Nozzles are arguably the most important part of a sprayer. They determine to a large degree the efficacy obtained from a pesticide, the amount of drift, and the overall satisfaction an applicator receives from an application. As a bonus, they are relatively inexpensive compared to the cost of a sprayer unit, usually comprising less than 1% of that investment cost.

There has been a bit of a revolution in the nozzle business, with new design innovation, improved materials, and a larger selection of features than ever before. With this large selection, choosing the right nozzle can be challenging. The good news is that there isn’t a bad nozzle on the market today. The bad news is that there are plenty of opportunities to use a good nozzle improperly. To avoid pitfalls, applicators must carefully determine their application goals, consider the target, the mode of action of the pesticide, the environment, and the sprayer features and capabilities before selecting a nozzle. This article is designed to assist applicators with this selection process.

**What are the Best Nozzles to Use?**

There are a large number of nozzles on the market today, and applicators may have some trouble deciding which specific nozzle is best suited to their needs. The main categories of nozzles are listed below to help with nozzle selection. Within each category, we find a number of manufacturers who make a similar product. Key differences are materials used (plastic, ceramic, steel), pressure ranges, and fan angles. Details on relative droplet sizes and recommended minimum water volume are identified in Table 1.

**Nozzle Categories**

1. **Conventional Flat Fan** - finest spray, reliable performance, drift prone, use at 20 to 60 psi
2. **Pre-Orifice** - reduce drift 50%, reliable efficacy at low volumes, use at 30 to 60 psi or higher
3. **Low-Pressure Air Induced** - reduce drift 50 to 70%, use at 30 to 60 psi or higher, > 5 gpa
4. **High Pressure Air Induced** - reduce drift 70 to 90%, use at 60 to 80 psi or higher, > 7 gpa

**Some Issues to Consider**

**Target Type and Mode of Action**

1. Grassy weeds and some broadleaf weeds (lambsquarters, kochia, cleavers) can be difficult-to-wet, meaning that larger droplets tend not to stick to their surfaces. Therefore, these require somewhat finer sprays or higher carrier volumes.

2. Contact modes of action require higher droplet densities than systemic products. Higher droplet densities are most easily achieved with higher water volumes or finer sprays.
**Carrier Volumes**
1. At 8 to 10 gpa, can use any nozzle successfully provided you choose the right pressure.
2. At 4 gpa and lower, must limit yourself to Coarse sprays and finer.
   a) nozzle types 1 to 3 above.
   b) make sure pressure and boom height sufficient to generate good overlaps.

**Nozzle Orientation**
1. At slow travel speeds, orient nozzle forwards for herbicide work. For dense, mature canopies, penetration will be best with the nozzles pointed down.
2. At fast travel speed (15 to 20 mph), we don't have enough information to make recommendation, but:
   a) coarse sprays oriented forward had the best deposition on vertical targets.
   b) coarse sprays oriented backwards may improve patterns at fast speeds.
3. Double nozzles (one pointed forward, the other backward such as in the Lurmark TwinCap) are a good idea to improve coverage on vertical targets such as wheat heads (for fusarium headblight control) or grassy weeds. In lab tests, using coarser sprays with these double nozzles significantly improved coverage, but in field tests, this did not result in a yield advantage with fungicides.

**Travel Speeds**
1. Fast travel speeds have both advantages and disadvantages, but the most important advantage is greater work rates. Disadvantages are greater dust generation, less uniform deposition (especially behind the tractor unit) and less canopy penetration.
2. On the whole, slower speeds are better. Travel as slowly as you can afford to given your workload.

**Boom Heights**
1. Lower boom heights are almost always preferable over high heights to reduce drift. For conventional nozzles with 80 degree fan angles, heights can be as low as 18” above target, 110 degree nozzles 14”. Lower heights reduce drift and improve overall targeting. Low-drift nozzles require higher heights (an additional 6”) to obtain good uniformity.
2. High booms increase nozzle overlap, which can be useful for low-drift nozzles and when pressures are low and patterns begin to collapse. But high booms can increase drift potential significantly. Use the lowest boom height you can that still offers you sufficient overlap given your boom movement.
3. Automatic boom levelers are available and have been useful for suspended booms under uneven terrain. These can make low boom heights practical.

**Canopy Penetration**
1. Droplet size does not have as much impact on canopy penetration as carrier volume.
2. Penetration improves with slower travel speeds and higher carrier volumes for any nozzle.
3. Air assist is one of the best ways to improve penetration, more effective than the above methods.
Table 1. Nozzle choices, pressures and volume recommendations.

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Type</th>
<th>Air-Induced</th>
<th>Smallest Size Available</th>
<th>Optimal Pressure (psi)</th>
<th>Relative Droplet size</th>
<th>Minimum Volume (gpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TeeJet XR</td>
<td>Conventional</td>
<td>No</td>
<td>0067</td>
<td>20 to 60</td>
<td>Smallest (*)</td>
<td>3</td>
</tr>
<tr>
<td>Hypro TR, VP, Albuz AXI</td>
<td>Conventional</td>
<td>No</td>
<td>01, 015, 015</td>
<td>20 to 60</td>
<td>*</td>
<td>3</td>
</tr>
<tr>
<td>Hardi FF</td>
<td>Conventional</td>
<td>No</td>
<td>0075</td>
<td>20 to 75</td>
<td>*</td>
<td>3</td>
</tr>
<tr>
<td>ComboJet ER</td>
<td>Conventional</td>
<td>No</td>
<td>0067</td>
<td>20 to 60</td>
<td>*</td>
<td>3</td>
</tr>
<tr>
<td>TeeJet DG</td>
<td>Pre-orifice</td>
<td>No</td>
<td>015</td>
<td>30 - 60</td>
<td>**</td>
<td>3-5</td>
</tr>
<tr>
<td>Turbo TeeJet, Hypro Guardian</td>
<td>Pre-orifice</td>
<td>No</td>
<td>01</td>
<td>15 to 90</td>
<td>**</td>
<td>3-5</td>
</tr>
<tr>
<td>Hardi LD</td>
<td>Pre-orifice</td>
<td>No</td>
<td>01</td>
<td>20 to 70</td>
<td>**</td>
<td>3-5</td>
</tr>
<tr>
<td>Hypro LD, Albuz ADI</td>
<td>Pre-orifice</td>
<td>No</td>
<td>015, 01</td>
<td>30 to 60</td>
<td>**</td>
<td>3-5</td>
</tr>
<tr>
<td>ComboJet SR</td>
<td>Pre-orifice</td>
<td>No</td>
<td>0067</td>
<td>30 to 60</td>
<td>**</td>
<td>3-5</td>
</tr>
<tr>
<td>ComboJet MR</td>
<td>Pre-orifice</td>
<td>No</td>
<td>0067</td>
<td>30 to 60</td>
<td>***</td>
<td>5-7</td>
</tr>
<tr>
<td>ComboJet DR</td>
<td>Pre-orifice</td>
<td>No</td>
<td>0067</td>
<td>60 to 80+</td>
<td>*****</td>
<td>7-9</td>
</tr>
<tr>
<td>Air Bubble Jet</td>
<td>Low Pressure Air Induced</td>
<td>Yes</td>
<td>01</td>
<td>30 to 60+</td>
<td>***</td>
<td>5-7</td>
</tr>
<tr>
<td>Greenleaf AirMix</td>
<td>Low Pressure Air Induced</td>
<td>Yes</td>
<td>005</td>
<td>30 to 60+</td>
<td>***</td>
<td>5-7</td>
</tr>
<tr>
<td>Lechler IDK / Hardi MiniDrift</td>
<td>Low Pressure Air Induced</td>
<td>Yes</td>
<td>015</td>
<td>30 to 60+</td>
<td>***</td>
<td>5-7</td>
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<tr>
<td>TeeJet AIXR</td>
<td>Low Pressure Air Induced</td>
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<td>5-7</td>
</tr>
<tr>
<td>Hypro Ultra Lo-Drift</td>
<td>Low Pressure Air Induced</td>
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<td>015</td>
<td>30 to 60+</td>
<td>****</td>
<td>5-7</td>
</tr>
<tr>
<td>TeeJet TTI</td>
<td>Low Pressure Air Induced</td>
<td>Yes</td>
<td>015</td>
<td>20 to 100</td>
<td>*****</td>
<td>7-9</td>
</tr>
<tr>
<td>Greenleaf TurboDrop, XL</td>
<td>Medium to High Pressure Air Induced</td>
<td>Yes</td>
<td>005</td>
<td>40 to 80+</td>
<td>****</td>
<td>6-8</td>
</tr>
<tr>
<td>Albuz AVI</td>
<td>Medium to High Pressure Air Induced</td>
<td>Yes</td>
<td>015</td>
<td>45 to 80+</td>
<td>****</td>
<td>6-8</td>
</tr>
<tr>
<td>TeeJet AI</td>
<td>High Pressure Air Induced</td>
<td>Yes</td>
<td>015</td>
<td>60 to 80+</td>
<td>*****</td>
<td>7-9</td>
</tr>
<tr>
<td>Lechler ID / Hardi InJet</td>
<td>High Pressure Air Induced</td>
<td>Yes</td>
<td>01</td>
<td>60 to 80+</td>
<td>*****</td>
<td>7-9</td>
</tr>
<tr>
<td>TeeJet TwinJet</td>
<td>Twin</td>
<td>No</td>
<td>01</td>
<td>30-60</td>
<td>*</td>
<td>3</td>
</tr>
<tr>
<td>TeeJet DG TwinJet</td>
<td>Pre-orifice Twin</td>
<td>No</td>
<td>015</td>
<td>30-60</td>
<td>**</td>
<td>3-5</td>
</tr>
<tr>
<td>TeeJet Turbo TwinJet</td>
<td>Pre-orifice Twin</td>
<td>No</td>
<td>02</td>
<td>20-90</td>
<td>***</td>
<td>5-7</td>
</tr>
<tr>
<td>Albuz AVI Twin</td>
<td>Air-Induced Twin</td>
<td>Yes</td>
<td>01</td>
<td>45 to 80+</td>
<td>****</td>
<td>6-8</td>
</tr>
<tr>
<td>Hypro TwinCap, others</td>
<td>Can accommodate most nozzle types depending on need</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Top Questions Asked by Producers About Nozzles

1) Which low-drift nozzle should I put on my sprayer?
   • That question is best answered with more questions:
     − What pressure is your sprayer capable of? (There are low- and high-pressure versions, Table 1)
     − What carrier volume do you use? (Use low-pressure air-induced or pre-orifice nozzles for < 6 gpa)
     − What is your travel speed range? (Use low pressure nozzles for greater range of speeds)
     − What is your tolerance to drift? (High pressure nozzles give better drift control, even at high pressures)
     − Do you use Group 1 or 10 products, contact modes of action, or consider grassy weeds a serious problem? (use higher pressures and volumes with any nozzle)

2) Why are your pressure recommendations different from those found in the manufacturers’ literature?
   • Manufacturers do not typically study the pesticide efficacy achieved with their nozzles. Instead, they limit themselves to measuring droplet size and pattern uniformity.
   • At catalogue pressures, the manufacturer feels that fan angles and patterns are acceptable. However, research has shown that low-drift nozzles lose some of their efficacy at low pressures even if the pattern looks OK. The main reason is that the spray simply becomes too coarse, and the pattern more variable, at the low pressures. The minimum pressures in our chart are for acceptable pesticide performance, based on research.

3) If lower pressure reduces drift, why do I need to have high pressure with air-induced nozzles?
   • Low pressures are a good way to reduce drift with conventional nozzles, but this can be dangerous with air-induced nozzles. High pressures are needed with these nozzles so that patterns are fully developed. They also provide flexibility in travel speed with rate controllers. Too low a pressure is the number one reason for poor performance with air-induced nozzles. Fortunately, drift reduction with air-induced nozzles at high pressures is still superior to conventional nozzles at low pressures.
   • Use a pressure that is in the middle of a nozzle’s recommended range. For example, if a nozzle is rated for 30 to 60 psi, aim for 45 psi. For an air-induced nozzle rated for 30 to 100 psi, aim for 60 to 70 psi. This approach gives you flexibility in travel speed when using a rate controller.

4) Do the air-vents on venturi nozzles ever get plugged, and if they do, what happens?
   • They rarely plug. If they do, the spray pattern gets a bit narrower and the spray gets a bit finer. Neither change is dramatic and spraying can continue. Normal nozzle inspection and cleaning is sufficient.

5) Many of the new nozzles are plastic and ceramic. How do these compare to steel for wear?
   • There are many different types of plastic materials used in nozzles. They wear at least as well and usually significantly better than steel. Care should be taken when cleaning, as they can deform irreversibly. Ceramic is the most wear-resistant material available, and can last 10-times longer than steel.

6) Do I need air-induction or can I just use low-pressure conventional sprays?
• Air-induction provides much more drift reduction than any comparable technology, even at high pressures. A low pressure conventional spray is not as coarse as an air-induced spray and many of the pre-orifice sprays. Nonetheless, lower pressures are still a good way to reduce drift. Air induction seems to improve spray retention on grassy weeds compared to same-sized droplets without air.

7) Should I get shrouds or low-drift nozzles to control drift?
• Nozzles are less expensive than shrouds per foot of boom (about half). With shrouds, finer conventional nozzles can be used if the user is nervous about the efficacy of pesticides with coarser sprays. Air-induced nozzles provide similar drift control, depending on the shroud and the nozzle. Both can be used together.

8) Is more coverage better?
• First we have to clarify the words: coverage usually means how much target area is covered by the spray. Greater coverage can be achieved with higher water volumes or making the application with smaller (and therefore more abundant) droplets. More coverage does not mean more dose, just more area covered with the same dose.
• It’s important to achieve a certain minimum amount of coverage for most products, although that amount depends on the product and the pest in question. If we are below that minimum amount, there is a significant benefit to improving coverage. But if we are already above that amount, any additional increase in coverage has minimal returns. If more coverage were always better, we’d all be spraying with mists.
• It is true that the goal is to get as much product on the target as possible. In the simplest terms, the more product on the target, the higher the dose, and the greater the effect. Getting more dose on the target isn’t as simple as using smaller droplets. The right droplet size depends on the target and the pesticide. Sometimes larger droplets are the most effective way to hit a target.

9) Don’t coarser droplets reduce coverage?
• Yes, they can, but it’s not important at reasonable water volumes. In most cases, coverage is very similar, and efficacy is the same for broadleaf herbicides and fungicides at label volumes (5 to 10 gpa). Grassy herbicides require some caution – don’t use a combination of very coarse sprays and low carrier volumes, and do maintain those higher pressures. Droplet number per square inch is more important than droplet size for determining efficacy. Pressure and volume should be adjusted to maintain at least 300 - 500 drops / square inch on water-sensitive paper, or 10-15% coverage.

10) Some nozzle manufacturers advertise that their nozzle gives larger and more uniform droplets, better coverage, and can be used at lower volumes than other nozzles. Is this true?
• No. Low-drift nozzles are designed to reduce drift, and they do this by eliminating many of the finer droplets and replacing these with larger ones. Therefore, a low-drift spray reduces the number of droplets available for coverage. In practice, this is offset by maintaining a higher carrier volume and optimizing pressure for the specific nozzle. If you want to reduce water volumes significantly, you need to use finer sprays to keep droplet number up. But you can compromise. Use a reasonable water volume (5 to 7 gpa) and an intermediate low-drift nozzle such as a low-pressure air-induced at 60 psi. You will have 70% less drift, but equivalent efficacy.

11) Is air assistance any good?
• Yes, air assistance is great for increasing dense canopy penetration. This means it can be useful for fungicides and insecticides, but is not necessary for herbicide application.
Although some claim that air-assistance can reduce herbicide rates, most of this effect is attributable to lower carrier volumes and very fine sprays. Older air-assist technologies can increase spray drift significantly. Newer technologies can reduce drift and improve coverage.

12) What nozzle is best for reducing herbicide rates?
- Success at reducing herbicide rates depends more on good agronomy than on a specific nozzle. Research, and experience, has shown that the following conditions favour the reduction of herbicide rates:
  - a competitive, vigorous, healthy crop (seeding practice, fertilizer placement, cultivar choice)
  - early crop emergence relative to weeds
  - small weed staging at spraying time
  - favourable growing conditions around spraying time
  - a strong, efficacious herbicide product for the weeds in question
- If these conditions are met, almost any application method will allow some rate reductions. If they are not, application method will not rescue a difficult weed problem.
- Think of nozzles not as tools for increasing efficacy, but as tools for doing the job in an efficient and timely manner. Low-drift sprays reduce your sensitivity to wind conditions, providing more opportunity to do the job on time. In pest control, timing is everything.

13) If aerial application can get away with 2 to 4 gpa for fungicides, why do I have to use 10 to 15 gpa with a ground sprayer?
- For fungicides, more water is usually better. Both aerial and ground sprays use as much water as economically and practically justifiable in each case. Aircraft can apply sprays in a more timely manner under some conditions, which can be more important than carrier volume.

14) How do I get rid of sprayer tracks?
- Sprayer tracks are hard to get rid of. Fast travel speeds, heavy sprayers, and dusty conditions appear to be the culprits. Some strategies involve placing higher flow-rate nozzles behind the wheels, moving the boom back away from the wheels, adding nozzles behind the wheels, or travelling slower.

15) How far can spray drift move?
- Fine spray droplets can move for many miles under the right conditions. They move farthest during temperature inversions (night or early morning) because high humidity keeps them from evaporating and calm air keeps them from dispersing. Topography is also important, as drift will follow low-lying areas. Windy conditions actually help disperse the spray. When it’s windy, a greater proportion of the spray will drift, but it also gets diluted rapidly.

16) How low can I go with water volumes and still get good results?
- The secret to using low water volumes is that coverage is maintained. Since lower volumes result in less water available per square inch, applying this water in smaller droplets compensates. That is fine as long as drift can be managed. Low water volumes typically reduce the effect of hard water. Unfortunately, canopy penetration and overall consistency can be reduced when water volumes are reduced too low. I would not recommend that less than 5 gpa be used for any product other than glyphosate. Remember, water is a relatively cheap input and it offers significant returns in terms of a quality job.
17) Can I use low drift nozzles with all my chemicals?

- Yes, as long as all the other guidelines (appropriate water volume and spray pressure) are followed. Among herbicides and weeds, broadleaf weeds and Group 2 and 4 herbicides can actually work better with coarser sprays. Grassy weeds and Group 1 herbicides prefer finer sprays. A Group 1 and Group 2 tank-mix can be applied with a Coarse to Very Coarse spray but water volume should be kept above 7 gpa.

18) Should I point my nozzles forward or backward or both?

- Canopy penetration is best when nozzles are pointed backwards. Coverage of vertical targets such as wheat heads or grassy weeds is best when nozzles are pointed forwards. Using a double nozzle provides the best of both worlds, but they work best with a coarse spray. Using a double nozzle with a fine spray mostly increased drift potential with few other benefits. Double nozzles are available in conventional sprays (TeeJet TwinJet), as an air-induced spray (Albuz AVI Twin), or can be custom configured using the Lurmark TwinCap or swivel nozzles.

19) How do I know what droplet size my nozzles are producing?

- All hydraulic and air-shear nozzles produce a wide range of droplet sizes, usually from 10 to 1000 µm. It’s the proportion of the volume in each size fraction that differs.
- Nozzle manufacturers may quote a droplet size number. This is usually the VMD, or volume median diameter (the diameter below which contains 50% of the total volume of the spray).
- Nozzle manufacturers now publish spray quality charts that identify the ASAE spray quality. These charts are available in catalogues or on-line. For examples, see
  - www.teejet.com/techcent/catalog_english/techinfo.pdf
  - www.turbodrop.com/chart_asae.html
  - www.hardi-international.com/huk_trade/sqc.html
  - www.wilger.net (enter site and select tip wizard)

Four Rules of Nozzle Selection

1. Choose the best nozzle type for your needs (see above for more details)
   a. Conventional Flat Fan
   b. Pre-Orifice
   c. Low-Pressure Air Induced
   d. High Pressure Air Induced

Determine your priorities before choosing a nozzle: Better drift control? (b,c,d). Best pressure range? (b,c). Lower water volumes? (a, b). All nozzles will give very good results provided you use them properly (see below).

2. Match water volume to spray quality

The coarser your spray, the higher your water volume must be. There are two main reasons for this. (i) you must have enough droplets per square centimetre to hit your target. This is most critical for pre-seed burnoff, where weeds are smallest, and low-volume, coarse sprays will likely miss weeds entirely. (ii) you need sufficient coverage on your target for the pesticide to do its job. This is most important for contact herbicides such as bromoxynil, glufosinate, and diquat, and for insecticides and protective fungicides. It is also important for grassy weeds, most of which have a hard time retaining very large droplets. Use at least 5 to 7 gpa for in-crop herbicides, 10 to 12 gpa for fungicides.
3. **Know and use the right pressure for your nozzle**
   Even a good nozzle won’t work well at the wrong pressure. Air-induced nozzles and some pre-orifice nozzles require higher pressures to operate properly. The most common reason for performance complaints is when the spray pressure of a low-drift nozzle is too low, resulting in poor spray distribution between nozzles (see next point). If your sprayer cannot produce sufficiently high pressures, you should not be using these nozzles. Try to do most of your spraying at these pressures: Conventional, 20 – 50 psi, pre-orifice, 30 – 60 psi, low-pressure air-induced, 40 to 60 psi, high pressure air-induced, 60 to 80 psi. Higher pressures increase drift potential, but less so for pre-orifice and air-induced nozzles.

4. **Ensure good patterns**
   Whereas finer sprays from conventional nozzles can re-distribute themselves with wind or turbulence, covering up poor patterns, the coarser droplets produced by low-drift sprays will go where they’re pointed. Therefore, there is only one chance to get uniform coverage across the boom. For coarse sprays, try to achieve a nozzle pattern width that is twice your nozzle spacing at the target height. Do this by selecting wider angle nozzles, increasing pressure, or adjusting boom height. This will ensure that the coarsest droplets at the pattern edge are mixed in with the more abundant, finer droplets found in the middle of a pattern.