

SPRAY NOZZLE DEMONSTRATION CURRICULUM

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SPRAY NOZZLE DEMONSTRATION CURRICULUM

OVERVIEW

This curriculum has been developed as a resource for those who would like to educate participants on the function and challenges associated with different nozzles that are used in common agricultural sprayers. This curriculum focuses on two main aspects of agricultural sprayer nozzles: how they function, and how to determine if they are functioning properly. Participants will learn that nozzle wear leads to

deviations in spray pattern and rate (gallons per minute; GPM) from the indicated manufactured output. They will also learn the difference between hollow cone disc-core, one-piece (also called molded), and air induction nozzles and their appropriate use. This curriculum should be used in conjunction with [Common Interchangeable Nozzles for Perennial Crop Canopy Sprayers](#) (McCoy et al. 2020).

INTRODUCTION

Nozzles are used in most agricultural spray applications (e.g., pesticides, foliar fertilizers, sun protection, hormone application), and many agricultural sprayers allow for the use of interchangeable nozzles to accommodate customization for those different applications. Nozzle type affects spray attributes like droplet size and distribution pattern. This curriculum uses a tabletop demonstration box to allow participants to see and understand different uses and attributes of nozzles. The nozzle spray patterns covered in this curriculum

are flat fan and hollow cone. Three different nozzle designs, the disc-core, one-piece, and air induction, are also used for demonstrating different nozzle types. This curriculum could be adapted to include other nozzles and spray patterns, if applicable, for the audience. Key learning objectives include (1) understanding why nozzle wear negatively impacts sprays, (2) understanding how nozzles and droplet size affect spray drift, and (3) being able to identify when different spray patterns are best used in agricultural settings.

HOW THE CURRICULUM IS ORGANIZED

The materials list and instructions for delivering the content is divided into an overall pre-lesson preparation as well as individual lesson pre-preparation. This format is meant to support

instructors who are not as versed in nozzle technology or function. Reading through these materials as well as the lessons before delivery is critical to successful presentation of the curriculum.

Curriculum Details

Prep time: 40 minutes.

Activity time: each of the three lesson will last approximately 15–20 minutes.

Materials List		✓
1.	Handout for participants: Common Interchangeable Nozzles for Perennial Crop Canopy Sprayer (McCoy et al. 2020).	
2.	Table that can support 100 lb (recommended size of four feet by six feet).	
3.	Flat-head screwdriver.	
4.	Tweezers or forceps (optional).	
5.	Two plastic cups, preferably clear or see-through.	
6.	Tabletop nozzle demonstration box, preferably one that has the capability of running two nozzles at once. Commercially available products (with examples below) include: AAMS-Salvarani Nozzle Demo Unit (Figure 1A), TeeJet Spray Demonstration Tank (Figure 1B), or SpotOn Portable Spray Case (Figure 1C). a. Access to power source and an extension cord if that power source is farther than two feet from the tabletop nozzle demonstration box. b. Three gallons of potable water. Buckets or containers should be used for filling the unit. Check ahead to ensure availability of water. Water makes the unit heavy. Add water to the demonstration box once it is on the table. Do not attempt to carry the demonstration box while full. Be prepared to fill and drain at or near the location of the class.	
7.	Black light strobe unit. Strobe lights are on some models of demonstration boxes (Figure 2). If box is not equipped with a strobe light, there are other commercially available products that can be used as a supplemental strobe light (an example of a commercial black light strobe unit that can be purchased: GKG UV Flashlight with three light modes).	
8.	Water sensitive paper (WSP). WSP is a yellow paper that turns blue with moisture (Figure 3). A total of 20 cards (5 per nozzle) at a minimum size of one inch by one inch are needed, but larger pieces of WSP are better for visualization. Total number of cards suggested accounts for error in collecting droplets during the demonstration. WSP can be purchased at many online stores like Sprayer Depot, Gempler's, and TeeJet. When handling WSP, wear gloves, because moisture or oils from your hands can leave blue spots or fingerprints on the cards. Store unused WSP in plastic bags or a sealed container in a dry location.	
9.	Handheld patternator, such as SpotOn Mini Patternator (Figure 4). Patternators provide a visualization of where spray is being directed. A handheld patternator is also included in the SpotOn Master Applicator Kit.	
10.	Nozzles. Purchase a minimum of three nozzles: one for the demonstration box and two for passing to participants to physically handle during the demonstration. Nozzles used in each lesson are listed before the lesson. All nozzles and operating guidelines are found in Table 1. If suggested nozzles are not available, use ones that are comparable in flow rate (GPM). Visual examples of nozzle types can be found in Table 2 of WSU Extension publication Common Interchangeable Nozzles for Perennial Crop Canopy Sprayers (McCoy et al. 2020).	

Materials List Examples

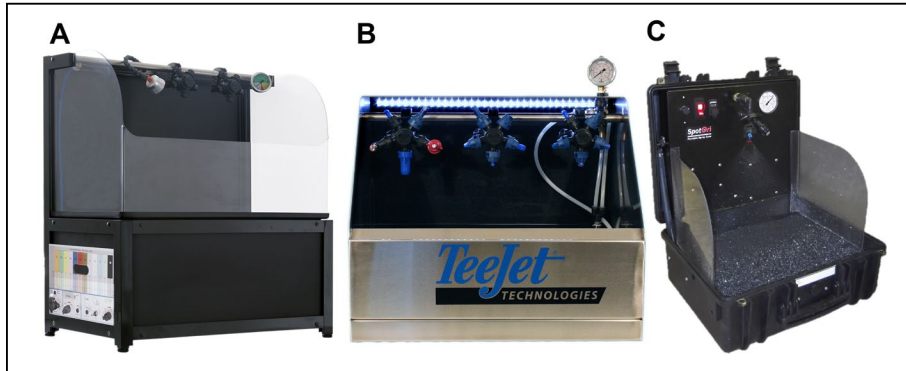


Figure 1. Three examples of spray demonstration units: [AAMS Nozzle Demo Unit](#) (A), [TeeJet Spray Demonstration Tank](#) (B), [SpotOn Portable Spray Case](#) (C). Any unit is acceptable, but it is easier for the lessons if there are at least two nozzle body wheels. Photos used with permission from AAMS-Salvarani, TeeJet Technologies, and SpotOn by Innoquest Inc, respectively.

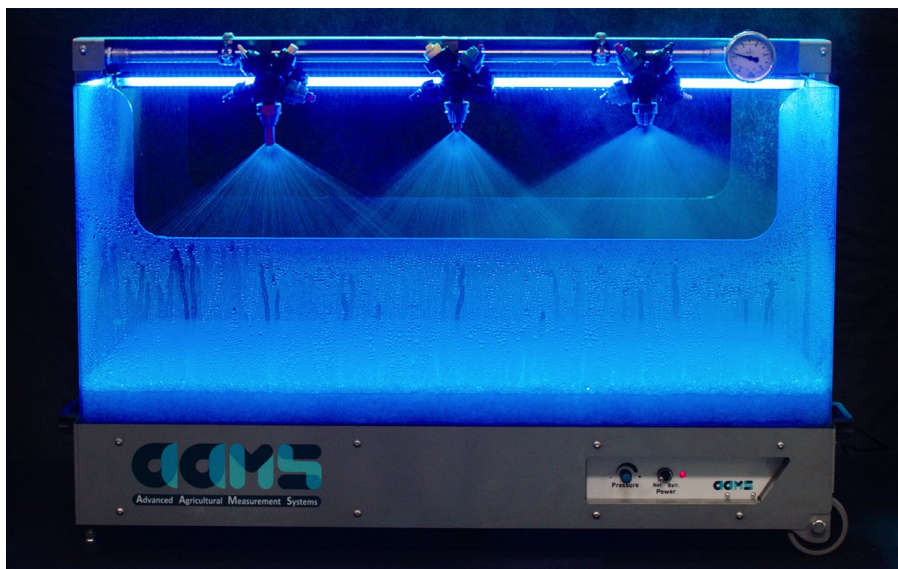


Figure 2. Example of an LED light integrated into the demonstration box. Photo used with permission from AAMS-Salvarani.



Figure 4. SpotOn Mini Patterator, sold by Innoquest Inc. (<https://innoquestinc.com/product/spoton-mini-patterator/>), is an example of a handheld patterator. Photo used with permission from SpotOn by Innoquest Inc.

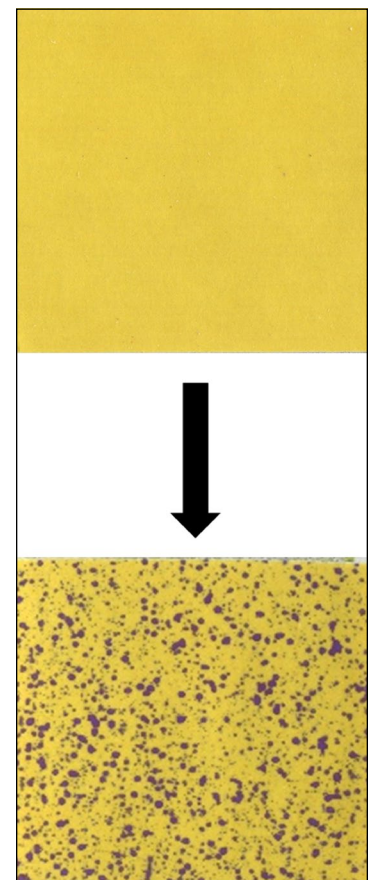


Figure 3. Water sensitive paper is yellow and turns blue when liquid contacts the paper surface. It allows for easy visualization of deposition and spray patterns. Photos by Margaret McCoy.

CURRICULUM OBJECTIVES

Lesson 1: Influence of Nozzle Wear on Nozzle Output and Pattern

New nozzles versus worn nozzles:

Demonstrate how worn nozzles can (1) increase the expected nozzle rate (GPM), leading to greater costs from overapplication, and (2) change spray pattern. This is done by using strobe lights and mini-patternator to compare output and patterns between good and worn nozzles of the same nozzle type.

Lesson 2: Influence of Nozzle and Pressure on Droplet Size and Drift

One-piece nozzles versus disc-core nozzles:

Demonstrate how nozzle design and operating pressure can influence droplet size and spray drift. This is done by comparing a one-piece nozzle to a disc-core nozzle at different operating pressures with the use of the strobe light and WSP for spray visualization.

Lesson 3: Influence of Nozzle on Droplet Size and Drift

One-piece nozzles versus air induction nozzles:

Demonstrate larger droplets from air induction nozzles, their effect on drift, and the droplet pattern created on the target. This is done by comparing spray from a one-piece nozzle and spray from an air induction nozzle at the same operating pressure, using the strobe light and WSP for spray visualization.

PRE-LESSON PREPARATION

1. **IMPORTANT!** Set up the table for the nozzle demonstration box, and only fill the demonstration box water reservoir after the box has been set on the table. Check to ensure the demonstration box has power and the strobe light is functioning. Have all the nozzles already in the rotating nozzle body in the demonstration box or nearby on the table during the demonstration.
2. It is highly recommended to have additional nozzles (reflective of those that are being demonstrated) so they may be passed around by the participants during the lesson.

Table 1. Example nozzles with model name, number, operating pressure, flow rate, and droplet size. The lessons associated with each nozzle type are indicated. Multiple manufacturers are provided for choice but not required for the lessons. Choose a manufacturer, and purchase three ceramic nozzles of each nozzle type for the associated lessons, along with one additional metal disc-core from that same manufacturer.

Nozzle Type	Model Name	Model Number	Spray Pattern	Pressure (psi)	Flow Rate at psi (GPM)*	Droplet Size*	Lesson
TeeJet							
Flat fan	VisiFlo flat fan	TP8002	flat fan 80°	40	0.200	fine	1**
One-piece (molded)	Conejet VisiFlo	TX-VK6	hollow cone	80	0.137	very fine	2 & 3
		TXA8001VK or TXB8001VK			0.139		
Disc-core	disc-core spray tips	DCER-2 with DC23-CER	hollow cone	80	0.140	not specified	2
Air induction	AITX Conjet	AITXA8001VK or AITXB8001VK	hollow cone	80	0.138	very coarse	3
Pentair Hypro							
Flat fan	AXI 80°	AXI-8002	tapered 80° flat fan	40	0.200	fine	1**
One-piece (molded)	ATR 80°	ATR-BROWN	hollow cone	80	0.133	very fine	2 & 3
Disc-core	ceramic disc & cores 13°–93°	DCC-02 with CRC-23	hollow cone	80	0.140	not specified	2
Air induction	ceramic TVI 80°	TVI-800075	hollow cone	80	0.106	extra coarse	3
Any Manufacturer							
Disc-core	disc-core (metal)	D5 disc with 23 or 45 core	hollow cone	Not to be used in the tabletop demonstration box; visual purposes only of metal nozzle.			2

* GPM = gallons per minute. Flow rate and droplet size can change if different pressures are used. Droplet size is classified by the American Society of Agricultural and Biological Systems Engineers in their online resource [Droplet Size Classification](#) (ASABE 2009). ** Two sets of flat fan nozzles will be required. One will be untouched and the other will be "worn."

LESSONS

Lesson 1: Influence of Nozzle Wear on Nozzle Output and Pattern

New Nozzles versus Worn Nozzles

Pre-lesson preparation:

1. Three new and three damaged flat fan nozzles (see Table 1) will be needed for Lesson 1. The best approach to quickly causing damage to the nozzle that reflects long-term wear caused during spraying is to wiggle a sharp object (e.g., a screwdriver, knife) inside the orifice opening of the nozzle. Easily visible signs of damage do not need to be present to induce irregular spray patterns for the lesson. One set of nozzles will be used for the demonstration box, additional nozzles will be passed around to participants for observation.
2. If you have two rotating nozzle body assemblies, place the new nozzle in the left assembly and the worn in the right assembly so that both can be operated simultaneously

Summary of Steps

1. Comparing spray patterns and output of a new versus worn nozzle.
2. Using mini-patternator to show streaking and poor pattern in worn nozzles.
3. Showing that signs of wear are not always visible on the nozzle.

Lesson Instructions

Step 1—Turn on the pump and raise pressure on the demonstration box to 40 psi (pounds per square inch). Be sure to mention that the nozzles are identical and should produce the same pattern (flat fan) and the same flow rate (GPM). Turn on the strobe light to show the spray pattern of the nozzles. Wait a few moments for participants to look at the two outputs. *Ask them the discussion questions 1 through 3 from Lesson 1, Step 1*, and have them share their observations. Then use two clear plastic cups to collect water simultaneously for a few seconds. Put the cups on the table, below each corresponding nozzle. *Ask question 4* about the output of the nozzles. Turn off the strobe light at the end of this demonstration as it can be bothersome and is not needed for the next step.

Lesson 1, Step 1

Discussion questions for participants:

1. Do you see any noticeable *differences in the nozzle output pattern* between the two nozzles? Describe the differences.
2. If you see differences, why would these types of *patterns or differences be occurring*?
3. Could you tell that the *output patterns were different* with your naked eye?
4. What do you notice about the output of water in each cup? Which cup has more water (higher output) and why do you think that is?

What to look for and explain:

The “good” (new) nozzle will have a consistent and uniform fan pattern. The “bad” (worn) nozzle will appear to have streams of liquid in certain areas. The “bad” (worn) nozzle will have a higher output relative to the “good” (new) nozzle; this would translate into overapplication of pesticides or fertilizers in the field. This essentially equates to more product being applied. Most changes in nozzle output are not discernible to the naked eye, but when using simple tools such as cups to measure the output, the visual difference becomes much easier to see. You can even ask participants to guess the percentage more in each cup and then say that it equates to the same percent increase in their chemical bill since more was applied. Clogged nozzle orifices can operate in reverse and lower the expected outputs.

Step 2—Use the handheld patternator to show how the nozzle output pattern is different. Rotate one nozzle to turn it off, then collect water by placing the patternator under the remaining nozzle that is on, far enough away from the nozzle to allow for all collection tracks to receive water (minimum one foot from nozzle body). It should only take about 15 seconds to fill, so remove quickly. Rotate the patternator up so that the small balls float to the top (Figure 5). This may take a few attempts to get a decent pattern, and you should practice before the demonstration. *Ask discussion question 1 from Lesson 1, Step 2.* Repeat patternator collection for the other nozzle. *Ask discussion questions 1 to 3.*

Lesson 1, Step 2

Discussion questions for participants:

1. How are the balls aligned, in a pattern or random?
2. Do you see any noticeable differences in the spray collection? Describe the differences.
3. How would the altered output pattern influence spray deposition onto different parts of the target?

What to look for and explain:

Worn nozzles affect the spray pattern and can cause more output to one area of the target and less to another area of the target (i.e., “banding”). This is seen with the different heights of the balls in the worn nozzle. Worn or damaged nozzles not only cause overapplication as seen in the previous step but also a poor spray pattern, leading to streaks and poor coverage.

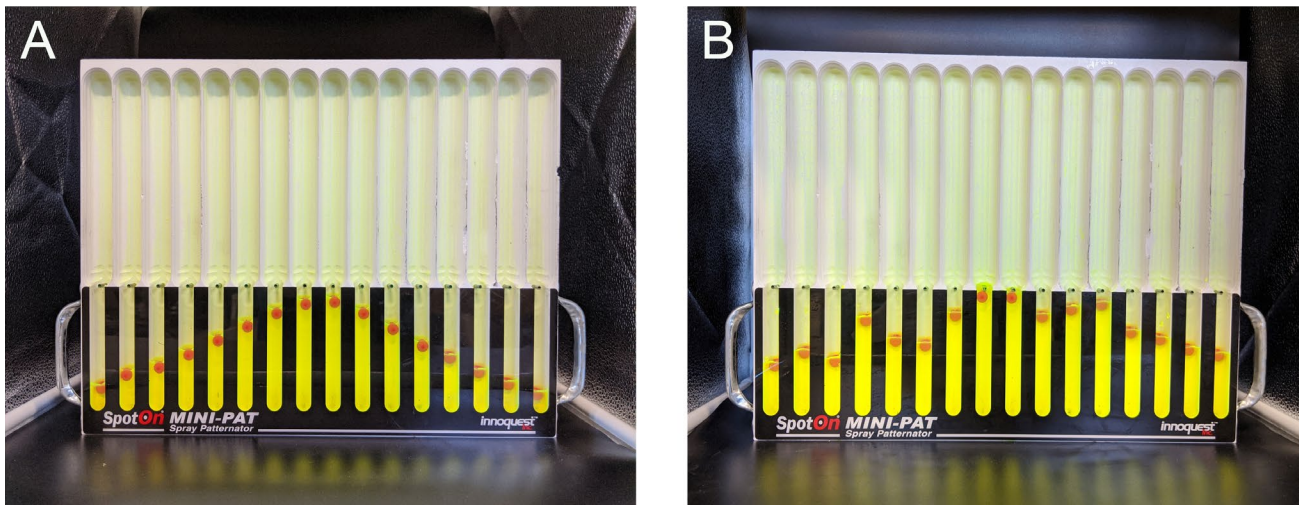


Figure 5. Examples of what new (A) and worn (B) nozzle output look like using a handheld patternator. Photos by Margaret McCoy.

Step 3—Pass around the spare nozzles used in the demonstration box or an example set of undamaged and damaged nozzles so participants can visually compare the damaged and new nozzle. *Ask the discussion questions listed for Lesson 1, Step 3.*

Lesson 1, Step 3

Discussion questions for participants:

1. Can you tell which nozzle is worn?
2. Why is it important to know when a nozzle is worn or not putting out the expected flow rate (GPM)?

What to look for and explain:

A damaged or worn nozzle often looks like a new nozzle, yet unseen changes can cause differences in output pattern and flow rate. Conversely, if your nozzles have decreased output, then check them to make sure there is nothing blocking the orifice. It is important to remove and clean nozzles after each use. Nozzle output should be checked prior to first use, and at least once per season. You should consider replacing nozzles annually. A discussion on nozzle material (brass, stainless steel, or ceramic) strength could be had here. Reference the *Common Interchangeable Nozzles for Perennial Crop Canopy Sprayers* publication from McCoy et al. (2020).

Tools to measure nozzle output include commercially available flow meters, such as the one from SpotOn. Monitoring nozzle output is key to not over or under applying materials during a spray application.

Lesson 2: Influence of Nozzle and Pressure on Droplet Size and Drift **One-piece versus Disc-core Nozzles**

Pre-lesson preparation:

1. Three of each nozzle will be needed: one-piece, ceramic disc-core, and metal disc-core (see Table 1 for more information), selected for similar flow rate and from the same manufacturer. One set of ceramic disc-core and one-piece nozzles will be used in the demonstration, the other two set of those nozzles will be used as spares for taking apart and to pass around to the participants. All of the metal nozzles will be for the audience to examine and will not be in the demonstration box.
2. Screwdriver needed for one-piece nozzle disassembly.
3. If you have two rotating nozzle body assemblies, place the one-piece nozzle in the left assembly and the disc-core nozzle in the right assembly so that both can be operated simultaneously.

Summary of Steps

1. Observing physical differences of metal and ceramic disc-core nozzles.
2. Observing and comparing physical appearance of one-piece nozzles with disc-core.
3. Examining spray appearance of disc-core and one-piece.
4. Using WSP to examine droplet size and pattern of disc-core and one-piece.
5. Raising pressure to see the effect on droplet size and drift.

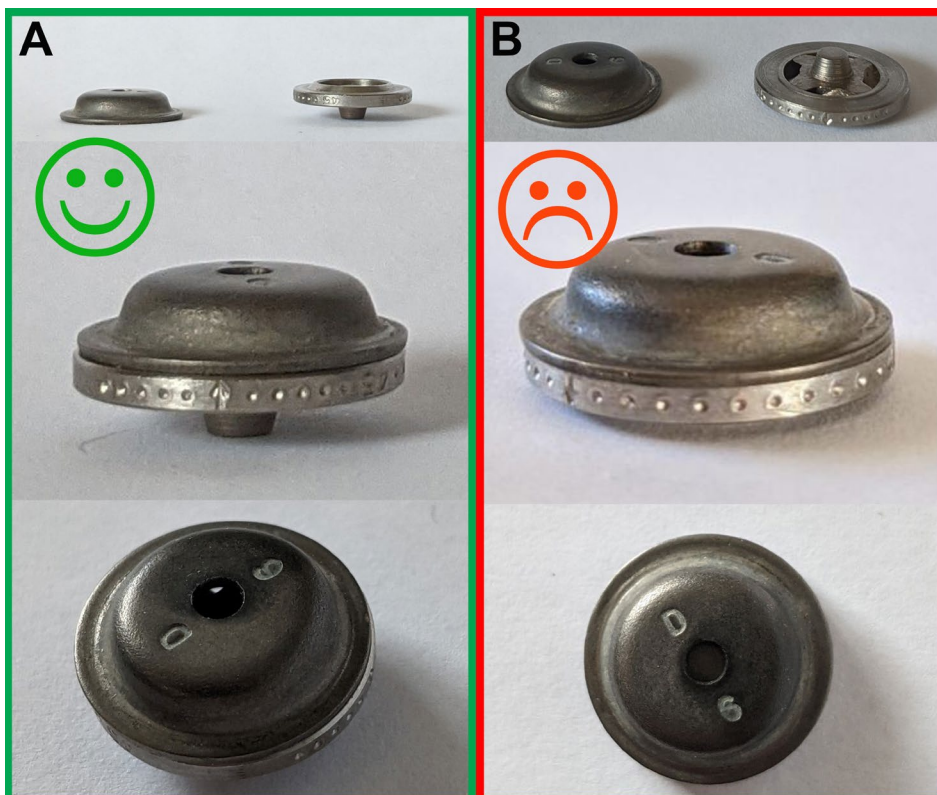


Figure 6. Examples of what correct fitting (A) and incorrect fitting (B) of disc-core nozzles look like with metal nozzles. The disc is the dome-shaped piece, and the core is the flat piece with a small nub (or nipple) at the bottom. Photos by Margaret McCoy.

Lesson Instructions

Step 1—Pass around the extra sets of metal and ceramic disc-core nozzles to participants. *Ask the discussion questions listed for Lesson 2, Step 1.* Grab the spare metal disc-core nozzle pieces. Be sure not to place them together as you describe the different components of the pieces (disc, core, nipple/nub, very small numbers that indicate model numbers). Now ask participants to correctly put the disc-core together. Note: putting the disc-core together correctly means that the nub (also called a nipple) of the core is pointing in the opposite direction of the disc's orifice opening (Figure 6). *Ask context questions listed for Lesson 2, Step 2.*

Lesson 2, Step 1

Discussion questions for participants:

1. Which way should the nipple point in a brass or stainless-steel nozzle?
2. How easy is it to see the numbers on the disc and on the core?
3. Ask if they use brass, stainless steel, or ceramic nozzles. Try to solicit reasons for why they chose ceramic or metal.

What to look for and explain:

Metal and ceramic disc-core nozzles are made up of two separate pieces. Discs have one hole (size relatively small or large depending on the disc number). The core (also referred to as a spinner) will have either two or four holes. Metal cores have a raised nub or nipple that needs to be placed away from the nozzles. Participants will see that if the nub on the core is placed towards the disc, it blocks some of the orifice of the disc, resulting in incorrect rates and droplet sizes. Improper installation is common. Ceramic cores are free of nubs and inserted directly into the disc. The disc and core are also numbered. It is much harder to see the small print on metal disc and core sets than it is to see on the ceramic sets, and it is even more difficult to read the numbering when the nozzles are worn and discolored from use.

Disc-core nozzles can be made from brass, stainless steel, plastic, or ceramic. Based on their resistance ratio, the brass nozzles are more prone to wear than ceramic (see McCoy et al. [2020] for more details), leading to overapplication seen in Lesson 1. However, ceramic nozzles are prone to cracking if the nozzle body is overtightened on the sprayer. Many people suggest to hand tighten the nozzle nuts when using ceramic nozzles as opposed to using a wrench.

Step 2—Now pass around extra one-piece nozzles and hold one of the nozzles in each hand. Ask the discussion question listed for Lesson 2, Step 2. After discussing observations, take a spare one-piece nozzle apart using a flat-head screwdriver to show that it houses the same technology as the two-piece disc-core.

Lesson 2, Step 2

Context question for participants:

1. Ask if any of the participants have used a one-piece nozzle and solicit their experiences, likes, and dislikes.

What to look for and explain:

This activity highlights material differences and how one-piece nozzles use the same technology as disc-core nozzles but have been incorporated into a single piece. One-piece nozzles are being used more frequently in agricultural canopy sprayers because of useful characteristics such as ease of identifying the nozzle (color of the body), ease of noticing when one has broken off or has been damaged and needs to be replaced, and the longevity or higher tolerance to abrasive materials because they are of ceramic construction. Many find that the longevity of ceramic one-piece nozzles, and their ease of installation, far outweigh their added cost (McCoy et al. 2020). Additionally, many newer sprayer models are recommending the use of one-piece nozzles over disc-core.

In contrast to the small print on disc-core nozzles, one-piece nozzles are colored, so they give a greater visibility from far away, and the color contrast with the printed information on the nozzle makes smaller lettering easier to read. One-piece nozzles are actually made of two pieces but are screwed together to create a component that can be installed easily. The material of the outside portion of the nozzle is plastic and the internal working parts of the nozzle are ceramic. (*Note:* some manufacturers also sell a stainless-steel internal component.) The colored exterior plastic matches that of the nozzle catalog information, and, for some manufacturers, the color indicates flow rate. The one-piece nozzle is larger than the disc-core and sticks out slightly from the nozzle body on the sprayer table demo box.

Step 3—Return to the demonstration box. Turn on the demonstration box water pump and strobe light, then raise the operating pressure on your associated demonstration box to 80 psi. Emphasize to the participants that both nozzles produce the same pattern (hollow cone) and have similar flow rate. *Wait a few moments for participants to look at the two nozzle outputs before asking them questions from Lesson 2, Step 3.*

Lesson 2, Step 3

Discussion questions for participants:

1. Do you see any noticeable differences in the spray droplets? Describe those differences.
2. Are there similarities?
3. Which nozzle looks like it is producing droplets that drift the most? Why do you think that is?

What to look for and explain:

When comparing the droplets from the two nozzles, there shouldn't be much difference, but participants may see somewhat smaller droplets produced by the one-piece nozzle and larger droplets produced by the disc-core nozzle. One-piece nozzles have "fine" or "very fine" droplets (60 to 145 μm and 145 to 225 μm , respectively; ASABE 2009) while the disc-core produces a broader range of droplets, and, thus, is uncategorized. In general, the larger the orifice in the disc, the larger the droplet. For reference, an average human hair is 100 μm .

Both nozzles are viable options for spray applications. Deciding which one to use could be a management choice that is based on target pest, comfort level of the person setting up or operating the sprayer, or availability of nozzles through local suppliers. Disc-core nozzles have historically been widely used, but they are less precise in droplet output than the one-piece nozzles.

Step 4—Use water sensitive paper (WSP) to show how droplet size and spray pattern differ between the one-piece and disc-core nozzles. This may take a few attempts since the WSP will likely become oversaturated with droplets if placed too close to the nozzle orifice. The best approach includes taking a piece of WSP, holding it with a tweezer or forceps, and very quickly passing the paper through the outer portion of the cone pattern. This allows for a less saturated WSP and gives decent droplet definition while still visualizing a representative droplet pattern for either nozzle (Figure 7). Repeat for the other nozzle type. *Once you have sprayed WSP for each nozzle, show the WSP to the participants and ask the discussion questions in Lesson 2, Step 4.*

Lesson 2, Step 4

Discussion questions for participants:

1. Ask participants if they see any noticeable differences in the spray droplet deposition and then have participants describe what those differences are.
2. Are there similarities?
3. Which one would you rather use in your sprayer? Why?

What to look for and explain:

Droplet size is important because not only do some chemical product labels specify a droplet size for a legal application, but droplet size also affects coverage and drift. Smaller droplets have a greater likelihood of drift as seen when looking at these nozzles side by side. To comply with the label, you may need to apply the product with a nozzle that produces a certain range of droplet sizes.

Reminder:

- One-piece nozzles will have a finer droplet, which can be seen by the “mist” surrounding the nozzle when in use. These smaller, finer droplets have a higher likelihood to drift. However, one-piece nozzles are very precisely made, so the manufacturers know exactly what range of droplet sizes they produce at a given operating pressure.
- Disc-core nozzles will also have fine droplets, but less of the droplets will be as fine when compared to the one-piece nozzle. These nozzles are not made as precisely as the one-piece nozzle, so they do not produce droplets in a specified size range.

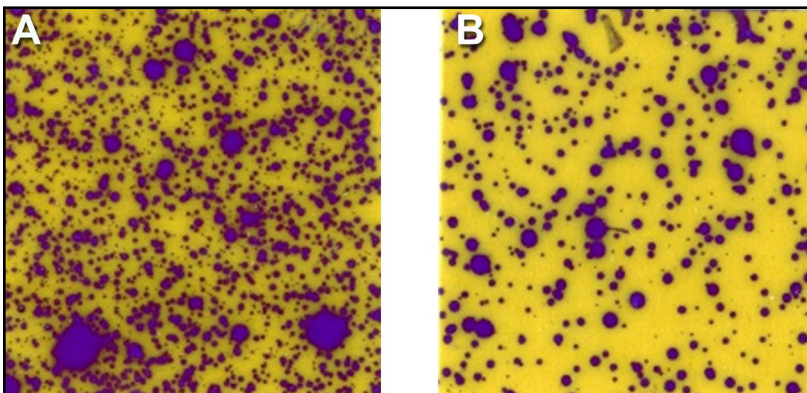


Figure 7. Water sensitive paper (WSP) sprayed with a one-piece nozzle (A) and a disc-core nozzle (B). The respective deposition pattern is representative of the droplet sizes created by each nozzle output. If the disc-core combination is changed, either in the demonstration or on a sprayer, the droplet sizes and coverage will change. Photos by Margaret McCoy.

Step 5—Turn on the strobe light for the demonstration box. Raise the operating pressure to 120 psi. Wait for participants to observe how the increase in pressure changes the spray patterns of the one-piece and disc-core nozzles. Lower the pressure to 40 psi. Wait for participants to observe how the decrease in pressure changes the spray patterns of the one-piece and disc-core nozzles. Within a nozzle brand, the flow rate of the nozzle is linearly related to the operating pressure, so keep the same nozzle manufacturer when you change the pressure. *Wait a few moments for participants to look at the two outputs before asking them the discussion questions in Lesson 2, Step 5.*

Lesson 2, Step 5

Discussion questions for participants:

1. What are noticeable *differences in the spray droplets* as pressure is raised and lowered?
2. Are there *similarities between or within a nozzle* among the pressure settings?
3. Is *drift* still a concern as the pressures change? Why?

What to look for and explain:

Nozzles can operate at a wide range of pressures; however, pressure affects the nozzle output (droplet size and rate), which is key to knowing when certain nozzles may be more suitable than others. Typically, higher pressure creates smaller droplets and higher rates (GPM). Smaller droplets are more prone to drift and drift farther in windy conditions. Higher temperatures also cause droplets to evaporate and sometimes become smaller. Many growers will increase the pressure to slightly increase the rate. While this is an acceptable practice, it should not be done without considering the effect on droplet size and the typical weather conditions for applications. Weed sprayers exemplify the use of using low pressures (<40 psi) to help ensure larger droplets that do not drift herbicides onto desirable plants.

Lesson 3: Influence of Nozzle on Droplet Size and Drift

One-piece versus Air Induction Nozzles

Pre-lesson preparation:

1. Three each of the one-piece nozzles and air induction nozzles will be needed for Lesson 3, selected for similar flow rate (GPM) (see Table 1). The same brand or manufacturer is needed for these nozzle selections as there are minor variations in droplet sizes between different manufacturers. One set of nozzles will be used in the demonstration, the other two sets of nozzles will be used as spares for taking apart and to pass around to participants.
2. Screwdriver needed for one-piece nozzle disassembly.
3. If you have two rotating nozzle body assemblies, place the one-piece nozzle in the left assembly and the air induction nozzle in the right assembly so that both can be operated simultaneously.

Summary of Steps

1. Observing physical differences between air induction and one-piece nozzles.
2. Observing differences in spray pattern and droplet size of air induction versus one-piece nozzles.
3. Using WSP to examine droplet size and pattern of air induction and one-piece.
4. Changing pressure to see the effect on droplet size and drift of air induction and one-piece nozzles.

Lesson Instructions

Step 1—Pass around the extra set of air induction and one-piece nozzles among the participants. Mention that both nozzles produce the same deposition pattern (hollow cone) and a similar flow rate (GPM). Hold one nozzle in each hand and ask participants to tell you about the similarities, differences, and other observations between the two nozzle types (*discussion question 1 from Lesson 3, Step 1*). Take apart a spare one-piece nozzle using the flat-head screwdriver (if the one from the previous lesson is still disassembled, use that one). Take apart a spare air induction nozzle; make sure not to lose the ceramic core as these may become loose and fall out. Pass around the disassembled nozzles among the participants.

Lesson 3, Step 1

Discussion questions for participants:

1. What *similarities and differences* do you observe between these two nozzle types?

What to look for and explain:

Both of these nozzles use the same construction technology. They also share similar technology as that of the disc-core, but the air induction nozzle allows for air to be introduced to the stream of water traveling through the nozzle via the small holes on either side of the base of the nozzle. This additional air increases the size of the droplet. These larger droplets are less likely to drift due to increased drag on the droplet. It also causes droplets to shatter or splatter upon contact.

Below is an *inexhaustive list* of attributes participants may observe or share about the nozzles:

- *One-piece nozzles* have a singular body (until taken apart). The material of the outside portion of the nozzle is plastic and the internal working parts of the nozzle are ceramic. Some nozzle brands may have a stainless-steel internal component. The color of the exterior plastic is coordinated with color schemes in the associated manufacturer catalogs that can assist with nozzle selection. This color is also often associated with nozzle flow rate. The size of the nozzle orifice hole is larger in one-piece nozzles than disc-core nozzles and is surrounded by a white plastic ring. The one-piece nozzle is roughly the same size as the air induction nozzle and sticks out from the nozzle body on the sprayer. This is also noticeable in the demonstration box.
- *Air induction nozzles* also have a singular body (until taken apart). The exterior material of the nozzle is plastic, and the internal working parts of the nozzle are ceramic. When the nozzle comes apart, the inner core of the nozzle can fall out. You need to be aware of this if you have to take the nozzle apart to clean debris. The color of the exterior plastic is coordinated with color schemes in the associated manufacturer catalogs that can assist with nozzle selection. This color is also often associated with nozzle flow rate. There are two holes in the base of the air induction nozzle body where air is introduced to the stream of water to create air bubbles inside individual droplets. The orifice size of an air induction nozzle is larger than any of the nozzles in previous lessons.

Step 2—Return to the demonstration box and turn on the water pump and strobe light. Raise the operating pressure to 80 psi. Emphasize that both nozzles produce the same spray pattern (hollow cone) and have similar flow rate (GPM). *Wait a few moments for participants to look at the two nozzle outputs. Then ask them discussion questions from Lesson 3, Step 2.*

Lesson 3, Step 2

Discussion questions for participants:

1. Do you see any noticeable *differences* in the *spray droplets*? Describe those differences.
2. Are there *similarities*?
3. Which nozzle looks like it is producing droplets that *drift* the most? Why do you think that is?

What to look for and explain:

When comparing the spray pattern between the two nozzles, there should be a large visual difference between the size of the droplets (see Lesson 3, Step 1 “What to look for and explain”). These two nozzles, while visually similar, produce very different droplets.

Both nozzles are viable options for spray applications. Deciding which one to use could be a management choice that is based upon target pest, comfort level of the person setting up or operating the sprayer, or availability of nozzle type from local suppliers. Flat fan air induction nozzles are often used in weed and boom sprayers because of their drift mitigation properties, but they have been shown to drastically reduce drift in canopy sprayers as well.

Step 3—Use water sensitive paper (WSP) to show how droplet size and spray pattern differ between the one-piece and air induction nozzles. This may take a few attempts since the WSP will likely become oversaturated with droplets if placed too close to the nozzle orifice. The best approach includes taking a piece of WSP, holding it with a tweezer or forceps, and very quickly passing it through the outer portion of the cone pattern. This allows for less saturated WSP and gives decent droplet definition while providing a visual representation of droplet patterns for either nozzle (Figure 8). Repeat for the other nozzle type. *Once you have sprayed WSP for each nozzle, show them to the participants and ask the discussion questions from Lesson 3, Step 3.*

Lesson 3, Step 3

Discussion questions for participants:

1. Ask participants if they see any noticeable *differences in the spray deposition pattern or droplet size* and then describe what those differences are.
2. Are there *similarities*?
3. Which one would you rather use in your sprayer? Why?

What to look for and explain:

Many growers will not favor the spray pattern of an air induction nozzle because it looks like less coverage. However, it is important to remember that pesticide efficacy (how well it controls the pest) is not always related to droplet size but rather the amount of active ingredient in an area. When choosing a nozzle, it is important to also consider the mode of action of the pesticide. Many systemic products will perform well using an air induction nozzle, especially if a large portion of the droplets remained on the canopy and did not drift off target. When certain contact pesticides rely on complete spray coverage, air induction nozzles might not be the best nozzle choice for those products. However, studies have repeatedly shown good control with air induction nozzles (Garcerá et al. 2017).

Below is an *inexhaustive* list of attributes participants may observe or share about the nozzles:

- *One-piece nozzles* will have a greater “cloud” or mist of small droplets surrounding it compared to the “rain-like” droplets that are produced by the air induction nozzle. One-piece nozzles have a “fine” or “very fine” droplet (60–145 μm and 145–225 μm , respectively; ASABE 2009). This nozzle will produce a set range of small droplets at a manufacturer specified pressure. The one-piece nozzle will create a lot more drift than the air induction nozzle.
- *Air induction nozzles* will have large droplets that shatter upon contact. Depending on the manufacturer’s specified pressure, air induction nozzles can produce droplets that have a categorized range from “medium” (226 to 325 μm) to “extremely coarse” (501 to 650 μm ; ASABE 2009). These droplets are larger and feel much like rain beneath the output, compared to the one-piece. For air induction nozzles to produce high flow rates, they need to be used at higher pressures. While higher pressures produce smaller droplets, the droplet size of air induction nozzles will still range from “coarse” to “extra coarse,” which is far larger than those of the disc-core or one-piece nozzles. For example, in weed sprayers where the use of flat fan air induction nozzles is more common, operating pressures frequently exceed 40 psi. This still results in a larger, less drift-prone droplet.

Step 4a—Turn on the strobe light in the demonstration box. Raise the operating pressure to 120 psi. Wait for participants to observe how the increase in pressure changes the spray patterns of the one-piece and disc-core nozzles. Lower the pressure to 60 psi. Wait for participants to observe how the decrease in pressure changes the spray patterns of the one-piece and air induction nozzles. Within a nozzle brand, the flow rate of the nozzle is linearly related to the operating pressure, so we recommend keeping the same nozzle brand (manufacturer). Otherwise, differences in nozzle outputs at different pressures might be more reflective of different nozzle brands than different operating pressure. Wait a few moments for participants to look at the two outputs before *asking them the discussion questions from Lesson 3, Step 4a*.

Lesson 3, Step 4a

Discussion questions for participants:

1. Ask participants if they see any noticeable differences in the spray patterns between the different operating pressures, then describe the differences.
2. Are there similarities?
3. Which one would you rather use in your sprayer? Why?

What to look for and explain:

This lesson reinforces the prior lessons on droplet size and drift. Increasing pressure will produce smaller droplets and decreasing pressure will produce larger droplets. A reminder can also be discussed on the effects of weather (high temperatures and wind) on drift.

One caution for demonstration is that as you lower the pressure make sure to stay within the operating pressure of the nozzle. Many air induction canopy nozzles are not listed for operating at less than 60–70 psi. Reducing the pressure too much will lead to more erratic patterns and droplet formation (forming a dribble or stream) in air induction nozzles. Staying within the pressure limits listed in the nozzle catalog is important for proper application.

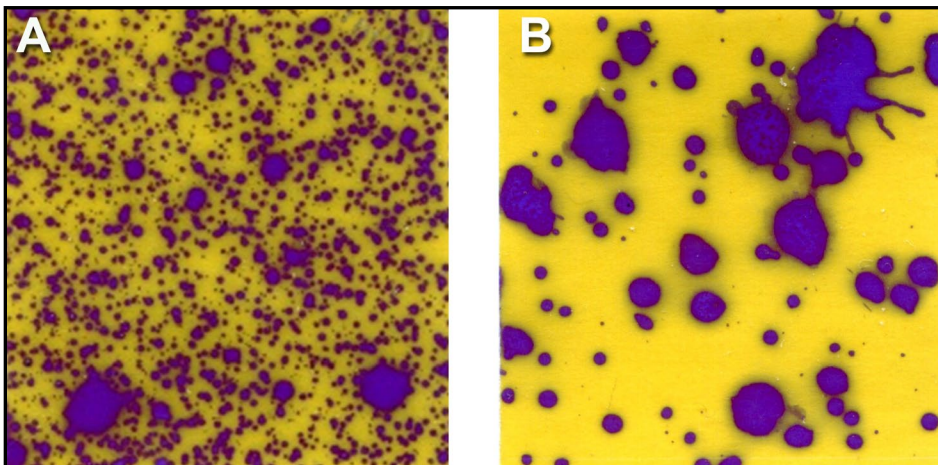


Figure 8. Water sensitive paper (WSP) sprayed with a one-piece nozzle (A) and an air induction nozzle (B). The respective deposition pattern is representative of the droplet sizes created by each nozzle output. Photos by Margaret McCoy.

Optional Step 4b—Use water sensitive paper (WSP) to show how the spray pattern is different at higher pressures. This portion is not necessary, but participants may be curious to see the affect pressure can have on droplet size and pattern, and what those differences may be. If this step is included, *ask them the discussion questions from Lesson 3, Step 4b.*

Lesson 3, Step 4b

Discussion questions for participants:

1. Ask participants if they see any noticeable differences in the spray droplet deposition and then describe what those differences are.
2. Are there similarities?

What to look for and explain:

When looking at spray pattern differences related to high operating pressure versus low operating pressure using WSP, there will be more deposition on each spray card. The “splatter” pattern of air induction nozzle droplets may be smaller and more numerous. This is because increasing pressure also increases the rate (GPM) of each nozzle.

OVERALL CONCLUSIONS FOR CURRICULUM

Inspecting nozzles prior to use is an important first step in ensuring maximum efficiency in your sprayer. Nozzles may look undamaged, but, upon closer inspection, may be worn or clogged. Changing ceramic nozzles annually and brass or stainless-steel nozzles multiple times in a season can help alleviate some of the issues of wear. The use of flow meters and other calibration techniques (Hoheisel et al. 2021) can determine if nozzle output is inaccurate.

The choice of nozzle used in a spray application should be influenced by ease of identifying correct nozzle installation, label regulations, intended target or crop, typical weather during spraying, sprayer selection, and mitigation of drift. Nozzle type and operating pressure influence droplet size and drift potential. Read through the nozzle catalog and understand appropriate nozzles for your sprayer and which ones are best for the products that target different pests or diseases.

RECOMMENDED READING

Barber, J. 2009. [How to Pre-empt a Significant Profit Drain: Nozzle Wear; Causes, Detection and Corrective Action Strategies.](#) *Spraying Systems Co.*

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Hoheisel, G.A., L.R. Khot, M.M. Moyer, and S. Castagnoli. 2021. [Six Steps to Calibrate and Optimize Airblast Sprayers for Orchards and Vineyards.](#) Pacific Northwest Extension Publication PNW749. Washington State University.

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