect on chemical effectiveness. See the chart below for more information.



Sprayer Calibration Ensures Optimal Performance

You may think you're ready to spray, but you need to calibrate your sprayer. The time investment is well worth it as it can help you avoid a re-spray.

Start by measuring your travel speed

Check tractor/sprayer speed. Don't rely on electronics. See how long it takes you to move over a 100' (30.5 m) or 200' (61 m) strip. (FIGURE 15 gives some commonly used speeds.)

- Do your test in the area to be sprayed or an area with a similar surface and select the engine throttle setting and gear that will be used when spraying.
- Fence posts or other permanent devices can be used as markers.
- The starting point should be far enough away to permit your tractor or sprayer to reach the desired spraying speed.
- Hold that travel speed between markers.
- Most accurate results will be achieved with the spray tank half full.
- Calculate your real speed. (FIGURE 16)

Speed in MPH	Time Required in SECONDS to Travel a Distance of:		
	100 Feet	200 Feet	300 Feet
1.0	68	136	205
1.5	45	91	136
2.0	34	68	102
2.5	27	55	82
3.0	23	45	68
3.5	19	39	58
4.0	17	34	51
4.5	15	30	45
5.0	14	27	41
5.5	—	25	37
6.0	—	23	34
6.5	—	21	31
7.0	—	19	29
7.5	—	18	27
8.0	—	17	26
8.5	—	16	24
9.0	—	15	23

Speed in km/h	Time Required in SECONDS to Travel a Distance of:			
	30 m	60 m	90 m	120 m
5	22	43	65	86
6	18	36	54	72
7	15	31	46	62
8	14	27	41	54
9	—	24	36	48
10	—	22	32	43
11	—	20	29	39
12	—	18	27	36
13	—	17	25	33
14	—	15	23	31
16	—	14	20	27
18	—	—	18	24
20	—	—	16	22
25	—	—	13	17
30	—	—	—	14
35	—	—	—	12
40	—	—	—	11

FIGURE 15: Speeds

$$\text{Speed (MPH)} = \frac{\text{Distance (ft)} \times 60}{\text{Time (seconds)} \times 88}$$

$$\text{Speed (km/h)} = \frac{\text{Distance (m)} \times 3.6}{\text{Time (seconds)}}$$

FIGURE 16: Calculate speeds

Travel speed tips

In general, slower speeds are better and produce more consistent results. Faster speeds reduce canopy penetration, increase dust and may cause drift problems. In addition, faster speeds may require larger nozzles that produce a coarser droplet which may reduce target coverage. Furthermore, they may result in vertical and horizontal boom movement which can negatively impact overall coverage.

Record the following information

- Nozzle type on your sprayer – all nozzles must be identical.
- Recommended application volume.
- Measured sprayer speed.
- Nozzle spacing.

Calculate the required nozzle output

See the chemical label to ensure you apply the right volume. Then, use the travel speed of your sprayer to calculate nozzle flow rate. (FIGURE 17)

Set the correct pressure

- Turn your sprayer on and check for leaks.
- Clean nozzles and strainers as needed.
- Replace one nozzle and strainer with an identical new nozzle and strainer.
- Determine the pressure required to deliver the nozzle output calculated from the formula above.
- Use conversion factors (page 33) to determine the weight of the spraying solution if different than the weight of water.

$$\text{GPM} = \frac{\text{GPA} \times \text{MPH} \times W}{5,940}$$

GPM = the nozzle flow rate in gallons per minute.
GPA = application rate in gallons per acre.
MPH = the ground speed in miles per hour.
W = the nozzle spacing in inches for broadcast spraying.

$$\text{l/min} = \frac{\text{l/ha} \times \text{km/h} \times W}{60,000}$$

l/min = the nozzle flow rate in liters per minute.
l/ha = application rate in liters per hectare.
km/h = the ground speed in kilometers per hour.
W = the nozzle spacing in centimeters for broadcast spraying.

FIGURE 17: Nozzle output formulas

- Turn sprayer on; adjust pressure.
- Collect and measure the volume of the spray from the new nozzle into a collection container. Fine-tune pressure until you collect your desired flow rate in GPM (l/min).

Check your system

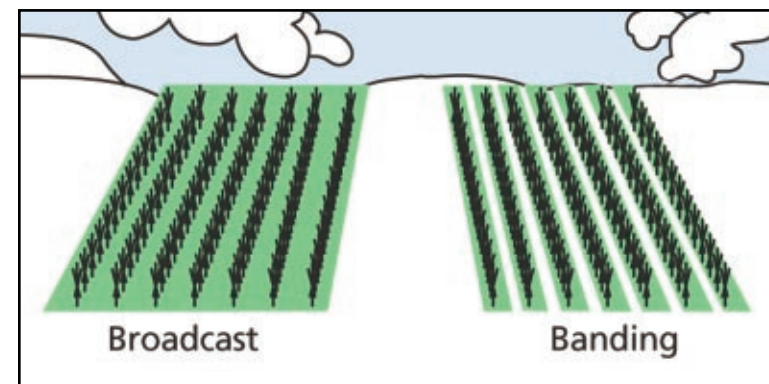
- Check the flow rate of a few nozzles on each boom section.
- If the flow rate of any nozzle is 10% greater or less than the new nozzle, recheck the output.
- If only one nozzle is faulty, replace with a new nozzle (and strainer, if necessary).
- If a second nozzle is faulty, replace all nozzles on the entire boom. Replacing only a couple of worn nozzles could cause distribution problems.

Broadcast versus banding and directed applications

The instructions just presented are for calibrating a sprayer for a broadcast application. For banding or directed applications, change the value of “W” in the formula.

- For single nozzle banding or boomless applications:
W = sprayed band width or swath width in inches or cm.
- For multiple nozzle directed applications: W = row spacing in inches or cm divided by the number of nozzles per row.

Use care when calculating for banding or directed applications. Make sure to read the chemical label carefully and understand the rate that is specified. Rates can be specified as Field Acres (Field Hectares) or Treated Acres (Treated Hectares). See FIGURE 18.



Field Acres or Hectares =

**Total Acres (Hectares) of area
to be sprayed**

Treated Acres or Hectares =

**Field Acres
(Hectares) × $\frac{\text{Band Width (in or cm)}}{\text{Row Spacing (in or cm)}}$**

FIGURE 18: Formulas for Broadcast or Banding

Parting Thoughts. Clearly there are many considerations when selecting spray nozzles. In the whole scheme of things, nozzles may not seem that important given you may spend a lot of your hard earned dollars on equipment and plant protection products. However, a poor choice in nozzles can have a significant impact on those other investments. We urge you to study this guide and give thoughtful consideration to the nozzles you use.





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