SIX STEPS TO CALIBRATE AND OPTIMIZE AIRBLAST SPRAYERS FOR ORCHARDS AND VINEYARDS

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Six Steps to Calibrate and Optimize Airblast Sprayers for Orchards and Vineyards

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Abstract

The goal for all pesticide applications should be to *get every drop to the crop*. Calibration ensures that the appropriate product rate is applied by the sprayer, while optimization ensures that the product is delivered onto the intended target. Calibrating and optimizing the sprayer are essential to sustainability, as they affect the environment, farm workers, and economic impact through fruit quality and pesticide costs. In six steps, this publication explains how to measure ground speed and nozzle output, check and adjust airflow and nozzle alignment, and verify coverage for an airblast sprayer. Methods are outlined for manual completion of the steps, and simplified formulas and suggestions for tools that can make the process faster are included.

Introduction

The purpose of this publication is to provide an efficient and inexpensive way to calibrate and optimize airblast sprayers. Calibration determines the volume or amount of water sprayed per acre. Optimization includes an array of adjustments made to the sprayer that maximize spray deposited on the intended target (e.g., canopy or fruit) and minimize spray lost to drift and deposition on the ground. This publication assumes that proper maintenance has been done and the sprayer is working properly and does not discuss routine equipment maintenance, although it is critical to ensure that the mechanical parts of a sprayer (e.g., pressure gauges, nozzles, pumps) are functioning properly.

For all pesticide applications, the goal should be to *get every drop to the crop*. Optimizing spray applications requires an initial time investment but will result in better coverage, improved pest control, and reduced crop loss. Pesticide applications are one of the most frequent operations carried out in an orchard or vineyard, and costs for a single spray can range from $40/acre to $150/acre, depending on the agrochemical (Gallardo et al. 2009; Pope et al. 2016). Spray that misses the target (e.g., leaves or fruit) may result in drift and cause adverse environmental impacts, increased risks for farm workers, and costly loss of product (Derksen et al. 2007; Vercruysse et al. 1999; Fenske et al. 2009). Increasing spray efficiency or reducing drift waste can increase profits. This publication outlines six steps for applicators to follow. These steps blend the concepts for both calibration and optimization, as seen in many other publications. Our methods provide a streamlined approach for quickly achieving optimized sprayer output and increasing spray application efficiency.

Step 1: Measure Tractor Ground Speed

Ground speed can affect many aspects of spray application, including coverage. Having accurate ground speed measurements is important because it is a primary factor in calibration calculations. Speedometers on farm tractors are notoriously unreliable for sprayer calibration. More recently, producers have relied on rate controllers to record speed. Speed should be checked annually for sprayers with and without rate controllers. If the rate controller is showing a different speed than your measured speed, you need to determine if it is a setting in the rate controller or a problem with the sensor (i.e., GPS [global positioning system] receiver or wheel sensor). A rate controller with a GPS unit must have the receiver mounted horizontally towards the sky while those with wheel sensors must have the tire radius and pressure correct in the computer for accurate detection.

Since the terrain influences speed, always check travel speed in the actual field as opposed to a gravel road. While conducting a speed test, it is important that these conditions are met:

1. Sprayer tank is half full.
2. Use the same tractor gear and engine speed (RPM) that will also be used for spraying.
3. Power take-off (PTO) is operating.
4. Fan is on.
5. Ground surface should be typical of orchard or vineyard conditions.
6. Run the course in both directions to minimize variations in the terrain.

Method 1: Manual Check

1. In the vineyard or orchard, mark a path at least 75 feet long with two flagging stakes (Figure 1). One can use other path distances as well. If the orchard or vineyard terrain is variable, use either longer paths or multiple paths over representative terrain to increase overall accuracy. If multiple paths are timed, simply take the average of all times and then calculate miles per hour as shown in the equation below.
2. With a stopwatch, record the time it takes for the front tire of the tractor to pass from one stake to the next in a chosen gear and engine speed (RPM) combination with PTO fan on.
3. Use the following formula to calculate the speed:

$$MPH = \frac{Travel\ distance\ (feet) \times\ 60}{Time\ (\mathrm{sec})\ \times\ 88}$$

Example:

It takes 27 seconds to travel over an 88-foot course.

$$MPH = \frac{88\, feet \times\ 60}{27\,\mathrm{sec}\ \times\ 88}\ = \frac{60}{27} = 2.2\, mph$$

Figure 1. Tape measure and flagging stakes used to measure and mark driving course. Photo by Gwen-Alyn Hoheisel, WSU.

Method 2: Use a Tool

GPS technology is available in many common electronic devices and can give an accurate assessment of speed. Options include purchasing a GPS receiver from a local sprayer manufacturer, using a GPS-enabled hiking or biking device, or smart phone application (Figure 2). While they all vary in cost, high-end devices tend to have better GPS reception and thus better positional accuracy. To better estimate the travel speed, such accurate measurements in positional change are required. Many of these tools have an option to map the route and rows sprayed.

The steps to measure speed are:

1. In the vineyard or orchard, start the GPS receiver unit or smartphone application.
2. Select a desired gear and engine speed (RPM) with the PTO and fan on.
3. Drive down a row for 20 to 30 seconds and look at the travel speed.
4. If needed, change gear or throttle combinations to obtain the desired speed, each time allowing 20 to 30 seconds for a stable reading on the GPS receiver unit.

Figure 2. Options to electronically measure speed. Map My Ride iPhone application (left), GPS by TeeJet (middle), and eTrex hiking GPS (right).

Step 2: Adjust the Direction of the Air and Spray

Air from the airblast outlet carries the spray droplets; *wherever air goes, droplets follow*. Therefore, it is critical to direct the air into the canopy. Options for adjusting air direction may be limited, but by adjusting nozzle orientation or shutting individual nozzles off, you can control where spray enters the airstream. Using flagging tape is a fast and inexpensive way to see the direction of airflow (Deveau 2015). The section below, Determining Air Direction, describes the methods for determining air direction and should be performed for *each* significantly different canopy shape, whether that is a result of a different vineyard or orchard block, or whether that is a result of changing canopy as the season progresses.

Determining Air Direction

1. Park the sprayer in the row.
2. Tie a two-foot piece of flagging tape (or ribbon) to the nozzle bodies and onto the ends of deflectors (if present). Flagging can also be tied to the end of a stick to enhance the visualization (Figure 3).
3. With spray nozzles turned off, turn on the sprayer, engage the tractor PTO and fan, and then adjust the RPM used for spraying. Note that if an engine-driven sprayer is being used then there is no PTO to engage.
4. Note the orientation of the flagging tape as sprayer air extends the flagging. To ensure spray is directed into the canopy, use only nozzles that have flagging oriented directly into the canopy and those slightly over the top and under the bottom of the canopy. Any nozzles oriented well above or below the canopy should be shut off. In addition, adjustments to top and bottom deflectors (if present) can be made to aim air (flagging) into the canopy.
5. Turn on the sprayer nozzles (water only) and observe where the spray goes. While maintaining safety, adjust the nozzle orientation (where possible) for desired spray distribution in the canopy. Any nozzles that spray too far above or below the canopy should be closed or turned off.
6. Record which nozzles are used for each planting or block, their orientation, and the deflector orientation.

Figure 3. Flagging tied to the nozzle bodies and to a stick to see the airflow. Photo by Gwen-Alyn Hoheisel, WSU.

Note on Deflectors

The rotation of any fan on axial fan sprayers, whether on a standard airblast or a multi-fan tower sprayers, causes a different air pattern on the right side versus left side of that fan. As a fan rotates in a clockwise fashion, air is pushed down on the right and lifted up on the left. This pattern is reversed for fans that rotate counterclockwise. Some sprayers have "air straighteners" mounted in front of the fan (looking from the front of the sprayer) or deflectors (Figure 4) that are mounted at the top and bottom of the sprayer body. Both can help even the airflow between the two sides. Many airblast sprayers may have too short of a deflector relative to the volume of air or may not have a deflector entirely. Oftentimes, top deflectors are removed because they hit fruit, but in modern, narrower, trellised canopies they are useful and do not interfere in the canopy.

Figure 4. Longer deflectors help guide the air to make it even on both sides. Deflectors are often set incorrectly by using similar positions on the right and left. If the fan is rotating clockwise, the right arm of the deflector (looking from the back of the sprayer) should be more vertical since air is already being pushed down, while the left side should be more horizontal to the ground to adjust for the air that is being pushed up by the fan. Photo by Steve Castagnoli, OSU.

Step 3: Match the Air Volume to the Canopy

The volume of air coming from the airblast sprayer should sufficiently replace the volume of air in a canopy. Spray should penetrate the canopy but not carry far beyond the other side. Many factors, like wind, canopy density, and tractor speed, will affect the volume of air displaced by the sprayer. In the future, there may be an automated method to adjust the air volume in real time (Khot et al. 2012) as canopy conditions change. However, significant improvements can still be made with manual adjustments a couple times in a season as the canopy develops, as outlined below. The directions below for determining the air volume can be followed, measured, and recorded throughout the season for two to three years as the canopy develops—these data can then be referenced in future years.

Determining Air Volume

1. Tie flagging tape to branches or shoots located at the top, middle, and bottom of the far side of the canopy from where the sprayer will travel (Figure 5).
2. Have a person stand at the end of the row to watch the flagging while driving the sprayer with settings established in the previous steps of checking ground speed and air direction.

Figure 5. Tying flagging tape to the opposite side of the canopy provides a quick assessment of appropriate air volume to canopy density. Note the green sprayer on the left of the trees and the blue flagging on the opposite side indicated by the red arrow. Photo by Gwen-Alyn Hoheisel, WSU.

3. The goal is to have the ribbons on the outside of the canopy from where the sprayer passes to lightly flutter. Adjust the sprayer accordingly as follows for best results (Deveau 2015):

- If the ribbons blow straight out, there is too much air being delivered, which is very common early in the season. Appropriate solutions depend on the features of the sprayer, but some possibilities include reducing fan gear from high to low to slow the fan speed, changing to a smaller fan diameter or fan blades with less pitch, driving faster, or changing the tractor settings to "gear up and throttle down" (see sidebar note on Reducing Air Volume).

- If the ribbons do not move, there is too little air. Solutions again depend on the features of the sprayer, but some possibilities include driving slower, increasing fan speed by changing to a higher fan gear, or installing a fan with a larger diameter.

Note on Reducing Air Volume

Reducing Fan Gear

Some sprayers have a gear to adjust fan speed. Reducing the fan speed to low is easy and will create less air volume. Some sprayers may have fixed fan speed, but there could be the option of installing a smaller fan or changing the pitch of the blades.

Gear Up, Throttle Down

This is a method where the tractor is placed in a higher gear to maintain travel speed but simultaneously throttled down (i.e., slow the PTO) to reduce the fan RPM. A reduction in RPM means the fan spins slower and therefore produces less air volume. This method is good for flat ground but can be a problem on hills where the tractor may not have enough power to climb the hill and maintain travel speed. Also, if the sprayer uses a centrifugal pump, the pressure will drop, resulting in less GPM per nozzle and the need to recalibrate. This is not needed if the sprayer has a diaphragm or piston pump as pressure will remain constant. This should be checked on a trial run before spraying. For more information see *Sprayers 101* (Deveau 2018).

Step 4: Select Nozzle Tips—Calculate and Record the Expected Nozzle Output

Now that the fan air and spray pattern reflect the size and shape of the canopy (Steps 2 and 3), the next step is selecting nozzles for a desired output. Nozzle selection is based on two standard measurements: gallons per acre (GPA), which describes the sprayer output, and gallon per minute (GPM), which determines the nozzle output. Once these measurements have been ascertained, use a manufacturer's nozzle chart to choose the appropriate nozzle. All nozzles are rated to deliver a specific GPM under a certain operating pressure (measured in pounds per square inch, or PSI). GPA is determined by your ground speed, row width, nozzle selection, and operating pressure. The desired sprayer output (e.g., 100 GPA) is achieved when you match your speed, pressure, and nozzle output. To do this, you will need to know the running pressure in PSI and the desired GPA. There are two methods that can be used to calculate nozzle output.

Method 1: Manually Calculate

1. Use the formula below to calculate the gallons per minute per side (GPMS).
$$\mathrm{GPMS} = \frac{\mathrm{GPA} \times \mathrm{mph} \times \mathrm{row\ width\ (feet)}}{990}$$
2. If the expected output from every nozzle on one side is the same, divide the GPMS by the number of nozzles on a side (i.e., GPMS ÷ number of nozzles per side = output per nozzle). If output is different for each nozzle location, then the total output of all nozzles must add to the GPMS.
3. The output from each nozzle should be proportional to the canopy density that the nozzle is targeting. For example, a large, open vase cherry tree may need two-thirds of the volume coming from the upper two-thirds of the nozzles while the rest of the volume comes from the lower one-third of the nozzles. If there are nine nozzles open with a desired 4.5 GPMS, then the upper six nozzles should put out two-thirds of the spray (0.66 × 4.5 GPMS = 2.97 GPM; 2.97 GPM ÷ 6 nozzles = 0.495 GPM for each nozzle). The remaining three nozzles should put out 1.53 GPM or 0.51 GPM for each nozzle. Adjustments on volume per nozzle

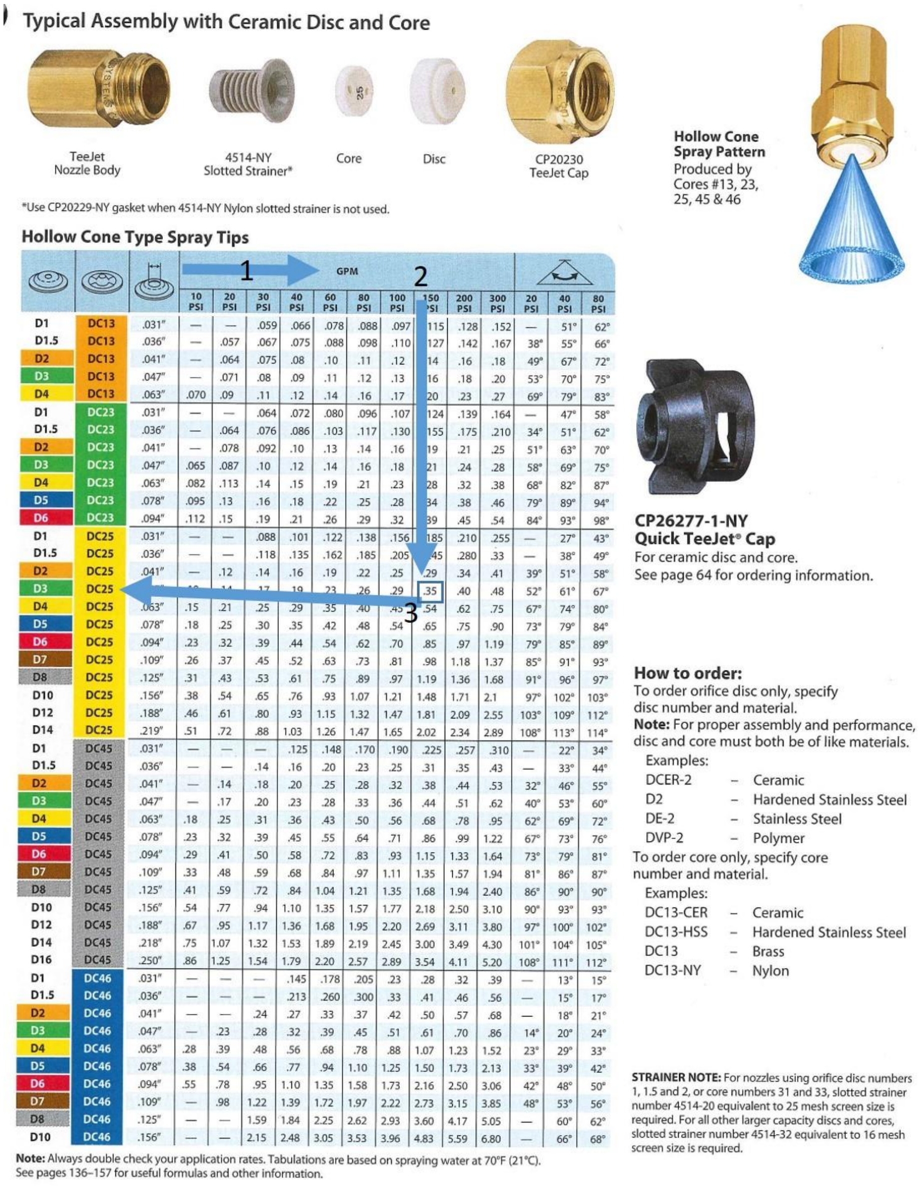
can be made after Step 6 when spray coverage is assessed.

4. To select nozzles with the expected output in GPM for each nozzle, use a nozzle catalog to find a nozzle output that is close to the calculated output (Figure 6). In general, nozzles with a hollow-cone spray pattern are used to spray the canopy of fruit crops. Several options of nozzles and materials are available. (See *Common Interchangeable Nozzles for Perennial Crop Canopy Sprayers* [McCoy et al. 2020], which describes in detail different nozzles and materials.) Ceramic is always preferred over other materials as it wears less and has a negligible cost difference. If purchasing nozzle sets, make sure to purchase discs and cores of the same material. To aid in the calculations and recording nozzle output, refer to Worksheet 1 (found in the Appendix).

Method 2: Use an App or Software

Smartphone applications (e.g., VineTech, Orchard Max), internet software (e.g., Turbomist Program), and many consultant companies will calculate the total expected output from each of the nozzles and suggest the proper disc and core combination. Some of the software programs also account for different canopy shapes and adjust nozzle output based on canopy density as described in Method 1. These alternatives minimize manual calculations and allow for quick adjustments.

Regardless of the method used, the desired output per nozzle and disc core should be recorded.



Typical Assembly with Ceramic Disc and Core

TeeJet Nozzle Body

4514-NY Slotted Strainer*

Core

Disc

CP20230 TeeJet Cap

Hollow Cone Spray Pattern Produced by Cores #13, 23, 25, 45 & 46

*Use CP20229-NY gasket when 4514-NY Nylon slotted strainer is not used.

Hollow Cone Type Spray Tips

			GPM											
			10 PSI	20 PSI	30 PSI	40 PSI	60 PSI	80 PSI	100 PSI	150 PSI	200 PSI	300 PSI	20 PSI	40 PSI	80 PSI
D1	DC13	.031″	—	—	.059	.066	.078	.088	.097	115	.128	.152	—	51°	62°
D1.5	DC13	.036″	—	.057	.067	.075	.088	.098	.110	127	.142	.167	38°	55°	66°
D2	DC13	.041″	—	.064	.075	.08	.10	.11	.12	14	.16	.18	49°	67°	72°
D3	DC13	.047″	—	.071	.08	.09	.11	.12	.13	16	.18	.20	53°	70°	75°
D4	DC13	.063″	.070	.09	.11	.12	.14	.16	.17	20	.23	.27	69°	79°	83°
D1	DC23	.031″	—	—	.064	.072	.080	.096	.107	124	.139	.164	—	47°	58°
D1.5	DC23	.036″	—	.064	.076	.086	.103	.117	.130	155	.175	.210	34°	51°	62°
D2	DC23	.041″	—	.078	.092	.10	.13	.14	.16	19	.21	.25	51°	63°	70°
D3	DC23	.047″	.065	.087	.10	.12	.14	.16	.18	21	.24	.28	58°	69°	75°
D4	DC23	.063″	.082	.113	.14	.15	.19	.21	.23	28	.32	.38	68°	82°	87°
D5	DC23	.078″	.095	.13	.16	.18	.22	.25	.28	34	.38	.46	79°	89°	94°
D6	DC23	.094″	.112	.15	.19	.21	.26	.29	.32	39	.45	.54	84°	93°	98°
D1	DC25	.031″	—	—	.088	.101	.122	.138	.156	185	.210	.255	—	27°	43°
D1.5	DC25	.036″	—	—	.118	.135	.162	.185	.205	45	.280	.33	—	38°	49°
D2	DC25	.041″	—	.12	.14	.16	.19	.22	.25	.29	.34	.41	39°	51°	58°
D3	DC25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.23	.26	.29	.35	.40	.48	52°	61°	67°
D4	DC25	.063″	.15	.21	.25	.29	.35	.40	.45	.54	.62	.75	67°	74°	80°
D5	DC25	.078″	.18	.25	.30	.35	.42	.48	.54	.65	.75	.90	73°	79°	84°
D6	DC25	.094″	.23	.32	.39	.44	.54	.62	.70	.85	.97	1.19	79°	85°	89°
D7	DC25	.109″	.26	.37	.45	.52	.63	.73	.81	.98	1.18	1.37	85°	91°	93°
D8	DC25	.125″	.31	.43	.53	.61	.75	.89	.97	1.19	1.36	1.68	91°	96°	97°
D10	DC25	.156″	.38	.54	.65	.76	.93	1.07	1.21	1.48	1.71	2.1	97°	102°	103°
D12	DC25	.188″	.46	.61	.80	.93	1.15	1.32	1.47	1.81	2.09	2.55	103°	109°	112°
D14	DC25	.219″	.51	.72	.88	1.03	1.26	1.47	1.65	2.02	2.34	2.89	108°	113°	114°
D1	DC45	.031″	—	—	—	.125	.148	.170	.190	.225	.257	.310	—	22°	34°
D1.5	DC45	.036″	—	—	.14	.16	.20	.23	.25	.31	.35	.43	—	33°	44°
D2	DC45	.041″	—	.14	.18	.20	.25	.28	.32	.38	.44	.53	32°	46°	55°
D3	DC45	.047″	—	.17	.20	.23	.28	.33	.36	.44	.51	.62	40°	53°	60°
D4	DC45	.063″	.18	.25	.31	.36	.43	.50	.56	.68	.78	.95	62°	69°	72°
D5	DC45	.078″	.23	.32	.39	.45	.55	.64	.71	.86	.99	1.22	67°	73°	76°
D6	DC45	.094″	.29	.41	.50	.58	.72	.83	.93	1.15	1.33	1.64	73°	79°	81°
D7	DC45	.109″	.33	.48	.59	.68	.84	.97	1.11	1.35	1.57	1.94	81°	86°	87°
D8	DC45	.125″	.41	.59	.72	.84	1.04	1.21	1.35	1.68	1.94	2.40	86°	90°	90°
D10	DC45	.156″	.54	.77	.94	1.10	1.35	1.57	1.77	2.18	2.50	3.10	90°	93°	93°
D12	DC45	.188″	.67	.95	1.17	1.36	1.68	1.95	2.20	2.69	3.11	3.80	97°	100°	102°
D14	DC45	.218″	.75	1.07	1.32	1.53	1.89	2.19	2.45	3.00	3.49	4.30	101°	104°	105°
D16	DC45	.250″	.86	1.25	1.54	1.79	2.20	2.57	2.89	3.54	4.11	5.20	108°	111°	112°
D1	DC46	.031″	—	—	—	.145	.178	.205	.23	.28	.32	.39	—	13°	15°
D1.5	DC46	.036″	—	—	—	.213	.260	.300	.33	.41	.46	.56	—	15°	17°
D2	DC46	.041″	—	—	.24	.27	.33	.37	.42	.50	.57	.68	—	18°	21°
D3	DC46	.047″	—	.23	.28	.32	.39	.45	.51	.61	.70	.86	14°	20°	24°
D4	DC46	.063″	.28	.39	.48	.56	.68	.78	.88	1.07	1.23	1.52	23°	29°	33°
D5	DC46	.078″	.38	.54	.66	.77	.94	1.10	1.25	1.50	1.73	2.13	33°	39°	42°
D6	DC46	.094″	.55	.78	.95	1.10	1.35	1.58	1.73	2.16	2.50	3.06	42°	48°	50°
D7	DC46	.109″	—	.98	1.22	1.39	1.72	1.97	2.22	2.73	3.15	3.85	48°	53°	56°
D8	DC46	.125″	—	—	1.59	1.84	2.25	2.62	2.93	3.60	4.17	5.05	—	60°	62°
D10	DC46	.156″	—	—	2.15	2.48	3.05	3.53	3.96	4.83	5.59	6.80	—	66°	68°

Note: Always double check your application rates. Tabulations are based on spraying water at 70°F (21°C).
See pages 136–157 for useful formulas and other information.

CP26277-1-NY
Quick TeeJet® Cap
For ceramic disc and core.
See page 64 for ordering information.

How to order:
To order orifice disc only, specify disc number and material.
Note: For proper assembly and performance, disc and core must both be of like materials.

Examples:
DCER-2 – Ceramic
D2 – Hardened Stainless Steel
DE-2 – Stainless Steel
DVP-2 – Polymer

To order core only, specify core number and material.

Examples:
DC13-CER – Ceramic
DC13-HSS – Hardened Stainless Steel
DC13 – Brass
DC13-NY – Nylon

STRAINER NOTE: For nozzles using orifice disc numbers 1, 1.5 and 2, or core numbers 31 and 33, slotted strainer number 4514-20 equivalent to 25 mesh screen size is required. For all other larger capacity discs and cores, slotted strainer number 4514-32 equivalent to 16 mesh screen size is required.

Figure 6. Example of a page from a nozzle catalog. The process is the same even if the manufacturer is different. To select nozzles, first go to the page with hollow cone patterns for either two-piece disc core or one-piece ceramic nozzles. Go across the top of the table (arrow 1) to the desired operating pressure, then go down the column (arrow 2) to find the closest output per nozzle. Last, move left along the row (arrow 3) to see the appropriate disc core. In this example, if a sprayer was operating at 150 PSI and we desired about 0.35 GPM, then a D3 nozzle with a DC25 core would be chosen. (*Image Source*: 2019 Tee-Jet nozzle catalog.)

Note on Deposition

Deposition is the amount of product that adheres to the target (i.e., leaf, bark, or fruit). There are three factors that can be manipulated rapidly to affect deposition: nozzle output, travel speed, and pressure (Figure 7). Nozzle output is determined in gallons per minute and the summation of all the nozzles (at a particular speed and pressure) should equal the desired gallons per acre. On a whole farm level with multiple crops requiring slightly different rates (e.g., 80 GPA vs. 100 GPA), changing the speed or pressure may be easier than changing the nozzles between individual blocks of crops. However, some sprayers are equipped with dual nozzles at each position or a "roll-over" nozzle body with an additional nozzle on the opposite side. Having two different nozzles available at each position will allow for greater changes in output than pressure or speed, which can adversely affect spray characteristics (droplet size) and deposition. Changing speed, nozzle, and pressure are all options to adjust rate, but the easiest solution is dependent upon sprayer design.

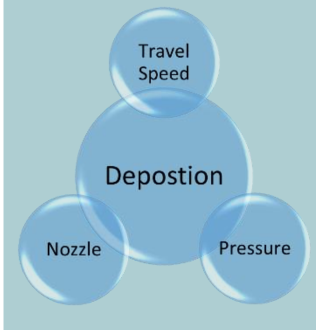


Figure 7. Deposition triangle depicts that the three factors of sprayer travel speed, nozzle, and pressure all interact to affect the amount of product on the target.

Step 5: Measure Nozzle Output

Verify nozzle output by placing clamps (Figure 8) over the nozzle and funnel spray into a graduated cylinder or flow meter. Commercial clamps made by AAMS (Figure 8) are more expensive but ensure minimal leaks. Homemade clamps are less expensive, but it is important that they have smaller tubes to eliminate air pockets, do not leak at the nozzle tip, and do not have elbows or bends that restrict flow. These issues can lead to inaccuracy in spray flow measurement. To measure the flow rate, you will need either a flow meter (Figure 9) or a stopwatch and graduated cylinder with the accuracy to measure in one-ounce increments.

Figure 8. Nozzle clamps to cover the nozzle and measure water output. This image shows both purchased and homemade options. From left to right are: AAMS clamp, Herbst clamp, homemade clamp from cow milking parts, and homemade clamp from plumbing parts. Photo by Gwen-Alyn Hoheisel, WSU.

Figure 9. Example of a low volume flow meter. This model is accurate for volumes under 1 GPM, which is appropriate for most nozzle selections. Photo by Gwen-Alyn Hoheisel, WSU.

Measuring nozzle output should be conducted at least once before the season begins and can also be conducted at any time in the year to assess nozzle wear.

1. Connect hoses to the nozzles (Figure 10).
2. Turn on the sprayer with water flowing. Confirm the PTO is on and that the pressure gauge is at the spraying PSI. Note that PSI can increase when nozzles are off, so it is important to read the pressure gauge when the nozzles are on with water flowing. Collect the nozzle output for 60 seconds by placing each hose into a graduated cylinder. Record the water volume and repeat for all nozzles. To save time, use multiple containers to capture water from several nozzles at the same time. Then, calculate gallons per minute with this equation:

   $$\text{GPM per nozzle} = \text{ounces per nozzle} \div 128.$$

   Alternatively, use a flow meter to quickly measure output in GPM and eliminate the math.
3. Any nozzle that is more than 10% off from the expected nozzle output should be replaced.

Step 6: Verify Coverage

The final step is to confirm spray coverage with water sensitive paper (WSP). This step is critical to see if the calibration and optimization adjustments made to the sprayer provide the intended spray coverage or if an additional adjustment is needed. WSP changes from yellow to blue when exposed to water or oil droplets, allowing you to visualize spray coverage.

When working with WSP, use care to handle the cards by the edges only or wear dry nitrile or latex gloves as any moisture or oil transferred from your hands to the card's top surface may turn it blue, obscuring spray results. Use one size of spray cards, preferably two inches by two inches for coverage verification. These can be attached to the top, middle, bottom, inner, and outer leaves of the canopy, or any other place to determine coverage. Attach WSP by either stapling to the leaves directly, securing metal clips in the canopy where cards are held, or securing other tags in the canopy that can have WSP taped to them. A fast and efficient way to place WSP is attaching it to PVC poles placed on the canopy. In addition, staple or tape WSP to small wood blocks that are placed on the *ground* one to three rows downwind beyond the sprayed row to determine how much spray drifted through the canopy onto the ground (Figure 11). Label the cards on their back side with their locations using a pen or pencil prior to placing them in the field to provide for easy comparison and assessment after spraying.

Figure 10. AAMS nozzle clamps connected to a sprayer. Output will be measured from each tube coming from the clamp. Photo by Gwen-Alyn Hoheisel, WSU.

Operate the sprayer at the calibration and optimization settings from the previous steps and drive past the canopies with the WSP (assess coverage using water only in the tank). Depending on weather, allow at least 10–30 min for the spray to dry on cards, then collect them and examine the coverage. In general, ideal spray coverage has many fine droplets evenly covering the card without long streaks or large patches of solid blue (Figure 12). Areas with all blue indicate too much material is being applied which leads to wasted material running off the leaves and fruit. The ideal spray coverage can vary based on pest or disease biology and chemical choice. For example, GF120 to control cherry fruit fly is best applied in large, extra course, droplets to ensure the flies are attracted to the bait. Conversely, a dormant oil works by physically smothering pests and disease, therefore it is critical to get even coverage with higher water volumes.

Make adjustments to the sprayer or nozzle output based on your results and make sure to consider the pest or disease biology and chemical choice. For example, if applying a contact insecticide for a moth that moves through the canopy, a completely blue spray card in the bottom of the canopy with low percent coverage in the upper canopy, requires either reducing nozzle output (GPM) in both lower zone and increasing output in the upper nozzles or angling the nozzles differently to put more material in the upper canopy. Also examine the ground deposition measured on the small blocks one to three rows from the sprayer. If all the spray cards are blue including those on the ground, consider reducing your air volume or liquid spray volume (i.e., GPA).

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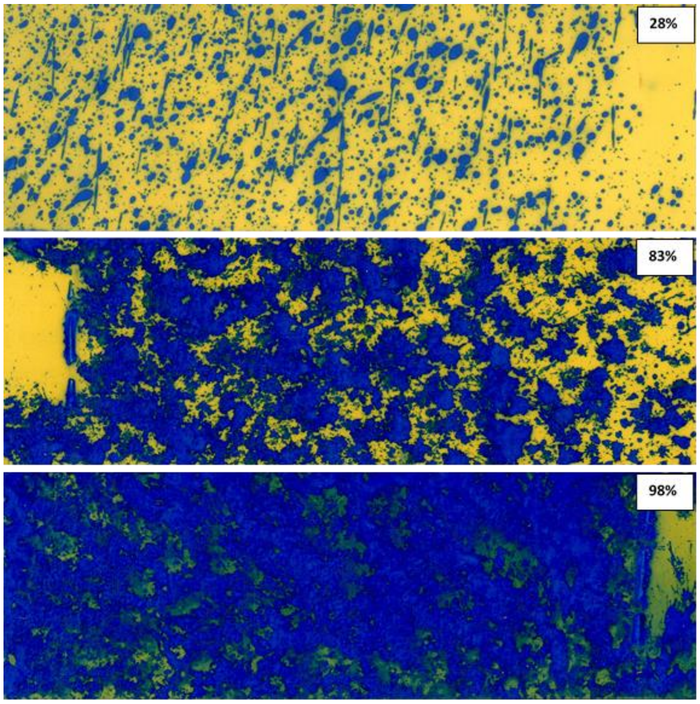


Figure 12. Water sensitive paper is yellow but turns blue when wet. The top card (23% coverage) is considered even coverage without too much runoff, while the other two are over-coverage (83%, 98% coverage), which can lead to pesticide runoff from the leaves or fruit. Refer to the instruction packet in the WSP for additional photos and coverage associated with different droplet sizes. Photo by Lav Khot, WSU.

Figure 11. A small wooden block with WSP taped to it placed on the ground one to three rows downwind from the sprayer to provide a visual assessment of how much spray is lost to the ground. Photo by Margaret McCoy, WSU.

Appendix

STEP 1: Calibrate the sprayer according to the following information:

WORKSHEET 1

Sprayer No.: __________ Tractor No.: __________ Gears: __________

RPM: __________ Speed (MPH): __________ Pressure: __________

Row Distance: __________ Gallons per Acre: __________

Gallons per Minute (GPM): ________

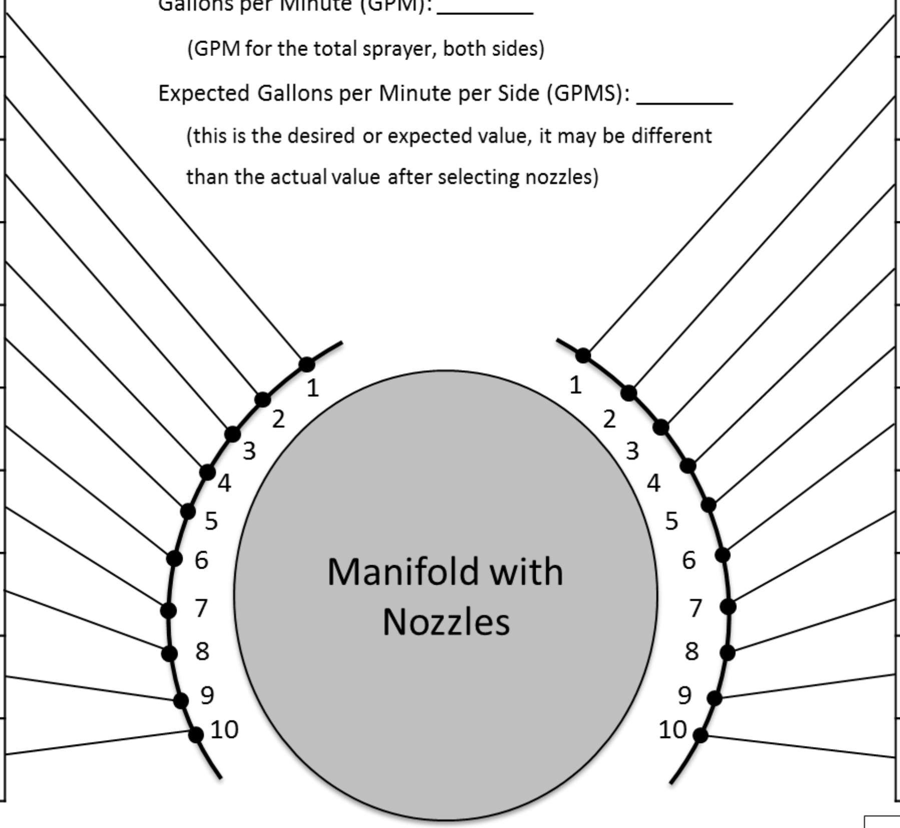
(GPM for the total sprayer, both sides)

Expected Gallons per Minute per Side (GPMS): ________

(this is the desired or expected value, it may be different than the actual value after selecting nozzles)

STEP 2: Select the nozzles from a catalog that match the desired pressure and expected GPMS. Use disc-core or 1-piece nozzles

GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	1
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	2
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	3
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	4
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	5
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	6
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	7
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	8
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	9
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	10



GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	1
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	2
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	3
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	4
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	5
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	6
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	7
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	8
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	9
GPM ________ DISC ______ or _____ CODE CORE ______ or _____ COLOR	10

Total GPMS: ______________
(May differ from expected)

STEP 3: Calculate the *actual* GPMS by adding the GPM for each nozzle. Repeat on both sides.

Step 4: Calculate the actual GPA with this equation and compare to desired. Slight differences in the GPM per nozzle may make larger cumulative differences

$$\text{Actual GPA} = \frac{\text{GPMS} \times 990}{\text{mph} \times \text{row width (feet)}}$$

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