Airblast 101

A Handbook of

Best Practices in Airblast Spraying

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Jason Deveau

ABOUT THE AUTHOR

Jason Deveau ("the Spray Guy") has been the Application Technology Specialist with the Ontario Ministry of Agriculture, Food and Rural Affairs since 2008. He obtained his BSc ('96) in Biopsychology from Mt. Allison University in Sackville, New Brunswick, his MSc ('98) in Plant Science at York University in Toronto, Ontario and his PhD ('03) in Plant Cell Electrophysiology at the University of Guelph in Ontario. Jason works on methods to improve the efficiency and efficacy of agricultural pesticide applications and develops educational resources for applicators.

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Contents

Introduction

Perhaps you're an airblast sprayer veteran looking to refresh your understanding or squeeze a bit more efficiency out of your applications. Perhaps you're new to airblast spraying and need foundational information. Maybe you're a farm manager, a government regulator, an agricultural extension specialist, an agrichemical sales representative or an academic researcher. No matter your occupation, if you want to learn more about airblast spraying, there's something here for you.

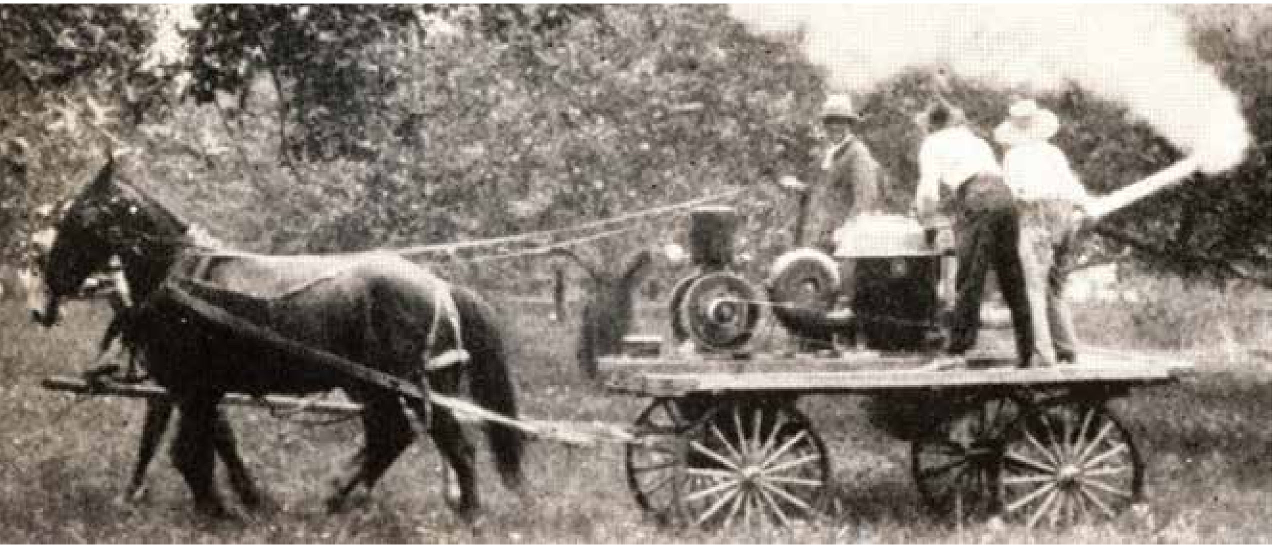
The scope of this book has grown a lot over the years, but it has always focused on three central themes.

1. Understanding the forces that influence droplet behaviour.
2. How to optimize airblast sprayers to match the target crop and minimize waste.
3. How to diagnose spray coverage and make changes to improve it.

You'll find basic information on sprayer maintenance, operation and cleaning, but always defer to the manufacturer's instructions and the agrichemical label. Appropriate personal protective equipment is encouraged, but not specifically addressed in this handbook. Considerable information about personal protection and safe pesticide handling is available through provincial and state extension programs such as the **Ontario Pesticide Education Program**.

On behalf of myself, and everyone that contributed to this handbook, I hope you find the information helpful.

Sprayers and best practices have changed a lot since the early 1900s. There's always more to learn.



PLEASE NOTE

Air-shear style airblast sprayers (e.g. Kinkelders, certain AgTecs, KWH, etc.) don't employ conventional nozzles and are uncommon in Ontario. Much of the content in this handbook will still apply to these sprayers, but there are a few significant exceptions. Special note is made where additional consideration is warranted for air-shear systems.

A classic “airblast sprayer” owned by Dr. B. Panneton, Quebec.

Contributors

I gratefully acknowledge everyone that edited, contributed to, inspired or otherwise supported the research and development of the Airblast 101 course and this handbook. Everyone benefits when information is shared freely. This handbook continues to improve because of professionals like you.

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Special thanks to the membership of **The Pesticide Stewardship Alliance**.

1.0 Why Airblast 101?

Why Airblast 101?

Airblast sprayer operators apply pesticides to ensure the health and marketability of their crops. Their success relies on three things – an understanding of safe pesticide handling, criteria for what and when to spray, and the skills to apply pesticides effectively and efficiently.

In 2008, Ontario's airblast sprayer operators had few resources to address application skills. Operators were at different levels of ability and understanding, and their pesticide applications had variable success.

In 2010, Airblast 101 was piloted in Ontario as a series of classroom-based courses to provide participants with practical tools for applying pesticides, plant growth modifiers and foliar nutrients in a more effective, economic and environmentally-responsible manner. Developed by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) with financial support from CropLife Canada, the content introduced a new operator to spraying, and refreshed a seasoned veteran.

The core of the pilot course was the participant's handbook. Relying heavily on illustration, the handbook was designed to guide participants through the course and become a lasting reference. The handbook was developed to primarily target the airblast sprayer operator, but also attracted a range of stakeholders including farm managers, government pesticide regulators, extension specialists, consultants and industry.

Over time, the course content evolved and expanded. By 2013, the handbook was in its 3rd version and more than 200 copies had been distributed throughout Ontario. Another 200 copies were printed for courses taught in British Columbia and Prince Edward Island and to satisfy requests by specialists in New Hampshire, Washington and Brazil. An industrial grant covered the printing of 300 more for the Ontario Apple Growers Association.

At the time of this printing, more than 1,000 copies of the handbook have been distributed at courses taught across Canada and in a number of the United States. This new 4th version has been greatly improved thanks to contributions by colleagues and feedback from course participants. This edition reflects the most current information and includes advanced techniques.

For the most up-to-date information about spray application in field and speciality crops, visit **www.sprayers101.com** and follow the conversation on Twitter **@Spray_Guy**.

Sprayers 101

DISCLAIMER

2.0 Application effectiveness and efficiency

Application effectiveness and efficiency

Spray application is one of the most important activities regularly done in any horticultural operation. It can also be one of the most expensive and time consuming. Integrated Pest Management (IPM) is a multi-step process that helps sprayer operators make informed choices about when and what to spray. But the decision to spray should not be the end of the process. The sprayer operator has a lot of decisions to make about sprayer setup and application method. These decisions determine if the application will be effective, and if it will be efficient. Efficient spraying saves money and reduces environmental impact. The goal is to be both effective and efficient.

DID YOU KNOW?

With the correct nozzles, an airblast sprayer should not have to operate over 200 psi for most horticultural crops. Reducing pressure by 50 psi saves about 5 horsepower, reduces wear-and-tear and noise.

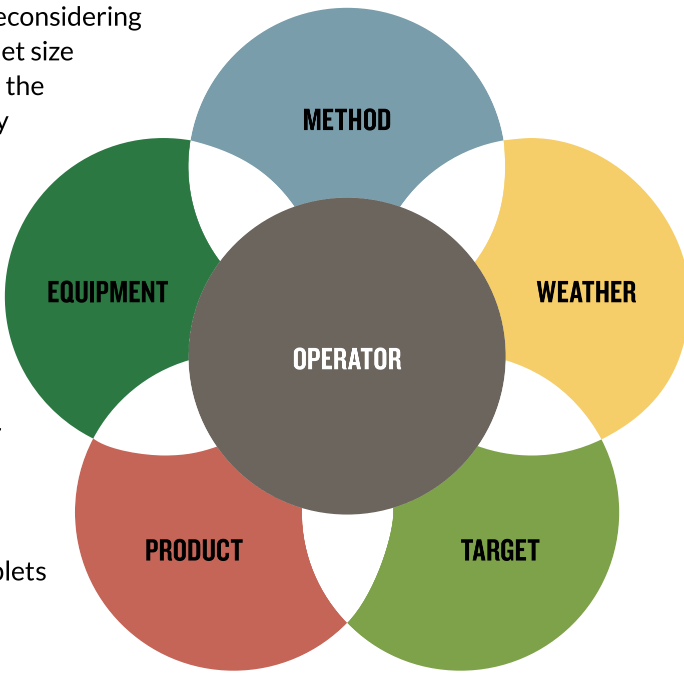
2.1 The six elements of effective and efficient airblast application

A quick Google search reveals a seemingly endless number of sprayer articles by government, industry and academia. There are differences in definitions, opinions on priorities vary, and classic sprayer wisdom is sometimes supported and sometimes debunked by current research. If you read enough articles you will find more similarities than differences, and common themes will emerge.

Most agree that the objective of spraying is the safe and timely delivery of an effective, uniform dose of product to a target area. Any product not deposited on the target (e.g. spray drift, sprayer leaks, run-off, etc.) reduces efficiency and is called wastage. The literature points to six broad elements that affect spray efficiency and effectiveness. Sprayer operators should actively consider all six elements before, and during, each spray application.

The days of "set it and forget it" are no more.

The six elements in the illustration – operator, method, weather, target, product and equipment – overlap because changing one element often means reconsidering others. For example, increasing droplet size to reduce drift potential also reduces the number of droplets sprayed. This may warrant higher spray volumes, which means you might require a more dilute tank mix to maintain the rate-per-area. Only the sprayer operator's decisions affect all the elements – that's why it's pictured in the centre. Technology or technique can not compensate for an inattentive operator. Operator skill and willingness to do a good job impacts the overall efficiency and effectiveness of every airblast spray application. Understanding how droplets behave (or misbehave) is essential.



The six elements of effective and efficient airblast application.

Airblast sprayers come in all shapes and sizes, like this Paris model Gregoire with two fans and deflector/boom “wings” intended to throw spray over additional rows on a single pass.

Each element has many contributing factors. Some factors might fit under multiple elements and certainly I've reorganized this list many times over the years. No matter how they are presented, all of these factors (and more) contribute to the success of airblast spray applications and should figure into the operator's considerations. Many of these factors are discussed later in the handbook.

EQUIPMENT	METHOD	WEATHER	TARGET	PRODUCT	OPERATOR
Sprayer Design	**Forward Speed**	**Wind**	**Canopy Structure**	**Mode of Action**	**Aptitude**
Air-Assist	Work Rate	Speed	Time of Season	Timing	**Attitude**
Direction	**Spray Technique**	Direction	Density-Area	**Spray Mix**	**Manager, Boss or Owner**
Volume	Alternate Row-Middle Spraying	**Temperature**	Canopy Management	Specific Gravity	
Speed	**Gear Up-Throttle Down**	Relative Humidity	**Target**	Adjuvants	
Deflectors	**Crop-Adapted Spraying**	Thermal Inversion	Size	Carrier Volume	
Spray Quality			Location	Application Rate	
Pattern					
Droplet Size					
Nozzle Orientation					

The expanded six elements of effective and efficient airblast application.

Ceramic disc & core nozzles DO NOT last forever. They wear with use and break easily when caps are over tightened. Check your sprayer nozzles regularly. Consider plastic, moulded nozzles with ceramic orifices, which outlast ceramic disc & cores.

3.0 Calibration

Calibration

When sprayer operators are asked to define calibration during workshops, their responses cover a wide range of activities. Here are the three most common calibration definitions.

- Sprayer inspection – more commonly known in Europe as sprayer check (e.g. is it worn out, broken or leaking?)
- Adjusting sprayer settings to match the crop and the environmental conditions (e.g. yesterday I sprayed semi-dwarf trees in high wind, today I'm spraying nursery whips in high humidity – should I change my sprayer settings?)
- Confirming sprayer output (e.g. is the rate actually sprayed per hectare what it should be?)

Here are some nasty disc & cores revealed during a calibration workshop.
It certainly explained the poor performance the operator was complaining about.
Is it time to replace yours?

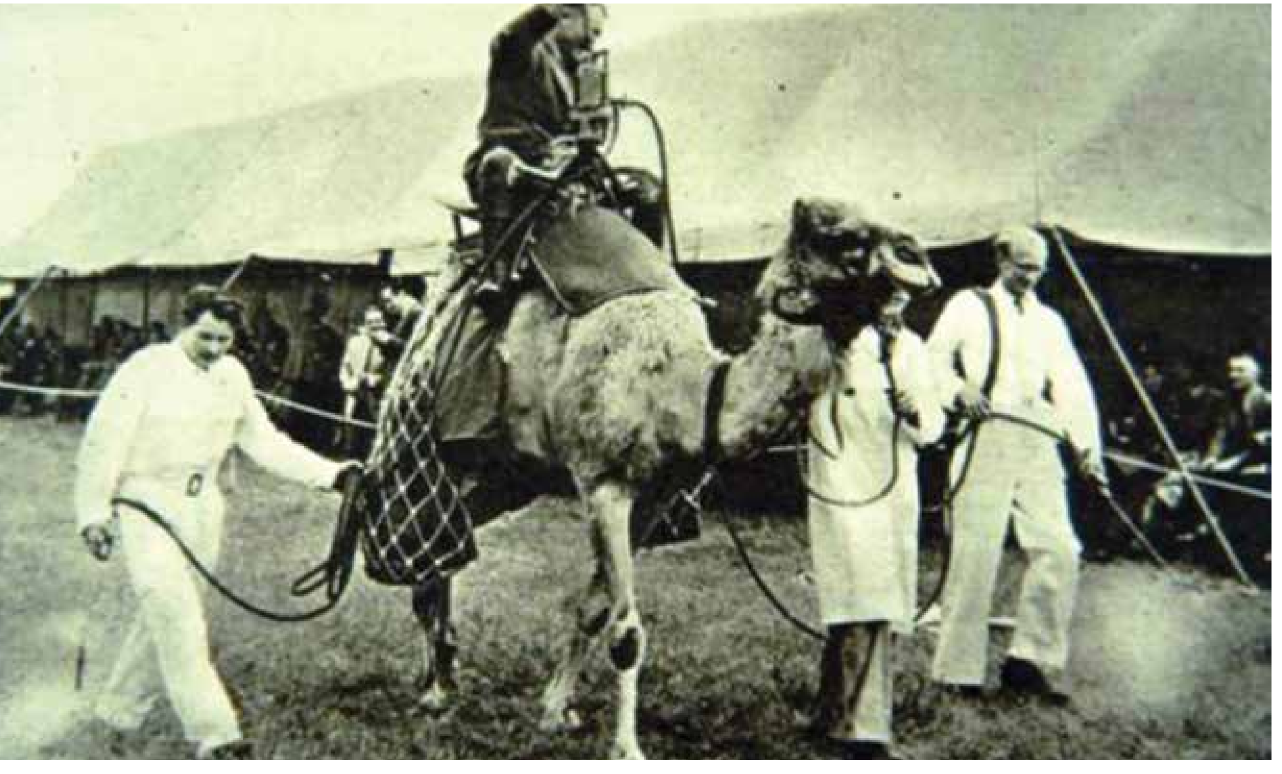
PHOTO CREDIT – DR. H. ZHU, OHIO.

Convention would suggest that the third bullet (confirming sprayer output) is the correct definition for sprayer calibration. But I believe calibration is holistic and includes elements from all three answers – it's simply a matter of knowing when to do what and why.

The obvious question of "how do I calibrate" will occupy much of this handbook. It is a requirement of Good Agricultural Practices (GAP) to calibrate any sprayer. At the time of this publication, GAP doesn't specify the calibration method, so I propose the methods described in this handbook. We'll begin with the sprayer inspection.

DID YOU KNOW?

Never mix and match different sprayer calibration methods. The calculations may not work. If you already have a method you are comfortable with, use it.



According to 1992's "Tools for Agriculture" a horse can deliver 500 watts of power over 10 hours, but the camel can deliver 650 watts over six. Ontario might not employ camels for spraying, but the old adage still applies: "the right tool for the right job".

PHOTO CREDIT – R. DERKSEN, OHIO. DATE AND LOCATION OF PHOTOGRAPH IS UNKNOWN.

3.1 Why, when and where to calibrate an airblast sprayer

SPRAYER INSPECTION

Why should I calibrate?

The operator should calibrate an airblast sprayer:

- to confirm the sprayer is functioning correctly
- to confirm each nozzle is delivering the desired rate (e.g. L/min. or gal./min.) and spray quality
- to ensure the desired rate (e.g. L/ha or gal./ac.) is applied to the crop
- to improve coverage and reduce product wastage (i.e. saves money and reduces unnecessary environmental impact)

When should I calibrate?

The operator should perform a sprayer inspection at the beginning of every spray day. Think of it as preventative troubleshooting or a safety check. Don't confuse it with the more involved pre-season maintenance inspection (see page 174).

Where do I calibrate?

Operators should perform the inspection in the yard where they store, maintain and/or fill the sprayer, that's when it's easiest to deal with any mechanical problems. Use clean water during performance check to avoid contamination to near by ground water, surface water and sensitive areas.

ADJUSTING SPRAYER SETTINGS

Why and when should I calibrate?

The operator might make these changes **several times a day** based on relatively simple visual tests. Make minor changes to the airblast sprayer setup:

- to match the physical size, shape and density of the crops (both between blocks and over the season)
- to account for environmental changes
- to reflect product mode-of-action and target location (see page 29).

Where do I calibrate?

Operators should adjust settings **throughout the spray day**, while in the target planting, to reflect changing conditions as required. Don't hesitate to get down from the tractor cab and make adjustments. It improves the spray job and helps alleviate operator fatigue.

CONFIRMING SPRAYER OUTPUT

Why and when should I calibrate?

The operator should confirm the sprayer is emitting the correct rate at the **beginning of the season** and after any significant change to the sprayer setup, including:

- new nozzles
- new tractor tires
- using a different tractor
- after replacing a pump or any lines/hoses

These changes require the dreaded “sprayer math” to determine how much pesticide is put in the tank **(see page 198)**.

Where do I calibrate?

Operators should confirm sprayer output **in the target planting** (i.e. the vineyard, nursery, orchard, hope yard, etc.) to avoid false readings. This is because ground speed can be up to 15% faster on pavement compared to the planting. Sprayers move slower on soft ground and tire slippage is a major cause for ground speed inaccuracies. Additionally, hilly terrain can cause a tractor to lug, resulting in a slower ground speed – where possible, calibrate on level ground.

4.0 Sprayer inspection

Sprayer inspection

Always wear appropriate personal protective equipment (as indicated on the product label), including hearing protection. Fill the thoroughly cleaned sprayer **(see page 167)** half full of clean water and park it on level ground. Much of this process can be performed at the filling station.

On the first fill of the day, before adding formulated product to the tank when it's half full (to facilitate good mixing), pause to perform the following five steps. This doesn't take very long to do.

1. Ensure lines/hoses and fittings do not show signs of wear or cracking and do not leak or bulge while under pressure.
2. Ensure filters, screens, strainers and nozzles are clean and unbroken.
3. Ensure tire pressure (tractor and sprayer) is correct and all guards (e.g. air-intake grill and PTO shaft shield) are in place and intact.
4. Ensure universal joint(s), sprayer-tractor hitch and all connections are clean, lubricated and secure.
5. Ensure each nozzle shut-off valve or nozzle body flip position is working.

This spray plane was left on the runway with the engine exposed for less than four hours. When the owners returned they found a precocious bird had built a nest. Perform regular sprayer inspections – you never know what you'll find!

PHOTO CREDIT – S. RICHARD, NEW BRUNSWICK.

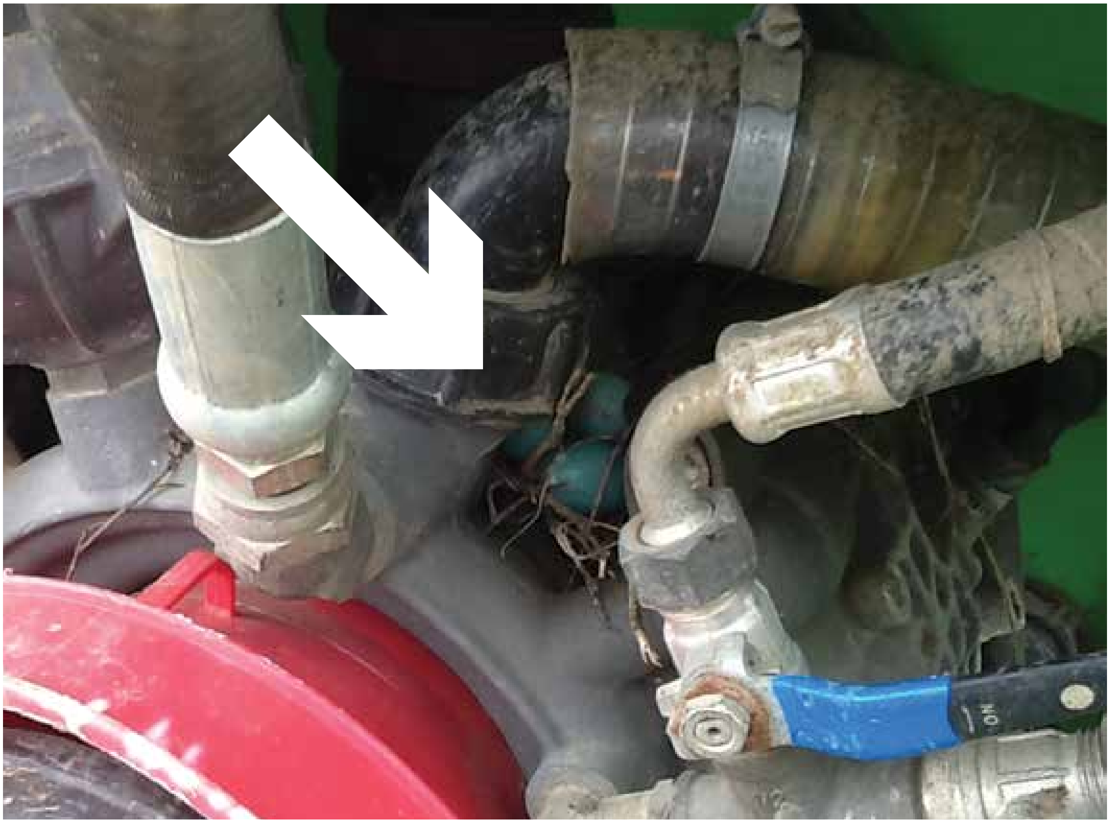
TEST SPRAY AND AGITATION CHECK

For PTO-driven sprayers, start the pump and set tractor engine speed to the desired rpms. For positive displacement pumps, adjust the pressure regulator to obtain the desired operating pressure. For centrifugal pumps, minor changes can be made to pressure using the regulator valve, but it may impact tank foaming and mixing. Perform the following steps:

- open the manifold valve to fill the lines and begin spraying
- ensure each nozzle sprays correctly
- ensure the agitation system is functioning properly
- ensure the tank is secure on the chassis and both crack and leak-free

Once complete, continue mixing and filling. If your sprayer manufacturer advises contrary or additional steps, be sure to perform them.

As a plastic suction filter ages, it can warp or become brittle. When this happens, the O-ring may no longer sit correctly and the unit may allow air to be drawn into the lines. They should be cleaned and inspected after every spray day. A shut-off valve lets you check the filter, even when there is liquid in the tank. The valve should be large enough to not cause a significant pressure drop.



You never know what you'll find during an inspection. I found a robin's nest hidden on this vineyard sprayer's pump.

Sprayer inspections become repetitive and it's easy to accidentally miss things. Have you ever driven home preoccupied, only to discover you don't remember how you got there? Using the checklist on page 28 keeps you engaged and will help ensure accuracy. Consider photocopying and laminating the checklist for repeated use with a dry-erase marker. It can also be downloaded from the horticulture section of www.sprayers101.com.

4.1 | Sprayer inspection checklist

CanadaGAP (good agricultural practices) requires sprayers to be calibrated, but does not specify how. Download this checklist at sprayers101.com. Consider printing and laminating it for repeated use with a dry-erase marker.

PUMP AND HOSES

- ☐ Leaky pump valves, diaphrams and/or plungers checked/replaced
- ☐ All hoses and fittings sound (while under pressure)
- ☐ Pump flushed and spray discharge clear
- ☐ Pump lubricated

FILTERS, STRAINERS AND NOZZLES

- ☐ All filters (tank basket, suction filter, in-line filters and nozzle strainers) clear and not damaged
- ☐ Check valve diaphragms clean and function
- ☐ All nozzles clean and unbroken
- ☐ Each nozzle shut-off and/or flip body is working

REGULATORS, GAUGES AND CONTROLS

- ☐ All gauges accurate
- ☐ Pressure and shut-off valves (ball or solenoid) work smoothly
- ☐ Regulator(s) and/or bypass valve(s) move easily
- ☐ Pressure gauge defaults to zero and does not bounce or leak

BELTS AND POWER TAKE OFF

- ☐ All belts have proper tension and no wear or cracks
- ☐ PTO greased, connection zones checked and guard in place

PROPELLER AND AGITATION

- ☐ Propeller has no nicks, cracks or residue, turns freely and has no lateral play
- ☐ Mechanical agitation shaft is supported, bearings lubricated and shaft packing suitably tight (no leaks)

AIRFLOW AND DIRECTION

- ☐ Ducts or deflectors are residue-free and can be adjusted
- ☐ Blade pitch and fan gear can be adjusted

SPRAY PRESSURE ADJUSTMENT

- ☐ Regulator/bypass adjusted to achieve desired pressure at usual tractor RPM
- ☐ Each boom operating at desired pressure for each nozzle combination

TIRES AND TANK

- ☐ Tires have correct pressure, tight bearings and no cuts
- ☐ Drain plug can be removed
- ☐ Tank has clear vents, is secure to chassis and has no punctures or damage

5.0 Adjusting sprayer settings

Adjusting sprayer settings

If you are a sprayer operator simply looking to confirm the sprayer is emitting the desired rate (e.g. L/ha or gal./ac.), jump ahead to **page 66**. But if you have purchased a new sprayer, you're spraying a crop you're not familiar with or are reconsidering your traditional practices, read on. When performed correctly, this somewhat qualitative form of calibration will help you optimize the fit between your sprayer settings and the target you wish to spray. This amounts to better coverage and less waste.

Handheld weather meters are convenient tools for measuring relative humidity, wind speed and temperature during calibrations and when spraying. The back-lit models are great for low light conditions. Take readings near the top of the spray swath.

Any calibration is only as good as the weather conditions during the calibration. A calibration in low wind, high humidity and moderate temperatures won't give the same coverage in high winds, low relative humidity and high temperatures. Droplets get blown off course and evaporate rapidly. Only calibrate the sprayer in weather conditions you would normally spray in.

I recommend using a handheld weather meter to monitor the conditions. Record those conditions along with your calibration notes. Local weather reports often don't match the conditions in the planting. Hold the weather meter as high as you can – take readings at the top of a spray swath. Reading wind, for example, at the orchard floor results in wind speeds that are about half that at the top of the orchard.

DID YOU KNOW?

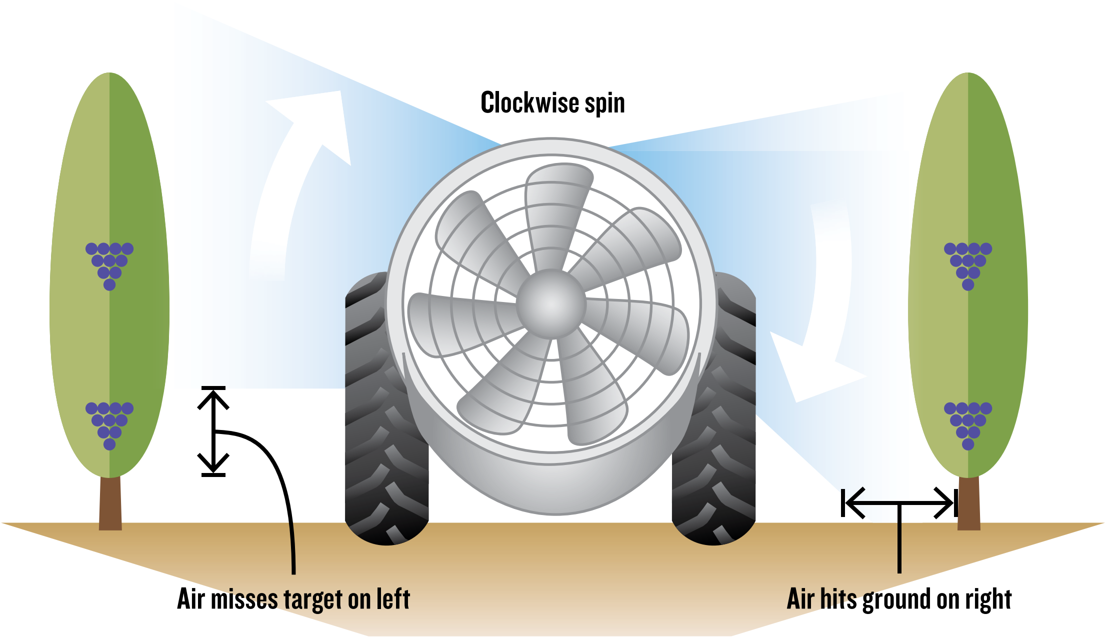
The weather conditions during spraying will affect everything. Only calibrate in conditions you would spray in, or your calibration settings may no longer be appropriate.

5.1 | Air direction

The air stream created by the sprayer fan (or turbine) carries the spray solution into the target (e.g. tree, bush, shrub, vine, etc.) and distributes it throughout the plant canopy. To reach all target surfaces, and achieve adequate spray coverage, all of the air in the plant canopy must be replaced by spray-laden air.

Air direction is important. Research has shown that radial fans without effective straightening vanes or deflectors make the air go up on one side and down on the other. In extreme situations, this might compromise the spray job (e.g. miss the lower portion of the target on one side of the sprayer) or it might simply waste spray and stir up leaf litter and dust. Here's how you can see if this is happening on your sprayer.

1. Park the sprayer in the alley between the rows – preferably with no cross wind.
2. Tie 25 cm (~10 in.) lengths of ribbon (not flagging tape) to the upper, middle and lowest nozzle bodies, and attach lengths to the deflectors (if present) using duct tape.
3. Turn on the air, but beware of the fan intake – if the ribbons are too long they won't stand straight out and may get sucked into the intake.



Without effective straightening vanes, some radial fans skew the air. Air hitting the ground can stir up leaf litter and dust, and may be a waste of spray. When it misses the lower part of a target, efficacy may be reduced.

Using a ladder to tie ribbons to nozzle bodies on a Turbomist sprayer tower.

The ribbons show air direction relative to the target canopy and reveal if the sprayer air is out-competing any ambient wind.

Ribbons tied to each active nozzle position will show where air (and spray) is aimed. Note the slight downward direction of the air on the bottom-left side of the sprayer versus the bottom-right. Don't use flagging tape, as shown here. It will stretch beyond 25 cm (~10 in.) and often breaks. I once covered an orchard floor with orange flagging-tape confetti – it was funny, but not terribly informative. Use 25 cm lengths of strong ribbon instead.

PHOTO CREDIT – M. WARING, BRITISH COLUMBIA.

By observing the ribbons, you can extrapolate where the deflectors should be aimed. Adjust the deflectors to just over- and under-shoot the target canopy. Deflectors should not be optional on fan-equipped radial airblast sprayers – they should be standard equipment. Deflectors compress spray-laden air into a tight stream that more easily reaches and penetrates canopies, preventing leaf litter and dirt from being stirred up. This helps keep the fan blades and grill clean, and reduces the potential for "sandblasting" on grape and berry crops.

For suspended airblast fans, such as over-the-row systems, the ribbons can still be used to adjust deflectors when present. Always be sure the air outlets do not point directly at one another. Research in Quebec and experience in Ontario has shown that crop penetration will improve by orienting the outlets in any manner other than in direct opposition (e.g. one forward, one back or both forward, etc.).

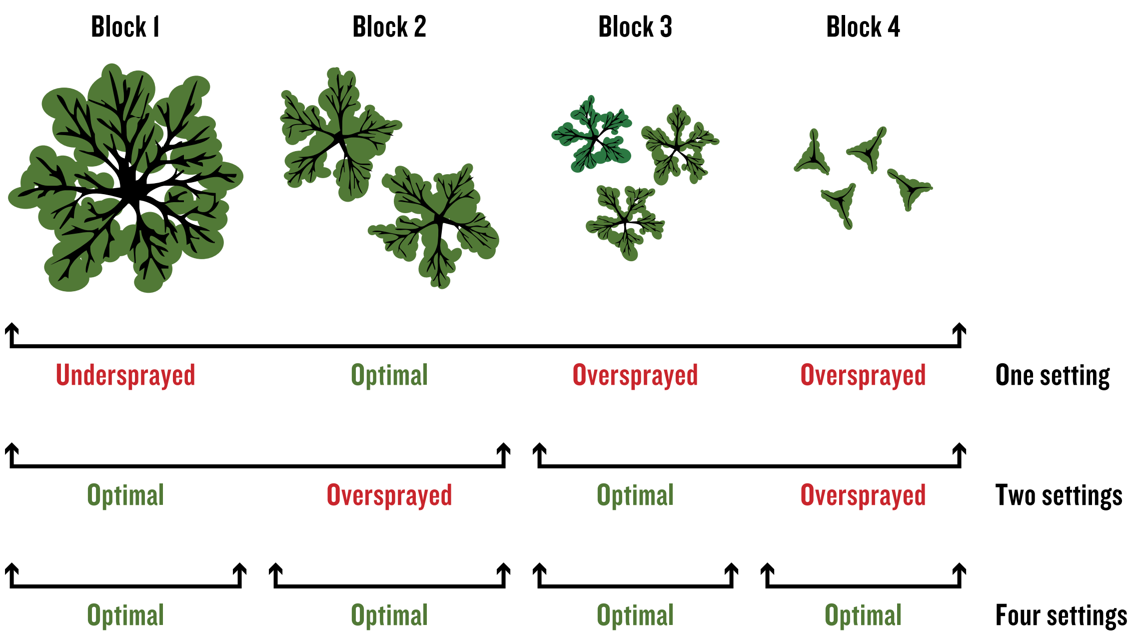
These homemade deflectors on an older engine-driven FMC made a big difference in this grower's operation. The side walls are important to help channel the air. They are longer than most deflectors (a good thing) but do not reach beyond the sprayer wheels. Once installed, the sprayer was able to reach the tops of 6 m (~20 ft.) McIntosh apple trees using lower rpms, improving coverage while reducing fuel costs, wear and noise.

Using a piece of scrap wood with a ribbon on the end to demonstrate how deflectors would channel air. Once convinced, the operators of these sprayers fabricated and installed deflectors on the top and bottom of the air outlets and have been very pleased with their performance.

For Turbomist sprayers without towers, upper and lower deflectors are not an option. These sprayers are designed to channel air using adjustable outlets. The air outlet is not a uniform width – it's widest about half-way down. Using ribbons to extrapolate air direction, aim the widest part of the outlet at the densest part of the canopy. This automatically repositions the booms, facilitating the next step where we turn off nozzles that will significantly over- or under-shoot the target **(see page 49)**.

When repositioning the air outlets on a Turbomist with no towers, aim the widest part of the outlet towards the densest part of the canopy, then turn off unneeded nozzles. Lubricate the nuts and bolts that hold the outlet bands tight. Never lubricate the bands themselves – this can cause the outlets to slip out of place as you drive. Keeping these bands clean is important. Sand caught between band and sprayer sometimes acts like ball bearings and may make it difficult to keep tower outlets firmly in place.

The calibration process should be performed for EACH significantly different crop or block sprayed with the sprayer. Some operators dedicate sprayers to certain blocks to minimize the number of adjustments required. This might mean re-ordering the sequence that blocks were traditionally sprayed. If that's not possible, multiple setups might be needed to reflect block diversity. You can minimize setups by grouping similarly-sized blocks together and calibrating to the worst-case scenario (i.e. the target with the greatest area-density, defined on page 53). Smaller blocks may be slightly oversprayed, but it's still an improvement in efficiency. Record the setup for each sprayer/block combination and keep a copy in the tractor cab(s).



Imagine an operation with four blocks of cherry trees, each very different in area-density due to age, variety, pruning, rootstock, etc. (shown here top-down). If an airblast sprayer had only a single calibration (one setting), larger trees would be undersprayed, and smaller trees would be oversprayed. If the blocks were grouped by size and the sprayer was adjusted to match the larger blocks, two blocks would receive optimal spray coverage and two would be oversprayed (two settings). With a unique calibration for each block (four settings), all trees would receive optimal coverage. It's up to the spray operator to decide the best approach for their operation.

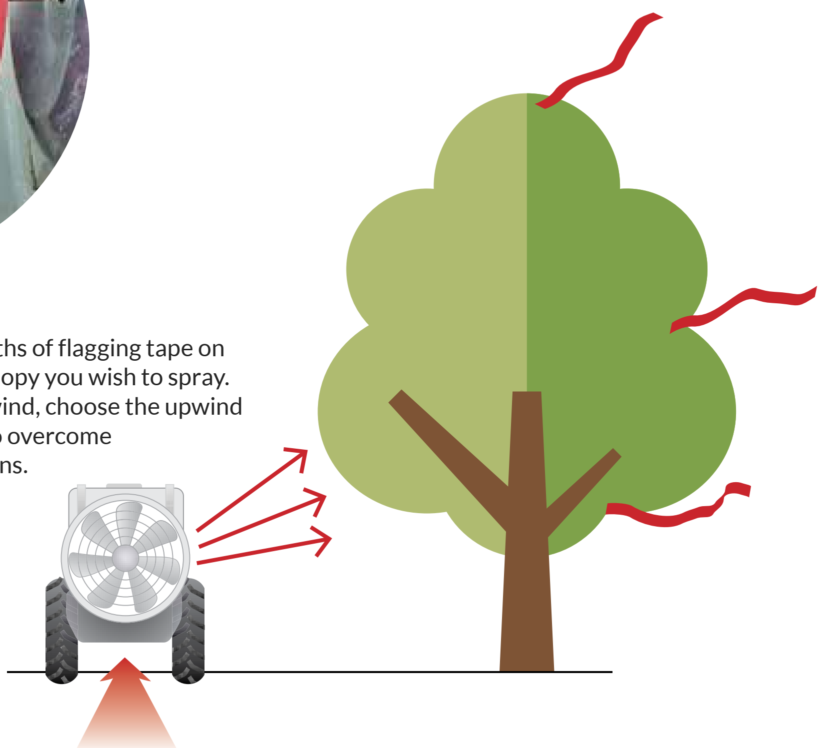
Watch a video on this calibration procedure at www.sprayers101.com.

5.2 | Air speed and volume

Once the air direction has been adjusted, match the air volume and speed to the crop. When making this adjustment, there are a lot of contributing factors, such as wind conditions, canopy structure and ground speed. There's an easy way to account for their collective impact.

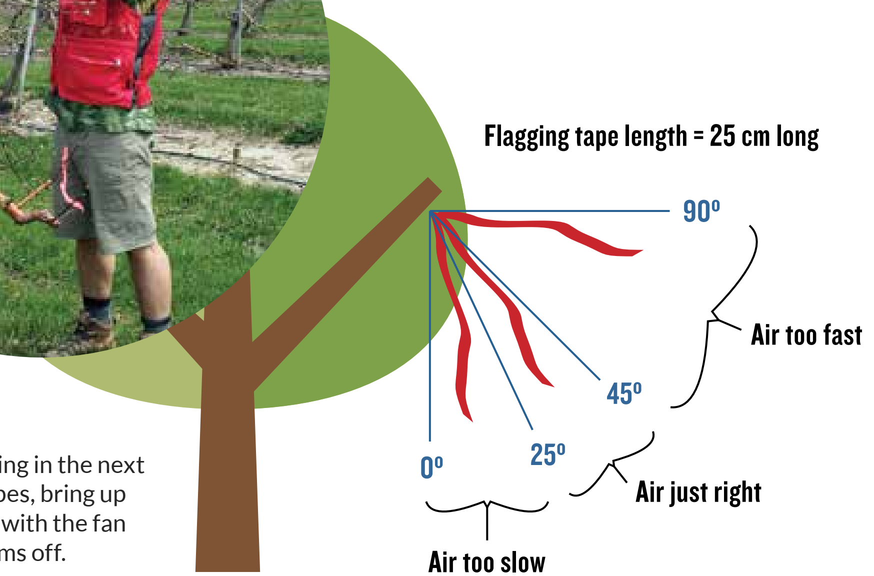
1. With deflectors already adjusted and the fan gear selected (if available), choose your tractor rpms (~540 rpm or less) and ground speed (typically ~5.0 km/h or ~3.1 mph in Ontario).
2. Attach 25 cm (~10 in.) lengths of flagging tape on the far side of the plant canopy you wish to spray. If spraying in a light cross wind, choose the upwind target so the tapes are blowing into the canopy, not away from it. Do this at the top, middle and bottom of the canopy for three plants in a row. This works for bushes, canes, hedgerows, trees, etc.
3. With a partner standing in the next alley watching the tapes, bring up the rpms and pass by with the fan on and the spray booms off.

A close up of an airblast gear box. There are usually two options – high or low.



Attach 25 cm (~10 in.) lengths of flagging tape on the far side of the plant canopy you wish to spray. If spraying in a light cross wind, choose the upwind target so the sprayer has to overcome the wind to move the ribbons. Do this at the top, middle and bottom of the canopy for three plants in a row.

The author tying ribbons on the up-wind side in an apple orchard just past green-tip. The red vest has lots of pockets to hold supplies and sprayer operators can see it clearly for safety. The Hawaiian shirt is because it's Friday.



With a partner standing in the next alley watching the tapes, bring up the rpms and pass by with the fan on and the spray booms off.

Air is too fast: Increase ground speed, reduce rpms or lower fan gear
Air is too slow: Reduce ground speed, increase rpms or raise fan gear

If the partner reports that the tapes did not move, the air from the sprayer may not have been enough to overcome the wind, and/or may not have been enough to penetrate the plant canopy. Reduce ground speed, increase rpms or raise fan gear until most of the tapes move. Despite your best efforts, they may not move at all, but the primary goal is to get the air (and spray) past the centre of the canopy, not out the far side. Spray coverage will be confirmed in a later step. If the flagging tapes stood straight out, there was too much air. Increase ground speed, reduce rpms or lower fan gear until no tapes stand out.

Repeat this process for EACH significantly different crop sprayed with the sprayer. As with air direction settings, multiple setups might be needed to reflect each block, or you might choose to group of similarly-sized blocks and calibrate air to the worst case scenario. Record the setup for each sprayer/block combination and keep a copy in the tractor cab(s).

Watch a video on the ribbon test at **www.sprayers101.com**.

Monitoring air speed with a Pitot meter on a multi-row Gregoire sprayer with suspended, over-the-row fans.

This Slimline sprayer is just one more interesting version of an airblast sprayer. It features a dozen Sardi fans with six nozzles apiece. The airspeed from each fan can be independently controlled for precise applications.

This method is not definitive and requires some interpretation. It is more important to ensure the tapes do not stand straight out rather than to move every tape. The goal is for the spray-laden air to penetrate the canopy just beyond the midpoint (e.g. the trunk), and not blow out the far side.

During an April calibration workshop in a peach orchard we encountered a situation worth noting. The cross wind was gusting up to 13 km/h (~8 mph), which was not ideal, but we were assembled so we proceeded. The sprayer was a smaller model and despite our best efforts it couldn't move the ribbons on the far side of the tree (which was at silver/green tip). When we placed water-sensitive papers in the tree, and turned the spray booms on, the papers received more than enough coverage throughout the canopy. How did that happen?

The sprayer was equipped with nozzles that produced large droplets and high volumes. And the moderate air combined with the high operating pressure provided sufficient force to drive the swath beyond the trunk, but not quite out the far side of the canopy. When the tree was sprayed from both sides, coverage was more than sufficient. This situation is more likely to happen in orchards that are semi-dwarf or larger. Obviously, calibrating in such a high wind isn't advisable (the downwind swath drifted terribly), but the situation did show how relying solely on this flagging tape diagnostic might give a false negative. This is why calibration must include an evaluation of spray coverage – described on **page 57**.

If you can't prevent the ribbons from standing straight out, you might consider blocking a portion of the sprayer air intake. This technique is not covered in this handbook because many sprayer manufacturers advice caution or do not recommend this practice. Instead, consider using the Gear up-Throttle down method, described on **page 43**.

Dr. Bernard Panneton (Horticultural R&D Centre, Agriculture and Agri-Food Canada) performed a series of experiments exploring the relationship between potato canopies and wind, and his observations extend to all broad leaf crops. Bernard showed that as wind speed increased, the percent of leaf surface area exposed to spray also increased, but only to a point. If the wind got too fast, the percent of leaf surface exposed to spray dropped significantly, up to 20% less. His interpretation was that low to moderate air speeds just ruffled the leaves, exposing their broad surfaces to spray more consistently. When air speed became excessive, leaves and twigs aligned with the wind, exposing only their thin edge to spray. The take home lesson is that spray is more likely to impinge on all target surfaces when air speed and volume are calibrated correctly.

As Bernard says with his charming French accent: "More air is not better."

Potato plant in a wind tunnel exposed to 0 km/h wind (still conditions).

PHOTO CREDIT – B. PANNETON, QUEBEC.

Potato plant in a wind tunnel exposed to 10.8 km/h (6.7 mph) wind (moderate wind speed). Note how the leaves ruffle, increasing the opportunity for spray coverage.

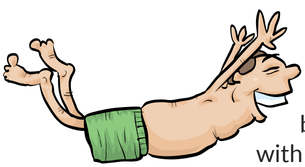
Potato plant in a wind tunnel exposed to 18 km/h (11.2 mph) wind (high wind speed). Note the deformation and reduced surface area.

5.3 | Gear up-throttle down

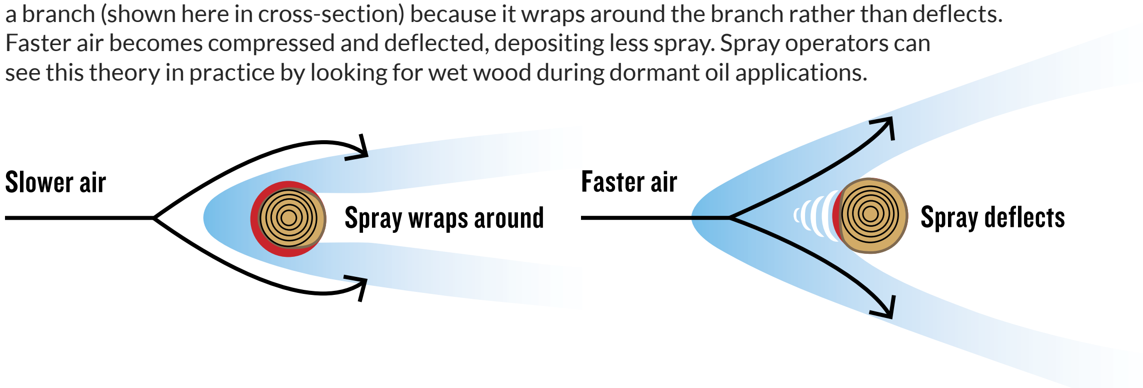
In 1977, David Shelton and Kenneth Von Bargen (University of Nebraska) published an article called "10-1977 CC279 Gear Up-Throttle Down" describing the merits of reducing tractor rpms for trailed implements that didn't need 540 rpm to operate. In 2001 (republished in 2009), Robert Grisso (extension engineer with Virginia Cooperative Extension) described the same fuel-saving practice. Again, it was noted that many PTO-driven farm implements don't need full tractor power. Why waste the fuel? He tested shifting to a higher tractor gear and slowing engine speed to maintain the desired ground speed. Testing was done on 700 diesel tractors. As long as the equipment could operate at a lower PTO speed and the tractor itself didn't lug (i.e. overload), as much as 40% less diesel was used.

For airblast operators with PTO-driven sprayers and positive-displacement pumps, Gear up-Throttle down (GUTD) has a lot of potential to reduce the PTO speed from 540 rpm to 350-375 rpms – saving fuel and slowing the fan speed. This is an excellent option when the fan is overblowing the target, even in low gear. Ground speed remains the same and so does operating pressure – there's no need to re-nozzle or recalibrate.

Slowing the fan speed can improve coverage. In early season, crops have relatively empty canopies. When an airblast sprayer passes by, a significant portion of the spray is blown through the canopy without hitting the target. The air carrying the spray is moving so fast that it causes droplets to slipstream around targets. Smaller droplets are more likely to miss the target because they have smaller settling velocities and are slaves to the entraining air.

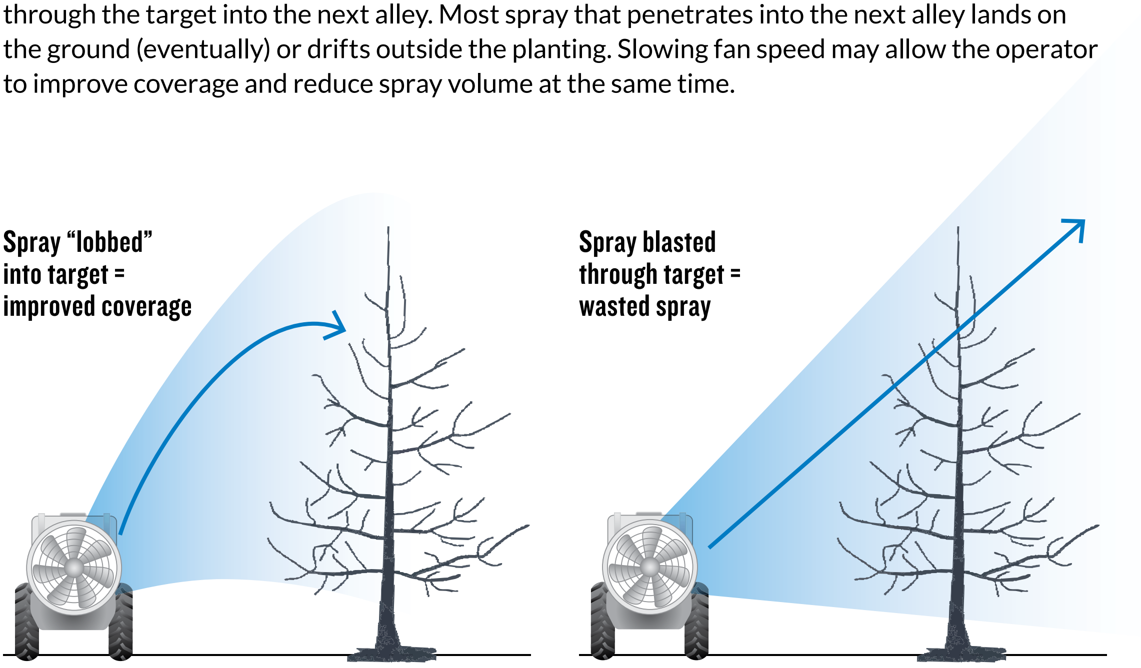


Have you ever done a belly flop? As you painfully sink to the bottom you might be wondering how "soft" water suddenly got so hard. When you compress water with force, it pushes back. It's similar with air. When air pushes hard against an object, it compresses like a hard shield and the rest of the air deflects around it. If the air is supposed to deposit spray, that's difficult to do through a hard shield of compressed air. And the deflected, fast-moving air will also carry the spray along with it, missing the target. Using slower air will deposit more spray (red) around a branch (shown here in cross-section) because it wraps around the branch rather than deflects. Faster air becomes compressed and deflected, depositing less spray. Spray operators can see this theory in practice by looking for wet wood during dormant oil applications.



When applying dormant sprays in orchards, only the wood on the sprayer-side gets wet (not all the way around) and high-speed air is deflected. With slower air, the air stream wraps around the wood to wet more surface area. Even fans in low gear often produce too much air for dormant applications, depending on the wind conditions.

The goal of GUTD for airblast sprayers is to use enough air to get the spray to the top of the target canopy and make any leaves flutter to expose all surfaces, without blowing the spray through the target into the next alley. Most spray that penetrates into the next alley lands on the ground (eventually) or drifts outside the planting. Slowing fan speed may allow the operator to improve coverage and reduce spray volume at the same time.



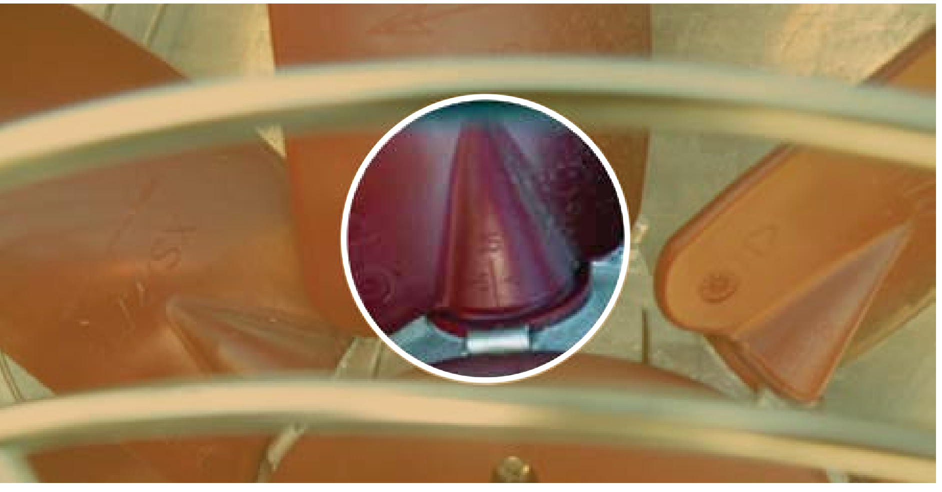
Use GUTD to reduce blow-through, improve coverage and potentially reduce the amount of spray required.

GUTD only works on airblast sprayers with positive displacement pumps (e.g. piston, diaphragm or roller). Airblast sprayers with centrifugal pumps, common in Ontario, would experience a drop in operating pressure and would have to be re-nozzled. If the sprayer is already operating at pressures above 150 psi, the pressure drop may be acceptable because operating pressures that high aren't often necessary. GUTD is also not intended for air-shear sprayers (e.g. Kinkelders, certain AgTecs, etc.) because dropping air speed below a certain threshold may compromise spray quality. The air needs to be fast enough to create and direct spray droplets.

When OMAFRA experimented with GUTD in 2013 we noticed the noise level on the sprayer dropped considerably. One grower shifted to GUTD settings in the middle of a dormant oil application in pears and reported that the trees immediately began to drip with excessive coverage. These are positive results. But in one instance the operator was already applying a low spray volume per hectare using air induction nozzles and the lowest fan gear. By further slowing fan speed using GUTD, coverage at the top of his cherry trees was compromised.

Here are some Ontario-based observations about the GUTD method. Don't let the caveat dissuade you, GUTD is recommended!

- Airblast sprayers with centrifugal pumps or air-shear nozzles make GUTD very complicated, and the method may not work.
- Growers who are already using very coarse spray droplets, reduced volumes and the low gear on their fan may compromise coverage with GUTD.
- Growers performing alternate row-middle applications should not use GUTD.
- If the tractor begins to lug (e.g. black smoke, sluggish response, strange sounds), GUTD won't work.
- This method is most useful during dormant applications, spring fungicide applications and in young or sparse crops.
- If you try GUTD, confirm spray coverage before and after.



Some airblast sprayers, like this one, feature fan blades with adjustable pitch to increase or lower air volume and speed. It's often a pain to try to adjust them, and most operators only try it once.

View videos on GUTD at **www.sprayers101.com**.

5.4 | Tower power

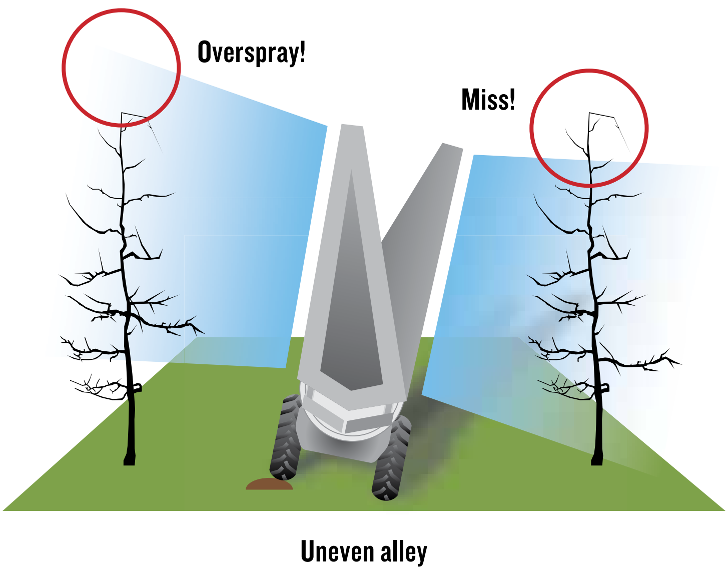
Spray towers warrant special consideration during calibration. Towers move the air and nozzles closer to the target compared to the curved booms on a conventional airblast sprayer. When the distance-to-target is reduced, the odds of droplets reaching the target are improved – with less pesticide drift and more spray deposit in the plant canopy. But don't get too close – nozzles need a minimal distance from the target to create an optimal spray pattern (see page 80).

Many growers report savings when switching from conventional airblast to towers. The towers are more efficient at depositing the spray and some operators report having to reduce their typical sprayer volumes to prevent run-off. I worked with one apple grower that switched from a conventional sprayer to one with a tower. His lakeside orchard was plagued by wind, and his conventional sprayer had a relatively small fan 60 cm (~2 ft.) in diameter that couldn't compete. Traditionally, the grower used higher spray volumes to compensate. This is the epitome of diminishing return on investment.

His new tower sprayer had a larger fan 90 cm (~3 ft.) in diameter and reduced the distance-to-target. He was able to reduce his spray output by more than 200 L/ha (~21.4 gal./ac.), while improving his overall coverage. This saved money and reduced environmental impact.

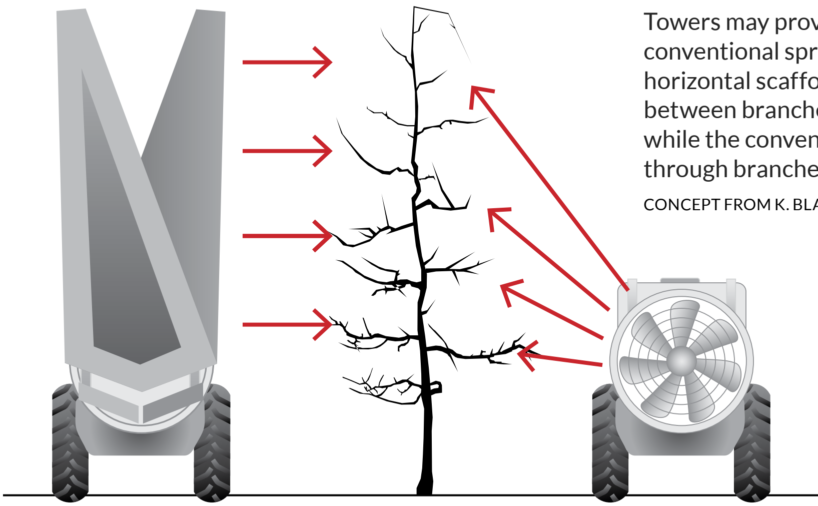
But, towers are not a good fit for all situations.

- Towers must be as tall as the highest target (e.g. treetop).
- Towers should be used on level ground. Towers will tip and yaw on uneven ground, potentially missing or over-shooting targets.
- Towers must be able to clear netting, trellises or an overhanging canopy.



The perils of towers on uneven ground. For towers to be effective, the tower must be at least as tall as the target. When the target is only slightly higher than the tower, some sprayer operators install an additional nozzle body on the top deflector plate to extend the reach.

Occasionally, I have discovered areas along tower outlets with reduced air flow. You can usually feel these "dead zones" with your hand (beware of flying debris), but it's better to observe short ribbons attached to the nozzle bodies as described in Section 5.2. In low fan gear, watch to see if any ribbons flag or appear slack from a lack of air. You can "borrow" air by re-positioning neighbouring deflectors. If that's not possible, try replacing the conventional nozzles in the dead zone with air induction nozzles (see page 101). Coverage should improve in that zone when pressure propels coarser droplets further than finer droplets.



Towers may provide better coverage than conventional sprayers in orchards with horizontal scaffolding. The tower sprays between branches, penetrating more easily, while the conventional sprayer has to spray through branches.

CONCEPT FROM K. BLAGBORNE, BRITISH COLUMBIA.

A homegrown airblast sprayer with tower. PVC ducts, sheets of plastic, a squirrel cage blower and grower ingenuity. This looks suspect and difficult to clean, but reputedly works very well in highbush blueberries.

Small tower – Side view

Rear view

Towers come in many shapes and sizes. Orchards aren't the only good fit for towers – grapes, bushes and canes can also benefit from small towers.

5.5 | Nozzle positions – on or off?

Once the air has been adjusted, decide which nozzles should be on or off. This will depend on the height of the crop, the angle of the spray (hollow cones generally produce a 60° to 80° cone as a function of design and operating pressure) and the orientation of the nozzle body. Some nozzle bodies can be swiveled up or down a few degrees to adjust the spray angle. An alternative is to permanently rotate the nozzle body fitting in the boom.

The ribbon diagnostic described earlier indicates air direction and shows where the centre of each nozzle is aimed. Use this information when deciding to turn off any nozzles that excessively over- or under-shoot the target canopy. Leave a little over-shoot in the upper-most nozzle because wind is most likely to deflect spray at the top of the spray swath. Studies have shown wind speed at the top of an orchard can be more than two times that on the orchard floor.

DID YOU KNOW?

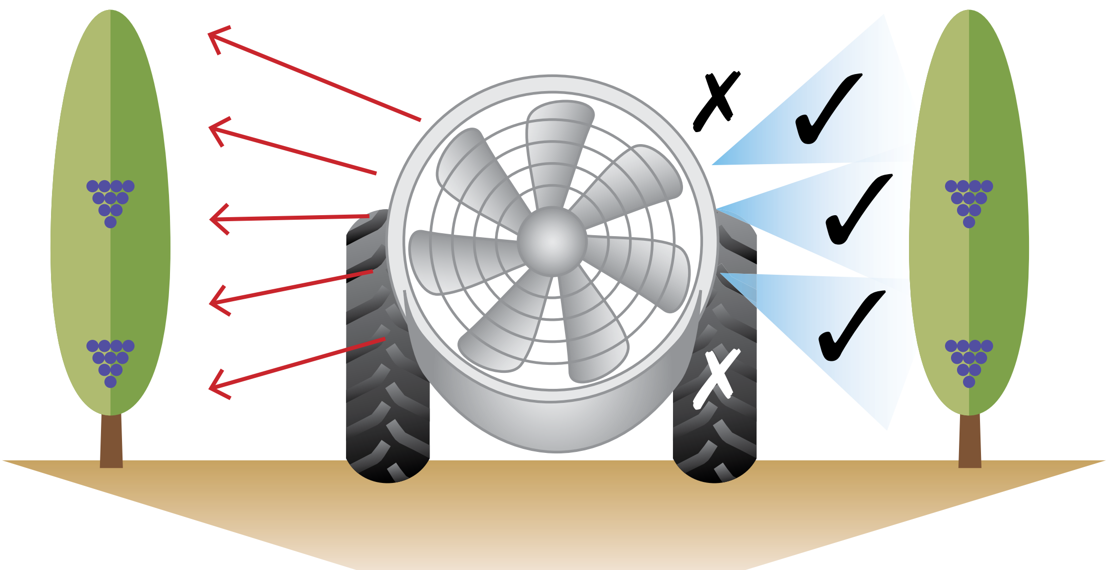
When aiming nozzles using the rollover, be careful not to swivel them too far or the valve will partially close and compromise the spray pattern.

It's best to use a ladder when re-nozzling a tower sprayer. There typically isn't a ladder available when the operator is out in a block and needs to change tips. Please be careful. Some sprayer chassis and tanks are designed to accept a climber, but even so they can be slippery.

THE BOTTOM NOZZLE

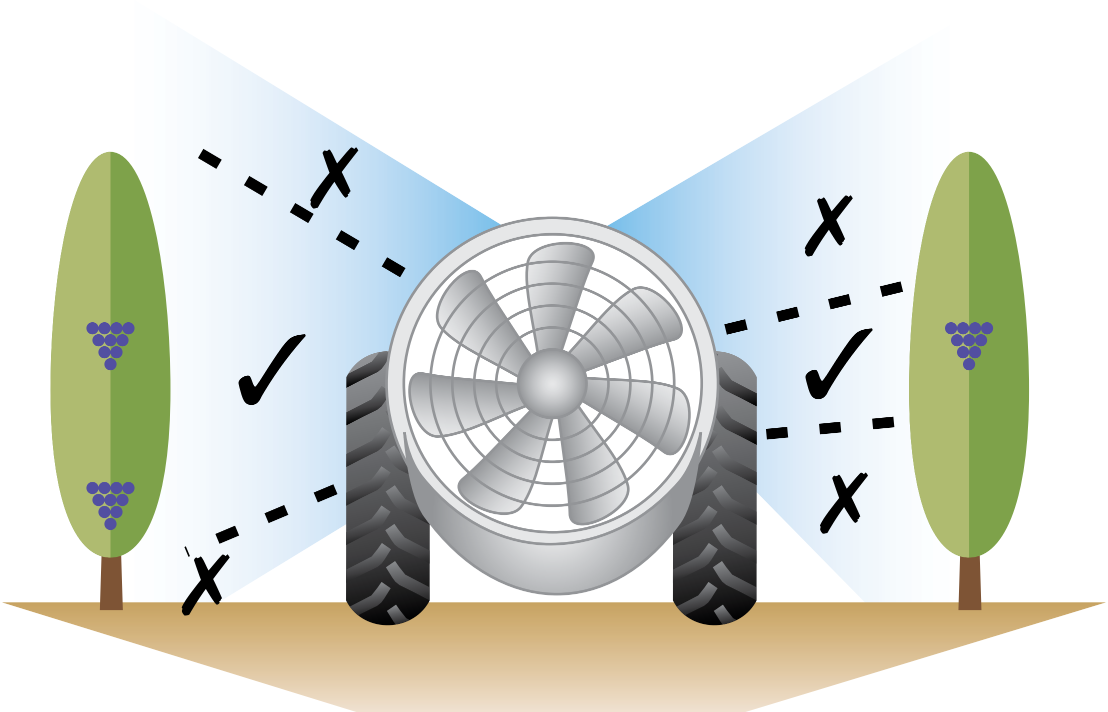
The ribbon only indicates the **centre** of the spray cone. The cone expands outward and overlaps adjacent cones. So, even if the centre of the lower-most nozzle intersects the bottom of the target canopy, you may still be able to turn it off because the nozzle above has that portion covered.

Many sprayer operators err on the side of caution and believe they should leave the lowest nozzle on. But most products (e.g. foliar fungicides or ingestible insecticides) are designed to be on the leaves, not in the grass or on the trunk. Why waste it? In my experience, perhaps half the airblast sprayers I've worked with didn't need the bottom-most nozzle on. Turning off that nozzle represented considerable savings in unneeded pesticide. Never turn the bottom nozzle off indiscriminately – always confirm coverage using water-sensitive paper, as described later on in the handbook in Section 5.7.



The ribbon diagnostic indicates only the centre-point of a hollow cone's spray pattern. The overlap from neighbouring nozzles might allow you to turn off the lower-most nozzle without compromising coverage. Confirm this with water-sensitive paper.

Adjust spray distribution across the boom at the beginning and roughly mid-way through the spray season to ensure the sprayer will uniformly cover the target with the optimal volume. These adjustments should account for both canopy growth and fruit set. As the season progresses in an orchard, fruit may cause limbs to hang lower and warrant a new spray distribution. Turning on the bottom nozzle position will help, but it doesn't account for the possible increase in density throughout the canopy. You may need more volume distributed across the entire boom. Another example is when grape bunches begin to close, sprayer operators may direct fungicides exclusively at the fruit zone and not the entire canopy.



Turn off nozzles that are not spraying the target.
The target may be the full canopy or a specific area like a fruit zone.

DID YOU KNOW?

Deflectors on airblast sprayers make a big difference to canopy penetration and deposition, but the factory-made top set is usually too small. Consider building your own and add side-walls to channel air.

Adjusting the nozzles on a fishtail-style nursery sprayer.

An older Hardi cannon sprayer used in an ornamental nursery. The nozzles are clustered with seven nozzles on top, four in the middle, one below. The settings on this manner of sprayer are relatively inflexible, making it difficult to control where the spray goes.

5.6 Match spray output to target area-density

For those crops that grow and fill over a season, consider changing the sprayer output and distribution at some point to ensure the sprayer provides sufficient coverage all season long. For example, orchardists use one setting at the beginning of the season that will last until petal fall. Volumes would then be raised and or re-distributed to last until the end of the spray season. Petal fall may not be the appropriate physiological cue for all crops, but it's a good reminder that if changes aren't needed yet, they soon will be.

The amount of spray volume needed to provide adequate coverage depends on the size of the plant (consider the height and the cross-sectional area) and the density of the foliage (a function of pruning practices and the time of season as leaves fill in). Taken together, these measurements are the "area-density". Adjusting sprayer settings to reflect the area-density of a crop can save money and reduce environmental impact during early-season applications and in young plantings. Mix the tank as you normally would to maintain the pesticide concentration on the label, but adjust the sprayer output to match the plant size. Performed correctly, you will be able to go further on a tank without compromising efficacy.

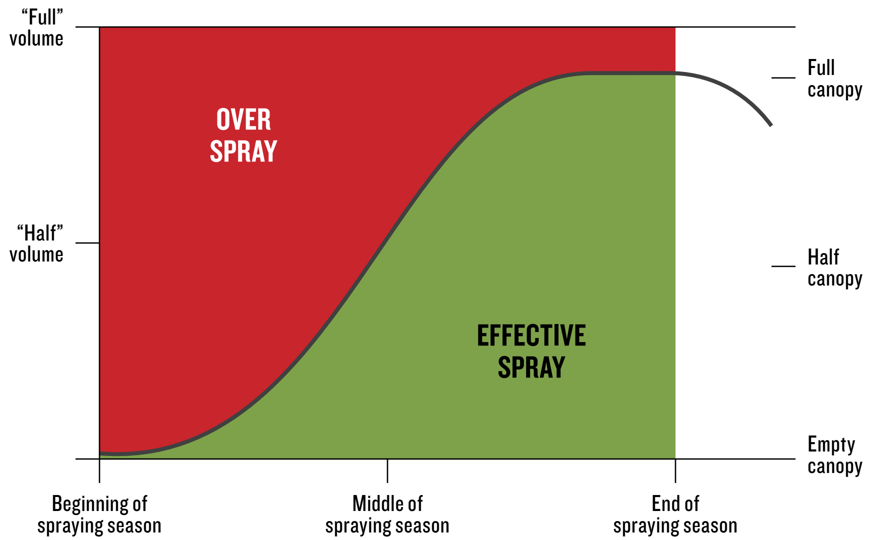
When two physiologically diverse blocks share an alley, use the sprayer settings suitable for the larger of the two. It's more important to ensure good coverage on the big block than to save on the smaller.

Always confirm you are achieving acceptable coverage using water-sensitive paper (see Section 5.7). The idea is to eliminate only that portion of the spray that misses or unnecessarily drenches the target. If you drop below the minimally recommended rate-per-area (e.g. the amount of formulated product per hectare or acre), it is considered an off label application, leaving you solely liable. Adjusting spray volume while maintaining spray concentration is the basis for the Crop-Adapted Spraying model – an advanced technique based on international practices and one we have tested for several years in apple orchards. It is described in greater detail later in Section 8.0.

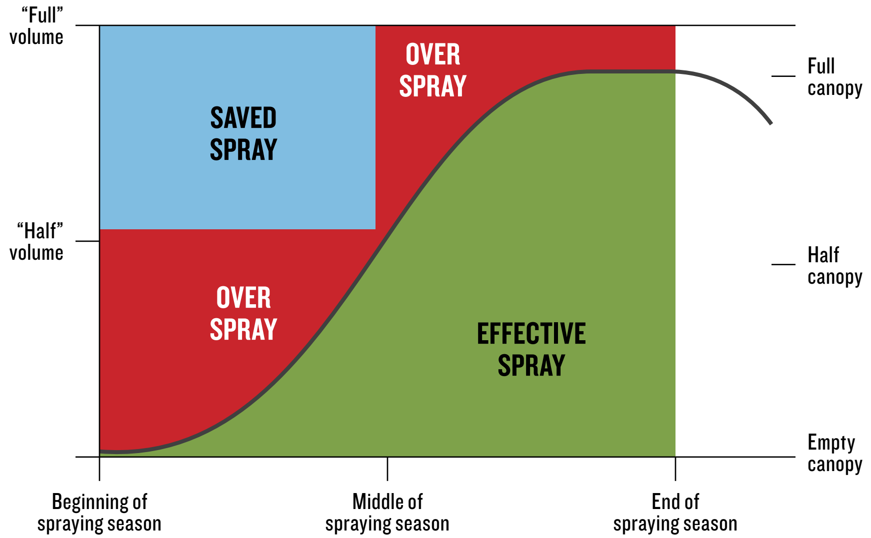
The first spray volume should give sufficient coverage to reach mid-season (a good physiological cue is petal-fall). The second volume should be sufficient to reach the end of the spraying season. If you only achieve minimal coverage during adjustments, you may not have enough to provide suitable control later on.

Unused fungicide | **Beautiful fruit** | **$4,140.00 (CAD) fungicide savings**

An apple grower adjusted his sprayer output for each block of apples and adjusted how much spray was needed early in the season versus after petal fall. Pest activity, disease and coverage were carefully monitored throughout the season. These leftover boxes of fungicide are how much he saved, and his apples were beautiful, even though he had a history of scab in the orchard in previous years. This is only possible when the sprayer is properly calibrated, and coverage and pest/disease activity is carefully monitored. Never reduce rates indiscriminately – it could compromise efficacy and increase the potential for resistance.



Graph 1: The curved line represents the leaf area in a canopy increasing over the growing season. The volume of the spray providing coverage is indicated in green. Spraying the same volume throughout the season means a lot of overspray (red) early in the season. The target isn't there yet.



Graph 2: Use one set of nozzles and/or pressure setting to spray less early in the season. Change sprayer output about midway through the season, or as required by canopy development – to save a lot of spray (blue) without compromising spray coverage. The first volume should give sufficient coverage to reach mid-season, and the second volume should be sufficient to reach the end of the spraying season. If you only achieve minimal coverage during adjustments, you may not have enough to provide suitable control later on.

Not every crop requires increased volumes over the season. Many nursery crops, such as evergreens, may not require volume changes. Our research has shown that mature high-density orchards generally only need a single volume. This is because early in the season, the wind moves unimpeded through the orchard, reducing spray coverage. As the canopies fill, there is less wind and more spray is available, accounting for the increase in area-density. Now THAT'S convenient.

It's early May in southern Ontario. This high-density orchard is on 4.25 m (14 ft.) rows and is receiving 375 L/ha (~40 gal./ac.) for spring protectant fungicide applications. A cross wind is coming from the driver's right, gusting up to 10 km/h (~6.2 mph). The sprayer fan is in low gear, traveling 6.1 km/h (3.8 mph). The water-sensitive paper is on the upwind side (the driver's right) and coverage is excellent. Experience in this orchard tells us that we do not need to raise the output over the season. As the trees fill in, the cross wind will be less, and more spray will be available for coverage.

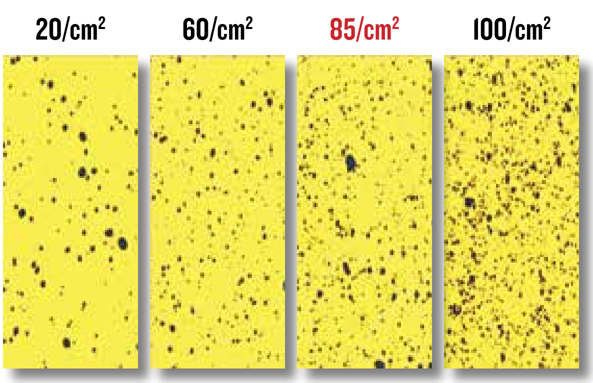
5.7 Evaluating coverage with water-sensitive paper

To confirm suitable coverage during or immediately following an application, some operators look for wet foliage, white residue or perform shoulder checks from the cab while spraying. These are good practices, but a more informative method uses water-sensitive paper that turns from yellow to blue wherever spray touches it.

Here's the over-the-shoulder view of an early morning spray application from the cab, taken with the sprayer operator's smart phone. You can't see coverage, but gaps in the spray will show if nozzles are plugged. You can also check to see if you are overshooting or blowing through the target.

PHOTO CREDIT – C. HEDGES, ONTARIO.

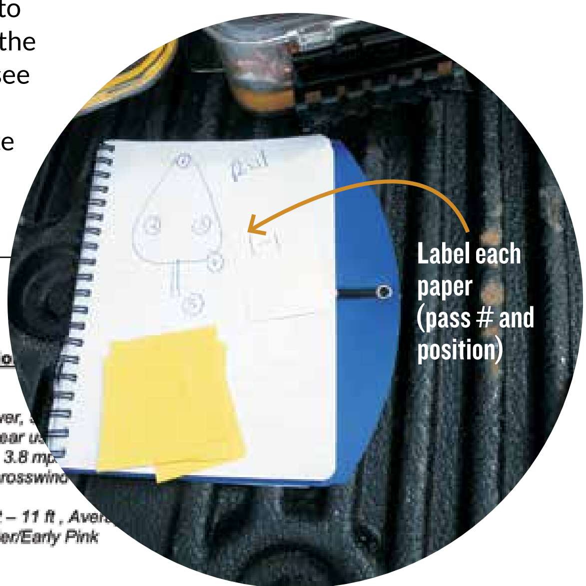
Water- and oil-sensitive paper is cheap, simple and available online or in person from your favourite sprayer equipment store. If they don't have it, they can order it. Plan ahead!



It's debatable, but 85 fine/medium-sized drops per square centimetre and about 10-15% total surface covered represents adequate airblast spray coverage for most foliar applications. These guidelines don't really fit applications made with very coarse droplets because there are fewer droplets that generally cover more area. In this case, focus more on the even distribution of spray and the 10-15% coverage. The extreme example of this is a drench (dilute) application of oil where total saturation is the goal.

Begin by creating a simple drawing of the tree, cane, bush, etc. you wish to spray. Label the drawing with unique numbers that correspond to where you are going to place the papers. Write the numbers on the back of each paper so you can see where they came from after they are collected. Plan to do this for three plants to get an accurate representation of coverage. Spray from both sides with both booms open per usual.

Draw the plant and label where you place water-sensitive papers



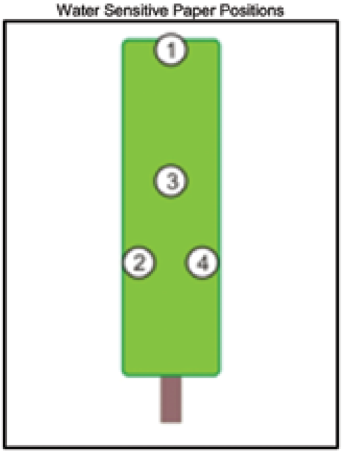
Dr. Jason Deveau, OMAFRA
Victoria Radauskas, OMAFRA
Date: May 6, 2015

Grower X's Orchard Sprayer Calibratio

General Information:
Sprayer: *John Bean Redline S28 with TeeJet roll-overs on Tower,*
nozzles/side, 32 inch diameter fan, BH3 tractor gear, low fan gear u
diaphragm pump (GUTD used), 150 psi, 52 gpa typical output, 3.8 mp
Weather Conditions: *10:00-11:00 am, 19°C, 53% RH, 4 km/h crosswind*
Block Name: *Trial Block*
Block Information: *Row Spacing – 14 ft, Drip Line – 5 ft, Height – 11 ft , Aver*
Shape – Column/Spade, Density – Half Inch Green/Tight Cluster/Early Pink

2015 CALIBRATION

Water Sensitive Paper Positions



Nozzle Types

Nozzle Position	Nozzle Setting	Output at 150 psi
1	Off	X
2	TXVK6 (Red)	0.182 gpm
3	Off	X
4	ATR Albuz (Lilac)	0.135 gpm
5	Off	X
6	TXVK8 (Grey)	0.25 gpm
7	Off	X
8	TXVK8 (Grey)	0.25 gpm
9	Off	X
10	TXVK8 (Grey)	0.25 gpm
11	Off	X
12	TXVK8 (Grey)	0.25 gpm
13	TXVK10 (Black)	0.313 (DEAD ZONE)
14	TXVK8 (Grey)	0.25 gpm
15	TXVK8 (Grey)	0.25 gpm
16	Off	X
Total Output		40.0g/ac

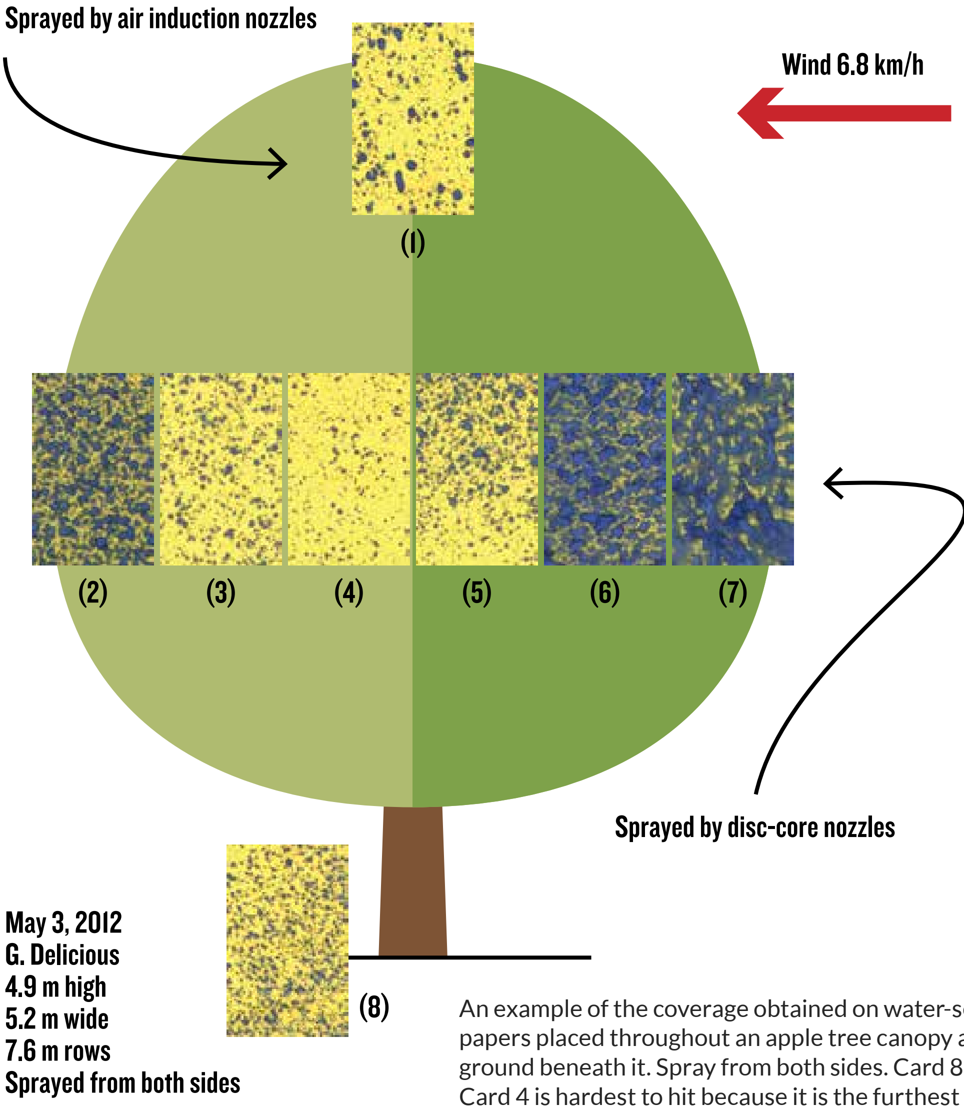
Coverage Notes

Position	Coverage
1	Light on up-wind side, but enough. Don't y iwigr tn k.
2	Mtffit nty mt v
3	Mtffit nty mt v
4	Mtffit nty mt v

G Notommts

Had two reds at top, no black + no green. Ran out of TXVK4 (Green) for position 4, Albuz ATR lilac rate close enough.

Create a simple drawing of the plant. Number positions on the drawing that correspond to where you plan to place the papers. Label the papers as well so you know where they came from. Consider writing the pass number and the position (e.g. 1-1 would be Pass 1, Position 1) so you can evaluate the changes to the sprayer settings from pass to pass. All the information from the calibration can then be entered into your spray records, like in this example.



An example of the coverage obtained on water-sensitive papers placed throughout an apple tree canopy and on the ground beneath it. Spray from both sides. Card 8 shows waste. Card 4 is hardest to hit because it is the furthest target on the upwind side. Card 6 and 7 may have been hit twice, once directly and once as wind blew overspray back.

Distribute the papers evenly throughout each target canopy. Place papers in key locations where pest damage has been an issue in the past (e.g. scab at the top of a tree, or spotted-wing drosophila at the bottom-centre of highbush blueberry), or wherever coverage is notoriously difficult. For example, place the papers at the top, centre and bottom of a tree canopy, and ensure they are evenly distributed from the outer edges of the canopy in towards the trunk.

Water-sensitive paper located at the top of an apple tree. The paper turns from yellow to blue where it's hit with spray. The coverage pictured here is excessive. Mark the locations using flagging tape so they can be retrieved and/or replaced when testing multiple settings.

Water-sensitive paper can be wrapped around cylindrical targets (like stems) to give panoramic coverage. Here they've been wrapped around plastic tubes, held in place with bobby pins.

CONCEPT – DR. B. PANNETON, QC.

I use spring-back paper clips and alligator clips to attach the papers to small branches. They can be used to represent upper- and lower-leaf surfaces if you staple them directly to leaves, or pin them parallel with the ground. You can wrap them around branches to monitor panoramic drench coverage. They can be stapled to the trunk to show if spray is aimed correctly. You can even orient them face-up and skewer them to the ground using wire flags to illustrate poor lower-nozzle positioning and/or canopy run-off. Put them wherever you want to know about spray coverage!

I've even used water-sensitive paper to reveal off-target drift – but it's not definitive because the papers don't resolve spray droplets that are less than ~50µm (the size of a few grains of pollen).

I typically orient water-sensitive paper to face the alleys so their sensitive faces are square to the sprayer as it passes. I often use two in each location, oriented back-to-back facing each alley. The important part is to be consistent. Mark the location in the canopy with some colourful flagging tape so you can find the papers after you spray. If you want to replace them with fresh papers to evaluate another pass, orient them the same way to make the comparison fair.

Water-sensitive papers located in five positions in an Empire apple tree. Two papers were pinned back-to-back in each position, distributed evenly throughout the canopy, facing the alleys. One paper was located at the lowest branch to determine if the lowest nozzle position needed to be on. Another paper was pinned to the ground face-up under the tree to show any excessive waste. Be creative, but be consistent from pass to pass.

The author placing water-sensitive papers in apple trees. Put them high, deep and in any other hard-to-spray places. Wear gloves because they also react to the natural oil on your fingers. Let papers dry before collecting them or they will smear and possibly stick together.

Once the papers are in place, pass by on one side with both booms open (as you would normally spray). Start spraying well before passing the target, and keep spraying afterwards to ensure coverage represents an actual application. Get out of the cab and examine the papers before passing by on the other side. Examine coverage at this point to see how wind is affecting the spray. Then pass by on the other side to complete the application.

Once papers are in place, pass by spraying with both booms open like a typical spray day. Be sure to start spraying well before passing the target, and keep spraying afterwards to ensure coverage represents an actual application. Examine coverage at this point to see how wind is affecting the spray. Then pass by on the other side to complete the application.

You might notice the outer portions of larger canopies receive more spray than the inside. This isn't surprising as spray must pass through the outside to get to the inside. Inner papers often receive proportionally less spray and should be prioritized when determining if you have sufficient spray coverage. That's also why the label recommendation of "spraying to the point of runoff" is not helpful. The outer portion of a canopy could begin to drip before the inner portion receives sufficient coverage. And how do you spray to the point of runoff? How do you know when to stop before it's too late?

When water-sensitive paper is sprayed to the point of run-off, the blue dye will drip. This is fine for a drench (dilute) application, but excessive for a typical concentrated application like foliar fungicides and insecticides.

When considering coverage, don't follow the droplet counts in the small guide that comes with the paper sensitive paper kit. These guidelines haven't been updated for a long time and are more appropriate for field crop applications – not airblast applications. Research and experience suggest that 85 discrete fine/medium-sized droplets per square centimetre and a total coverage of 10-15% should be sufficient for most foliar insecticides and fungicides. Remember, this is only a suggested threshold and in the case of coarser sprays, focus more on even distribution and the 10-15% coverage.

There's no easy way to define a black-and-white threshold between sufficient and insufficient spray coverage. When you retrieve and examine the papers, think about how the product is intended to work.

- Is it a contact, translaminar or locally systemic pesticide?
- What are the odds that an insect or spore will come in contact with residue?
- Will I be spraying again soon (e.g. fungicide) and will the spray already on the leaves have residual activity?

Remember that protectant fungicide applications are often layered. What one spray misses, the next will catch. "Sufficient coverage" is often less than most sprayer operators think. In my opinion, any problems with disease are as likely due to application timing as spray coverage. Great coverage with a contact fungicide won't help if it's too late.

DID YOU KNOW?

A pack of 50, 1″ x 3″ sheets of water-sensitive paper is about $50 CAD. You can cut the 2″ x 3″ variety in half to stretch their use. Next time you buy shoes, save the desiccant pouch and put it in with the papers to keep them dry.

Watch a video on water-sensitive paper at **www.sprayers101.com**.

5.8 Other methods of evaluating coverage

While water-sensitive paper is versatile, cheap and easy to use, it has its shortcomings. Placement and orientation of the paper is very important. It's easy to hit papers on the outside of the canopy with the sensitive-side facing the sprayer. It's considerably harder when they are at the very centre of the canopy, or hiding behind fruit. When the thin edge of the paper is oriented to the spray (i.e. facing the ground), there is very little surface and it can be difficult to hit.

As noted in **Section 5.7**, the papers won't show the finest droplets (<50 µm), so there may be coverage even though you can't see it. Spray coverage is a good indicator for protection – when considered with the product's mode of action (contact or locally systemic) and any possible re-distribution by rain or dew – but it isn't definitive.

While coverage is a good indicator, improved coverage does not always mean improved efficacy.

Some sprayer operators use other methods to confirm coverage. Kaolin clay is an inert compound that leaves white residue when dry. Dyes like rhodamin (red), tetrazine (orange) and negrozine (black) can indicate coverage on white targets like cardboard or receipt paper. Fluorescent dyes such as phosphorus can be sprayed at dusk and illuminated under black lights, but it can still be difficult to see.

These methods for confirming coverage give the sprayer operator a lot of information because spray lands on the actual target, not a piece of paper hung in the canopy. But these techniques require a lot of time and effort, and are typically out of reach for most operators. And you can't do multiple applications on the same canopy to compare the effect of sprayer settings on coverage. Once the target is sprayed, it's sprayed.

Kaolin clay and fluorescent dies sprayed into fruit canopies give a lot of information about sprayer coverage, but are inconvenient compared to water-sensitive paper.

If you live where there's snow, dye is a great way to see if your weed control methods are providing suitable coverage.
PHOTO CREDIT – M. JØRGENSEN FOR BETTERSPRAYING.

Use enough air to just ruffle the leaves. This exposes all surfaces, even briefly, to the spray. Too much air will align leaves with the spray, exposing only their thin edge and making coverage difficult. Too much air may also cause leaves to shingle (overlap), and create shadows on the water-sensitive paper like the grape leaves here have done.

6.0 Confirming sprayer output

Confirming sprayer output

Up until now, the handbook has described qualitative methods to adjust the sprayer settings to match the target. What follows is still part of that process, but aligns with the more classic definition of calibration. These diagnostics require tools and methods that quantify sprayer performance. In other words, warm up your calculators because here comes some sprayer math. What? You like math! See **page 199** for examples of situations that require sprayer math.

6.1 | Pressure gauge accuracy

Many operators use budget pressure gauges on their sprayers and have never changed them or tested their accuracy. This makes it difficult to assess sprayer performance and output. Sprayer performance has a direct impact on coverage, efficiency and efficacy. A faulty gauge may cause you to spray more or less product than intended. Spraying more that intended means wasted product and money, and potentially leaves higher residue levels. Spraying less than intended may compromise coverage.

Here are a few indications that your pressure gauge needs replacing:

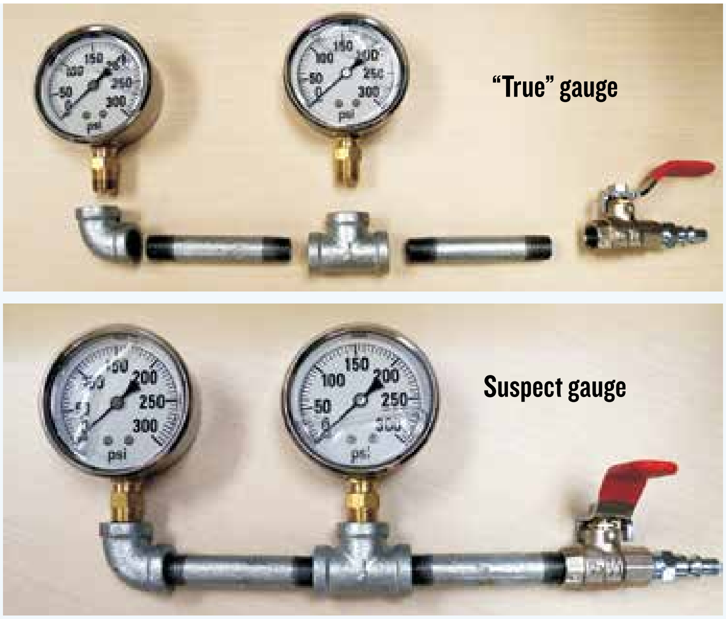
- gauge has an opaque or unreadable face
- mineral oil leaking or mostly gone
- needle does not rest on zero pin when sprayer is not under pressure

It's not always obvious that a gauge needs replacing. Some operators will simply go out and buy a new gauge when they suspect an issue. But even brand new gauges can be inaccurate right off the shelf. In order to test a gauge you need to apply a known pressure to see if it is reading accurately.

In a past sprayer workshop, one participant had a great suggestion for testing gauges. His idea was to use an air compressor (which most farms have) and some simple plumbing. This tool (pictured on page 69) allows you to test your suspect gauge (set in the tee) against a known working gauge (set in the elbow) for less than $40.00. We constructed a "Pressure Gauge Tester" using the following parts:

PART	PRICE (CAD)
2 x ¼" by 3" Galvanized nipples	$2.69 ea
¼" Galvanized 90° elbow	$3.19
¼" Galvanized tee	$3.19
¼" Ball valve (threaded)	$8.19
*Plug air connector (A over ¼")	$2.99
Teflon pipe tape	$0.89
†300 psi liquid-filled gauge	$17.80

* Depending on the quick-connect fitting on your compressor.
† Test gauge range should match your existing gauge.
Sprayer gauges should be twice as much as your typical operating pressure.



The Pressure Gauge Tester. The "true" gauge is in the elbow and can be compared to the suspect gauge in the tee.

CONCEPT FROM K. VOEGE, ONTARIO.

There are also commercial pressure gauge testing units available, such as this mannometer from aams-salvarani.

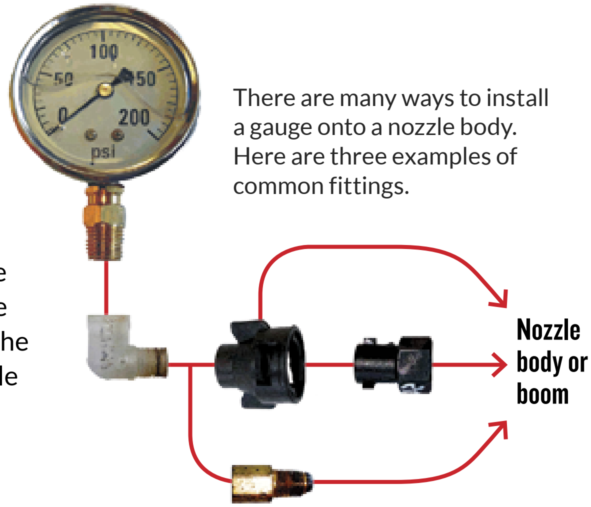
6.2 | Confirm sprayer pressure

Another way to confirm that the main pressure gauge is accurate is to install a second oil-filled gauge (that has been tested) in-line beside the main pressure gauge at the regulator. This may not be possible with some sprayers. Some newer Durand-Wayland sprayers have a gauge located near the pump, under the chassis where it is not visible from the tractor. Others inset the gauge into the side of the tank with no room for a second gauge.

Pressure in the booms is often less than the desired operating pressure and must be accounted for (a phenomenon known as "pressure drop"). This is a function of hose diameter and fittings, and on tower sprayers it includes the distance the spray travels between the pump and the nozzles. Dress appropriately because you're going to get wet performing this diagnostic. Fill a clean sprayer about half-full with water. Install an oil-filled pressure gauge in the highest nozzle position of one of the two booms. The nozzle cap or entire nozzle body may need to be removed for this step. For metric fittings – which can be hard to find – contact your sprayer dealer.

Two gauges keep each other honest – this GB (Italian-made Good Boy) is sporting a homemade assembly that cost ~$50 to assemble, including the second gauge. The silver spray paint on the black pipe prevents rust and makes it look pretty darn sharp.

With the tractor parked, bring up the rpms to get the lines to the desired operating pressure. Open the booms and compare boom pressure (at the nozzle) to your desired pressure. All nozzles should be open during this test – that means both booms. For positive displacement pumps, adjust the main pressure regulator until the gauge on the boom reads the desired pressure. For centrifugals, it is possible to make small changes to the pressure using tractor rpms and the bypass valve. Note any pressure differential for later considerations regarding nozzle output and spray quality.



There are many ways to install a gauge onto a nozzle body. Here are three examples of common fittings.

When sprayers that employ a positive-displacement pump are switched from double to single boom operation (e.g. when border spraying or during turns), the pressure can change considerably. Most units will experience a pressure increase that increases the boom output.

Spraying from one boom. This operator checked to make sure the pressure didn't increase when he closed the second boom. High pressures or sudden spikes could indicate a faulty regulator valve.

Pressure change can be greatly reduced by matching the regulator spring to the operating pressure and by properly sizing the regulator to the pump volume. Many sprayers come equipped with regulator springs matched to the maximum pressure range of the pump, often 41.5-62 bar (600-900 psi). These springs are unable to control the pressure down at 7-14 bar (~100-200 psi), where most Ontario airblast sprayers operate. The springs are so stiff the liquid pressure is can't act on the spring and the valve acts as a flow control (throttling) valve rather than a pressure control valve. Liquid pressure is difficult to control using a throttling valve – it can't compensate if the tractor engine speed drops while driving uphill, reducing sprayer output. This phenomenon can also cause pressure gauges – that should be matched to your normal operating pressure – to spike.

Some sprayers (e.g. Turbomist) attempt to compensate with a bypass valve that shunts any excess volume through an additional throttling valve back to the tank. The throttling valve bypasses the volume that normally would be spraying out through the closed boom. The result is that the pressure should remain constant when a single boom is shut off.

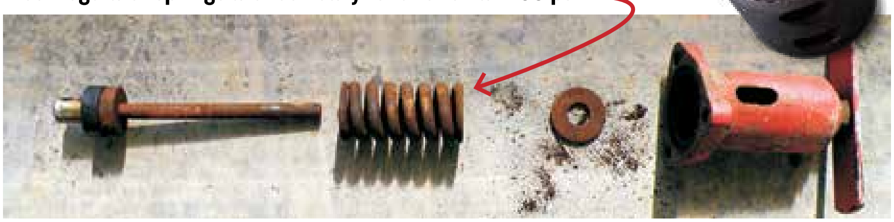
Here's how to set the Turbomist bypass.

1. With PTO at application speed and both booms open, adjust regulator to calibrated operating pressure.
2. Close one boom.
3. If pressure increases, open throttling valve to achieve calibrated operating pressure. If pressure decreases, close throttling valve to achieve calibrated operating pressure.
4. Repeat process for the other boom, and find a compromise position for the valve.
5. Some operators choose to remove the handle from the Turbomist throttling valve once it is set so they don't accidentally bump it later. That's fine, just don't lose it. Further adjustment may be required when transitioning between dilute and concentrated volumes.

Valve springs and seats wear out, such as this regulator assembly. Check them each season.

Worn pressure relief valve

Most regulator springs are too heavy to function at ~150 psi.



You should be able to compress them by hand. If not, replace it with a spring with a more appropriate tension.

6.3 Why does the pressure gauge spike?

Have you ever seen this happen? You finish spraying, turn off the booms and the pressure gauge briefly spikes off-scale. This is very bad for the gauge and will eventually cause it to fail. What is going on?

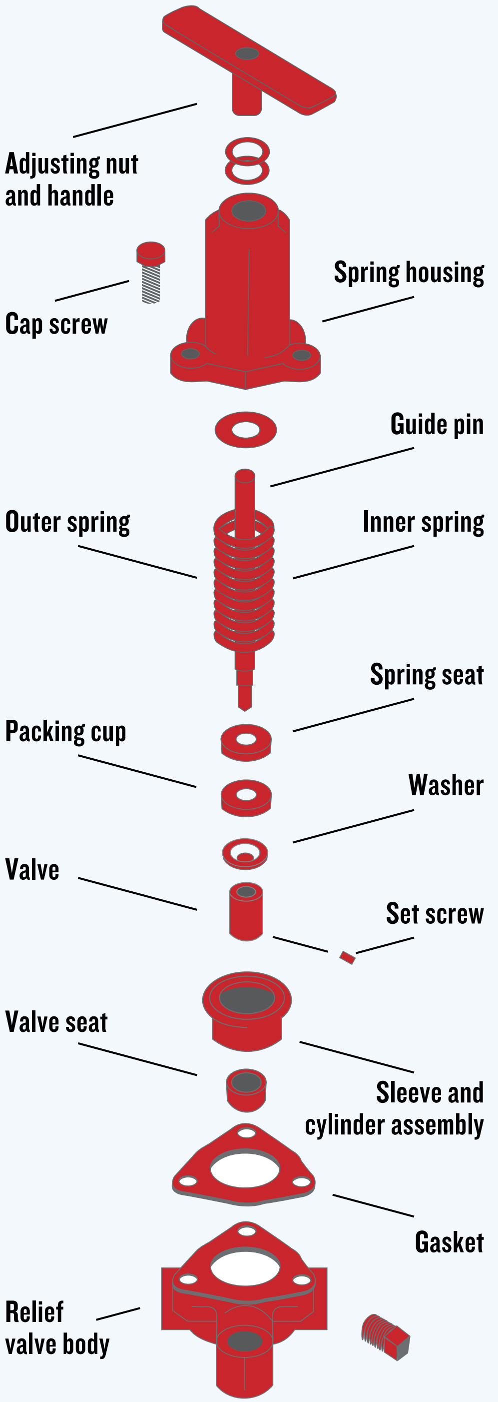
Spiking is caused by insufficient or restricted regulator capacity. The regulator must maintain the desired system pressure through the normal speed range of the sprayer, regardless of the number of booms (or boom-sections) that are on or off. Maintain system pressure by balancing the sprayer pressure against the regulator spring, which must move freely across a range of flows. Mr. Murray Thiessen consulting ag mechanic shared the following wisdom and experience.

A pressure gauge spiking beyond its range.

MAINTENANCE

- If the regulator spring cavity is packed with dirt, limiting valve travel, clean the housing and spring, and then lubricate and adjust.
- If the regulator is partially seized or sticky, and the piston and cylinder bores are caked with spray, they will 'hold' the valve until the pressure/spring balance overcomes the friction. Sometimes the valve, and/or the valve guide pin are seized. Disassemble them, clean all sliding surfaces, then lubricate and adjust.
- If the valve/seat wear has created a leak, repair (or replace) the regulator, then lubricate and adjust. Any leak (external or internal) can contribute to this condition – tightening the spring isn't the solution. You may have already tightened the spring to compensate, but this loads the spring past the pressure balance point you want to spray at. This means when the booms are shut off, the pressure increases until it reaches the 'new' spring balance point.
- If the spring is damaged (e.g. bent, corroded, etc.), replace it, lubricate and adjust.


FMC pressure regulator.



An FMC pressure regulator in exploded view.

DID YOU KNOW?

Be sure to read the operator's manual before you do anything. Understand your sprayer's design before you perform any maintenance, adjustments or calibration.

CALIBRATION

The regulator spring may be improperly sized for the desired spraying pressure. Many sprayers come equipped with regulator springs matched to the maximum pressure range of the pump, not the desired operating pressure. These springs are unable to control the pressure. They are so stiff the liquid pressure can't act on the spring and the valve essentially acts as a flow control (throttling) valve rather than a pressure control valve. Liquid pressure is difficult to control using a throttling valve – it can't compensate for changes in flow (like engine speed dropping when driving uphill or closing booms or nozzles). These changes in flow can cause pressure gauges to spike when they don't match your normal operating pressure.

An improperly sized spring can either be too weak, or too heavy.

- The spring may be **too weak** for the pressure being used (i.e. any adjustment bottoms out). To obtain sufficient pressure the operator tightens the spring until it is virtually collapsed, creating a fixed orifice. When the booms are closed the 'fixed orifice' doesn't compensate and pressure rises to force the increased flow through that small orifice.

- If the spring is **too heavy** for the pressure being used, any adjustment barely touches the spring when pump is turned off. In this case, the pressure used will not deflect the spring, so the operator closes the regulator until the fixed orifice creates sufficient restriction to flow to achieve the desired pressure. When the booms are closed the fixed orifice doesn't compensate and pressure rises to force the increased flow through, or until the spring begins to deflect.

In either situation, the spring must be sized so it is in the centre-third of its flex range (i.e. rest state > fully collapsed) at the desired pressure. You can buy springs from the sprayer dealer or hardware supply. Try to maintain original length and diameter of the coil, while varying the diameter of the wire.

ENGINEERING

- The regulator supply and return may be too small for the pump flow. Consult hose and fitting catalogs for flow capacities and lengths. Re-size the hoses and fittings appropriately, and then adjust the regulator.
- There may be kinks or sharp bends in the supply and return lines. Re-route the hoses and/or fittings to avoid kinks and sharp bends, and then adjust the regulator.
- The regulator may be too small for the pump flow. Consult a regulator catalog for flow capacities and replace the regulator with an appropriate size. Calibrate the regulator spring and adjust.
- Regulator valves have a 'cracking' pressure – when the valve just starts to open. Well-designed regulators have small pressure changes from cracking to full flow. That information is in their catalogs. Poorly designed regulators have large pressure changes between these two ratings and these regulators should be avoided.
- The pump may be too big for system. This often happens when sprayers are upgraded and pumps are replaced. Consult the catalogs and reduce pump size or speed, or increase the sizes of the hoses, fittings and regulator.
- There may be a hydraulic agitator jet on the regulator 'tank' line. An agitator jet applies considerable back pressure to a system, and when booms are closed the increased flow causes more than a linear increase in pressure.
- The sprayer system as a whole may be poorly engineered. Inspect and draw a flow path of the sprayer system. Examine where everything is going, or not going. Is it possible someone made changes that the manufacturer did not intend? Consult the manufacturer if you are uncertain. Sometimes, it will have to be re-engineered, which may require expert consultation.

Your pressure gauge can tell you a lot more than your operating pressure – indicating a problem with your regulator, pump, lines or overall sprayer engineering. **Don't ignore it – address it.**

6.4 | Calibrate ground speed

Ground speed must be slow enough to allow the spray-laden air from the sprayer to completely replace the air in the canopy. Driving too slow prolongs the operation and blows spray through the canopy, missing the target and increasing wastage.

DID YOU KNOW?

In a 2010 survey of orchard airblast sprayer operators in Ontario, the average ground speed was about 5 km/h (~3.1 mph). Responses spanned from 3 km/h to 7.5 km/h (~1.9 mph to ~4.6 mph).

Calibrate the ground speed in the field to account for speedometer errors due to wheel size, tire wear or slippage. I recommend simply using your smart phone's GPS to determine your ground speed. If you don't have a smart phone, follow these steps to calculate your ground speed.

1. Measure out a distance of 50 m (164 ft.) and mark the start and finish positions with wire marker flags. The course should be level.
2. Fill the sprayer tank half full of clean water.
3. Select the gear and engine speed you'll use to spray. Be sure the fan is going, but don't discharge spray. If the PTO isn't running, it could cause errors.
4. Bring the sprayer up to speed for a running start and begin timing as the front wheel passes the first flag. It's easier if there are two people.
5. Stop the timer as the front wheel passes the second flag.
6. Run the course two more times, staying out of any ruts.
7. Determine the average time for the three runs (see example).
8. Calculate ground speed using one of the following formulae, depending on preferred units:

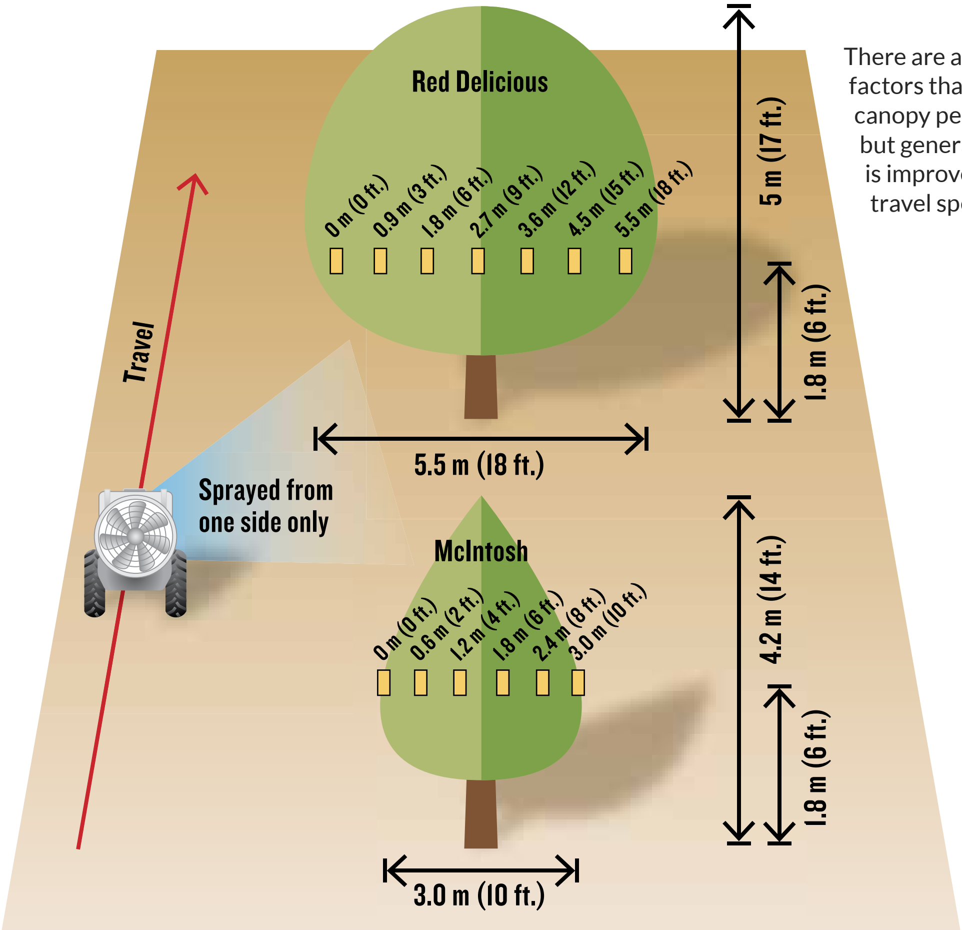
$$\text{Ground speed (km/h)} = \frac{50\text{ m} \times 3.6\text{ (a constant)}}{\text{Avg. drive time (s)}}$$

$$\text{Ground speed (mph)} = \frac{50\text{ m} \times 2.2\text{ (a constant)}}{\text{Avg. drive time (s)}}$$

6.5 | How fast is too fast?

Sprayer operators are always pressed for time. A common practice is to drive faster to complete the job more quickly. Studies have shown it takes time for spray-laden air from the sprayer to displace the air in the plant canopy. Lead-footed airblast sprayer operators know that slower ground speeds generally improve spray penetration and deposition, so why do they still drive too fast?

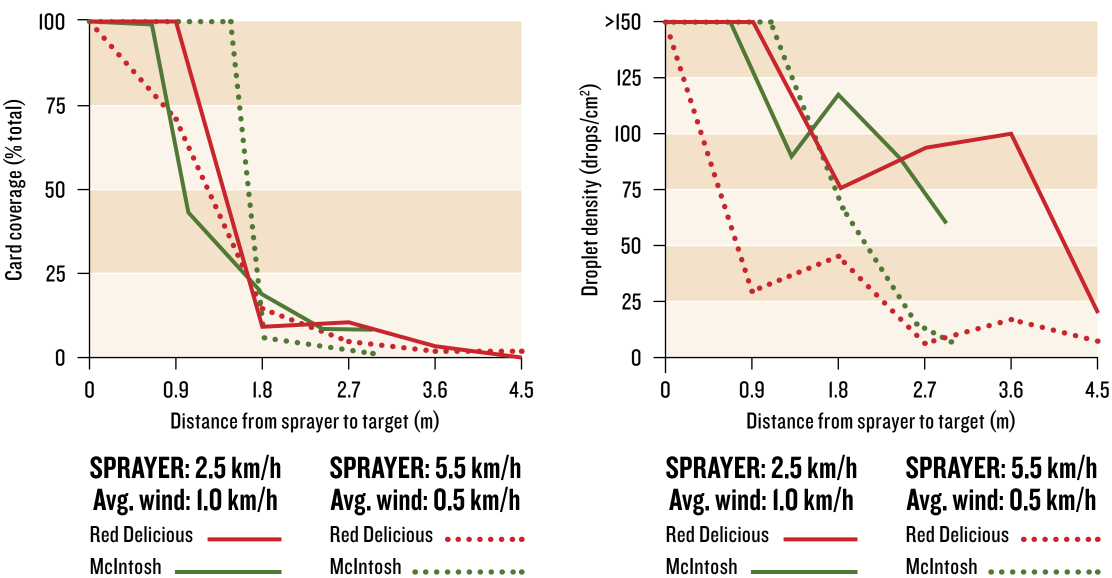
Maybe operators need to see it to believe it – even if the experiment has been repeated many times in many other places. "Sure, that may be true in Michigan, but this is Ontario!" And so, here are the results of some quick demonstration trials performed in Ontario with a 3-pt hitch GB airblast sprayer in an apple orchard.



There are a lot of factors that affect canopy penetration, but generally coverage is improved at slower travel speeds.

Spray penetration trials in apple canopies. You might notice there is no tractor cab and the operator isn't wearing PPE. We were spraying water from a clean sprayer.

The operator changed nozzle rates to spray the same volume at 2.5 km/h (~1.5 mph) as at 5.5 km/h (~3.4 mph), spraying from one side of the canopy in light wind. Water-sensitive paper was evenly distributed along the widest part of the canopy, facing the sprayer. The percent of each paper covered (percent) and the droplet density (drops per cm^2) was recorded for each position. The result – the slower the ground speed, the more drops penetrated the canopy.



Notice that the slower ground speed (solid lines) deposited more drops per cm^2 than the faster ground speed (broken lines). Percent coverage was about par.

So, no matter where you live, canopy penetration depends on canopy density, canopy width, ground speed, wind conditions and the air speed/volume from the sprayer. That's a lot of factors. Fortunately, the collective influence can be seen using a few 25 cm (~10 in.) lengths of flagging tape on the far side of the target canopy. If they flutter as you drive by, great! If they don't move, or if they stand straight out, something may be wrong **(see Section 5.1)**.

Many of today's sprayers have gear boxes on their fans to lower the air speed and volume for early season applications or for smaller crops. If you've never tried to shift the gear before, you may encounter resistance. P. Splinter, Ontario, used a lot of WD-40 and a creative position to gain leverage.

6.6 | Nozzles

The topic of nozzles requires a brief departure from the calibration process. Nozzles meter out the spray solution as droplets, making it more likely to cover a target evenly and accurately. There are a staggering variety of nozzles available, so selecting the right nozzle for the job requires an understanding of how droplets behave (or misbehave). Once the spray leaves the nozzle, the operator has no more control over the application, so it's important to account for as many contributing factors as possible.

SPRAY QUALITY

Spray quality is an umbrella term that describes the range of droplet sizes, the number of droplets and the spray shape emitted by a nozzle. Spray quality sometimes includes the nozzle rate (e.g. L/min. or gal./min.) in that definition. Nozzles create a variety of spray qualities depending on their design, the operating pressure, the amount of air-shear and the viscosity of what's being sprayed.

DROPLET BEHAVIOUR

A single, hydraulic nozzle produces a range of droplet sizes, spanning from smaller to larger diameters and measured in microns (µm). The American Society of Agricultural and Biological Engineers (ASABE) publish a reference standard called s572.1. It uses symbols to describe the average (or more accurately, median) droplet size emitted by a nozzle for a given pressure. In North America, these categories go from "Extremely Fine – XF" to "Ultra Coarse – UC". There is less range in the original European system. Nozzle manufacturers include this information in their catalogues so an operator knows what to expect from a nozzle insofar as it's potential for drift. Unfortunately, these symbols are sometimes accompanied by a colour, which should not be confused with the colour of the nozzle. Nozzle colour means something else entirely.

The ISO 10625 reference standard links nozzle size (i.e. flow rate) to a colour coded reference chart to make it easy to determine nozzle flow rate at a glance. Where the nozzle manufacturer follows this convention, the colour of the nozzle itself represents the rate (e.g. L/min. or gal./min.). For example a "red" flat fan means the nozzle emits 1.51 L/min. metric (0.4 gal./min.) of water at 70 °F and 40 psi. Red flat fans are sometimes referred to as "Oh-Four's" for short.

CATEGORY	SYMBOL	DV0.5 (VMD) µm
Extremely Fine	XF	~50
Very Fine	VF	<136
Fine	F	136 - 177
Medium	M	177 - 218
Coarse	C	218 - 349
Very Coarse	VC	349 - 428
Extremely Coarse	XC	428 - 622
Ultra Coarse	UC	>622

The ASABE s572.1 name, symbol and range of droplet sizes used to describe the median droplet diameter produced by nozzles.

TIP SIZE	ISO COLOUR	CAPACITY
01	Pure Orange	0.4 (0.1)
015	Traffic Green	0.6 (0.15)
02	Zinc Yellow	0.8 (0.2)
025	Signal Violet	1.0 (0.25)
03	Genetian Blue	1.2 (0.3)
035	Brown Red	1.4 (0.35)
04	Flame Red	1.6 (0.4)
05	Nut Brown	2.0 (0.5)
06	Signal Grey	2.4 (0.6)
08	Traffic White	3.2 (0.8)
10	Light Blue	4.0 (1.0)
15	Yellow Green	6.0 (1.5)
20	Black	8.0 (2.0)

Droplet size is sometimes associated with a colour. But don't confuse this with the colour of the actual nozzle. Here are the ISO 10625 nozzle colours and rates (e.g. L/min. or gal./min.). There are even more rates than shown here.

To my knowledge, all the major nozzle manufacturers voluntarily observe these standards for flat fan nozzles, but speciality tips like hollow cones are another matter. Some do, and some do not. Always check with the manufacturer's nozzle catalogue to be sure.

Finer droplets have a low "settling velocity" – taking a longer time to fall out of the air. Coarser droplets have a high settling velocity – falling out of the air more quickly. Imagine you are outside, facing into in a light wind and holding a golf ball and a ping-pong ball in one hand. The ping-pong ball represents a fine droplet, and has much less mass than the heavier golf ball (representing the coarse droplet).

Now, toss them into the wind.

The golf ball will follow a simple trajectory, arcing up into the air and falling again mostly due to friction and gravity. The ping-pong ball behaves more like a soap bubble – wind, thermals, humidity and many other factors will change where it goes before it eventually falls because it is too light to resist them. It may even land behind you, blown by the prevailing wind.

Watch a video on the golf ball/ping-pong demo at **www.sprayers101.com**.

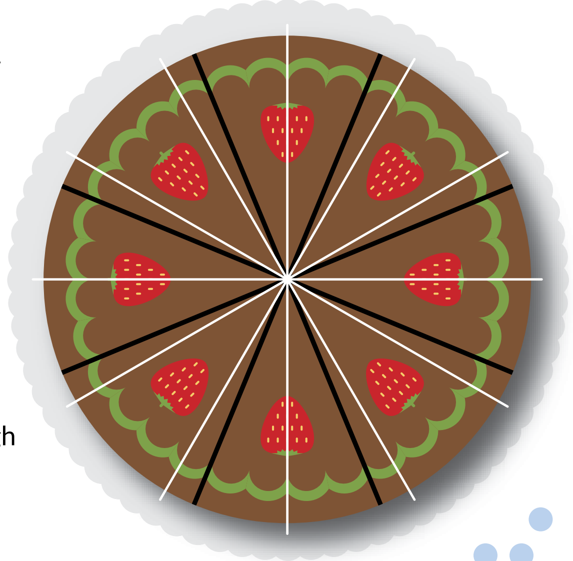
A few years ago I gave a workshop in a nursery. The operator was spraying whips – young, tall trees with very few lateral branches like a forest of leafless sticks. He was using a cannon sprayer to spray 30 rows of whips (15 from each side) and didn't like the look of the spray blowing through the trees. He decided it was unnecessary to use the air, and relied solely on pressure to propel the droplets. We set up water-sensitive papers throughout the whips and had him spray from both sides with the fan off.

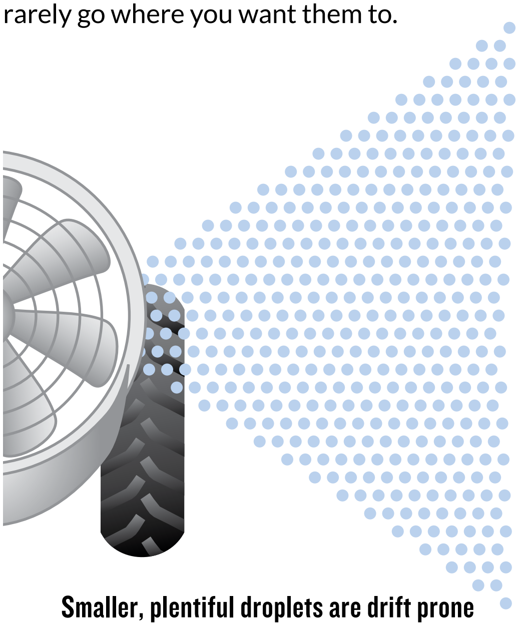
The coverage was erratic. Trees closest to the sprayer were drenched. But there was an unpredictable array of good, bad and ugly coverage throughout the rest of the trees.

We replaced the papers, and asked him to spray again with the fan on, but only from one side (just to prove a point). When we recovered the papers this time, coverage was greatly improved in consistency and in overall quality. In fact, it was night and day compared to spraying with no air, and that was only when spraying from one side! The fate of finer droplets is more difficult to control. This is why sprayer air direction and speed is so critical – the air generated by the airblast sprayer carries the spray to the target before releasing it to deposit in the canopy.

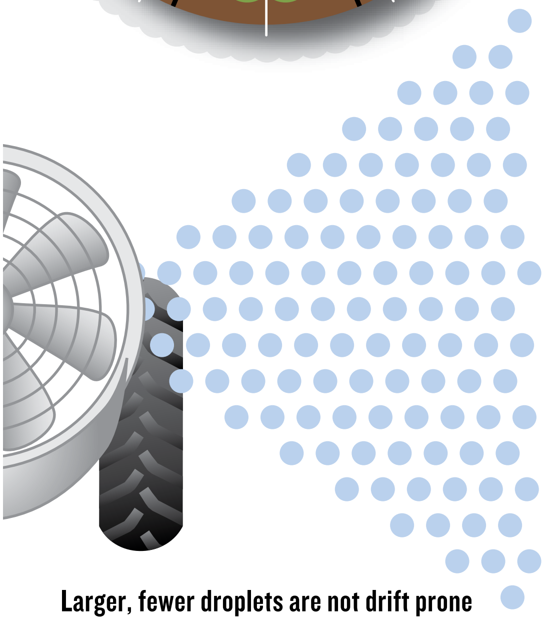
So why would anyone choose to spray finer droplets when coarser droplets behave more predictably?

Well, imagine the volume a nozzle emits as a cake. No matter how many slices you cut the cake into, you still have the same amount of cake. The finer the slices, the more people can have a slice, albeit not very much. Similarly, the finer the median droplet size emitted by a nozzle, the more droplets are available to provide coverage. In fact, every time the median droplet size doubles, there are eight times fewer droplets created! Now you might be thinking the finer the spray, the better. But fine droplets are very difficult to control. Even though there are more of them, they misbehave and rarely go where you want them to.



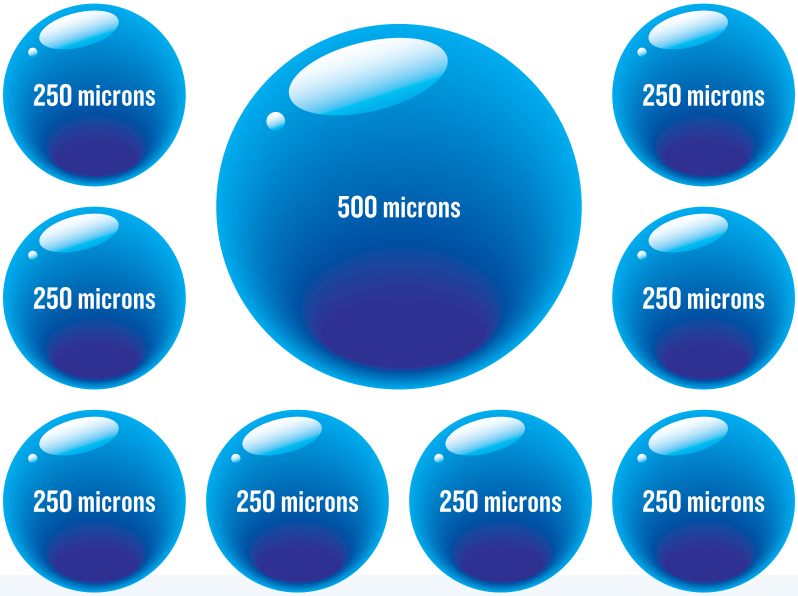


Smaller, plentiful droplets are drift prone



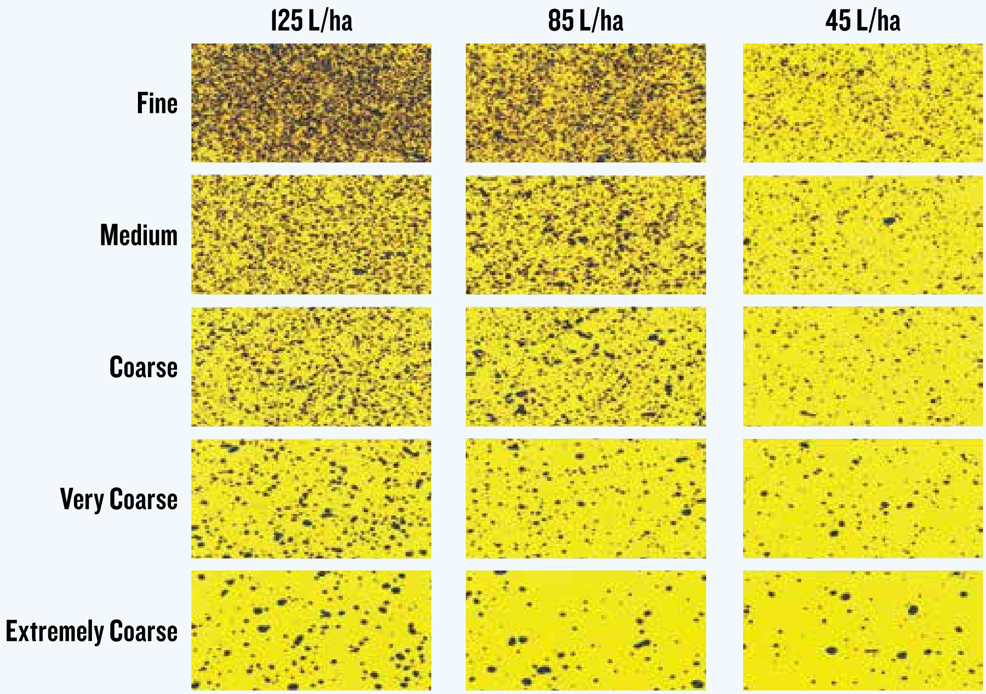
Larger, fewer droplets are not drift prone

Theoretically, every time the median diameter of spray is doubled, there are eight times fewer droplets. Conversely, every time the median diameter of spray is halved, there are eight times more. The point is, the larger the droplets the fewer there are, and vice versa.



These water-sensitive papers were sprayed under controlled conditions to demonstrate the role droplet size plays in coverage. As the droplets get finer, there are more of them, increasing coverage. This represents lab conditions. In real life, many drift off target before impinging. As the droplets get coarser, there are less of them, and coverage may be compromised. To compensate for this, higher volumes are used.

PHOTO CREDIT – DR. T. WOLF, SASKATCHEWAN.



What if the target is the underside of a leaf, or an area deep inside in a dense canopy? If coarser droplets behave like golf balls, they move in a single direction unless some other force deflects them. They shatter, ricochet, and run off targets. Finer droplets waft and change direction rather easily, and will follow turbulent air behind and under targets if there is sufficient air to carry them. Finer droplets are also less likely to accumulate to the point that they begin to run off the target.

The net result is the sprayer operator must find an appropriate balance in the range of droplet sizes. Small enough that there are a lot of drops that can move with sprayer air to deposit all over the canopy, but large enough that they can be directed into the canopy and not drift away if they miss.

Don't be discouraged. If it was easy, anyone could do it.

6.7 | Selecting nozzles

Selecting nozzles for a conventional airblast sprayer is not a simple decision. Airblast-applied agrichemicals are very specific to target and timing, and many of the crops traditionally sprayed with an airblast sprayer are being planted in higher densities, changing the volumes required. Airblast operators are increasingly concerned with improving coverage while minimizing off-target losses. They recognize that multiple sets of nozzles may be required during the spray season to match the variable shape, size and density of their crops **(see Section 5.6)**.

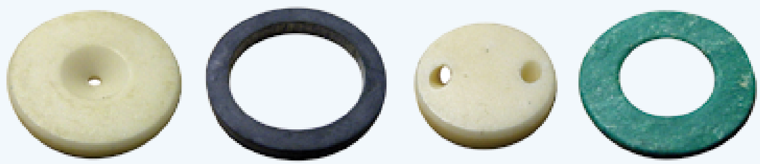
For example, a large apple orchard may require five different nozzle combinations over a season. One set for dilute applications like a dormant oil drench. Two sets for high-density blocks – one for spring and one for after petal fall. And two sets for semi-dwarf blocks – one for spring and one for after petal fall. The operator should be choosing each nozzle set to give a specific spray quality.

Hollow cone spray patterns are the most common choice for airblast sprayers, but full cone or even flat fans are occasionally used. Typically, disc & core (aka disc & whirl) combination nozzles are used to produce the hollow and full cone patterns. Some require spacers and washers and some do not. They are available in many materials and diameters, ranging from hard ceramic to soft brass.

TeeJet disc-core. Available in poly, brass, stainless and ceramic. Fits most airblast sprayers.

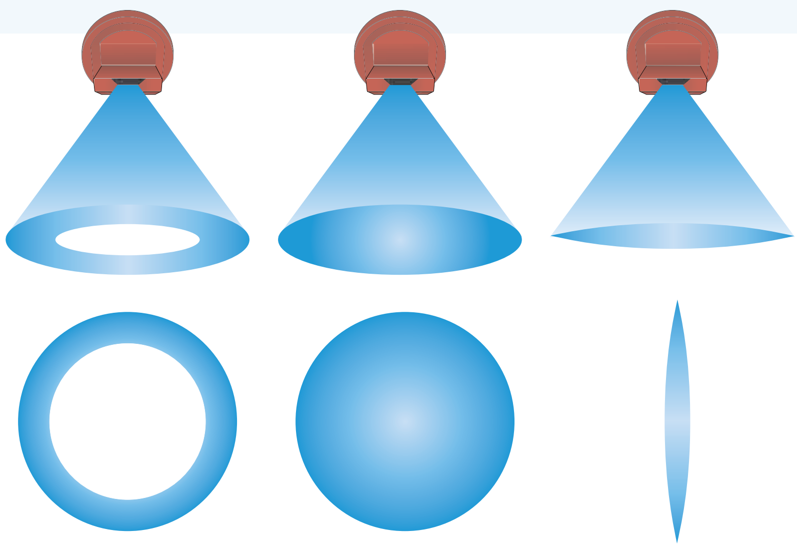
Hypro Albuz disc-core. Available in poly and ceramic. Fits most airblast sprayers.

Older FMC disc-whirl with spacer and gasket. Available in ceramic only. Smaller diameter version found on old Economist sprayers.



Older European-style disc-core with spacer. Ceramic disc and steel core often found on older European imports like the GB.

Disc & core, or disc and whirl, nozzles are often used on airblast sprayers to create hollow and full cone spray patterns. They differ in diameter, material and whether they require gaskets and spacers.



Hollow cone **Full cone** **Flat cone**

Three common spray shapes for airblast sprayers – hollow cone, full cone and occasionally, flat fan.

Full cone cores (top row) and discs (bottom row). All other factors being equal, the rate of tip wear depends on what it's made of. Poly and brass do not wear well under higher pressures and ceramic (while brittle) is generally held to last the longest.

The rate of tip wear depends on sprayer pressure, product sprayed, hours used and the material the nozzle is made of. Upgrading to a harder, more durable tip can reduce maintenance costs, but costs more initially. I suggest that brass tips should not be used for day-to-day operation, but are ideal for calibration. Owning a library of brass discs and cores will allow you to experiment to find the best nozzle configuration for your sprayer (see Section 6.9). Once you've determined the best rate for each nozzle position, purchase the equivalent rate nozzles in the more expensive ceramic disc & core, or preferably, moulded (see page 93).

All nozzles wear out eventually – even ceramic. At minimum, replace softer materials biannually, or when two nozzles are emitting 10% (or preferably 5%) more than the manufacturer's rated output. This will save money in over spray and/or reduced coverage from a degrading spray quality.

DID YOU KNOW?

The inner edges of nozzle orifices are extremely delicate. Stop cleaning them with wires, or even toothpicks! Keep a can of compressed air (used for cleaning keyboards) in your cab to blow out stuck or dirty nozzles, or simply carry replacements.

Two brass cores demonstrating the potential for wear. Note the distorted orifices and raised edges on the core used for 100 hours in an apple orchard. That's less than half a season for this particular operation.

A ½" thick, 310 stainless steel plate. It was an in-line gate valve at Nanticoke GS in Ontario designed to hold back fly ash (like talcum powder). It is completely eroded through. Imagine what wettable powders sprayed 200 psi do to a finely machined nozzle orifice? Check your nozzles regularly!

DONATED BY R. DUPP, ONTARIO.

READING NOZZLE TABLES

In Ontario, most airblast sprayer operators use disc & core (or disc & whirl) combination nozzles. Depending on the manufacturer, the disc plate is defined by its diameter in 64ths of an inch. The core or whirl plate might be described by the number of holes (e.g. 2-hole, 3-hole, etc.), or some other manufacturer-specific nomenclature (e.g. 45s, 25s etc.). The rates emitted by combinations of disc & core are determined using water sprayed over a range of pressures. Sprayer operators have access to this information in the form of nozzle tables.

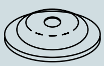
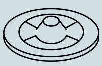
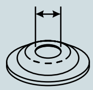
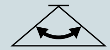
Most nozzle catalogues have tables similar to the TeeJet example on the **next page**. If you don't have a current catalogue, ask your sprayer parts supplier for one. They're free. The higher the pressure (shown along the column headings), the higher the rate emitted by the disc & core combination (shown along the row headings). If you want to know how

DID YOU KNOW?

Many growers say their tanks empty in the same place every time, so their nozzles aren't worn. This is only half the issue. Nozzles can be distorted, compromising spray quality, and still produce an acceptable rate. A distorted spray quality can have a negative effect on spray coverage.

much your nozzle is emitting at a given pressure, find your nozzle on the left, find your operating pressure along the top, and the rate is where they intersect. Or if you have a rate in mind, and want to know which nozzle is the best choice, find your operating pressure along the top, and look down the column until you find your rate. Then, look left to the nozzle combination.

It's a rare and wonderful thing to find exactly the rate you're looking for. You may have to make concessions to operating pressure to achieve your desired rate, or you might have to accept a rate that's close to what you want, but not exact.

			US GAL./MIN.												
			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	DC31	.0319	.08	.11	.13	.15	.18	.20	.23	.27	.31	.37	49°	47°	43°
D1.5	DC31	.0369	.10	.14	.17	.19	.23	.26	.29	.35	.40	.48	57°	65°	53°
D2	DC31	.0419	.12	.16	.19	.22	.26	.30	.33	.40	.45	.55	62°	63°	61°
D3	DC31	.0479	.13	.18	.21	.24	.29	.33	.37	.44	.50	.60	63°	65°	63°
D1	DC33	.0319	.09	.11	.12	.14	.17	.20	.22	.26	.30	.37	27°	32°	35°
D1.5	DC33	.0369	.12	.15	.17	.19	.23	.26	.30	.36	.41	.50	37°	43°	45°
D2	DC33	.0419	.13	.17	.21	.24	.29	.33	.37	.45	.52	.63	45°	52°	55°
D3	DC33	.0479	.15	.21	.25	.29	.36	.41	.45	.55	.63	.76	48°	54°	57°
D4	DC33	.0639	.20	.28	.34	.39	.47	.54	.60	.73	.83	1.02	50°	56°	61°
D1	DC35	.0319	.08	.11	.13	.14	.17	.20	.22	.26	.29	.35	19°	23°	26°
D1.5	DC35	.0369	.10	.14	.17	.19	.23	.26	.29	.34	.39	.46	23°	27°	29°
D2	DC35	.0419	.14	.18	.24	.25	.30	.34	.37	.45	.51	.60	40°	44°	47°
D3	DC35	.0479	.16	.22	.26	.30	.36	.41	.45	.55	.62	.74	45°	50°	52°
D4	DC35	.0639	.27	.37	.44	.50	.60	.70	.79	.93	1.1	1.3	68°	70°	71°
D5	DC35	.0789	.34	.48	.58	.66	.80	.92	1.0	1.2	1.4	1.7	67°	69°	71°
D2	DC56	.0419	—	—	.21	.25	.30	.35	.39	.47	.55	.67	—	14°	17°
D3	DC56	.0479	—	—	.29	.34	.41	.48	.53	.65	.75	.92	—	20°	23°
D4	DC56	.0639	—	.39	.48	.55	.67	.78	.87	1.06	1.23	1.51	20°	26°	29°
D5	DC56	.0789	.38	.54	.66	.76	.93	1.08	1.20	1.47	1.69	2.08	26°	32°	34°
D6	DC56	.0949	.55	.78	.95	1.10	1.35	1.55	1.74	2.13	2.46	3.02	34°	39°	41°
D7	DC56	.1099	.76	1.07	1.32	1.52	1.86	2.15	2.40	2.94	3.40	4.16	45°	52°	54°
D8	DC56	.1259	.96	1.36	1.67	1.93	2.36	2.73	3.05	3.73	4.32	5.28	52°	57°	59°
D10	DC56	.1569	1.35	1.91	2.34	2.70	3.31	3.82	4.26	5.22	6.03	7.39	62°	65°	67°

This nozzle table for TeeJet disc & cores is fairly typical of any manufacturer's nozzle table. Find the disc & core combination in the two left-hand columns, and follow the row until it intersects your operating pressure to determine the rate in US gallons per minute. Or if you know your ideal rate already, find the best disc & core combination for a given pressure to achieve that rate. Multiple combinations can give the same rate but different spray quality.

Looking up the nozzle rates during a spring calibration. The operator was running at 190 psi, but the catalogue only listed 180 psi and 200 psi. When the increments are only 20 psi, it's fairly safe to approximate the output. When the table only lists in 50 psi increments, it is more difficult to determine the rate without testing the output. This issue usually occurs at pressures above 200 psi, and that's very high for most horticultural operations. Consider using a lower operating pressure and larger capacity nozzle, if possible.

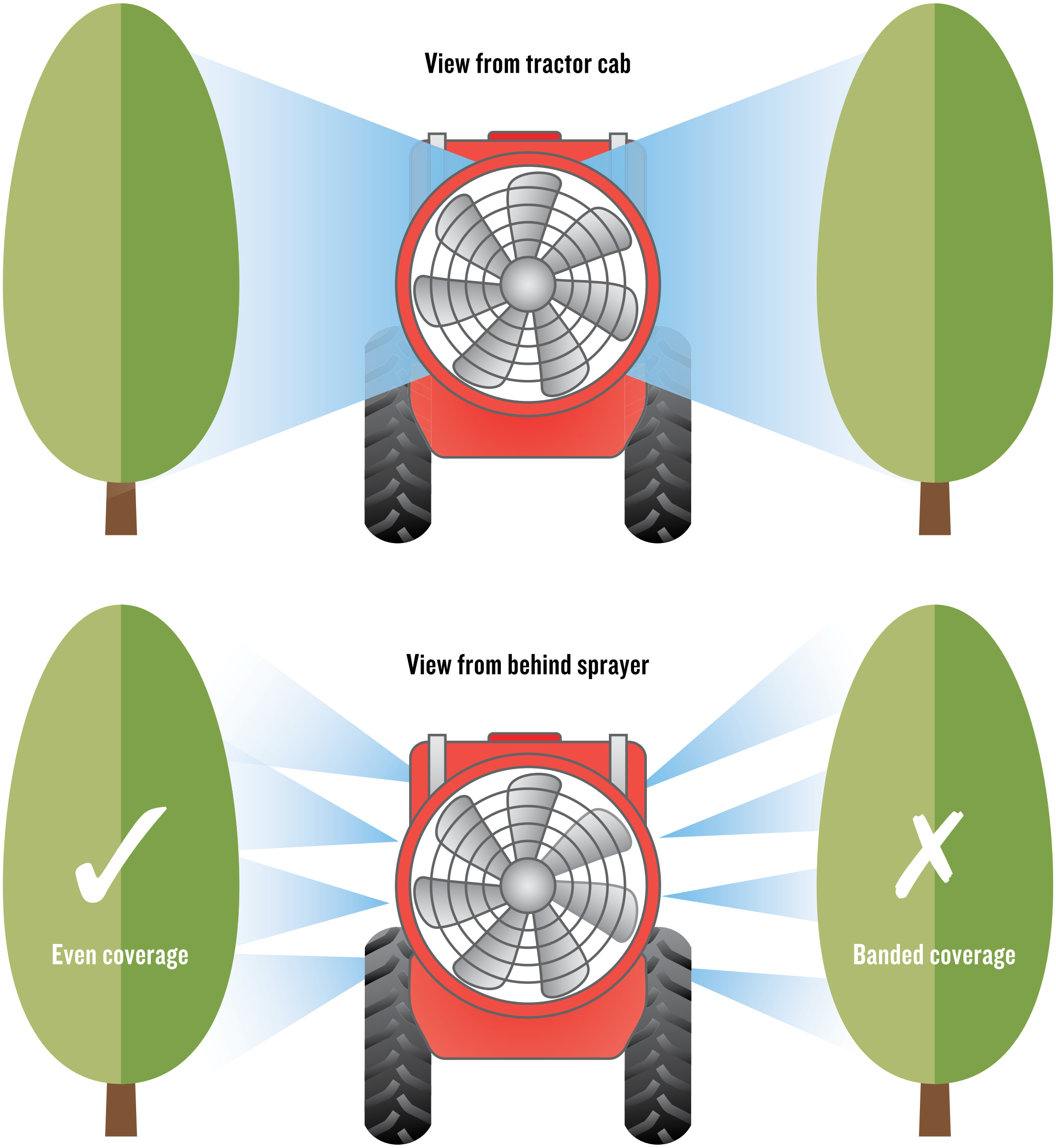
You might notice that different disc & core combinations can create the same rate. The rate may be the same, but the median droplet diameter and the angle of the spray cone are different. Most nozzle tables clearly indicate the different spray angles, as shown in the last three columns in the TeeJet table.

The angle of the spray cone can have a big impact on spray coverage when the target is very close to the sprayer (i.e. in a vineyard or when spraying canes or berry bushes). If nozzle angles are too small, the spray may throw farther but not overlap sufficiently before it reaches the target.

DID YOU KNOW?

The larger the disc orifice, the larger the spray angle. The larger the core, the smaller the spray angle. With certain exceptions, raising the pressure increases the spray angle. Read the manufacturer's catalogue carefully!

To check for overlap, park the clean sprayer in the alley between crops and start spraying water. Have someone stand behind the sprayer and look for gaps in the swath. It might look very different from what the operator thinks they are seeing from a shoulder check. Creating a full spray swath that spans the entire canopy is a function of nozzle spacing, distance-to-target and sprayer air-settings. Spray swath can be affected by humidity, wind speed and wind direction at the time of spraying.



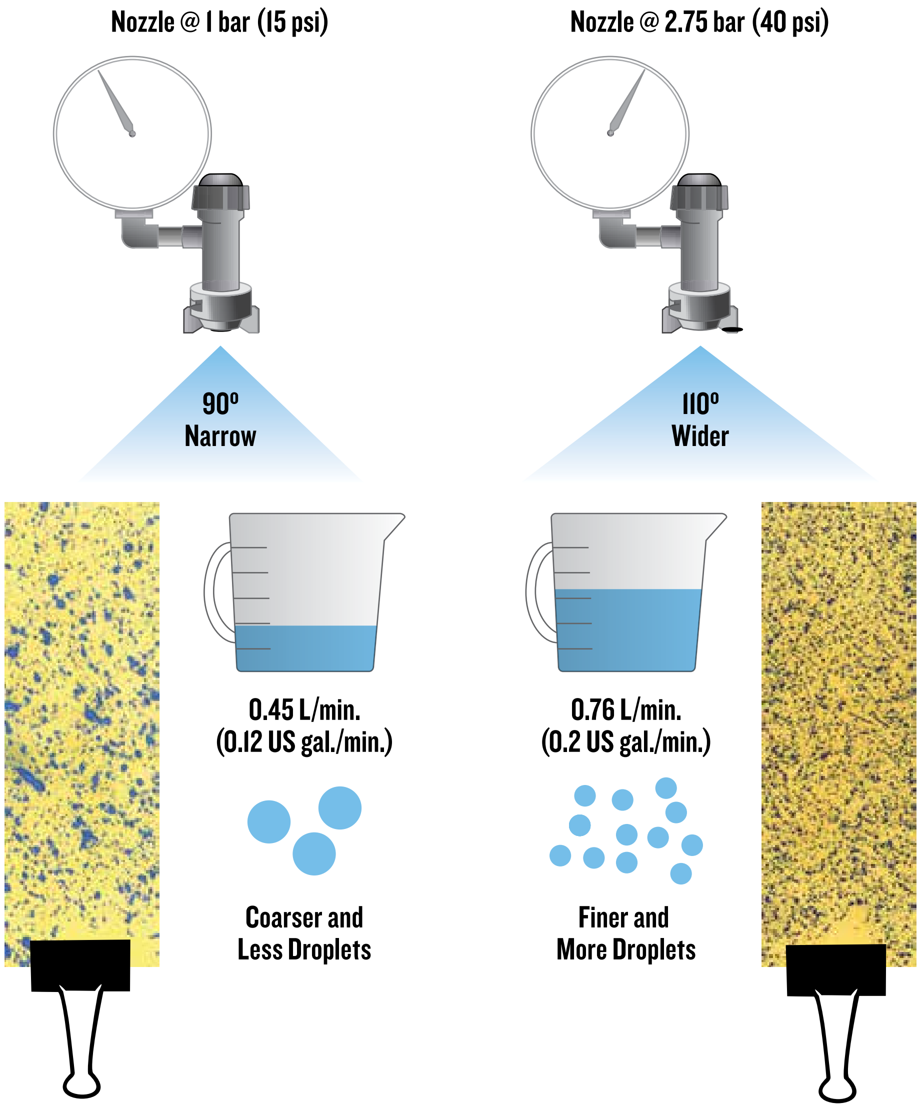
Shoulder checks may not show you what's really happening. Have someone stand behind the sprayer while spraying clean water to see if the nozzle spray spans the entire canopy with no gaps.

Two hollow cone nozzles on top and five full cone nozzles below. Note the lack of spray overlap with the full cones for the first few metres. This would be a concern if the target were closer to the sprayer, such as grape or berry. Also note that the top two nozzles should not be on – their spray will likely not reach the intended target.

PRESSURE AFFECTS SPRAY QUALITY

By now, you should have noticed how integral pressure is to rate and spray quality. Lower pressures reduce nozzle rate, increase median droplet size and typically reduce spray angle. Higher pressures increase nozzle rate, reduce median droplet size and typically increase spray angle.

Pressure affects all aspects of rate and spray quality. Using a flat fan nozzle as an example, a lower pressure increases the median droplet diameter, reduces the droplet count, reduces the nozzle rate and typically reduces the spray angle. A higher pressure decreases the median droplet diameter, increases the droplet count, increases the nozzle rate and typically increases the spray angle. Always operate a nozzle in the middle of its recommended range so it can handle small changes in pressure during spraying (such as from a rate controller, or changing PTO speeds on hilly terrain).



Pressure can be used to make modest changes to rate while spraying. This is how rate-controllers work to compensate for changes in ground speed and maintain a constant overall rate per hectare or per acre. Pressure should not be used to make significant changes to nozzle rates – it's inefficient and takes a four times change in pressure for a two times change in rate. Increased pressure increases nozzle wear and pressure changes may negatively impact the spray quality if the nozzle is pushed outside its recommended range. Simply switch nozzles when a significant change in rate is required.

MOULDED NOZZLES

We all know that combination disc & core nozzles can be aggravating. Here are a few common issues.

- It's hard to read the numbers stamped into the plates to determine rates, especially when they are covered with fungicide.
- It's easy to accidentally put the core in backwards, sometimes changing the spray quality. Remember that if your core has a bump in the centre, that side faces the nozzle body.
- Some require gaskets that wear out and affect spray quality if they are off-centre. Gaskets can also be difficult to pry out of nozzle bodies, even when you turn the bodies downwards and "spank" them to release the nozzle. This technique usually requires using a pick that can damage the nozzle orifice. I own an array of scary dental tools for this purpose.
- If you over-tighten caps, you know the terrible sound of accidentally crushing ceramics – a little more than finger-tight is sufficient.
- It's easy to lose a disc or core if you drop it in the grass while cleaning out a clogged tip in low light. You might never find it again. Always carry spares.

Before calibrating a sprayer I often ask how diligent the operator is about cleaning nozzles and strainers (a daily practice, ideally). Many say they do so regularly, and many actually do. But when I remove the caps I occasionally find crushed ceramic core plates hidden under the discs. The caps were over-tightened and the cores crumble as soon as they are removed. It's obvious the nozzles and strainers were rarely inspected or cleaned.

Moulded tips are a great alternative. Available in hollow cone patterns they often, but not always, fit the existing nozzle bodies.

Here are the obvious advantages.

- It takes less than a minute to swap a moulded tip, and they cannot be mounted backwards.
- Moulded tips are brightly coloured and easier to find if accidentally dropped.
- The tip colour indicates the flow rate, which is very useful when switching between blocks that require different nozzle arrangements. This may also help with any language barriers when communicating the desired nozzle arrangement to seasonal workers. Many operators keep a simple pictoral key in the tractor cab matching nozzle colours to blocks.
- There is evidence that moulded tips with ceramic insets outlast ceramic disc & core assemblies.
- Perhaps best of all, conventional hollow-cone moulded tips are about the same price as ceramic disc & core. Those with the air-induction (see page 101) feature are more expensive.

There are also a few drawbacks to moulded tips.

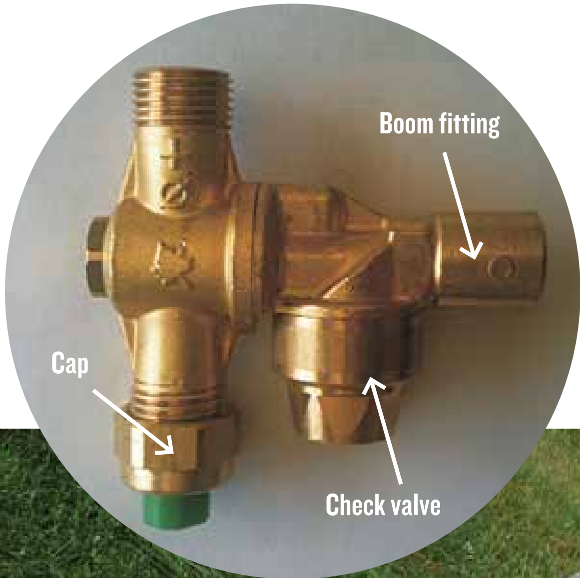
- Moulded tips will not produce as much output as disc & core. They may not be suitable for some dilute or otherwise high-volume applications (e.g. plant growth regulators or dormant oils).
- They are not available in full cone patterns. This typically isn't a problem.
- Some operators report they are more difficult to clean, but this only applies to older, threaded TeeJet tips where the core is unscrewed from the body for cleaning. Newer tips (like Hypro-Albuz and the TeeJet TXR ConeJets) are compression-fitted and pop apart easily using your fingernail.

NOZZLE BODIES

If you are considering switching from disc & core combination nozzles to moulded nozzles (and I encourage you to do so), you need to know if they will fit your existing nozzle bodies.

Many sprayers use roll-over, dual nozzle bodies so two nozzles can be mounted in each boom position for quick-changes from dilute to concentrated applications, or to change the spray distribution from block to block. However, some sprayers (like Turbomist) employ single nozzle bodies. Their technique is to double the density of the bodies on the boom, arranged in an alternating A-B pattern. By shutting off each alternate nozzle you can use the As or the Bs. This gives the added flexibility to "double-up" in positions along the boom where more spray is required. This strategy isn't ideal, but works in a pinch (see image on next page).

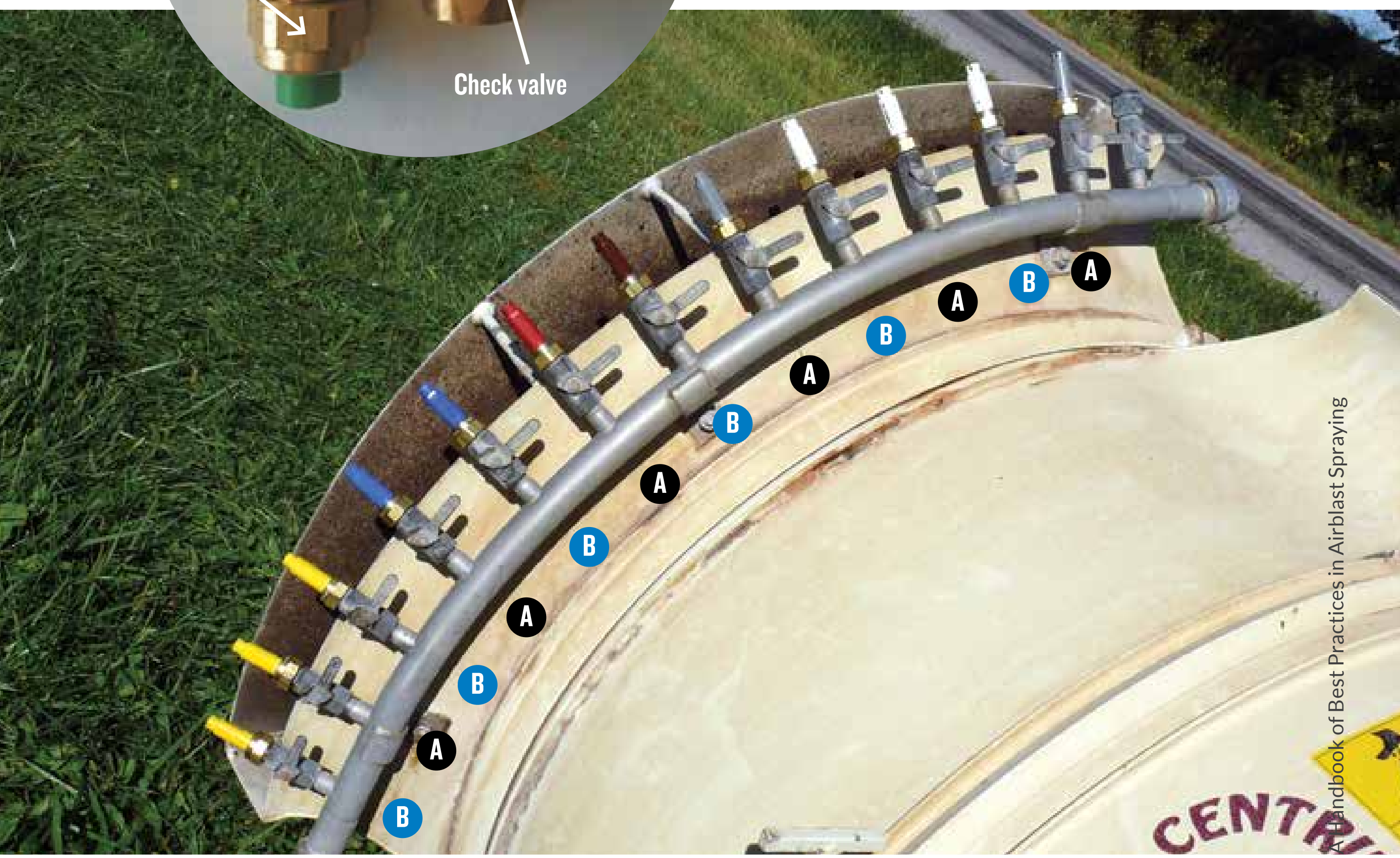
A typical brass roll-over style dual nozzle body with cap and optional check valve.



DID YOU KNOW?

Be aware that with time and use, the valve in the nozzle body will wear. If it wears enough to move on its own, it could block the liquid path and lower flow at the tip.

Some sprayers do not use roll-over nozzle bodies. Instead, they double the density of the bodies on the boom for use in an alternating A-B pattern.



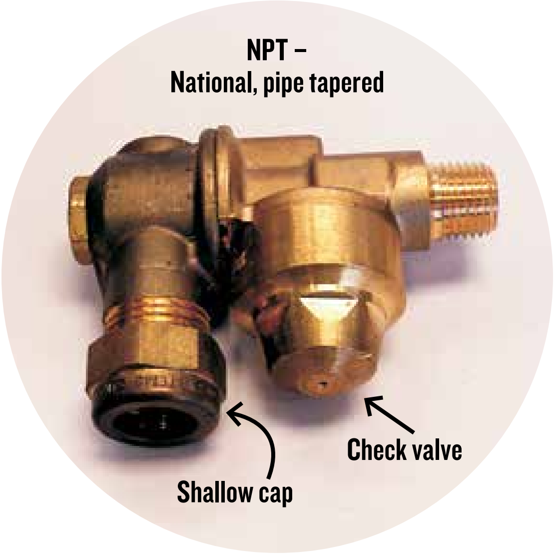
Old FMC with nozzle bodies that do not have check valves. Once the pressure is off, the booms begin to drain through the lowest nozzle. This is a waste of pesticide and unnecessary environmental contamination.

If your sprayer has roll-over bodies already, check the diameter of the body outlet (where the nozzle rests) and the outlet cap (which secures the nozzle tightly against the body outlet). Check to see if your sprayer uses an unusual diameter nozzle, like older FMC disc & whirls or the older European large-diameter pink ceramic disc & cores. Moulded nozzles won't fit in those bodies, so you'll need to replace them.

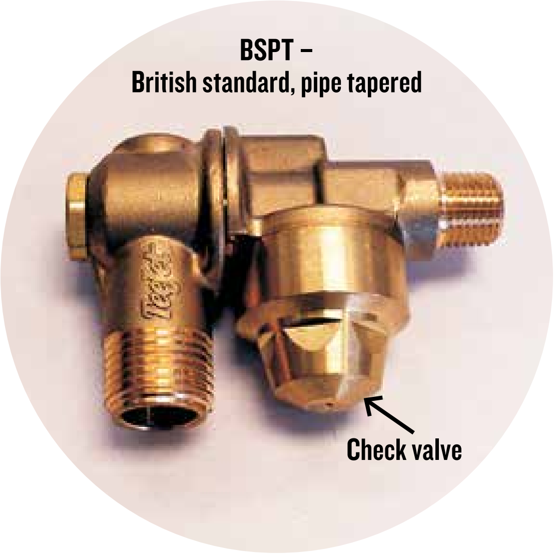
Replacing nozzle bodies costs about $50.00 CAD per body. Be aware of the following options and considerations.

- There are four inlet thread types: NPT, BSPT, NPS and BSPP. The inlet thread sizes are 1/4" female, 1/4" male and 3/8" male. 1/4" female is not available on the NPS or BSPP inlet thread types.
- The roll-over feature allows you to turn off the nozzle, but it also allows you to reposition the tip +/- 15° from centre. Be aware that moulded nozzles protrude and may hit the edge of the sprayer duct when they are turned. Ensure they'll clear any possible obstructions.
- Make sure the bodies you get have diaphragm check valves. They are an option worth having to prevent the boom from draining when not spraying and improving on-off reaction time. In my opinion, they should be mandatory. If your sprayer doesn't have them, consider purchasing mesh nozzle strainers with built-in ball valves. You have to be very diligent to keep them clean, but they work well as an alternative to check valves.
- Nozzle bodies have either single or double outlets. The doubles are very convenient because they allow you to switch between two nozzles quickly and easily. Be sure they'll clear any obstructions with the nozzle installed.
- Nozzle bodies **do not** come with the nozzle caps – you have to order them separately. This was an unpleasant surprise the first time I ordered a set of bodies. The standard caps are brass hex nut-style but there are also nylon wing-style caps that don't require a wrench.

Old FMC roll-over bodies removed in favour of moulded-nozzle-compatible roll-overs with check valves.

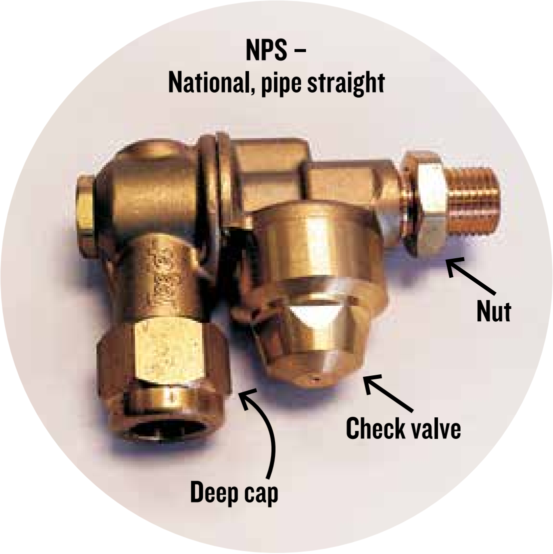


National, Pipe Tapered (NPT) single-sided, brass roll-over nozzle body with check valve. Note the shallow cap pictured here.

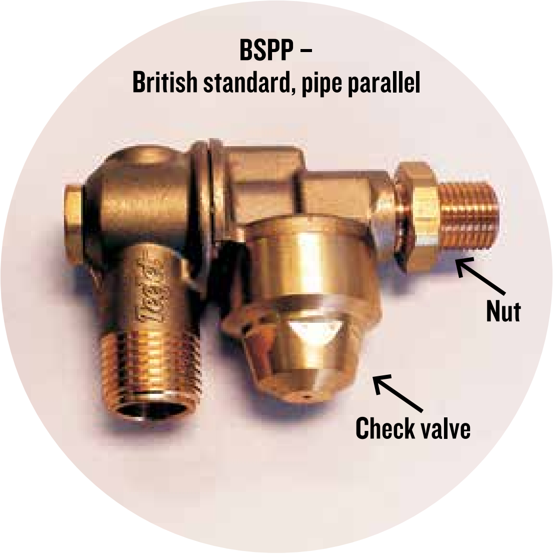


British Standard, Pipe Tapered (BSPT) single-sided, brass roll-over nozzle body with a check valve.

Older nozzle bodies can seize in the boom, requiring novel approaches to removing them. In this case, the mechanic is heating the fittings before unscrewing them. I took this picture with a zoom lens to avoid getting too close! If you plan to do this, be very careful to do it an open space using PPE like gloves and a respirator. Years of residue buildup should be anticipated and respected. The filter on the cigarette isn't appropriate.

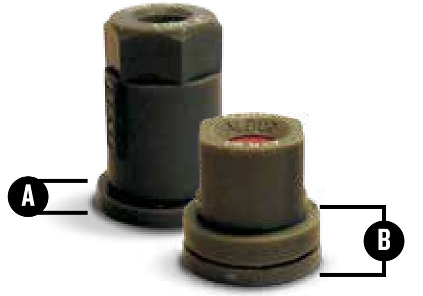


National, Pipe Straight (NPS) single-sided, brass roll-over nozzle body with check valve. Note the deep cap pictured here.



British Standard, Pipe Parallel (BSPP) single-sided, brass roll-over nozzle body with a check valve.

Regarding the cap depths, sprayer operators may be using an optional gasket between the cap and the tip, and hopefully are using strainers between the tip and the body. Those take up room, so a deeper cap may be required. Another reason for variable cap depth is because of the nozzle shoulder. For example, TeeJet sells an A and a B option for older moulded hollow cone tip. The B style has a thick shoulder, similar to Hypro-Albuz moulded nozzles. If you have tips with thick (B) shoulders, shallow caps may not thread onto the body outlet. Alternately, if you have a deep cap and a nozzle with thin (A) shoulders, the cap will be completely tightened but will not compress the shoulder against the body outlet to form a seal and spray will escape around the loose nozzle.



Moulded hollow cone nozzles come in the thin shoulder (A) or thick shoulder (B) varieties. The B-style is the ISO standard and is preferred.

In an effort to clear up some of the complication, TeeJet now sells the TXR line of hollow cone tips that meet all ISO requirements, including colour coding and the thicker (B) shoulder. They are my preferred TeeJet-brand tip if you are considering moulded hollow cones for the first time – don't go back to the older TeeJet models that do not conform with ISO 10625.

LIPCO sprayer in a mature, high-density orchard.

Changing nozzles and observing spray quality using clean water.

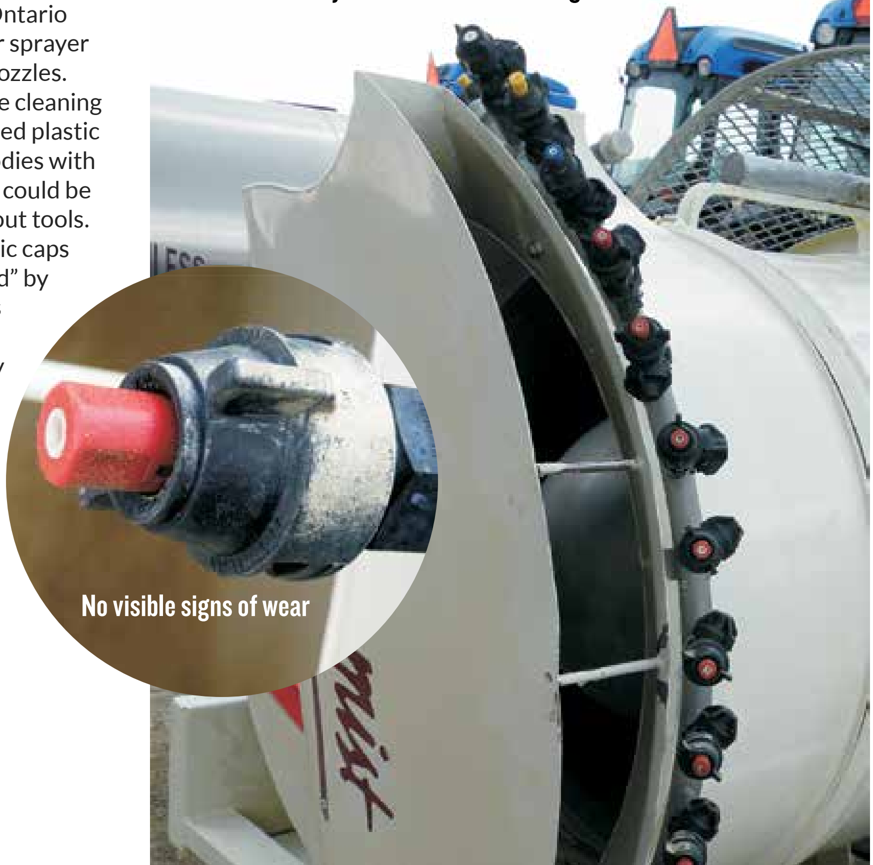
No matter which moulded nozzle, nozzle body and cap combination you choose, there's always the possibility for incompatibility. I suggest getting one of each before buying a whole set to ensure there are no issues. For example, in 2015 we attempted to re-nozzle a European LIPCO over-the-row sprayer for a high-density Ontario apple orchard. It was a beautiful machine, equipped with Albuz AVI-110 (air-induction) flat fans.

We felt we should take advantage of the shrouds that block much of the orchard wind and use a smaller droplet size to improve coverage. When we attempted to use TeeJet hollow cones, we found the diameter or their older VK hollow cone nozzles was too large for the Albuz caps. When we tried their new TX hollow cone nozzles, we had a better fit, but discovered that much of the spray pattern extended beyond the reach of the entraining air, so it simply didn't go anywhere. This explained why there were flat fans on the sprayer in the first place – they lined up with the air more effectively. Live and learn. In the end, we used Albuz ADI-110 flat fans, which fit the caps, lined up with the air and produced medium, and more plentiful, droplets to give better coverage.

It may seem complicated at first blush, but it is worthwhile to switch to moulded nozzles. Examine your sprayer and determine which tips, nozzle bodies and caps will get the job done. Field sprayer operators have used moulded nozzles for many years for good reason.

The ingenuity of farmers never ceases to amaze me. An apple operation in Simcoe, Ontario decided to switch their sprayer fleet to air induction nozzles. In order to make nozzle cleaning more efficient, they used plastic field sprayer nozzle bodies with quarter-turn caps that could be removed quickly without tools. I wondered if the plastic caps would be "sand-blasted" by the air, but three years later (and counting), there haven't been any problems. Be aware that an O-ring and seat washer may be required to hold the nozzle firmly in the quarter-turn cap.

Plastic quarter-turn nozzle bodies on an airblast sprayer – three years of use and counting...



AIR INDUCTION NOZZLES

Air induction (or Venturi) nozzles create coarser droplets that are less prone to spray drift, compared to the finer droplets produced by conventional hollow cone nozzles. Operators report less “mist” hanging in the crop while spraying with these tips and the sprayer does not appear to create an obvious, opaque plume – that’s good when there are bystanders but can be difficult to assess from the sprayer cab during a shoulder check.

Coarse/Extremely coarse droplets
Larger, fewer, not drift-prone

Fine/Medium droplets
Smaller, plentiful, drift-prone

Note the difference in the visibility of the spray swath when spraying coarser (left) versus finer (right) droplets.

Beyond my own experience, I am aware of more than 30 peer-reviewed, international studies that indicate applications from air induction hollow cones are as efficacious as conventional hollow cones. But there are some conditions where they may not be a good fit.

- When the canopy is very dense (e.g. un-pruned trees or grapes with a closed canopy) coarse droplets don’t penetrate as well. Canopy management is a must.
- When the canopy is very wide, coarse droplets lose momentum and fall out of the air more quickly than finer droplets, affecting penetration depth. This is typically a concern in older orchards.
- If the operator is already using a low volume (e.g. L/ha or gal./ac.), there may not be enough droplets to provide sufficient coverage – especially when disease pressure is high.

These are extreme situations, and failures are rarely reported as a result of using air induction nozzles. When used with sufficient volume and on a reasonable canopy, spray distribution can be excellent. Always confirm coverage with water-sensitive paper when you make a change to your sprayer.

Air induction nozzles on a Turbomist. On the left are conventional flat fans. On the right is the same rate using air induction flat fans. When this image was captured, the sprayer operator apologized for forgetting to turn on the right-hand boom. It actually was on but he could not see the coarse spray from the cab! Some operators find this unnerving.

Watch a video on the air induction flat fan at www.sprayers101.com.

DID YOU KNOW?

A red hollow cone air induction tip does not necessarily have the same flow rate as a conventional red hollow cone nozzle. Always consult nozzle tables for rates.

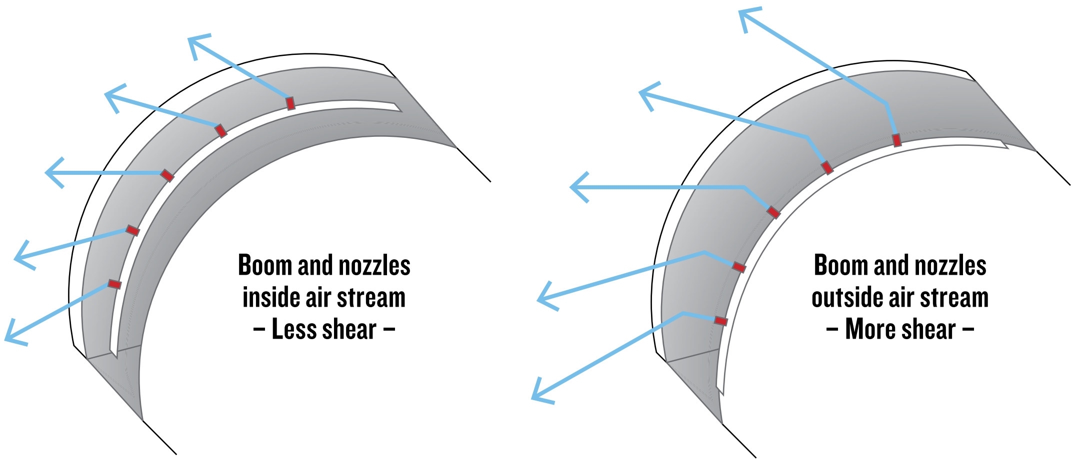
Here are a few emerging uses for air induction nozzles on airblast sprayers.

- Use air induction nozzles in the top two positions on each side of the sprayer, and conventional moulded hollow cones in the remaining positions. The top nozzles are often the biggest contributors to off-target movement of spray and the larger droplets produced by the air induction nozzles tend to fall out of the air rather than drift away. The ballistic movement of coarser droplets tends to keep them moving in a straight line after leaving the nozzle, helping to direct them to the tops of trees.
- Try replacing the conventional nozzles in any tower “dead zones” with air induction nozzles. Coverage should improve in that zone because pressure propels coarser droplets further than finer droplets. We’ve seen significant improvements using this technique in high density orchards.

Reaching the tops of 5-6 m (~16-20 ft.) hop plants on 2 x 2 m (~7 x 7 ft.) spacing can be a tall order. This Rears sprayer is doing a good job of it, but would air induction in the top positions help?

PHOTO CREDIT – D. GROENENDALE, WASHINGTON.

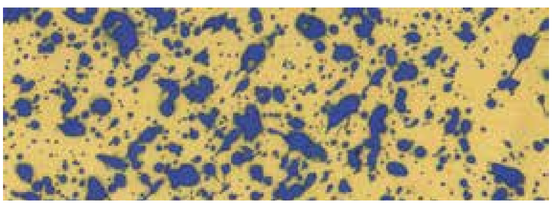
The spray quality produced by an air induction nozzle is affected the by air speed and the location of the nozzles on the sprayer, relative to the air outlet. Coverage patterns on water-sensitive paper indicate that nozzles located outside the air stream (e.g. Turbomist) result in smaller droplets then nozzles located inside the air stream (e.g. Durand-Wayland). This is due to air-shear – known to "shred" spray as the angle between the nozzle and the entraining air stream becomes more acute. The effect may be more pronounced with the air-filled droplets created by air induction nozzles.



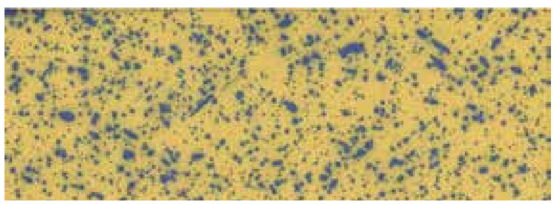
The more shear, the more and the smaller the droplets

The more acute the angle between air and spray, the more air-shear and the higher the numbers of finer droplets.

Air-induction tip location inside the airstream



Air-induction tip location outside the airstream



Air shear reduces droplet size and increases droplet quantity

Left: water-sensitive paper sprayed with an air induction nozzle located within the air stream.
Right: water-sensitive paper sprayed with an air induction nozzle outside the air stream. This comparison may be exaggerated because the left paper was from a higher volume spray and less-dense canopy than the right. But the droplets captured by the papers are always finer when nozzles are positioned outside the entraining air.

Here's a story. It was spring when we calibrated an older FMC with a 0.6 m (2 ft.) fan in low gear. We were spraying mature high-density Royal Gala at tight cluster. The operator was travelling at 5.5 km/h (~3.4 mph) spraying ~400 L/ha (~42.7 gal./ac.). He runs his sprayer at the lowest operating pressure I've ever encountered on an airblast sprayer at 60 psi. It was 10 a.m., the wind was a light 2 km/h, relative humidity was ~55% and the temperature was ~20 °C – beautiful conditions for spraying. Two water-sensitive papers were clipped back-to-back, facing the alleys at the top of an 11 foot tree. The nozzle in the top position was a TeeJet TXVK 18 ~0.9 L/min. (0.24 gal./min.) at 60 psi. The coverage was marginal. Given the fact that it was early spring, the wind was so light and the paper was at the top of the tree, it didn't make me confident. Such small droplets could easily be blown off-course as the wind picked up. We decided to install an air-induction hollow cone in that position. The TeeJet AITX 8002 emitted the same rate ~0.9 L/min. (0.24 gal./min.) at 60 psi, but sprayed fewer and larger droplets. When the papers were recovered, we decided to go up one more nozzle size to increase the droplet count. We used the TeeJet AITX 80025 ~1.1 L/min. (0.3 gal./min.) at 60 psi. Later, we scanned the water-sensitive papers using software developed by Dr. Heping Zhu (USDA ARS in Ohio). The results are presented on **page 106**.

DID YOU KNOW?

Air, not pressure, propels fine droplets. Raising the pressure creates more fine droplets, and they don't travel much further. So, if you are trying to get spray to go higher, don't increase the pressure. Rather, adjust the air and/or try air induction nozzles in the top positions to lob coarser drops.

The tree-top coverage obtained using three different nozzles in the top position during a spring calibration. The percent coverage and droplet density generally increase with nozzle rate. However, switching to an air induction nozzle reduces droplet count and a higher rate is sometimes required to compensate.

TARGETS BACK-TO-BACK AT TOP OF 11 ft. TREE

Temp = 20ºC (68ºF), RH = 55%, Wind = 2 km/h (1.25 mph)

Average of both papers

	Rate (gpm)	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)	% Coverage	Deposits/cm^2
TXVK 18:	0.24	267	539	1,159	21	219
AITX 8002:	0.247	255	593	2,140	17	207
AITX 80025:	0.3	290	680	1,985	25	216

TXVK 18
(0.24 gpm @ 60 psi)
~M or C droplets

AITX 8002
(0.247 gpm @ 60 psi)
XC droplets

AITX 80025
(0.3 gpm @ 60 psi)
UC droplets

6.8 Calculate sprayer output for each side

Let's return to calibration.

Perhaps you just bought a new sprayer. Let's assume you have some idea what your target sprayer output should be (e.g. 550 L/ha or ~59 gal./ac.), but you don't know what nozzles you need to achieve it. A set of nozzles on one boom, when added together, produce the output per side. Use one of the following formulae, depending on the units you prefer. These formulae are for airblast sprayers with two booms. For airblast sprayers with only one boom (e.g. cannon sprayers common in nurseries and highbush blueberry operations) reduce the constant by half: 1,000 becomes 500, 500 becomes 250 and 1,200 becomes 600.

$$\text{Output per side (US gal./min./side)} = \frac{\text{Target sprayer output (US gal./ac.)} \times \text{Ground speed (mph)} \times \text{Row spacing (ft.)}}{\text{1,000 (a constant)}}$$

$$\text{Output per side (L/min./side)} = \frac{\text{Target sprayer output (L/ac.)} \times \text{Ground speed (km/h)} \times \text{Row spacing (m)}}{\text{500 (a constant)}}$$

$$\text{Output per side (L/min./side)} = \frac{\text{Target sprayer output (L/ha)} \times \text{Ground speed (km/h)} \times \text{Row spacing (m)}}{\text{1,200 (a constant)}}$$

These formulae are for airblast sprayers with two booms. For airblast sprayers with only one boom – cannon sprayers common in nurseries and highbush blueberry operations – reduce the constant by half: 1,000 becomes 500, 500 becomes 250 and 1,200 becomes 600.

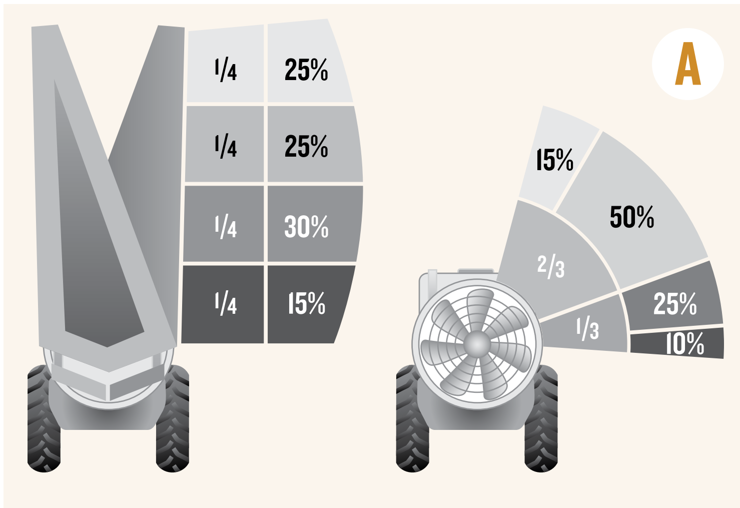
Adjustable ducts on cannon sprayers make them adaptable to many nursery crops, such as hoop house crops (top) and container crops (bottom). Note the change to the calibration formulae when calculating for one-sided airblast sprayers such as these.

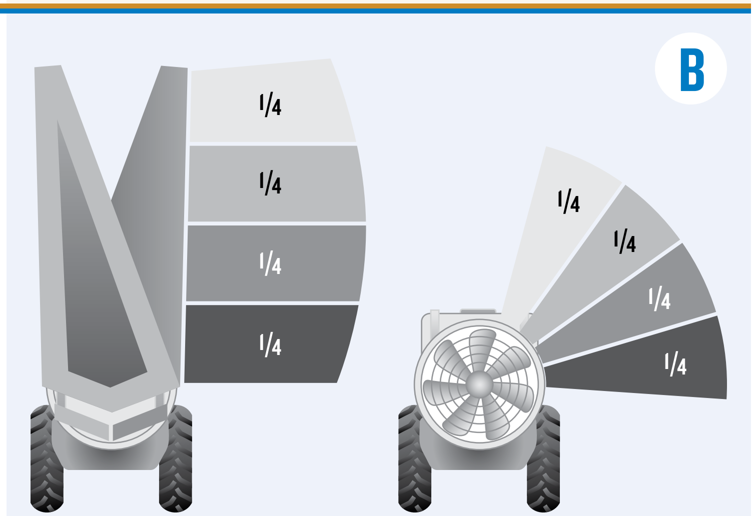
PHOTO CREDIT – M. LANTHIER, BRITISH COLUMBIA.

6.9 | Distribute spray over the boom

When you know your ground speed and ideal output per side, you have to decide how much spray comes from each nozzle position. In other words, how will you distribute the spray over the boom? You know how many nozzles will be active because you have already adjusted for canopy overshoot and undershoot using the ribbon test (see Section 5.1). Operators will often distribute spray to direct most of the volume at the thickest foliage, or shift higher volumes towards the fruit zone in grapes. Some operators spraying tall targets (e.g. almonds, hops) may use high-volume full cones in the top boom positions to ensure spray reaches the highest part of the target.

Work at Ohio State showed that if the target is a uniform depth and moderate height, like trellised trees, the operator can safely distribute the spray evenly over the boom. Tower sprayers that make the distance-to-target more consistent for each nozzle may also use the same rate in each position.





A. Suggested spray distribution for airblast sprayers on classic spindle apple trees.
B. If the canopy is of uniform depth and nozzles are approximately the same distance-to-target, such as a vine or high-density apple, spray distribution should also be uniform (i.e. each nozzle sprays the same rate). These distributions may change when there is fruit to protect.

This application, staged with water, may appear to be effective, but it is definitely not efficient. Turn off nozzles that do not need to be on – most of the overspray never lands on the intended target.

PHOTO CREDIT – M. LANTHIER, BRITISH COLUMBIA.

The same sprayer looks better once it's been adjusted to match the crop.

PHOTO CREDIT – M. LANTHIER, BRITISH COLUMBIA.

6.10 | Validate sprayer output

Once you have confirmed ground speed, operating pressure and selected the nozzles, your sprayer should spray the predicted rate (e.g. L/ha or gal./ac.). Up until now, much of the calibration has been qualitative, so a final validation is required.

Nothing's easy, is it?

One way to check is to fill the sprayer with enough water to spray one hectare and then spray the hectare. If the tank is empty, the sprayer output is as expected. In my experience, most operators do not have an accurate test hectare marked off. This method may also give a false positive if some nozzles are partially blocked while others are worn. You may think that's improbable, but it happens. I once encountered a 20 nozzle ginseng sprayer suffering from nozzle rate variance on almost 50% from tip to tip, and yet the collective boom rate was bang on. I've also seen brand new ceramic disc-core nozzles out-of-spec by +/-10%.

Still another way to confirm sprayer output is to fill the sprayer to a known volume using the sight tube or a graduated dip stick. Spray for a given amount of time and determine the difference in volume remaining in the tank. That will give a rate. This method can be defeated by parking the sprayer on a grade, or setting the dipstick incorrectly in a tank with a rounded bottom. It does not account for ground speed and is not a recommended method.

My preferred method is to measure the actual output-per-minute of each nozzle. This method does confirm nozzle accuracy. Ground speed should be tested separately **(Section 6.4)**. While wearing appropriate personal protective equipment, perform this "timed output test".

1. Clean the sprayer, fill it half-full with clean water and park it on a level surface.
2. With the fan off, bring the sprayer up to operating pressure. Start spraying with all nozzles open. Prevailing winds shift so you're going to get wet. Dress appropriately.
3. Place a collection vessel under the nozzle to be tested. Use a 1 m (~3 ft.) length of 1 in. diameter braided hose to direct the spray into the vessel. This size hose is stiff enough to allow the operator to hold it securely against the nozzle body with one hand, while standing out of the spray and holding the collection vessel in the other.
4. Collect spray for one minute. If the collection vessel overflows, collect for 30 seconds. One minute is preferable because it improves the accuracy. Remember to double the output you collect if only measuring for 30 seconds.
5. Determine the nozzle output by looking at the graduations on the side of the collection vessel or weighing the output on a kitchen scale. If using a scale, one millilitre of clean water weighs one gram. Remember to "tare", which means subtract the weight of the collection vessel.

6. Convert the findings to either U.S. gallons per minute or litres per minute – whichever corresponds to the ratings in the nozzle manufacturer's catalogue.
7. Replace any nozzles that are 10% more or less than the rated output; 5% is a preferable limit, if possible. If two or more nozzles are worn, replace all the nozzles at the same time.

Anyone that has tried the timed output test in Canada knows that it sounds easy until you try it. The problem is converting between metric and US imperial units. Canadian sprayer operators tend to use both because label rates are in metric, but most sprayer equipment is rated in US imperial. Here are the most common calculations required for the timed output test:

If collecting in ounces, converting to U.S. gallons per minute:	**US gallons per minute**	=	**Output in ounces per minute** / **128 (a constant)**
If collecting in millilitres or grams converting to U.S. gallons per minute:	**US gallons per minute**	=	**Output in grams or millilitres per minute** / **3,785.4 (a constant)**
If collecting in ounces, converting to litres per minute:	**Litres per minute**	=	**Output in ounces per minute** / **33.8 (a constant)**
If collecting in millilitres or grams converting to litres per minute:	**Litres per minute**	=	**Output in grams or millilitres per minute** / **1,000 (a constant)**
If collecting in ounces, converting to imperial gallons per minute:	**Imperial gallons per minute**	=	**Output in ounces per minute** / **153.7 (a constant)**
If collecting in millilitres or grams converting to imperial gallons per minute:	**Imperial gallons per minute**	=	**Output in grams or millilitres per minute** / **4,546.1 (a constant)**

The SpotOn SC-4 calibration vessel is much easier, faster and more accurate than the classic pitcher-and-stopwatch approach to timed output tests.

A dairy inflation used to collect spray from a nozzle on a tower sprayer. Wear appropriate PPE – you will get wet.

Many sprayer operators loathe nozzle calibration. Fortunately, there are now electronic calibration vessels like the ATI Agritronics AppliMax Spray Nozzle Calibrator, or the Innoquest SpotOn SC-4 (above, left). Both collect the spray and give a fast and accurate digital result in US gallons per minute, ounces per minute or litres per minute. You need a hose to both direct the spray into the vessel and slow it down to prevent splashing. Further, the spray has to be very clean because foaming can wreak havoc with the readings.

When calibrating airblast nozzles it can be challenging to hold a braided hose over a nozzle body while juggling a pitcher or collection vessel. The hose can pop off, affecting the reading and increasing the chance of spraying the person performing the calibration. Dr. Heping Zhu (ARS USDA) passed on a tip to use dairy inflations that snug over the entire nozzle body, freeing a hand (above, right). This can work, but the hose is short, can crimp when bent, and doesn't easily fit over check valves.

A passive flow meter. The soft rubber fitting is held tightly over the nozzle and the flow is allowed to pass vertically through the meter. According to one manufacturer, the floating ball indicates the rate with an absolute precision of 3-10% and a relative precision between identical nozzles of 1.5%.

Some operators use passive flow meters (above), but they are difficult to source in North America because they aren't very accurate. They're fine for comparing relative flow from tip to tip, but the act of suffocating the exit orifice with the unit affects the rate. This is true of any calibration device that could restrict flow from the nozzle, and it has an exaggerated effect on air induction nozzles. Here's a story:

The aams-salvarani clamp is secured behind the nozzle cap and the rubber seal snugs over the nozzle. A hose barb directs flow to a calibration vessel.

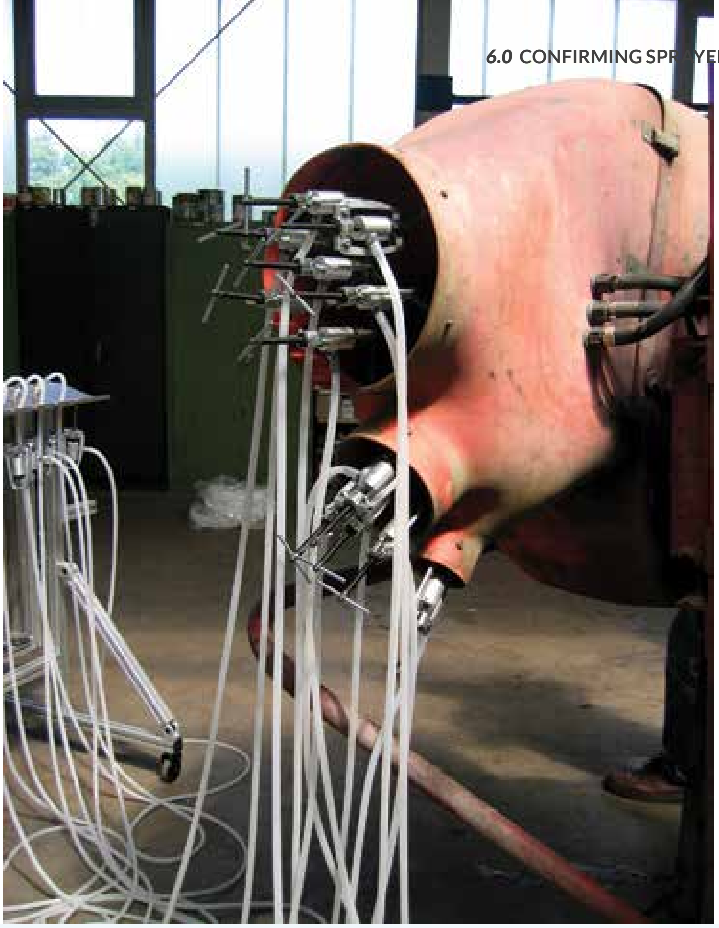
At a demo in Pennsylvania I was introduced to aams-salvarani's calibration clamp (right). The unit is quickly and easily secured over the nozzle body, and with enough of them the calibrator can collect from any nozzle without ever getting wet or spilling a drop **(page 115)**. This is far less arduous than using hose clamps, which leak, strip and are generally a pain.

We wanted to try the clamps at the demo, and that's where we learned that the back pressure created by the clamp could affect the reading. For a conventional tip (such as disc-core or moulded hollow cone) the impact would be minor, but we were warned that smothering an air induction nozzle would have a big impact. We decided to test it by comparing the flow from a flat fan air induction nozzle to one with plugged air inlets. The result was dramatic. When air inlets are plugged, and the nozzle is spraying into liquid rather than into the air, there is an increase of flow from the tip by as much as 15% (bottom, **page 115**).

So, when calibrating nozzles, avoid smothering air inlets on air induction tips, and be aware that a nozzle spraying into liquid rather than air will increase output from the nozzle.

With enough aams-salvarani clamps, lines can run to collection vessels for hands-free nozzle calibration. Over-tightening the clamp could cause leaks, so use only enough pressure to seal the tip. Let the lines fill, and collect at your leisure.

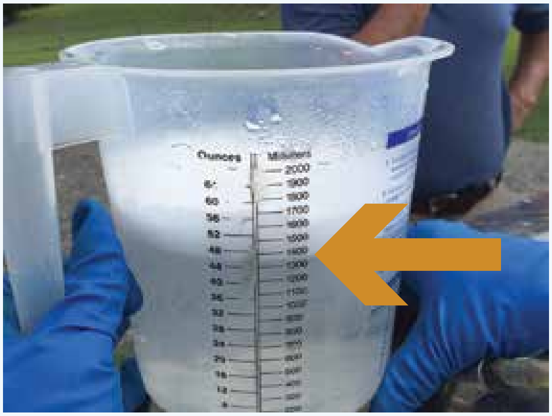
PHOTO CREDIT – J. LANGENAKENS, BELGIUM.



1,200 mL (0.317 gallons)

1,200 mL (0.317 gallons) collected from an air induction flat fan with open air inlets.

1,350 mL (0.357 gallons)



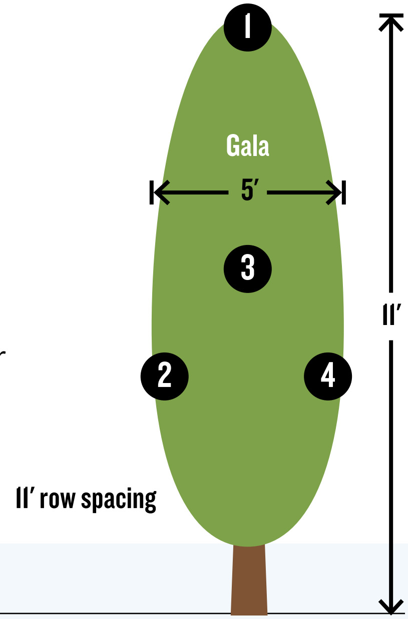
1,350 mL (0.357 gallons) collected from the same air induction flat fan with plugged air inlets. This represents more than a 10% increase in flow. This differential would be higher if the nozzle was spraying into liquid and not into the air as it was here.

7.0 Troubleshooting poor spray coverage

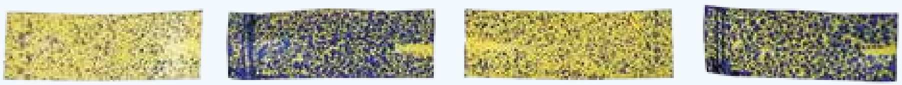
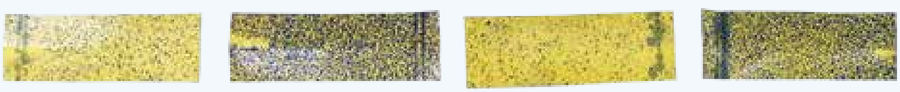
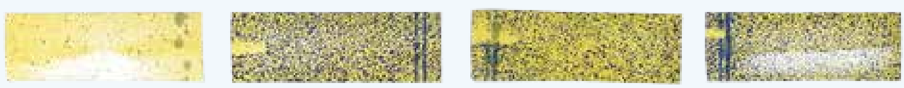
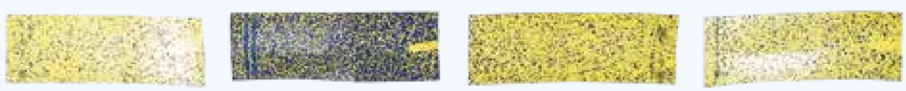
Troubleshooting poor spray coverage

Assuming there are no mechanical or maintenance problems, water-sensitive paper can be used to diagnose sprayer performance. If the papers don't show what you want to see, you have to troubleshoot to identify and fix the issue.

When troubleshooting, only make one change at a time for each test pass so you can isolate what's wrong. Each pass requires a new set of papers located in the same place, oriented the same way, so the comparisons between passes are fair. Mark the locations with bright flagging tape. And write the pass number and canopy position on the back of paper prior to placement so you can compare the passes later on. Don't collect papers until they've had an opportunity to dry a little, or they will smear and stick together.



April 17, 2014, 10:00 am – 12:30 pm, 14 °C, ~65% RH, Wind 7-10 km/h

		Papers	POSITION 1	POSITION 2	POSITION 3	POSITION 4
660 L/ha 18 nozzles	CONTROL		22.3% / 161 d/cm²	22.3% / 161 d/cm²	22.3% / 161 d/cm²	22.3% / 161 d/cm²
400 L/ha 18 nozzles	TRIAL 1		17.8% / 175 d/cm²	45.2% / 136 d/cm²	9.3% / 128 d/cm²	39% / 172 d/cm²
400 L/ha 16 nozzles	TRIAL 2		4.5% / 54 d/cm²	36.5% / 1671 d/cm²	25.8% / 195 d/cm²	32.7% / 194 d/cm²
400 L/ha 14 nozzles	TRIAL 3		17.6% / 141 d/cm²	56.6% / 94 d/cm²	17.6% / 127 d/cm²	21.6% / 140 d/cm²

(Ideal coverage: 15% and 85 drops/cm²)

This image shows the results of a sprayer calibration in a high-density Gala apple orchard. Water-sensitive paper was placed in the target tree in four positions and sprayed with the grower's typical method of 660 L/ha (70.5 gal./ac.) using 18 nozzles. By making small adjustments to the spray distribution over the boom and adjusting driving speed and air handling, the spray operator achieved minimally acceptable coverage using 400 L/ha (42.7 gal./ac.) over 14 nozzles according to the Crop-Adapted Spraying method (see page 136). It required adjustments over four passes before coverage was satisfactory.

You might come across these common situations while troubleshooting spray coverage. The suggested fixes are somewhat generic but typically work. Each situation assumes favourable conditions for spraying – steady light wind, moderate humidity and moderate temperature.

Confirm coverage in the same environmental conditions you intend to spray in.

SITUATION	SUGGESTED FIXES
1. <15% coverage and <85 fine/medium droplets/cm^2 at top of target (e.g. tall targets such as hops or trees).	• Wind might be stealing fine droplets. Try coarser droplets (e.g. using air induction nozzles). You may have to increase volume to compensate for reduced droplet counts. • Deflectors may not be channelling air and spray correctly – extrapolate air direction using ribbons on deflectors. • Fan may have to be set to higher gear, or if using GUTD, return to 540 rpm to increase fan speed. If still insufficient, you may need a sprayer with higher air capacity.
2. <15% coverage and <85 fine/medium droplets/cm^2 deep in canopy – sometimes papers on outside of canopy are visibly wet.	• Ground speed may be too high. Use flagging tape indicator on far side of target and see if air is getting through. • Canopy maintenance may be required (e.g. pruning, hedging, leaf stripping, etc.). No sprayer can consistently penetrate really dense canopies. • Fan may have to be set to higher gear, or if using GUTD, return to 540 rpm to increase fan speed. If still insufficient, you may need a sprayer with higher air capacity. • Increase carrier volume.
3. Papers are drenched, dripping or show channels of running liquid.	• Reduce spray volume, either overall or in key locations on the boom corresponding to the drenched papers. • Ground speed may be too low. Use flagging tape indicator on far side of target and see if too much air is getting through. If so, increase ground speed.
4. Considerable overspray above target row.	• Turn off upper nozzles until spray JUST clears target. • Deflectors may not be channelling air and spray correctly – extrapolate air direction using ribbons on deflectors.
5. Considerable blow-through beyond target row.	• Slow the fan speed by shifting to low gear, or using GUTD method. • Ground speed may be increased as long as coverage is not compromised. Use flagging tape indicator on far side of target and see if air is getting through.
6. Ground under target row is drenched.	• Rotate lower nozzles slightly upward, but do not shut them off. If ground remains drenched, turn them off entirely. Each hollow cone produces up to an 80° spray angle, so the next higher nozzle often compensates by spraying lower than expected. • Deflectors may not be channelling air and spray correctly – extrapolate air direction using ribbons on deflectors.

Some sprayers, such as Rears, Turbomist, FMC or this Durand Wayland have an option for electronic 'eyes' that detect spray targets. The boom will shut off completely if there is a gap in the planting, saving a great deal of wasted spray. It is less applicable in trellised plantings where it has been known to be "fooled" by wires and posts.

SITUATION	SUGGESTED FIXES
7. ≥15% coverage and <85 fine/medium droplets/cm². Remember this coverage threshold is only a point of reference – not a hard fact – and does not apply when using coarser droplets.	• Increase spray volume, either overall or in key locations on the boom corresponding to the undersprayed papers. • Wind might be stealing fine droplets. Try coarser droplets (e.g. using air induction nozzles). You may have to increase volume to compensate for reduced droplet counts. • Ground speed may be too high. Use flagging tape indicator on far side of target and see if enough air is getting through. If not, decrease ground speed. • Canopy maintenance may be required (e.g. pruning, hedging, leaf stripping, etc.). No sprayer can consistently penetrate really dense canopies.
8. Inconsistent coverage on outer edge of canopy (e.g. one spot never seems to get spray).	• Nozzle spray angle may be too acute (e.g. full cones), and spray is not overlapping before reaching target. Try wider spray angles. • Some tower sprayers have 'dead spots' in their air. Check for limp or flagging ribbons tied to nozzle bodies and/or deflectors. Deflectors may need to be adjusted, or adjacent nozzle body angles repositioned to compensate. Try an air induction nozzle in the dead zone. • Canopy may be brushing against nozzles as the sprayer passes, temporarily blocking them. Canopy management required.

Solenoids separate boom into three sections

This Turbomist has been outfitted with sensors that detect the presence of a canopy. Each eye corresponds to a boom section, turning the section on and off as required and improving efficiency. If it's not there, why spray it?

7.1 | Canopy management

Managing the canopy of any perennial crop (e.g. pruning, hedging, leaf stripping, etc.) is an important consideration. The benefits are many. The canopy affects the health of the plant, quantity and quality of the yield, allows light and air to circulate, and keeps the crop manageable. For an airblast sprayer operator, the need for canopy management is quite simple:

If you can't see it, odds are you can't spray it.

Picture this. It's late April, and an apple grower and I are calibrating his sprayer. We achieve excellent spray coverage in the target block, shake hands and part ways. In late May I get a phone call from the grower. I assume it's time to adjust his settings to match the growing canopy, but no. He called to say he suspected apple scab in one of his blocks. Since I was the last person to adjust his sprayer, the unspoken implication was that I'd better come fix matters.

As I drove back out to his orchard, I considered what the problem might be:

- bad product choice
- poor application timing
- spraying in inclement weather
- cutting rates
- resistance (a long shot)

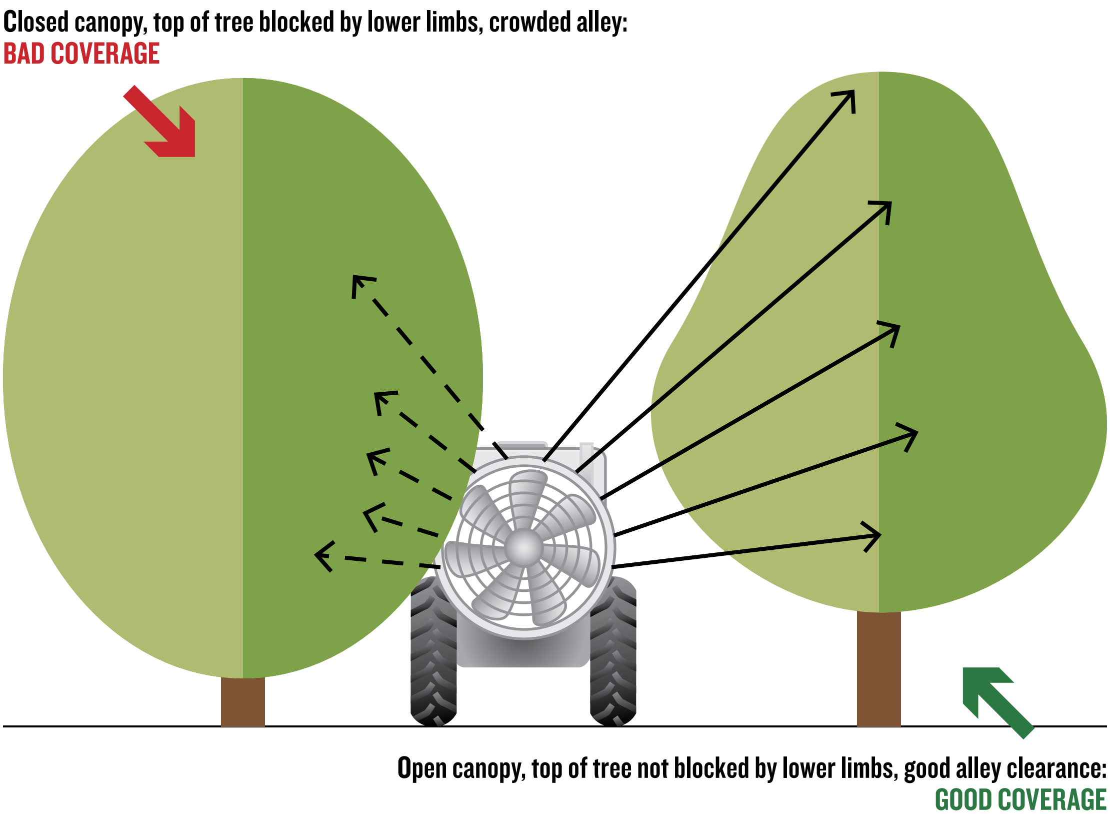
Maybe it was ego, but I couldn't believe it would be the calibration. We left ample volume to provide sufficient coverage to get the grower to petal fall. We ensured the spray swath was slightly higher than top of the tallest tree, accounting for wind. We did everything right to match the sprayer to the canopy.

When I arrived, he took me to a block I hadn't seen before. We didn't calibrate the sprayer to match this particular group of trees, but he figured since they were about the same height, the sprayer would do its job. It was immediately obvious to me what the problem was. But I knew if I simply told him outright, the lesson might not stick. And so, with respect to that old proverb, I taught him to fish rather than give him one. We spent the next few hours trying to fix our alleged calibration problem by exploring:

- slower ground speed
- higher fan gear
- higher rpms to increase fan speed
- changes to deflector settings
- air induction nozzles in top positions
- higher sprayer output

Of course, none of these adjustments had any great impact on coverage because the problem was that the alley had grown so tight that branches were brushing the cab of the tractor (see page 124). The canopy was so dense you couldn't see the trunk! I asked the grower to move the sprayer down the row to a tree I saw that was far less dense than the others. We returned the sprayer to our original calibration settings and achieved excellent coverage once again. The only solution was to prune the trees, and once his workers did this, coverage improved considerably.

An airblast sprayer can only do so much. Sometimes it comes down to canopy management.



Closed canopies and tight alleys will almost always compromise spray coverage.

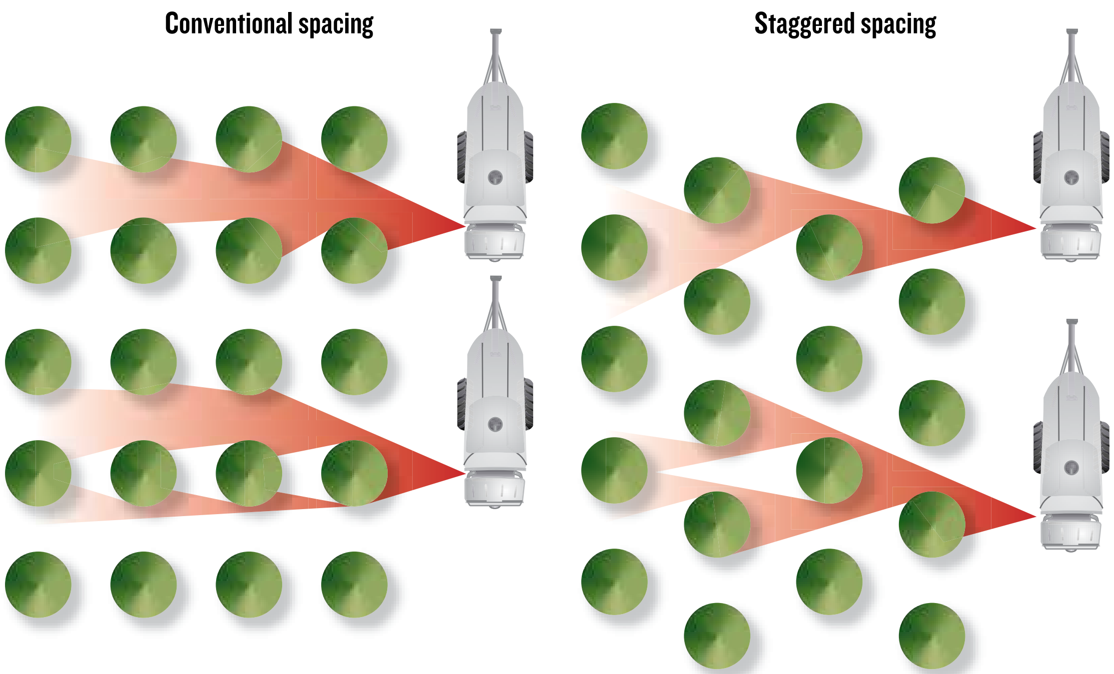
If the canopy is brushing against the tractor, it may intercept spray before it expands fully. Essentially, it temporarily blocks nozzles.

Canopy management isn't just an orchard issue. For highbush blueberry crops, coverage problems may stem from insufficient pruning. How can spray reach the lower, inner portion of a mature bush to control spotted-wing drosophila if the canopy is too thick?

Sometimes it's not the canopy, it's the plant and/or row spacing. Many nurseries arrange container crops, shrubs, whips and cedars as tightly as possible. This may optimize how many plants will fit on a given area, but it compromises sprayer access (due to the reduced number of alleys) and may cause plants to block one another from the spray (see page 126). Nursery sprayer operators often use cannon sprayers to throw spray over and through all those rows of plants, but cannon sprayers produce excessive coverage at the beginning of the swath and increasingly erratic coverage as a function of distance.

Coverage can be improved by reducing the distance the spray has to travel (i.e. leaving more alleys and reducing the density of planted rows). I also suspect that staggering plant spacing from row to row to reduce mutual shading might allow spray to penetrate more easily. We're planning to explore this concept in cedars, but for now it's only a theory.

An orchardist taught me this trick: If you want to know if spray will penetrate a canopy, you should be able to see the trunk (A). You should also be able to see sunlight through the shadow at high noon (B).

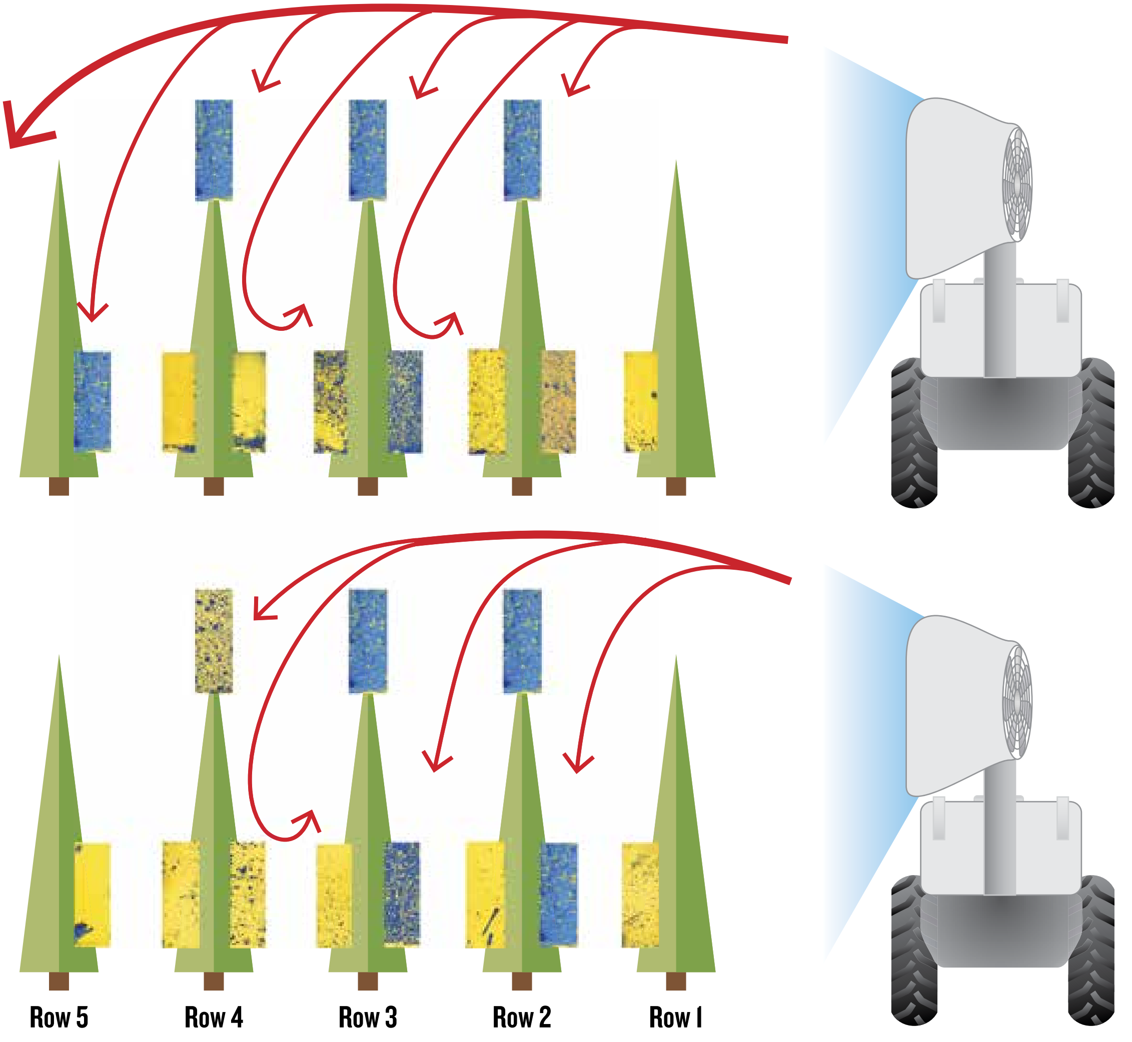


Staggered spacing may improve spray penetration through multiple rows

This is speculative, but the when nursery shrubs, trees and container crops are planted in perfect grids, mutual shading probably prevents spray from penetrating deeply into the planting. By staggering the spacing, spray may be able to penetrate more easily between rows. This can be accomplished without reducing the number of plants per hectare significantly.

A cannon sprayer attempting five rows of cedars. This sprayer will eventually spray in from the other side, but experience has shown that coverage will be compromised in the centre rows and excessive in the outer rows. Spraying multiple rows may save time, but coverage is almost always erratic.

BEFORE CALIBRATION



AFTER CALIBRATION

Calibrating a cannon sprayer can greatly improve coverage consistency. **Before calibration** (top) the sprayer was equipped with full cone nozzles in the upper boom positions and excessive air was employed in an attempt to force spray through the canopy. Although the sprayer would eventually pass down the far side of the five rows, only the water-sensitive papers in the tops of the trees indicated suitable coverage after a single pass. A great deal of spray simply blew away. **After calibration** (bottom) considerably less air and spray was used, and coverage on water-sensitive papers placed lower in the trees and facing the sprayer showed more consistent coverage. If you are noticing papers with poor coverage after calibration, remember the sprayer has yet to pass down the other side, which will fill in the blanks. The lesson here is not to bite off more than your cannon sprayer can chew – the further away spray travels from the sprayer, the harder it is to achieve consistent coverage.

The results of a cannon sprayer calibration in a container crop nursery. The cannon sprayed 1,000 L/ha (107 gal./ac.) and tried to cover too many rows in a pass. The water-sensitive paper showed insufficient and inconsistent coverage. When it was recalibrated to spray 550 L/ha (~59 gal./ac.) and to drive more rows, reducing the distance spray had to travel, water-sensitive paper showed considerable improvement.

A Jacto cannon sprayer in a nursery. Many nursery and berry operations elect to spray multiple rows in one pass, but spray coverage suffers the farther away from the sprayer it goes. Independent research has shown that coverage is not reliable at half the distance typically claimed by many cannon sprayer manufacturers because of canopy density and weather. Always confirm coverage with water-sensitive paper.

PHOTO CREDIT – M. LANTHIER, BRITISH COLUMBIA.

Inspecting cannon sprayer coverage in cedars using water-sensitive papers. There is a reason people use cedars as wind breaks – they are hard to get spray through.

7.2 | Alternate row middle spraying

Alternate row middle (ARM) spraying is an application method where the airblast sprayer does not pass down every alley during an application. The sprayer operator relies on the spray to pass through one or more rows and provide acceptable coverage to the entire canopy (or canopies) on a single pass.

Some state agencies promote ARM spraying to various degrees, and many sprayer operators, whether they admit it or not, have used this method of spraying. When I tell operators I have reservations about ARM spraying, they defend it.

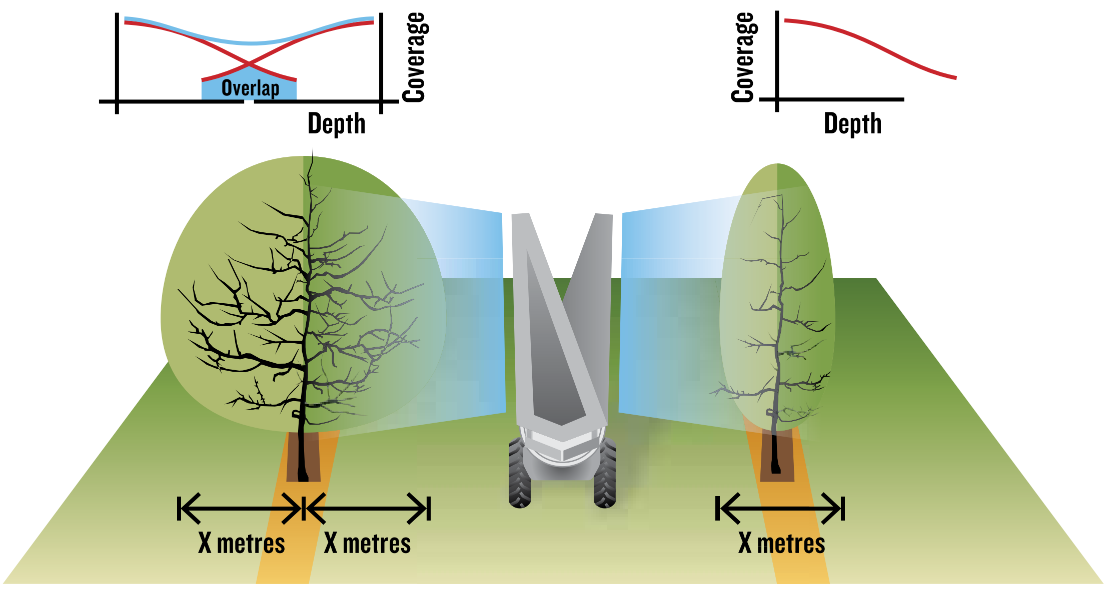
Here is how I reply to common justifications for ARM spraying.

ARGUMENTS FOR ARM SPRAYING	MY REPLY
I do not have enough spray capacity to spray every row when time is short.	You need more sprayer capacity. Get another sprayer so you can get spray on in time. As an interesting aside, a rule of thumb is one sprayer can provide timely coverage to 20 ha (50 ac.) of orchard.
ARM spraying saves money and reduces environmental impact because I use less pesticide.	Technically, if you travel every second row with a sprayer calibrated to travel every row, you have indiscriminately reduced your carrier and chemical inputs by half (or more). Without close monitoring you may compromise your efficacy, and over time may encourage the development of pest populations.
I only perform ARM spraying early in the season when canopies are empty, or only on young plantings.	I grudgingly grant this one as long as coverage is closely monitored. I've prescribed it myself in young or sparse plantings where I couldn't get the sprayer output low enough to prevent drenching the targets. It's not common.
The spray plume in the alley beyond the target row must mean the spray is providing adequate coverage. More is better!	If the spray is blowing through the canopy, it isn't landing in the canopy. Further, if the air speed/volume is too high, droplets can 'slipstream' past the target without impinging on them **(see page 43)**. I've removed water-sensitive paper from canopies with barely any spray on them despite the plume in the downwind alleys. It looks like a magic trick, albeit an unhappy one.
Uncooperative weather doesn't always leave me enough time to spray the entire crop, and it is the lesser of two evils to spray alternate rows than not at all. I'll make sure I come back to spray the other rows later.	My initial thought is that you may not have sufficient sprayer capacity (i.e. consider getting another sprayer). However, sometimes the weather simply doesn't cooperate, so choosing to do half a job requires an understanding of the products' mode of action. If you are spraying an insect at a particular stage of development, there's no "coming back later" to get that generation – if you missed, your window has closed. If it's a protective fungicide that offers no kick-back, then once the disease has infected tissue, the damage is done. Get the spray on as best you can, but if it washes away before it has a chance to dry sufficiently, be prepared to reapply at the earliest opportunity as long as the label allows it.
ARM has always worked in the past.	Would you mind randomly picking six numbers between 0 and 49 for me? You're a very lucky person.

A very popular argument in favour of ARM spraying comes from orchardists that are shifting from semi dwarf to high-density plantings. They ask how it is different to spray a 1.2 m (4 ft.) diameter tree from one side compared to a 2.4 m (8 ft.) diameter tree from both sides.

Before tackling that question, understand that my reservations come from research that has shown that coverage is almost always compromised when spraying from one side of a canopy. The spray must pass through the canopy to reach the far side, and the canopy filters droplets from the air as it passes through. This reduces the number of droplets available to cover the far side. In addition, high velocity spray will create "shadows" where any targets on the immediate far side of a leaf or branch become shielded and receive little if any coverage. And fine droplets slow quickly as they leave the nozzle and take a long time to settle. As the entraining air slows and becomes erratic, the droplets float and change course, making their behaviour hard to predict. Spray coverage becomes increasingly inconsistent the further the spray has to travel through and is reduced the further the spray has to travel through a canopy.

Returning to the scenario posed by the orchardists, we now know coverage is reduced as a factor of distance. Spraying from one side gives a single opportunity to cover the middle and far side of a canopy. Spraying from both sides provides an opportunity for an overlap in coverage. Essentially, the centre of a canopy receives the cumulative benefit of two sprays. Coverage is improved when spraying from both sides, period.



Spraying from one side gives a single opportunity to cover the far side of a canopy. Spraying from both sides provides an opportunity for an overlap in coverage. The centre of a canopy receives less spray than the outside, but is essentially sprayed twice resulting in a compounding effect.

Why, then, do some sprayer operators claim that ARM works? Well, because sometimes, it does! Just because coverage is reduced doesn't mean it isn't sufficient to protect the crop. It simply means that the potential for poor coverage and reduced dose is dramatically increased by ARM applications.

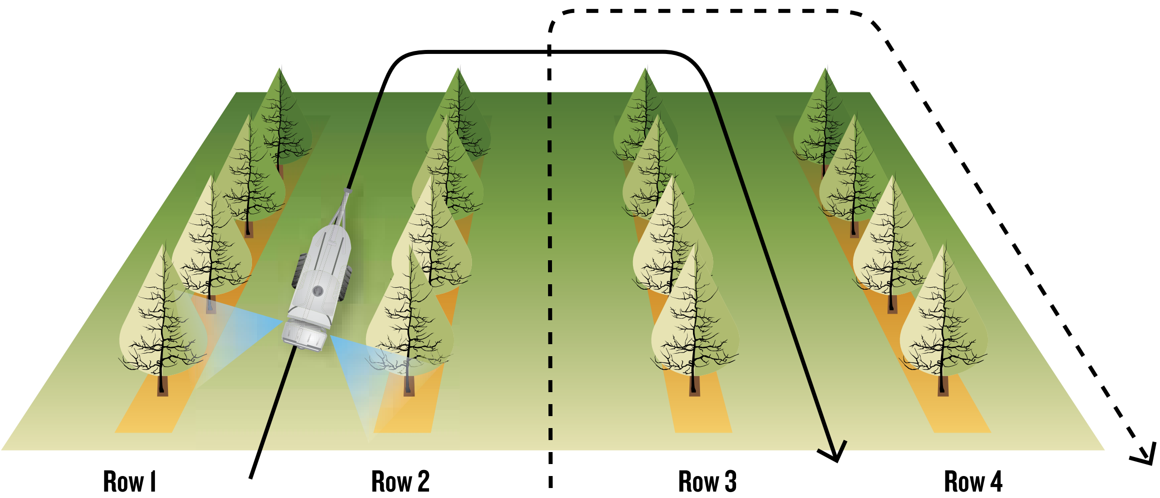
A sprayer operator might perform ARM applications successfully for years before conditions conspire to defeat the application:

- unfavourable wind
- poor timing
- increased pest pressure
- poor pruning practices
- excessive ground speed
- high temperatures
- low humidity
- insufficient spray volume
- several other factors that might occur simultaneously and reduce coverage below a minimal threshold for control

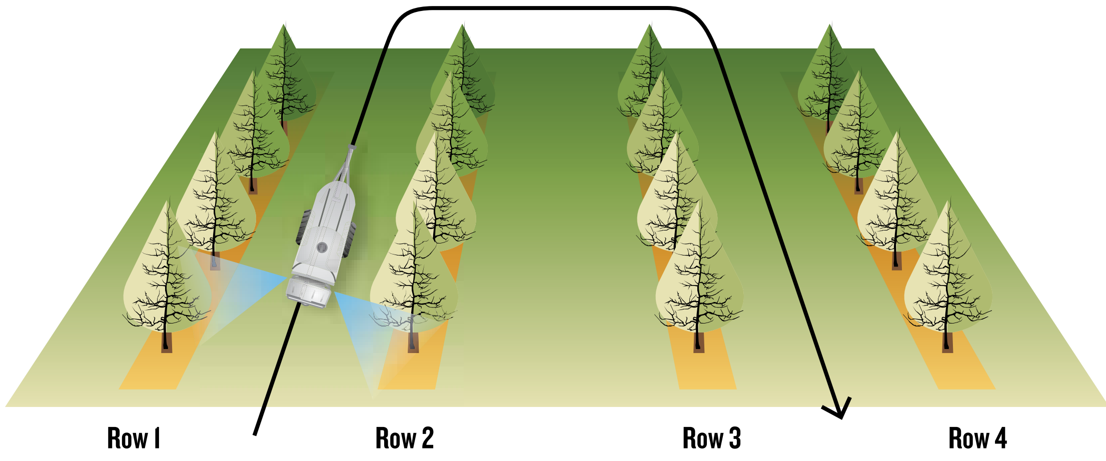
This confluence of bad luck may not happen the first year, or the second, but it will eventually.

Product failure isn't the only concern. Repeated reduced dosages may play a role in developing resistance. In situations where the operator recognizes insufficient coverage, they may have to spray more often to compensate, negating any savings in time or product. Reduced dosage is a common error when a sprayer operator elects to use ARM.

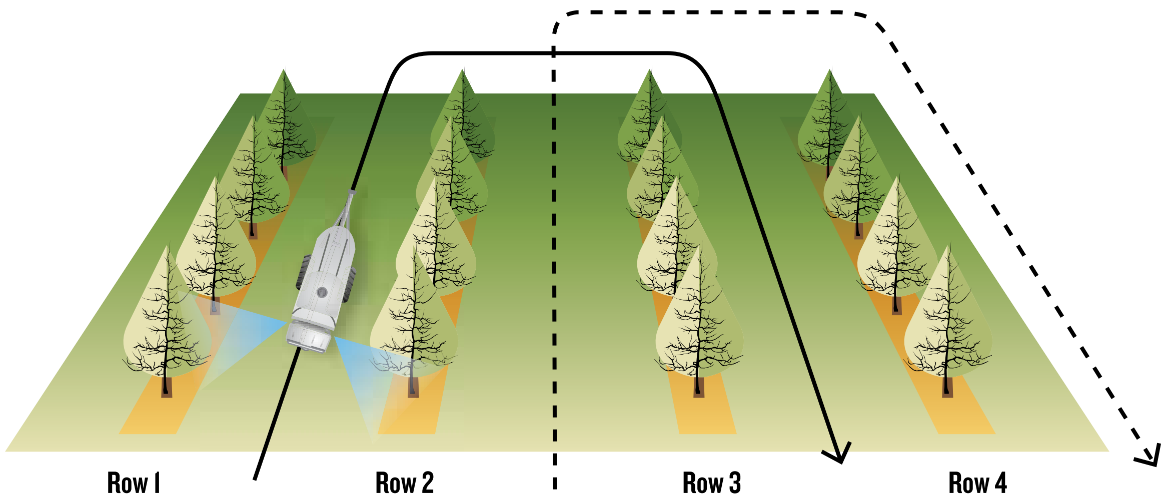
The next three illustrations present three situations referred to by sprayer operators as "Alternate Row Middle" spraying.



Situation 1: The sprayer has a typical calibration for spraying every row, but only drives alternate rows. The first application (solid line) covers different rows from the second application (broken line). The operator will claim to spray more frequently, but generally does not perform the second application unless there is high pest pressure. The result is half-a-dose per hectare per application.



Situation 2: The sprayer is calibrated for double output compared to a typical every-row situation, and the operator drives alternate rows. The result is that the hectare gets the whole dose per application, but coverage is always inconsistent.



Situation 3: Since the sprayer will only drive alternate rows, the operator cuts the output by half compared to a typical every-row situation. The first application (solid line) covers different rows from the second application (broken line). The result is a quarter-dose per application, and if the operator chooses to spray a second time, the hectare will only ever get half-a-dose. Yes, this happens.

The final word on ARM applications – they should be performed with extreme caution. I've used them myself in early season applications in new plantings, but never without confirming coverage with water-sensitive paper, and never in conditions that might further compromise coverage to the point that the application does not give control.

Well, I thought it was funny. My apologies to J. Luymes from British Columbia (pictured) and Obi Wan Kenobi (not pictured… or is he?)

Now here's a man that knows how to spray! Dr. T. Wolf, Agrimetrix Research & Training (Saskatchewan) demonstrating that his spraying skill is only surpassed by his balance... and hopefully his sense of humour. Sorry Tom, I simply couldn't resist.

8.0 Crop-adapted spraying

Crop-adapted spraying

Up to this point, you may have noticed there has been a lot of attention to the process of achieving sufficient coverage and reducing waste. A few operators that try these calibration techniques may discover they need more spray mix to get good coverage. Many more discover that a properly calibrated sprayer means they don't need as much. What should the operator do when considering how much pesticide to use in the tank?

This is a tricky subject. Sprayer operators are told the label is the law. Quite often in the United States, and certainly in Canada, efficacy data is required to prove the agrichemical product works as advertised, and the label rates reflect that data. Products are tested to ensure that when used correctly, the risk to the operator, bystanders and the environment in general is acceptably low. Labels ensure pesticide residue is at a safe level when re-entry and post-harvest intervals are observed. And labels include invaluable information about when and how to apply products, with warnings about tank-mix partners and adverse weather.

Labels are very important – particularly those sections about safe handling, weather and tank-mix warnings, and re-entry and post-harvest intervals. As for rates…

Imagine a sprayer operator is spraying an apple orchard with a fungicide. The label clearly prescribes 100 grams (3.5 oz.) of formulated product per hectare. The operator has always sprayed big trees with 1,000 L/ha (~107 gal./ac.) of spray mix and had good control. They finish spraying the big trees and move on to a block of newly planted, high-density trees. Should they still apply 1,000 L/ha (~107 gal./ac.) of spray mix? Most operators would say 'No, of course not', because there is so much less tree canopy on a hectare of high density compared to the larger, older trees.

As semi-dwarf orchards make way for high-density orchards, sprayer operators are faced with the challenge of adjusting their spray practices to match the size, shape, area-density and stage of growth of the trees. The same issue was encountered in the 70s when growers moved from standard apple trees to semi-dwarf varieties.

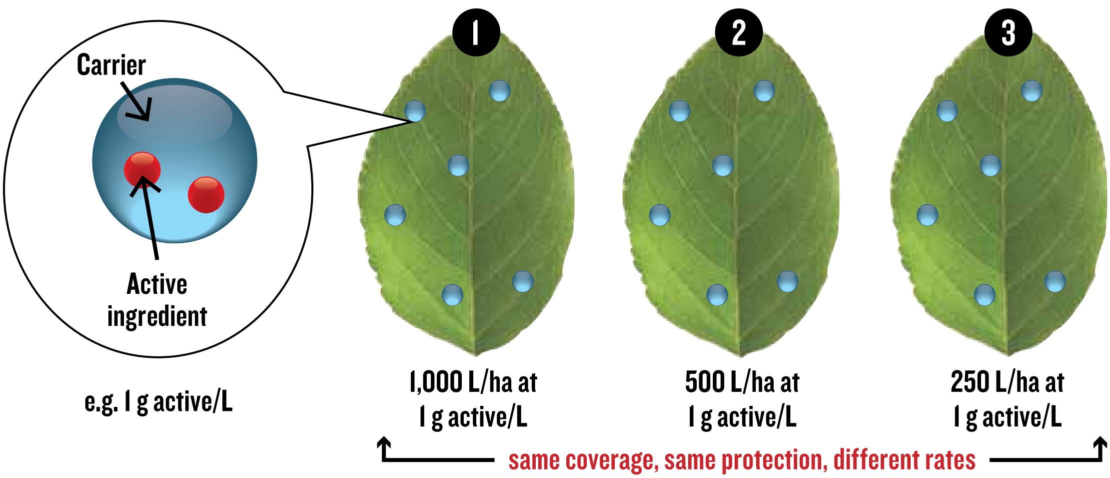
Back then, growers used a pro-rata formula called Tree-Row Volume to reduce their output from ~3,750 L/ha (400 gal./ac.) to approximately 1,000 L/ha (~107 gal./ac.). The method worked, and todays' agrichemical products developed for use in apple orchards in Canada are generally tested in 1,000 litres of spray volume per hectare (with the exception of products intended to drench the target). There are others that spray the tree to drip, ostensibly ensuring the tree gets the prescribed rate. Neither method reflects a grower's typical practice.

If today's airblast sprayer operator decides to change their rate-per-hectare by reducing the amount of spray solution expelled, they generally do so in an ad hoc manner that results in an application that is technically "off-label". The risk and liability falls squarely on them.

They are compelled to make this choice because pesticides labelled for crops like trees, shrubs, vines and canes really shouldn't have rates that reflect the area of a planting. They should reflect the crop area-density – the amount of target canopy in a planting, not the area the plants are on. Many international studies have demonstrated this conclusively.

Since 2010, Ontario has been developing the Crop-Adapted Spraying (CAS) model for apple orchards. It's an adaptation of several other international models such as Leaf Area Indexing (LAI) and PACE+ that have shown great success in matching the amount of spray solution required to the size, shape and density of the planting, rather that the planted area. A free downloadable app is available for Apple and Android smartphones at www.sprayers101.com for those interested in trying it.

CAS allows an operator to adapt rate per hectare (or per acre) so the foliar dose consistently meets a minimal coverage standard, even if the size, shape and density of the canopy is different between blocks. CAS does not allow the operator to apply more pesticide than the label allows. But when there is very little target, the model generates pro rata reductions that should achieve the same level of control.



The ultimate goal of CAS is to adapt the amount of active ingredient per unit ground area such that the amount of active ingredient per unit target area (usually the leaf area) remains constant for canopies of varying shape and density. When this is achieved with sufficient accuracy, the pesticide efficacy is maintained. These three plants are all significantly different in size. When calibration is appropriate to each plant, the foliar coverage "experienced" for each plant will be the same, in spite of differences in the amount of solution expelled per ground area.

At present, this model has only been tested in apple orchards, and only with non-organic insecticides and fungicides. Plant growth modifiers (e.g. Apogee, stop drops, thinners, etc.) and dormant oil drenches have not been tried. Download the app, and follow these steps if you are spraying a pome orchard with an airblast sprayer. I hope to expand the model to other crops in the near future.

STEP 1

Sprayer should receive all seasonal maintenance prior to first use and undergo a visual inspection before each spray day (see Sections 12.0 and 4.0).

STEP 2

Park sprayer in an alley between rows of trees and tie 25 cm (~10 in.) lengths of ribbon to the ends of the deflectors (if present) and the nozzle bodies. Turn on the air and extrapolate where the nozzles and deflectors are aimed. Adjust deflectors and turn off nozzles that will spray over or under the tree canopy. Consider using air-induction hollow cones in the top positions of each boom to reduce drift. You may have to increase the rate in those positions to compensate for the fact that nozzles producing larger droplets produce fewer droplets.

STEP 3

Confirm ground speed with a half-full sprayer in the orchard using GPS or a calibration formula (see Section 6.4).

STEP 4

Affix 25 cm (~10 in.) ribbons to far side of three trees. Tie them at the top and at the widest portions of the canopies. Drive past in the spraying gear at the ideal rpms with the air on, and ensure the ribbons waft outwards. This will determine if more/less air is required from the airblast sprayer, and if operator should speed up or slow down during spraying. This is also an opportunity to perform Gear up-Throttle down if sprayer is using a positive displacement pump.

STEP 5

Place water-sensitive paper at the top, centre and bottom of the tree canopy and spray water. As an approximation, if coverage exceeds 15% surface-area and 85 discrete droplets per square centimetre, reduce output in those positions by replacing nozzles with lower outputs. If less than ideal coverage is achieved, increase the nozzle rates in those positions. Excessive coverage may be unavoidable in the outer edge of the canopy, given that spray must pass through to get to the centre. Ambient wind speed and humidity have significant impacts on coverage. See page 119 for troubleshooting bad coverage. Only test coverage in conditions similar to your typical spraying conditions. Remember, there should be enough coverage to account for seasonal growth, described in Step 6.

STEP 6

When the canopy grows and fills in sufficiently, usually after petal fall, repeat steps 4 and 5. If you are suspicious that the spray is being stretched too thin or you are unsatisfied with the coverage, you may have to increase the output. This is more of an issue with larger trees. Early in the season, wind travels relatively unimpeded in a high-density orchard and will blow the spray off course, reducing coverage and requiring higher water volumes or possibly more air to compensate. As the trees fill in, the average wind speed is reduced and more spray can impact on the target. Increasing spray volume after petal fall may not be required in a high-density orchard.

When the correct sprayer settings and volumes have been determined, the operator mixes their spray tank for a typical application to a semi-dwarf orchard. The sprayer will cover more orchard than it has in the past, and the operator will have to re-assess how many tanks are required pre and post petal-fall. Don't go below 400 L/ha (43 gal./ac.). I've only ever gone lower in new plantings. The leaves will receive the same absolute amount of active ingredient as in a larger, denser orchard; the difference will be that the spray is not wasted through overspraying.

This method of application is really no more sophisticated than turning off nozzles that are aiming at the ground or above the target. It takes time for operators to get comfortable with the new volumes (and reduced dosage per hectare) and regular scouting is highly encouraged to confirm they are achieving control.

9.0 Filling the sprayer

Filling the sprayer

When it comes to reliable information on tank mixing, one of your best sources for information may be the point-of-sale or agrichemical rep that sells the tank-mix partners. They know their products best and want to see you succeed – and you'll come back to buy more. Tell them what you plan and ask them how best to proceed. They may have information that never makes it onto the product label. You should also consult your local government or academic extension programs for an unbiased opinion, or consider enlisting the help of a professional crop advisor. Take advice from other growers at coffee shops with a grain of salt. The following pages provide basic information about filling and mixing.

9.1 | Jar test for tank-mix compatibility

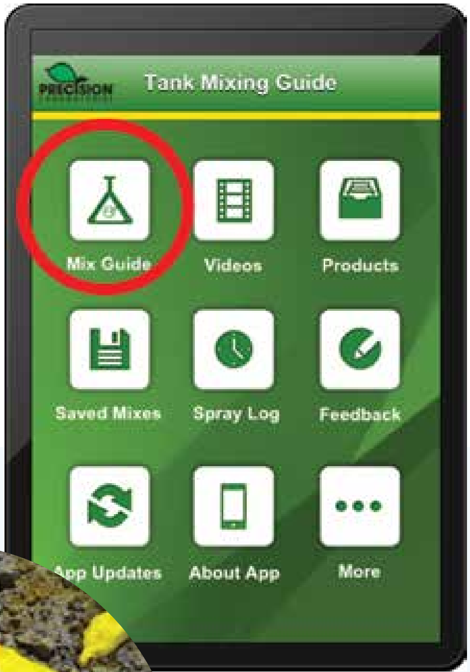
Are you considering a new tank mix? Perhaps two new fungicides or an interesting new adjuvant? Know what you're doing before you risk an untested tank mix. In Canada, users of commercial class pest control products for crop protection or vegetation management are permitted to apply unlabelled tank mixes of registered pest control products as long as:

- each partner is registered for use on the crop
- tank-mix only includes an adjuvant when specifically required by one of the mix partners
- application timing of each partner is compatible with crop and pest staging
- each partner is used according to the product label
- no partner is specifically excluded on any other partner label

The order you add each product to the tank, or inductor, is critical. The old acronym W.A.L.E.S. (Wettable powders, Agitate, Liquid flowables, Emulsifiable concentrates, Surfactants) is becoming increasingly inadequate for today's formulated products. Some extension specialists have condemned it outright. Making sure you have the right mix, in the right order, is made easier with free tank-mix apps from companies like **DuPont** or **Precision Laboratories** that work on Android and Apple systems.

The Precision Laboratories app, for example, is easy to use. At the startup screen, select "Mix Guide". Select the category of the product you want to tank mix and then select the product(s) from the alphabetized list. The app analyzes your selections and suggests the best order to add to the tank. These are US products and may have different names in Canada if they are registered at all. The app has other appealing features you can explore, such as saving your mixes for future reference and accessing instructional videos.

Precision Laboratories' Tank Mixing App startup screen.



Select from five categories and choose up to 19 tank-mix partners.

An example of physical incompatibility in the sprayer tank.

PHOTO CREDIT – DR. J. REISS, ILLINOIS.

A gelatinous mess made by using an inductor as a mixing vat for incompatible products.

PHOTO CREDIT – DR. J. REISS, ILLINOIS.

DID YOU KNOW?

Always wear personal protective equipment (PPE) when performing a jar test. Do so in a safe and ventilated area, away from sources of ignition.

Always check the product labels for information on compatibility of spray materials. "Compatibility" refers to the physical and/or chemical compatibility of two or more products in a solution. If you are concerned, perform a jar test.

1. Measure 500 mL (1 pt.) of water into a 1 L (2 pt.) glass jar. This should be the same water you use in the spray tank.
2. Add ingredients according to the table below, stirring after each addition.
3. Let the solution stand in a ventilated area for 15 minutes and observe the results. If the mixture is giving off heat, these ingredients are not compatible. If gel or scum forms or solids settle to the bottom (except for the wettable powders) then the mixture is likely not compatible (see examples of physical incompatibility on page 144).
4. If no signs of physical incompatibility appear, test the mixture using a spray bottle on a small area where it is to be applied. Look for phytotoxic indications, such as plant damage, and monitor efficacy (hard to do unless you actually fill the sprayer and try it on a few plants).

TANK-MIX ORDER FOR PERFORMING A PESTICIDE COMPATIBILITY TEST

ORDER	INGREDIENT	QUANTITY FOR 500 mL OR 500 g OF PRODUCT LABELED FOR 1,000 L OF FINAL SPRAY VOLUME
1.	Compatibility agents	5 mL (1 teaspoon)
2.	Water-soluble packets, wettable powders and dry flowables	15 grams (1 tablespoon)
3.	Liquid drift retardants	5 mL (1 teaspoon)
4.	Liquid concentrates, micro-emulsions and suspension concentrates	5 mL (1 teaspoon)
5.	Emulsifiable concentrates	5 mL (1 teaspoon)
6.	Water-soluble concentrates or solutions	5 mL (1 teaspoon)
7.	Remaining adjuvants and surfactants	5 mL (1 teaspoon)

Commercial compatibility kits are available from most agrichemical suppliers. They contain a few plastic "jars" and disposable micropipettes. By following the instructions included with the kit, you can easily reduce large labelled volumes (such as 1.0 kg of product in 500.0 L) of multiple products to small volumes at the same ratio.

Beware of putting dissolving bags in the tank basket. When the fill water hits them, it splatters all over the place (see page 146). It's best to remove the basket and drop the bags into a half-full tank that's agitating. Give them time to dissolve and suspend.

Adding pesticide to the sprayer may not be straightforward. Many operators place dissolvable pouches in the basket so they can be broken up by the hydraulic return, or the fill water. But fill water often splatters out of the basket, and the bags can “puff” open, releasing product into the air creating unnecessary contamination and operator exposure. That’s why I recommend that operators remove the basket, add the pouches to a half-full tank with the agitator on, then give the pesticide time to dissolve or suspend.

I have heard of a situation where adding pouches to a half-full tank – with the hydraulic and mechanical agitator operating – might cause problems. In this case, the pump sucked in the partially dissolved bag coating and collapsing the inner screen because the pump was starved for water and created a lot of suction. The operator had to rebuild the pump because the Viton seals burned out rapidly without water. This operator now premixes slurry, or adds pouches to the basket while standing upwind and away from potential splatter. Choose the safest and most effective method for your situation.

DID YOU KNOW?

A compatibility test will only reveal physical incompatibility between products in a tank mix – they will not reveal any other form of antagonism, such as products inactivating one another, or the potential for phytotoxicity. The only way to know for sure is to apply the mix to a few test plants and keep an eye on them over the season.

9.2 | Adjuvants

Spray adjuvants are tank-mix additives that either physically or chemically influence the efficacy, consistency or safety of pesticides. For example, adjuvants can improve the handling characteristics of a spray solution (e.g. water conditioners, de-foamers, emulsifiers). They can improve uptake into a target plant and/or improve the amount of contact between spray droplet and target surface (e.g. non-ionic spreaders). They can also modify droplets to reduce the potential for wastage from drift or run-off (e.g. anti-drift additives, stickers).

Note how little of the droplet contacts a waxy leaf (left). This hydrophobic reaction between water and wax can be overcome using a non-ionic spreader. And note how the droplet gets hung up on the trichomes (hairs) on a leaf before it reaches the leaf surface (right). A non-ionic spreader would reduce droplet surface tension allowing it to splash onto the leaf.

PHOTO CREDIT – DR. H. ZHU, OHIO.

Watch a video on droplet action at **www.sprayers101.com**.

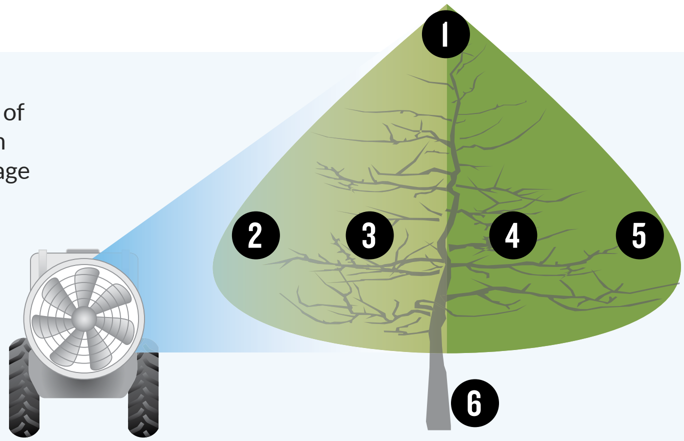
Some pesticide labels require the use of adjuvants in the tank mix for the pesticide to work correctly. They are not formulated with the product because of expense, bulk or product stability, and must be added during loading. For a pesticide to work as advertised, include any adjuvants required by the label. In some cases, we are encouraged to use adjuvants to improve an application, even though they are not on the label.

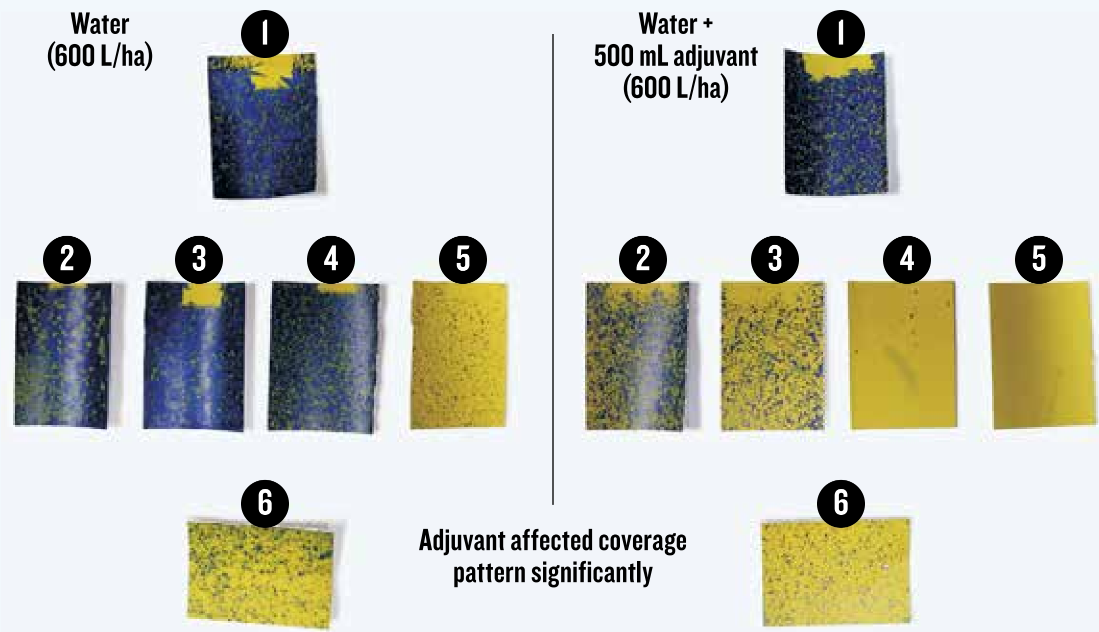
There are potential benefits to introducing some unlabelled adjuvants, but there are also potential problems. The difficulty is that unless someone tests a specific tank-mix combination for a specific crop, the results cannot easily be predicted. For example, when a tank mix is incompatible, an adjuvant could cause phytotoxicity, create more drift when used with the wrong nozzle, deactivate or enhance a tank partner, and/or potentially reduce spray coverage.

We once conducted a trial to test an adjuvant intended to reduce run-off and drift. Water-sensitive papers were placed in the canopies of a 40 year old McIntosh orchard, which was then sprayed from one side in late May. The papers in the left panel (dilute control) were sprayed with 600 L/ha (64 gal./ac.) of water. Those in the right panel (adjuvant) were also sprayed with 600 L/ha (64 gal./ac.) but included the label rate of 500 mL (1 pt.) of adjuvant. The water-plus-adjuvant reduced drift and runoff, as advertised, but did not penetrate as deeply into the canopy or spread on the papers, which is a concern if the operator was performing alternate-row middle spraying or needed better coverage (e.g. for mites). It was an unexpected side effect.

For better or worse, even small amounts of adjuvants can have a significant effect on spray coverage. Always test spray coverage when using a new adjuvant in a tank mix.

Key – Six papers, sprayed from one side





Adjuvant affected coverage pattern significantly

There is no simple answer regarding unlabelled adjuvants – there are too many possible product/adjuvant/plant combinations. If you intend to experiment with an adjuvant, perform a jar test to test for physical incompatibility. Then spray a small volume of the tank mix on a few trial plants to ensure there are no unexpected chemical issues (e.g. phytotoxicity or inactivating tank-mix partners) or coverage issues.

Every sprayer operator should have a copy of Purdue Extensions' 2015 *Adjuvants and the Power of the Spray Droplet – PPP-107*. It is a comprehensive handbook describing of how water quality and adjuvants affect the performance of pesticide applications and it's available for **download**. I consult it regularly.

9.3 | Water quality

Water quality can affect pesticide performance. The four variables are:

- pH (acidity & alkalinity)
- dissolved minerals (water hardness or softness)
- suspended particles (dirty water)
- temperature

pH

If the pH of your spray water is higher than 7.5, it is alkaline enough to affect some pesticides. The ideal carrier pH for pesticides is slightly acidic (pH 4.0-6.0). Alkaline water can break down certain insecticides during mixing, and inactivate some fungicides if left in the tank too long. Time is also a factor. A pH of 3.5-6.0 is typically acceptable for spraying and short term storage (~12 hours) of most spray solution in the tank. A pH of 6.0-7.0 is acceptable if the pesticide is sprayed immediately. A pH of 7.0 or greater requires a buffer or acidifier. The three methods for measuring pH are a probe and meter (the most accurate method, costs ~$30), litmus paper or a field kit (e.g. **www.preiser.com**, **www.hoskin.ca**).

Litmus paper is a fast and simple way to test pH.

DID YOU KNOW?

pH is short for the Latin *Potentia Hydrogenii* which is the potential for water (H_2O) to break down into hydrogen (H^+) and hydroxide (OH^-). Measured on a scale of 1.0 to 14.0, pH 1.0 is very acidic, pH 7.0 is neutral and pH 14.0 is very alkaline.

DISSOLVED MINERALS

Dissolved minerals are usually an issue with herbicides (e.g. salt-formulated) and can be affected by certain minerals dissolved in water. Test your dissolved minerals using Total Water Hardness test kits (e.g. **www.H2OKits.com**). They are packaged as individual test strips. The foil packets are small enough to fit in your pocket, and are ideal when testing out in the field (~$10 for 40 tests).

SUSPENDED PARTICLES

Certain products (usually herbicides) can be negatively affected by suspended silt and organic matter. Water turbidity can be measured using a Secchi disk (more appropriate for waterways), a turbidimeter (very expensive) or an inexpensive turbidity test such as **Lamotte**.

TEMPERATURE

Water temperature affects pesticide solubility – so colder temperatures slow emulsification and dissolution. To avoid problems with tank mixing, avoid using water that is less than 10 °C or more than 27 °C. Extreme temperatures may also affect product efficacy.

- Permit a little extra time for dissolution in cold water with water dispersible granules
- If you add an oil-based product before a granular in cold water, agglomerates can plug up the sprayer parts like screens and nozzles.
- Water-based products tend to thicken in cold water.
- Warmer temperatures can cause "oiling" where emulsifications become less stable and increase the amount of residue on sprayer parts. Generally, it's best to get oil-based products on as soon as possible while using high agitation.

Commercial products are available to reduce pH, soften hard water and clear dirty water. Follow the pesticide label and the water treatment product label, exactly. For more information on how water affects spraying, consult Purdue Extension's **Adjuvants and the Power of the Spray Droplet – PPP-107** and ***The Effect of Water Quality on Pesticide Performance – PPP 86***.

9.4 | Agitation

Agricultural products are formulated to be as emulsifiable as possible, but many do not mix well in water. They contain elements that do not dissolve (e.g. wettable powders) or they may be petroleum distillates (e.g. emulsifiable concentrates). Other products are heavier than water and form precipitates (e.g. fertilizers and powdered metals like copper). That's why good agitation is very important.

Effective agitation requires water to "sweep" the bottom of the tank so that any precipitated material is picked up and re-mixed. Turbulence is often not enough. If there is too little agitation, the pesticide will be applied unevenly and not always at the required rate. If there is too much agitation, the pesticide may foam (which can be controlled using anti-foamers) or cause an invert emulsion (a gel). There are two common types of airblast sprayer agitation: mechanical and hydraulic.

Mechanical agitation is produced by paddles attached to a shaft mounted near the bottom of the spray tank. While relatively effective, this system cannot always sweep the very bottom of the tank, so there is always some material that precipitates out of reach. If your nozzles and screens plugging frequently, and is there "sludge" left at the bottom of the tank after spraying… you have an agitation issue.

Note the two paddles set at 90° to one another on the mechanical agitation shaft in this very cool "cutaway" Turbomist sprayer.

With enough pump capacity, a hydraulic return in the tank basket is a great way to agitate as you mix. A return in an old FMC (above). A mixing nozzle in the basket of a Hol sprayer (right).

Hydraulic agitation is accomplished by returning a portion of the pump output to the tank. Cylindrical and oval tanks are the ideal configuration for the sparging (i.e. rinsing) type of hydraulic return agitation system. This system consists of a tube located longitudinally along the wall of the tank, with volume booster nozzles aimed at the centreline so they sweep across the bottom. Volume booster nozzles take a small amount of water pumped into their venturi chamber and create a vacuum that draws three to four times that volume from the surrounding water and expels it out the end. For hydraulic agitation to the effective, the agitator nozzle(s) should be fed by a dedicated line from the pressure side of the pump (not the pressure regulator). They should have a valve to throttle the flow or completely shut it off to prevent foaming, which can be considerable.

10.0 Spray drift

Spray drift

Pesticide spray drift is the aerial movement and unintentional deposit of pesticide outside the target area. Aside from being illegal, there are a lot of compelling reasons for avoiding it.

- Every droplet that drifts means less spray is deposited on the target, resulting in reduced efficacy.
- Drift can be measured in financial loss associated with wasted pesticide, wasted time and reduced crop quality/ quantity. Plus, if an application is unsuccessful, the operator may have to re-apply, incurring further cost.
- Pesticide drift increases any risk of damage to human health, susceptible plants (e.g. adjacent crops), non-target organisms (e.g. wild and domestic animals, pollinating insects, etc.), the environment and property.

We'll limit this discussion to two forms of pesticide drift: particle drift and vapour drift. There are situations where the two definitions can overlap.

Particle drift is the off-target movement of pesticide droplets (or solid particles) that occurs at the time of application. It is generally on a scale of tens-of-metres, but temperature inversions can carry it much farther.

Vapour drift is the off-target movement of pesticide vapours that generally occurs in hot, dry conditions many hours after the application and is exacerbated if the pesticide is volatile. If vapour gets caught up in a light breeze, moves downhill during a temperature inversion, or is redistributed in precipitation, movement is can be on a scale of kilometres.

Drift cannot be entirely eliminated, but sprayer operators can greatly reduce the potential for pesticide drift. Most of the information that follows relates to particle drift, but it's always a good idea to follow these best practices. Research and modeling have shown that the three biggest impacts of particle drift are:

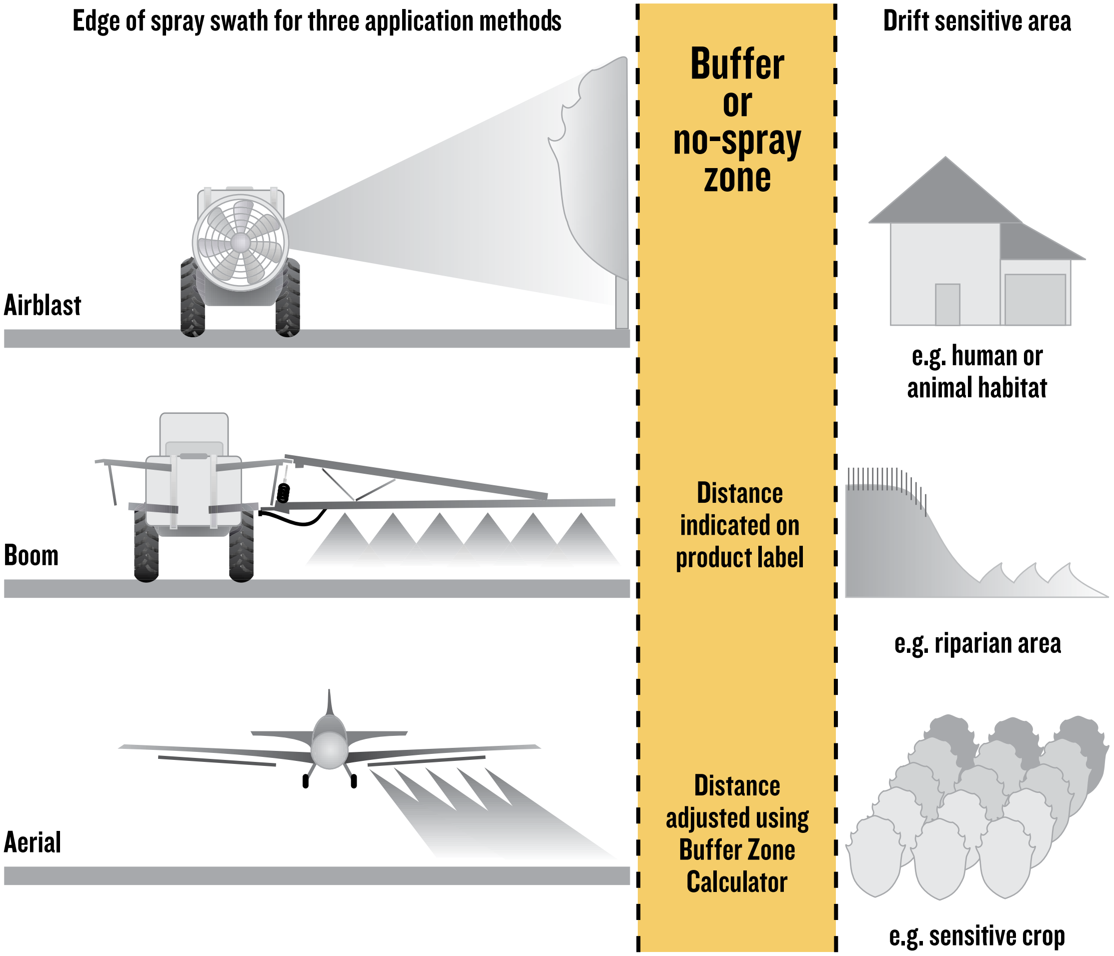
- wind speed
- nozzle-to-target distance
- nozzle size (i.e. median droplet size)

These factors also affect particle drift:

- high operating pressures reduce median droplet size
- high ground speeds increase drift, especially if driving into the wind (i.e. increased apparent wind speed)
- high temperatures and low relative humidity cause droplets to become smaller due to evaporation

Here's how to greatly reduce the potential for particle drift.

- Reduce the distance between nozzle and target. For a horizontal boom sprayer, such as a herbicide sprayer, lower the boom to the lowest practicable height. A good rule of thumb is that the boom should be the same distance to the target as the nozzle spacing. For an airblast sprayer, consider a tower sprayer.
- Use the coarsest effective droplet size, generally achieved through the use of lower pressure combined with higher-rate nozzles, or air induction nozzles at rates slightly higher than conventional hollow cones.
- Observe labelled buffer zones and recommended sprayer settings. In Canada, using optimal sprayer settings in the right environmental conditions may reward the sprayer operator with buffer-zone reductions: **http://www.hc-sc.gc.ca/cps-spc/pest/agri-commerce/drift-derive/calculator-calculatrice-eng.php**.
- Spray when wind speeds are light to moderate and move away from any nearby sensitive crop, landscape or environmental areas. Plant windbreaks to help manage wind.
- Change sprayer settings if the wind increases during spraying or halt the job until conditions improve.



Buffer zones or no-spray zones physically separate the end of the spray swath from the nearest downwind sensitive area.

Consider planting windbreaks between your operation and sensitive downwind areas. Windbreaks should filter pesticide-laden air, not block it completely (~50% porosity). There are potential impacts to nearby crop rows, such as creating shade as well as cool, still air conditions. Contact your local nature conservancy to discuss the right plants and management plan for you.

Anyone using pesticides is responsible for their safe application. The Ontario *Pesticides Act* requires that licensed spray applicators carry a specialized liability insurance policy that provides appropriate coverage for their business. Operators who work on a “for hire” basis (e.g. a licensed spray applicator) or away from their own farm operation will need additional coverage. Where drift damages adjacent crops, insurance adjustors generally ask these questions.

- Was the damage to the applicator’s own crop? If so, it is unlikely there will be coverage under any insurance policy.
- Was the damage to a neighbour’s property? If so, the applicator’s liability policy may respond.
- Was the product being applied according to label directions?

It’s not only field sprayers that drift.

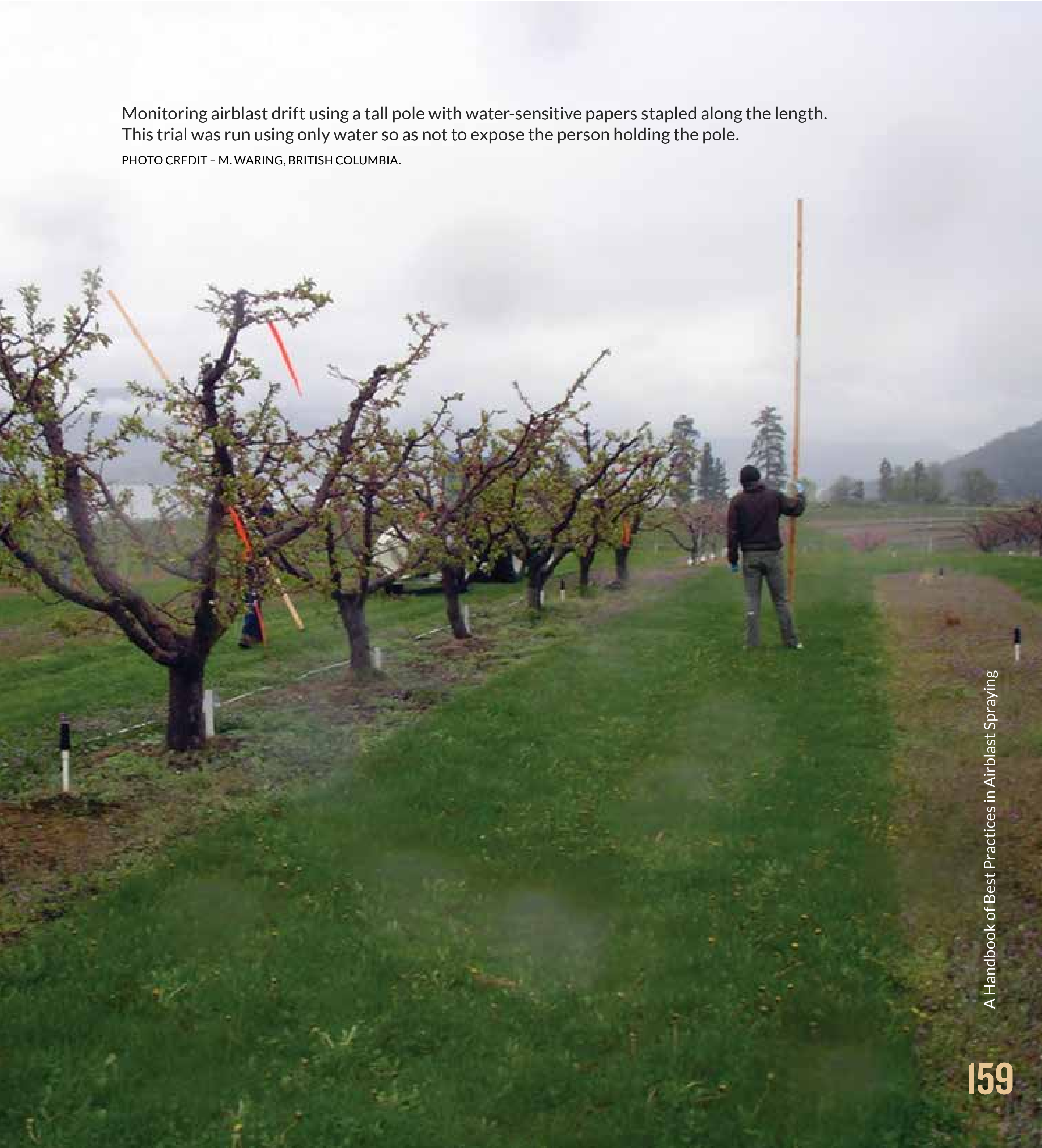
PHOTO CREDIT – G. AMOS AND D. ZAMORA, WASHINGTON STATE.

If you suspect your crops or property have been damaged by pesticide drift, follow these steps. The contact info is specific to Ontario, so substitute your local authorities.

- Diagnose the problem. Many other factors can cause symptoms that appear to be herbicide drift. Look for evidence of weed damage, damage patterns and evidence of nearby spray application.
- Contact the appropriate people. Talk to your neighbour or the sprayer operator to find out what was sprayed, when it was applied, (and who did the application).
- Contact your regional Ministry of the Environment and Climate Change (MOECC) office. MOECC officers can do a site visit, take samples of tissue and soil, and have them analyzed for the suspect herbicides. Herbicide residues degrade very quickly, so sampling must occur as soon as possible. Contact the nearest regional MOE district office or call the Spills Action Centre at toll free: 1-800-268-6060. Ministry locations are available at **www.ontario.ca/environment** or in the Blue Pages of the telephone directory. Where appropriate, the offending applicator may face charges under the *Pesticides Act*.
- Contact your property and crop insurance adjustors, and advise the applicator to contact theirs.
- Document all details of the problem, including your spray records, weather data, photographs with times and locations.
- Document loss. Find a similar planting – same age, cultivar, rootstock, etc. At harvest time, you will need to document yields and quality from the damaged area, and from an undamaged area. For perennial crops like vineyards, orchards, asparagus, berries, etc., document the effects for several years after the damage occurred. Note any impacts on vigour and cold hardiness.

Managing spray drift is everyone's responsibility. Extremely low, and often invisible, amounts of spray drift can be very damaging, long after the application.

Watch a spray drift and drift mitigation video at **www.sprayers101.com**.



Monitoring airblast drift using a tall pole with water-sensitive papers stapled along the length. This trial was run using only water so as not to expose the person holding the pole.

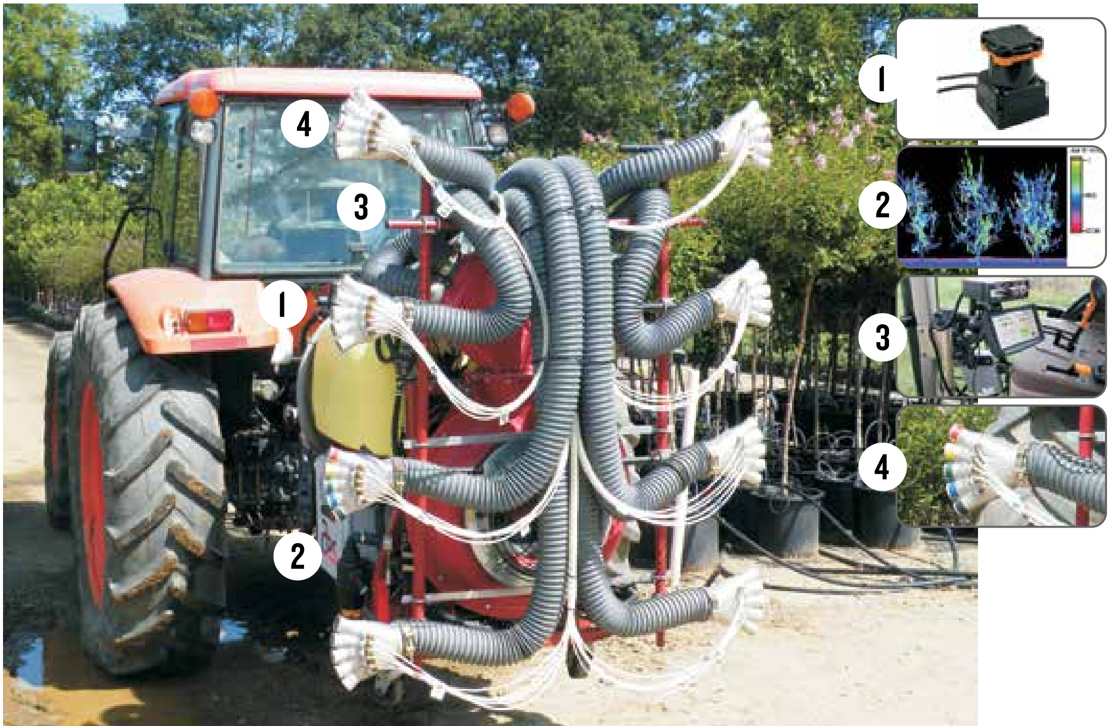
PHOTO CREDIT – M. WARING, BRITISH COLUMBIA.

10.1 | Equipment to reduce drift

For airblast sprayers, here's how to reduce the potential for drift.

- Adjust fan settings to produce the minimal effective air speed throughout the season.
- Increase droplet size by using lower pressures, air induction nozzles or disc & core (or disc & whirl) nozzles that produce a coarser median droplet size. As the median droplet size is increased, be careful to ensure there are enough droplets to achieve sufficient coverage.
- Use air induction nozzles in the highest operable nozzle positions so most spray falls back into the crop.
- Use deflectors to channel air into, not over or under, the target.
- Use towers to reduce distance-to-target and direct air into the target. Be careful not to get any closer than ~50 cm (~20 in.) or coverage may be compromised.
- Use foliage sensors that turn boom sections on and off to match the size and shape of the canopy.
- Switch to a tangential, recycling, tower or multi-duct sprayer. Many of these sprayers are rare in Ontario, but they are available. Ask your local retailer for more information.

Anatomy of an Intelligent Sprayer. Dr. Heping Zhu (USDA, ARS) led a team to develop this prototype nursery sprayer that monitors crop density and adjusts air speed and nozzle rate on the fly. There is very little drift or waste and coverage is excellent. 1) LiDAR sensor for determining canopy density. 2) Software matches air and rate to the target shape, size and density. 3) Sprayer operator's control station. 4) Air outlets combined with five nozzles that use pulse-width modulation to change nozzle rate. It's not for sale yet, but perhaps in the future.



DID YOU KNOW?

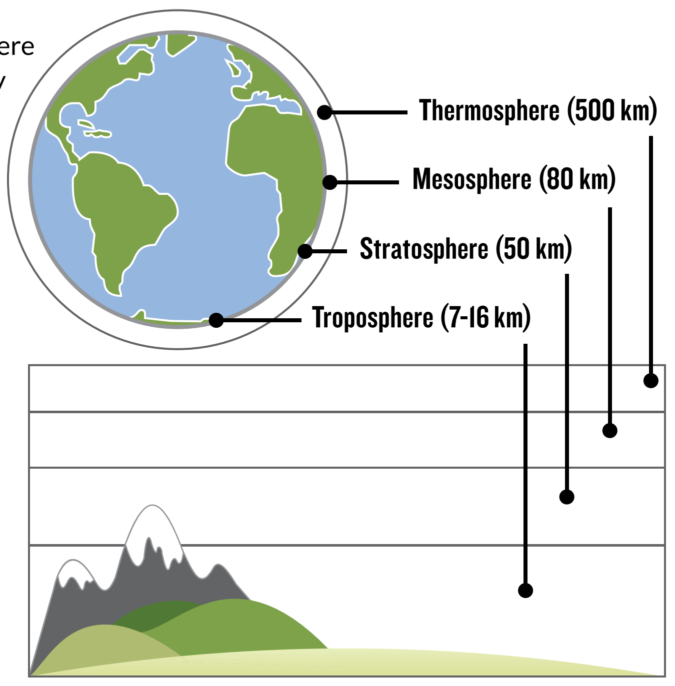
Drift increases significantly with increasing wind. Spray when wind is light to moderate and moving away from sensitive environmental areas. Never spray during periods of dead calm because spray stays suspended until the wind changes and can then be carried up to several kilometres off target.

10.2 | Surface inversions

In April 2014, Andrew Thostenson, NDSU extension published an excellent **factsheet** explaining what thermal inversions are, how to detect them and how they affect pesticide spray drift. That factsheet inspired this chapter.

THE ATMOSPHERE

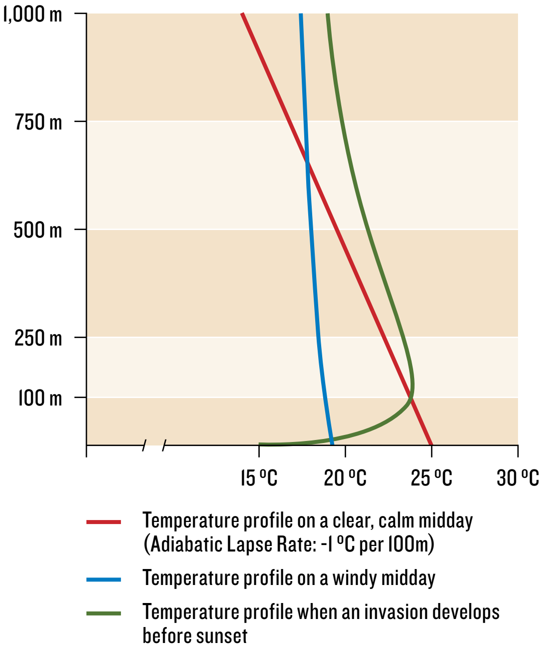
The earth is surrounded by a bubble of air called the atmosphere. You can't see it, but imagine it as a bubbling, swirling mass that moves like water. The lower part of the earth's atmosphere (the surface boundary layer) is directly influenced by the earth's surface and everything on it. As it drags and percolates over the surface, it experiences relatively rapid changes in wind speed, temperature and humidity (on a time scale of an hour or less).



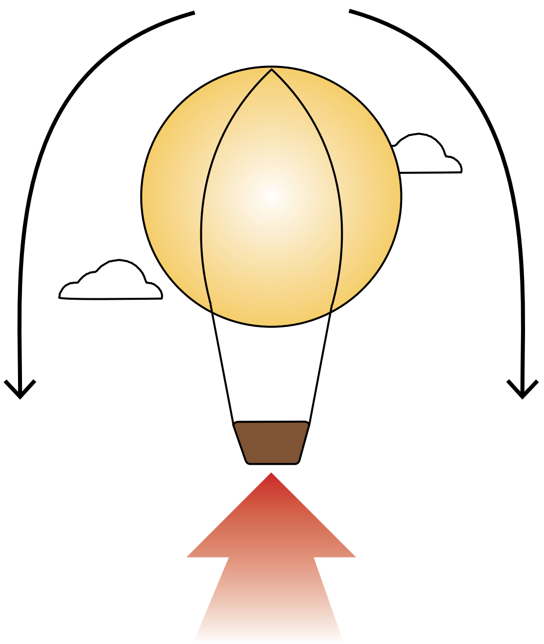
The earth's atmosphere. The illustration of the earth is to scale, but the landscape is not. Our focus in on the surface boundary layer.

ATMOSPHERIC TEMPERATURE

Dry air naturally cools with elevation, at a rate of about 1 °C/100 m (~1 °C/10 ft.). This change, called the Adiabatic Lapse Rate is caused by pressure changes with elevation. As we move up, the weight of the overhead atmosphere decreases, pressure drops and air expands. That expansion takes work and that creates the cooling effect (red line in graph below). See how simple thermodynamics are?



Three possible atmospheric temperature profiles in the lower troposphere.



A hot-air balloon is a metaphor for convection cells that create thermal turbulence.

When we add the effect of daytime solar heating and night time cooling, the rate of temperature change is affected, and changes how airborne particles like spray droplets settle, flow and disperse.

Let's consider a clear, relatively calm day.

Early morning

On a clear, relatively calm morning, the sun emits short wave radiation, which is absorbed by the earth's surface. The surface conducts some of this energy deeper into the ground as well as heating the air near the surface. This creates a temperature gradient where the surface is warmest and the air gets cooler with elevation (red line in graph above).

As the air warms and expands, it becomes less dense and rises, similar to a lava lamp or hot air balloon. As it rises, cooler air sinks and the air begins to circulate in a convection cell. This is called thermal turbulence, and is a very effective way for airborne particles, such as pesticide spray, to be rapidly diluted. This is also how the atmosphere disperses pollution.

If the morning were overcast instead of clear, the clouds would intercept much of the sun's radiation, absorbing or reflecting it. As a result, the earth's surface would still warm up, but much more slowly. Thermal turbulence would be suppressed.

Mid-late afternoon

As the sun passes over and the wind starts to rise, the convection cells get disrupted by the wind and experience mechanical turbulence (blue line in graph on page 162). This type of turbulence mixes warmer air near the ground with cooler air above it, and also suppresses thermal turbulence.

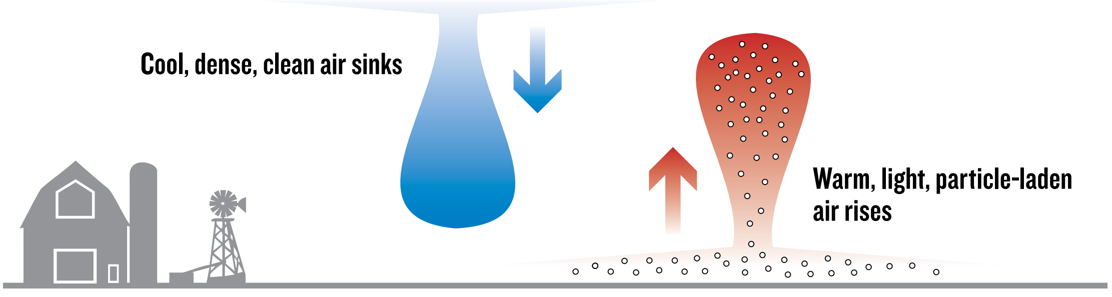
Mid-afternoon to night

As the energy from the sun lessens, the soil begins to cool, and cools the air next to it. Once the air cools enough to be colder than the air above it, we have the beginning of a temperature inversion (green line in graph on page 162) – the reverse of the typical day-time temperature profile. The height of the inversion grows with time, reaching a maximum of about 100 m (~33 ft.) by sunrise. Within the inversion layer, thermal turbulence no longer exists.

HOW INVERSIONS AFFECT DISPERSION

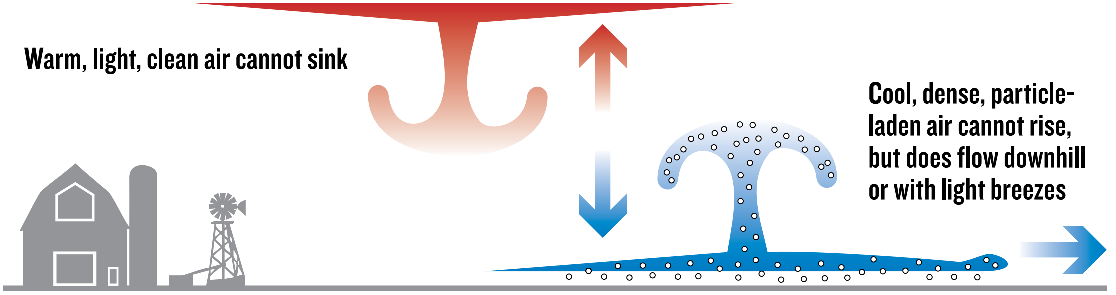
We now know that during a sunny day, solar energy warms the earth's surface and the air near the surface, more than air above it (red line in graph on page 162). We also know that this causes convection cells to circulate. The rising parcel of air will cool and shrink as it rises through the relatively cooler air above it. Conversely, cool parcels of air fall freely through warm air, and the resulting mixing action allows airborne particles (such as pollution or pesticide spray) to become much less potent at ground level. This action helps protect us from drift damage.

Thermal turbulence allows particle-laden warm air to rise and clean cool air to fall.
This disperses air-borne particles like pollution or pesticide.



Now let's imagine an air parcel that is displaced upward during an inversion. This time the air parcel is cooler than the air above it, and gets denser as it begins to rise. This prevents air from rising, and it returns to the layer where it started. In other words, air stays where it is. The same holds for a sinking parcel of air – it starts off warmer (and less dense) than the air below it, but warms further as it falls. As a result, air will want to rise back to its origin.

Thermal turbulence is suppressed during a temperature inversion. Particle-laden cool air at the surface cannot rise, and warm, clean air cannot fall. No dispersion occurs and the concentrated, particle-laded air tends to move downhill or laterally with light winds.



In an inversion, air does not mix by thermal turbulence. Spray drift (or vapour) stays concentrated in the air where it was released. And cool, dense air tends to move downhill or laterally with light winds, taking any spray drift particles with it.

HOW CLOUDS AND WIND AFFECT INVERSIONS

Clouds absorb energy from the sun and the long-wave radiation from the earth's surface. They also reflect radiation from the earth back to the soil. That's why overcast nights are warmer than clear ones.

Inversions are only mildly affected by light wind (e.g. 6-8 km/h (3.7-5 mph)), but as the wind increases and mechanical turbulence mixes the air, the strength of the inversion will be reduced and the atmosphere will approach a neutral condition **(blue line in graph on page 162)**. In this condition, airborne particles are not dispersed by thermal turbulence, but some mixing will occur. There may not be an inversion, but spraying is not advisable if the wind gets too high.

Extended periods of mostly clear skies in the evening or night when the wind is light means a high probability of strong temperature inversions. Conversely, cloud cover usually means a near neutral atmosphere, so no strong inversion.

HUMIDITY AFFECTS INVERSIONS

Inversions form more rapidly when there is less water vapour in the air to absorb radiation. Once humid air has cooled to the dew point, water condensation gives off energy and warms the air a little, slowing the formation of the inversion. Inversion conditions can exist long before fog forms. Fog is not a good indicator for the beginning of an inversion…you're already in one!

If you see fog, dew or frost, you're already in an inversion. The air has become cold enough to condense or even freeze water.

SOIL CONDITIONS AND SHADE AFFECT INVERSIONS

This is a complex issue, but soil conditions that make inversions more intense include low soil moisture, freshly tilled soils, coarse soils, heavy residue and closed crop canopies. Inversions in shaded areas (e.g. behind windbreaks) start sooner and last longer. See the **NDSU factsheet** for more detail.

INVERSIONS AND SPRAY DRIFT

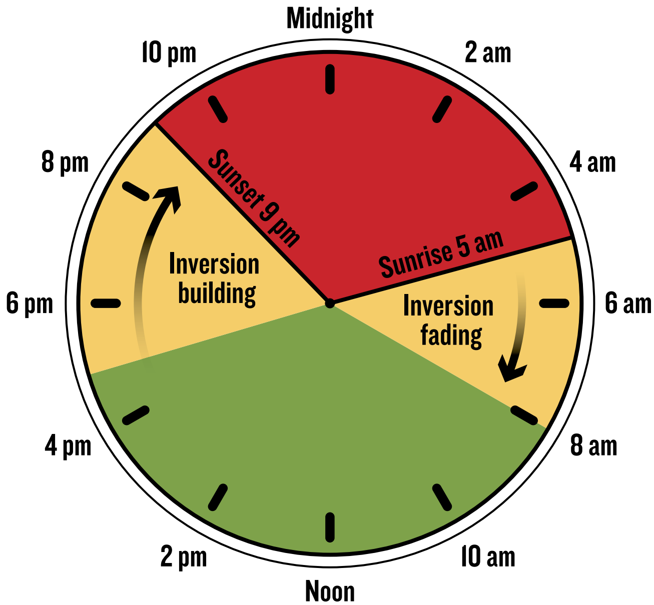
When you spray during an inversion, the larger drops fall quickly (per normal). Smaller lighter droplets fall very slowly (a few centimetres per second) and do not disperse. Small droplets move with the air they were released into, evaporating very slowly, over great distances. These small particles, as well as vapours from volatilizing products, are capable of moving for kilometres.

SPRAY TIMING

Once inversions form, they persist until the sun rises and warms the earth's surface, or until winds increase and mix the stationary layers of air together, re-establishing a more neutral temperature profile. Spraying in the evening poses the greatest risk for pesticide drift when conditions favour inversions. Very early mornings (e.g. around sunrise) are not much better. At sunrise, the inversion will be at its maximum height.

The rising sun will warm the earth and create turbulent conditions, starting near its surface (e.g. a few metres). It takes a few hours of sun for the inversion to burn off to a sufficient height to adequately disperse once again. Most inversions will have dissipated two hours after sunrise – which may be the best choice for spraying.

Inversions occur to some extent every day. It's the intense and prolonged inversions we want to be especially aware of. On this hypothetical 24-hour clock, we see the inversion fades in the morning and grows in intensity through the evening. Do you spray in the morning or at night? Be mindful or pollinating insects. When there's a strong inversion, consider early morning spraying over evening/night.



DETECTING AN INVERSION

The only sure way to know if you are in an inversion is to take two air temperature readings – the first about 10 cm (~4 in.) from the ground, and the second about three metres off the ground. If the surface air temperature is cooler, you are in an inversion. The magnitude of the difference indicates how strong the inversion is. Accurate measurements are difficult to manage with conventional thermometers. It's easier for sprayer operators to watch for these cues.

- Large temperature swings between daytime and the previous night.
- Calm (e.g. less than 3 km/h wind (~1.8 mph)) and clear conditions when the sun is low.
- Intense high pressure systems (usually associated with clear skies) and low humidity where you intend to spray.
- Dew or frost indicating cooler air near the ground (fog may be too late).
- Smoke or dust hanging in the air or moving laterally.
- Odours traveling large distances and seeming more intense.
- Daytime cumulus clouds collapse toward the evening.
- Overnight cloud cover is 25% or less.

If you suspect a strong inversion, don't spray.

11.0 Airblast sprayer cleaning

Airblast sprayer cleaning

Sprayers should be cleaned at the end of each day (even if the same pesticide will be sprayed the next day) and definitely before switching products. Next to sprayer math, this is one of the more distasteful parts of spraying for many operators, and is not performed as often or as thoroughly as it should be. Residue on and in the equipment can damage sprayer components, may be incompatible with other products and leads to unnecessary operator exposure. Before cleaning a sprayer, read the sprayer operator's manual and consult the pesticide label for any special instructions.

Essentially, the cleaning process relies on three core activities:

- removing as much of the remaining spray solution as possible
- diluting the remainder as much as possible and using it to clean the sprayer interior
- cleaning the sprayer exterior

As Tom Wolf says, "Cleaning a sprayer is a lot like doing the dishes." Use the right detergent, Soak the hard stuff. Be thorough. Rinse properly. If you're efficient, and accept that this process is part of the spray day, sprayer cleaning doesn't have to be unpleasant or time-consuming. Tom has very clean dishes.

11.1 | Triple rinsing

Experience, and some math **(see Section 15.0)**, is helpful to make sure the last tank empties nicely at the end of the last row. Some operators speed up or slow down to accomplish this. That's not recommended, but sometimes unavoidable. Even when the tank appears empty, sprayers can retain several litres of spray solution in the sump and lines. Rinsing the system multiple times with low volumes has proven more effective at reducing pesticide residue concentration than a single, high-volume rinse.

The effectiveness of the triple-rinse was reaffirmed in 2014 when Colorado State University conducted a state-wide survey of field sprayer clean-out practices. It wasn't airblast sprayers, but the principle is the same. More than 50 respondents provided samples of their clean water source, their pesticide tank solution and samples of rinsate from each sprayer rinse in their typical cleaning process. Surprisingly, some of the lowest levels of pesticide residue came from triple-rinsed sprayers using only water. When the Colorado researchers inquired further, they discovered these operators never let product sit in the tank for prolonged periods. They were diligent about cleaning at the end of every spray day, never leaving product in the tank overnight.

A wooden sprayer tank. You know that had to be tough to clean thoroughly.

Once the sprayer is "empty", use clean water to fill the tank to 10% of its capacity (or add nine parts water to one part spray solution remaining in the tank and lines). Agitate and circulate it through the entire sprayer for five to 10 minutes. Open and close any lines or valves during this process to ensure everything is exposed to the rinse. Using low volumes may not be possible with centrifugal systems where the tank must be filled above the top of the pump for priming. Low-volume rinsing may not be suitable for certain pesticides. If methods conflict, always follow pesticide label guidelines for cleaning instructions.

The clean water for this process is usually carried in a separate tank on the sprayer or on a support vehicle. While still rare in Ontario, low-volume, automatic tank rinse systems are available on newer airblast sprayers. They generally consist of a small supply tank mounted above the pump to supply clean water to rinse nozzles inside the tank. The number and orientation of the tank rinse nozzles should provide enough water to contact all surfaces inside the tank. These systems reduce operator exposure, save time and should be used regularly to prevent seizing.

Perform the triple rinse in the planting that was just sprayed. The dilute rinsate can now be flushed through the lines and sprayed out through the nozzles onto the crop. You can choose to overspray treated areas again at a lower dose (label permitting), or use a hedgerow or target row that has been set aside for this purpose.

Do this two more times. The discharge should be clear – not cloudy.

Now bring the sprayer back to the mixing/loading area to finish the cleaning process. The sprayer should be cleaned in rotating locations to prevent residue buildup. If cleaning in the farmyard, ensure washing is performed away from wells or open water and any washings are secured. This isn't always realistic. Operators often wash the sprayers in the same location on crushed gravel far from sources of water. We'll assume, for the sake of a good night's sleep, that the next steps take place on a permanent loading/mixing pad.

This Hol sprayer is a Holland import and is relatively new to Ontario. It features a 150 L (40 gal.) clean water reservoir and tank rinse nozzles for a convenient in-field triple rinse.

11.2 | Moderately clean

If you're planning to spray the same product again, follow these steps after triple rinsing.

1. Use a bucket of water and a brush (e.g. an old toothbrush). Remove, inspect and clean the suction and in-line screens. Remove, inspect and clean the nozzle strainers and nozzle tips, too.
2. Hose down and clean the exterior of the sprayer. Scrubbing with a push broom works well.
3. Replace all the parts and you're done.

Keeping the sprayer clean, inside and out, as part of the spray day. K. Bell is pictured giving his FMC a bath. This picture was staged – he normally wears PPE and so should you.

11.3 | Decontaminated

If you are changing products, follow these steps after triple rinsing.

1. Fill the tank about 1/2 full of water and add tank cleaning adjuvants like ammonia at 3%/100 L (~25 gal.) water (this raises the pH and helps remove those products whose solubility benefits from this) and detergent at 1.0 kg/150 L (2.21 g/40 US gal.) water (this removes the oily layer formed by EC formulations). Commercial cleaners like All Clear or Cleanout conveniently combine these properties in one jug. Adding a surfactant or a commercial cleaner can generate a lot of foam – have a de-foamer handy.
2. Use a bucket of cleaner solution from the tank and a brush (e.g. an old toothbrush). Remove, inspect and clean the suction and in-line screens. Remove, inspect and clean the nozzle strainers and nozzle tips, too.
3. Meanwhile, agitate and circulate through the entire sprayer for five to 10 minutes. Open and close any lines or valves during this process to ensure everything is exposed to the rinse.
4. You might spray a small volume through the booms, but drain the vast majority through the plumbing system. Collect some for cleaning the exterior of the sprayer.
5. Clean the exterior of the sprayer. Scrubbing with a push broom works well.
6. Rinse it all off, replace all the parts and you're done!

Ammonia cleaner products do not "neutralize" pesticides – they raise the pH, improving the solubility of some products (typically herbicides, so not as applicable to airblast). **Do not use chlorine bleach.** It is not as effective a cleaner as ammonia and can form chlorine gas when mixed with ammonia-containing liquids.

12.0 Airblast sprayer maintenance

Airblast sprayer maintenance

Airblast sprayers are precision tools that must be kept in good operating order to ensure proper spray quality. The daily sprayer inspections discussed in **Section 4.0** can be considered a form of "preventative" maintenance since the operator will (hopefully) find small problems before they become big problems. The diligent operator should also follow a regular sprayer maintenance schedule throughout the season, according to the sprayer manufacturer's recommendations. It's like having your car serviced every 6,000 kilometres, except in this case, sprayer maintenance schedules are often associated with the number of working hours. Many sprayer operators are guilty of ignoring their airblast sprayers and babying their tractors. Don't neglect your sprayers!

We'll restrict our discussion to the two universal maintenance activities for sprayers in North America: pre-season maintenance – the first start up after long-term storage, and winterizing the sprayer – preparing the sprayer for long-term storage. If the steps outlined here differ from the manufacturer's recommended practices, go with the manufacturer; your warranty may depend on it.

This used Myers sprayer was imported from Europe by a vineyard in Prince Edward County, Ontario. Many European countries require regular sprayer maintenance inspections before the operator can use them. The stickers on this sprayer show that it was maintained and calibrated correctly. In certain countries, sprayers that are not compliant are "grounded" until the issue is remedied, and the owner is charged a hefty fine. We don't require this level of compliance in North America...yet.

12.1 | Pre-season maintenance

Never assume that following the manufacturer's winterizing instructions means your sprayer is ready for immediate hook-up and use in the coming season. Parts seize, scale breaks away from surfaces and small beasties sometimes choose to eat, or make their homes, in cozy sprayers.

Plan to spend at least half a day per sprayer. It may not take that long or it might take longer. Pressure gauges snap off, fittings crack, welds might need repairing and bearings seize. Be sure you have a plan to get replacement parts before you start.

After buying a new-to-me three point hitch GB sprayer, I ran a pre-season maintenance inspection. I was assured it was winterized correctly before it was stored. But every nozzle body was packed with what looked like wet chewing tobacco. I have no idea how it got in there, but I'm guessing a lack of appropriate filtration was a big factor.

Visual checks of secure nuts are made possible using a paint pen.

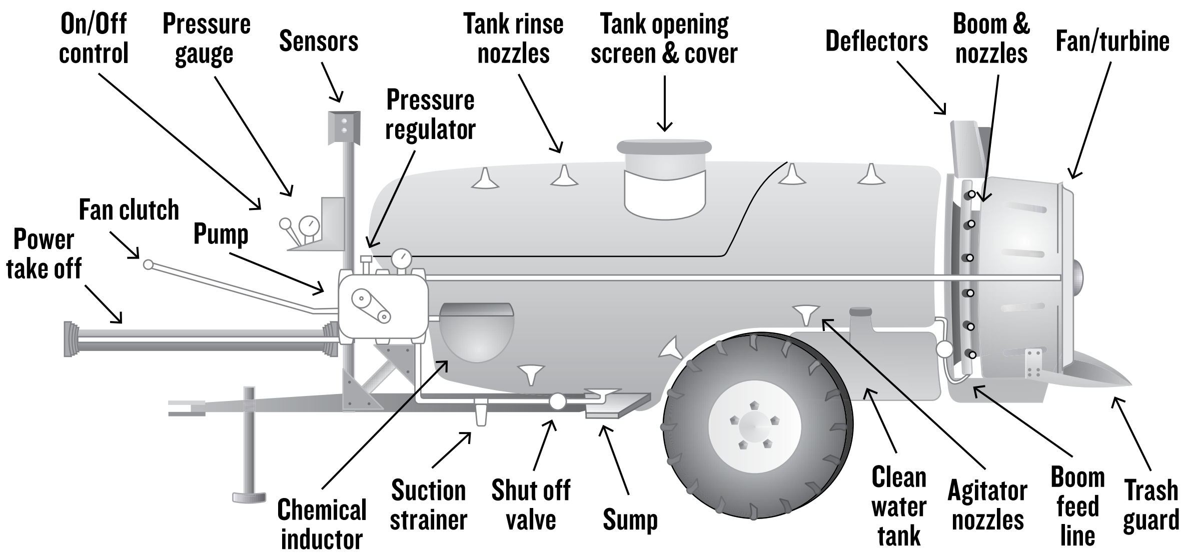
DID YOU KNOW?

It is important that all necessary personal protective equipment is used when calibrating, maintaining, adjusting and cleaning sprayers. PPE's should protect against both contamination and physical injuries.

If you have a brand new sprayer, here are a few maintenance tips.

- Get to know your new sprayer. Read the operator's manual and the manufacturer's specifications to understand what the sprayer is supposed to do, and what it's not supposed to do.
- Loosen, lubricate and re-tighten the gear clamps to ensure they last. Always back them off a bit first before tightening them to avoid stretching them.
- Apply light gear oil to the PTO telescope.
- Follow all the hoses and use a paint pen to number the hose ends with the corresponding connection. Now you'll always know where they go.
- Apply thread release (aka 'never seize') to all the bolts. A lubed bolt or stud should never release easily. If it does seize, put the nut or bolt back on and clean the thread to avoid damage and try again.
  - Use a torque wrench (not impact tools) when replacing nuts and remember to read the manufacturer's specifications to ensure they are tightened correctly. Never extend a torque wrench handle with a pipe and don't hold them anywhere but on the knurled handle or they won't be accurate.
  - Use a paint pen to draw a line across the nut, washer and chassis as a quick visual check for loose nuts.

The anatomy of a generic, but fully-loaded, airblast sprayer.
Newer sprayers have all these features and more.



If the sprayer has been in long-term storage (e.g. winterized), follow these steps to help prevent costly breakdowns, inconsistent spray application and increase the lifespan of the sprayer equipment.

There's always residual liquid in the lines. Wear chemical-proof gloves!

THE PUMP

One of the most common causes for faulty pump performance is "gumming" or corrosion inside the pump. Get into the habit of flushing the pump (and the entire system) with a solution that will chemically neutralize whatever you sprayed that day (see Section 11.0). This will dissolve most residues remaining in the pump and leave it clean for each use.

With filters and nozzles removed, fill the tank with clean water and pump it through the system until the discharge is clear of dirt, sludge or scale that might be present in the tank, pump, and hoses or lines. The discharge should be clear – not cloudy.

Once the system is flushed, lubricate and check the pump. Maintenance for pumps is pump-specific. The sprayer operator's manual will give detailed instruction on how to care for yours. Sprayer pumps can be divided into two categories – positive displacement pumps and non-positive displacement pumps.

POSITIVE DISPLACEMENT PUMPS

These include Roller, Diaphragm and Piston pumps. They are self-priming and traditionally operate at "high" pressures. Flow from these pumps is directly proportional to the pump speed, which is why they require a relief valve and bypass line between the pump outlet and the nozzle shut-off valve.

Roller pumps are the most popular pump with farmers worldwide, but I've never seen one on an airblast sprayer. The seal and roller materials should be selected based on their compatibilities with the pesticides.

Diaphragm pumps are compact and popular for use with abrasive and corrosive pesticides. Their oil-filled piston chambers protect the pump materials. These are commonly found on airblast sprayers. Hypro recommends changing oil after 40 hours of break-in operation and every 500 hours after that. The diaphragms should be replaced every 1,000 hours. I'm told EPDM (black) diaphragms are a better choice for airblast sprayers, while the Desmopan (amber) diaphragms are really for lawn care sprayers.

Piston pumps are similar to car engines. They are relatively low-flow and high-pressure, and suited for use with handgun sprayers. The piston cup materials should be selected based on their compatibilities with the pesticides. These are commonly found on airblast sprayers.

Sometimes the pump may be referred to as a "piston-diaphragm" pump, combining features of the two.

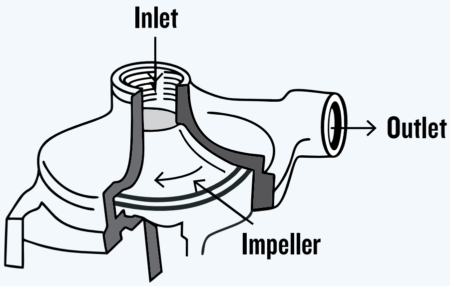
NON-POSITIVE DISPLACEMENT PUMPS

These include Turbine (or Transfer) and Centrifugal pumps. They must be primed and traditionally operate at "low to medium" pressures, although there are models available that can go up to 13 bar (190 psi). Flow from these durable pumps comes from a rotating impeller that feeds liquid through the lines instead of pumping per stroke. If the outlet is closed, the impeller spins harmlessly, so a relief valve is not needed.

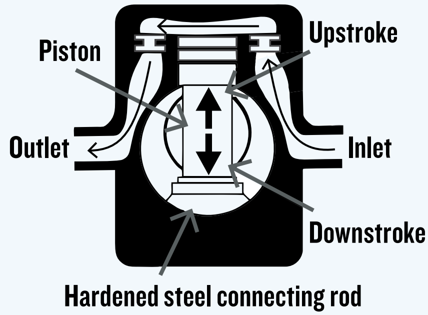
Centrifugal pumps are found on many airblast sprayers in Ontario, but I rarely see them anywhere else. The lack of a pressure regulator valve and the difficulty separating PTO speed from pressure make it more difficult to match the sprayer to the target. Corrosion is the big concern. If the sprayer was winterized correctly, it should have been cleaned and flushed with a 50% solution of antifreeze with a rust inhibitor. The ports should have been plugged after to keep air out. Unplug them before running the pump clear.

Three types of sprayer pump commonly found in Ontario airblast sprayers. These images were created with kind permission from the Ontario Pest Education Program.

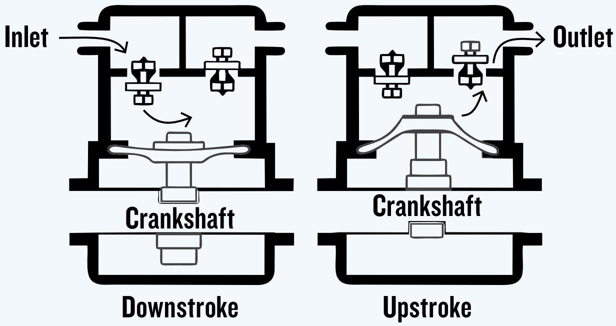
Centrifugal



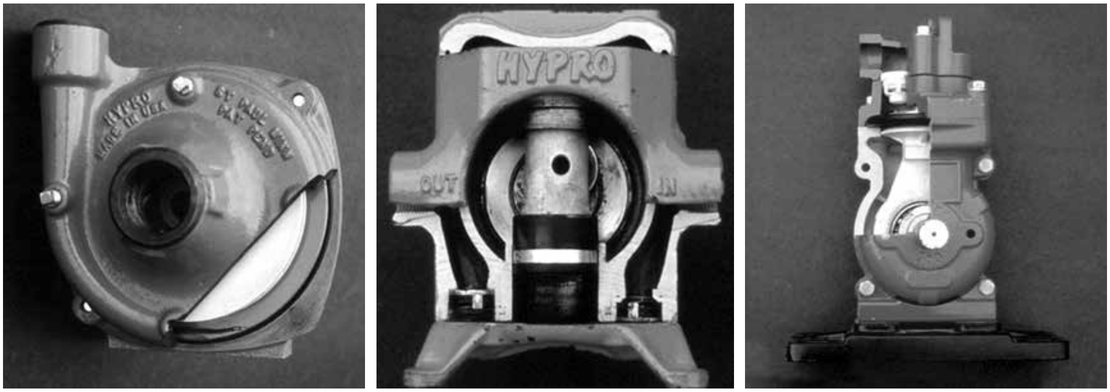
Piston



Diaphragm



Centrifugal	Piston	Diaphragm



Photos of three sprayer pumps that have been cut away to expose their inner workings.

THE HOSES

Under-sized hoses and fittings and splices can severely reduce the capacity of any pump. Suction hose diameter should be at least as large as the pump intake opening. Examine all hoses and connections for cracks or leaks while under pressure. Avoid splices where possible.

THE SCREENS AND STRAINERS

If you don't already have three levels of filtration (including the tank-opening basket) then consider slotted strainers, which are more forgiving than mesh strainers, behind the nozzles. If you don't use them because they plug up, look to your agitation system. If there is sludge in the sump at the bottom of the tank when you're done spraying, you're not mixing and/or agitating your spray solution properly and will have a gummed pump and clogged strainers and nozzles. The problem may also be your sprayer hygiene. You should be cleaning strainers and nozzles after every spray day. Remove slotted or mesh nozzle strainers and scrub them with a bristled brush – flushing will not clear them.

Inline filters shouldn't look like this. This was a serious tank-mix incompatibility issue. Do you clean yours at the end of every spray day?

PHOTO CREDIT – M. LANTHIER, BRITISH COLUMBIA.

This plastic 'sight glass' indicates how full the tank is. They become opaque and unreadable in a season or two, but they're very easy to replace. Can you see through yours?

THE PRESSURE GAUGES

The relief valve on your sprayer should always be in the bypass position during startup. If your gauge spikes, the gauge may be permanently damaged and read high. An opaque or leaking gauge should be replaced. Replacing old gauges can help an operator improve sprayer performance.

Use the oil-filled variety of gauge to eliminate a bouncing needle. You can also get suppressors that fit between the gauge and sprayer to prevent pulsing. Consult the section on testing pressure gauge reliability in Section 6.1.

Gauges should be rated twice as high as your highest operating pressure. If you typically spray at 10 bar (150 psi), have a gauge rated up to 20 bar (300 psi) so you can see small changes in pressure more clearly. If your needle is pointing straight up, you know your pressure is approximately correct.

DID YOU KNOW?

The pressure gauge scale should be twice as high as your highest operating pressure. If the pressure spikes during start-up, it could be a problem with the regulator, and cause damage to your gauge.

THE WHEELS

At minimum, check the tire pressure. Hard tires drive faster, but leave compacted ruts. Soft tires drive slower, but disperse weight better. Airblast sprayer wheel assemblies should be cleaned and inspected as part of regular annual maintenance. Wheel bearing maintenance before long-term storage may prevent water from corroding the bearings (see Section 13.1).

THE BELTS AND POWER TAKE-OFF (PTO)

Check all belts for wear, proper tension and to ensure they are true (i.e. perfectly aligned) and power is transmitted efficiently.

Grease the PTO splines and tubes (often) and clean the connection zones. When the sprayer is hitched to the tractor, the PTO should be level to prevent vibration and strain on turns. Never operate the sprayer without a shield in place!

Check the belt alignment. If the belt is not exactly true (i.e. in line), it will not operate efficiently and may wear out more quickly.

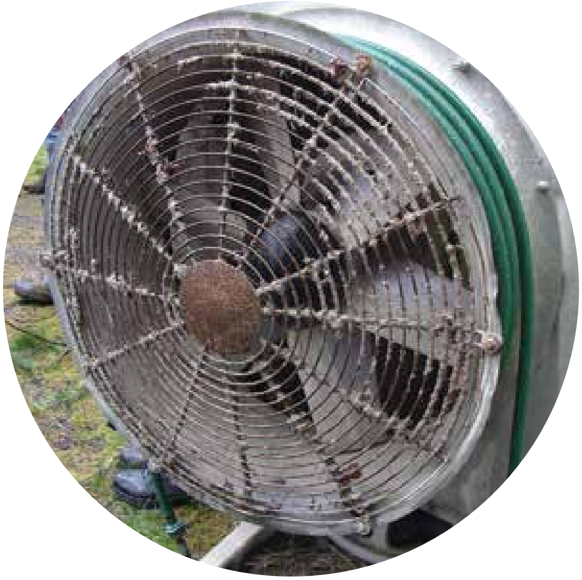
Universal joints seize and break more often than you think. Check and grease them regularly.

THE AGITATOR

Many spray materials do not mix well and one of the common causes of uneven application is poor agitation. If you find deposits at the sump in the bottom of the sprayer after an application, your agitation is probably insufficient. For mechanical agitators, check for propeller wear and ensure paddles are secure on the agitator shaft.

If the agitator shaft is leaking a little, tighten the packing. The packing gland is a common source of leaks. Keep it properly greased. If a leak occurs you can usually repair it by tightening the bolts on the packing gland by a half turn, but if that doesn't work you may have to remove and repack (or replace) it.

A leaky mechanical agitator – a little is all right, but a lot means you have to tighten or even repack the gland.



A dirty grill. Make sure to clean sprayer equipment thoroughly, but avoid using a pressure washer which can drive grease out of sealed bearings.

PHOTO CREDIT – M. WARING, BRITISH COLUMBIA.

THE PROPELLER

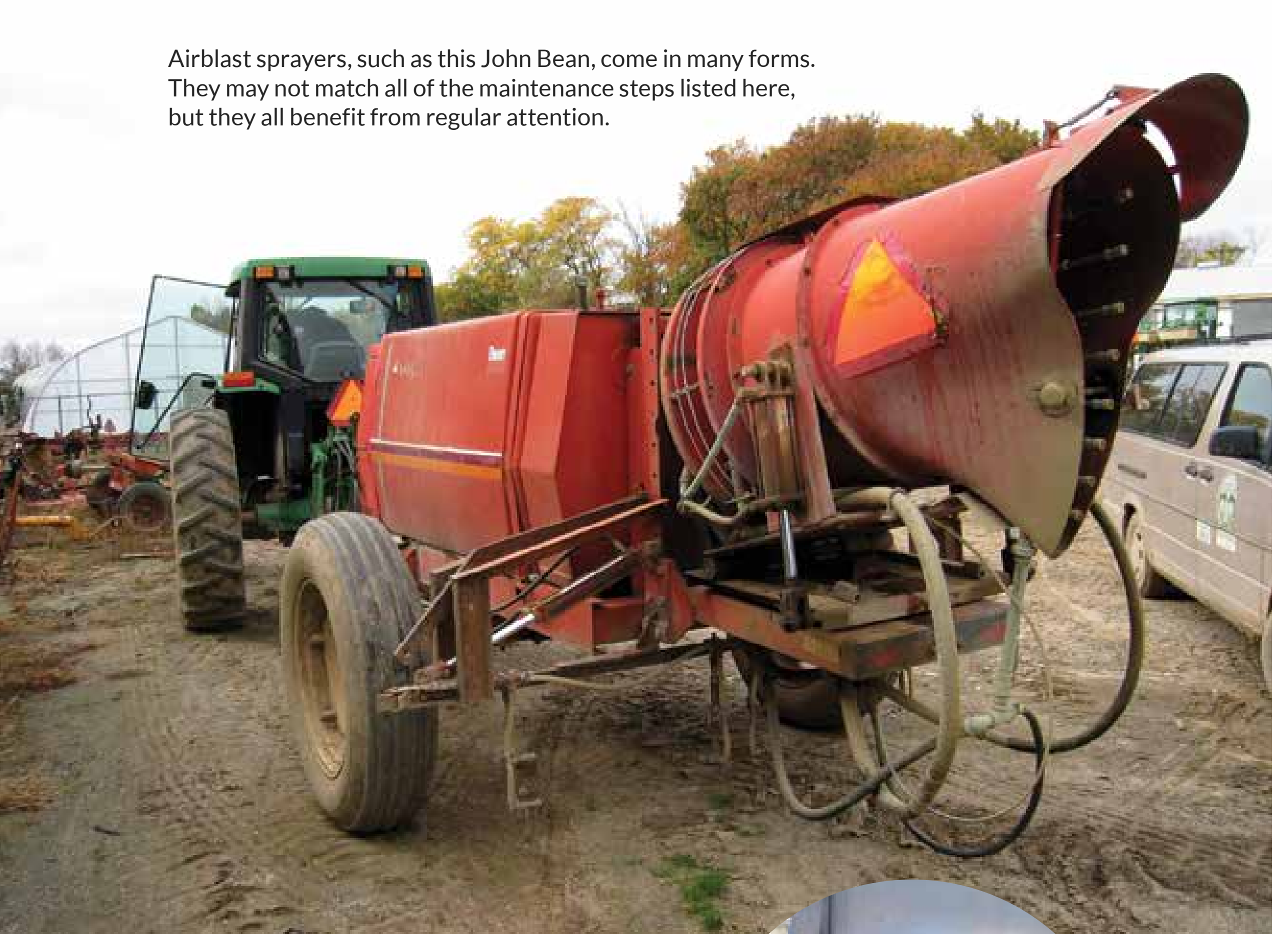
Check the propeller blades for any nicks or cracks that could imbalance the propeller and produce vibration. They should be scraped clean to remove any accumulated residue. Tighten the bearings, lubricate the moving parts, check for loose bolts and broken brackets and clean the trash guard, if present. Ensure the fan entrance grill is securely in place and has not been punctured or damaged.

Sprayer operators have reported that installing bottom deflectors prevents the fan from stirring up dust and leaves. This has reduced the caking on the fan blades and protects adjacent plants from possible physical damage.

THE NOZZLES

We've already discussed nozzle maintenance at length, but take the opportunity during maintenance to ensure nozzles are performing as intended **(see Section 6.10)**.

Airblast sprayers, such as this John Bean, come in many forms. They may not match all of the maintenance steps listed here, but they all benefit from regular attention.



Winterizing an airblast sprayer with engine antifreeze will work, but it's toxic to plants and animals, and must be rinsed out thoroughly. Superior oil will also work, but it only stays emulsified for one season – after that there is a chance of corrosion or rust. The best choice is antifreeze for RVs, which is non-toxic and only costs ~$5.00 for 3.78 L (1 gal.) – enough to circulate through the entire sprayer.

13.0 Winterizing

Winterizing

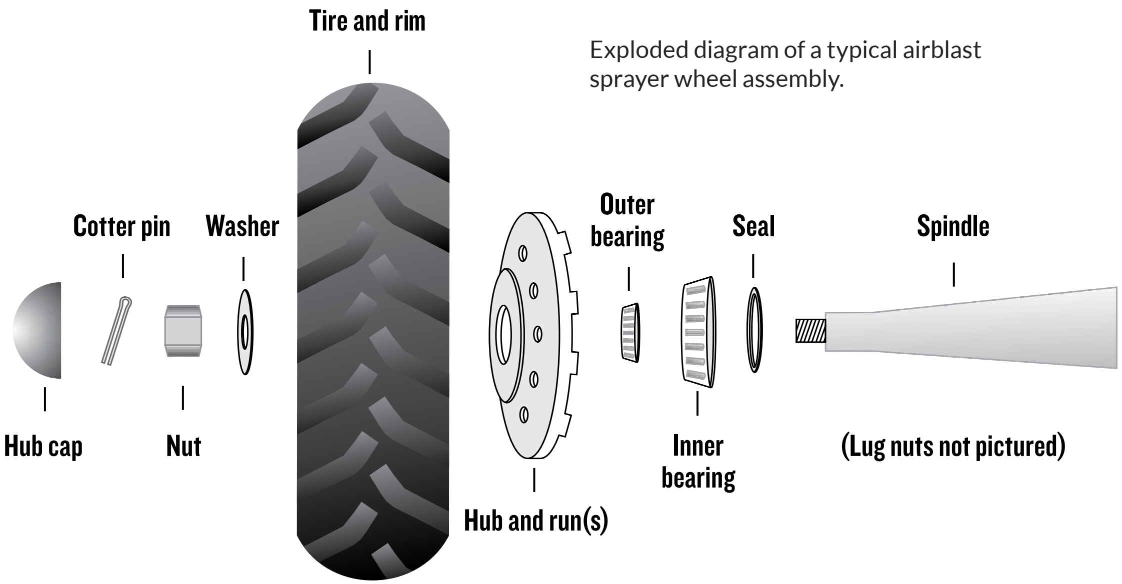
If you are preparing the sprayer for long-term storage, follow all the steps from **Section 11.0**, but don't reinstall the strainers and nozzles. Follow these directions instead.

- Store nozzles and strainers in a safe, dry place.
- With the agitation on, circulate undiluted plumbing antifreeze (the sprayer already has 5-10 L (~1.5-3 gal.) of water in the system from the decontamination process) for five minutes. Spray some through the boom and out the nozzle bodies to protect the check valves, and then drain it through the plumbing system.
- If required, drain and flush crankcase and refill with new oil.
- Take this opportunity to touch up the paint.
- Leave the valves open, and the tank lid loose.
- Protect plastic parts from sunlight.
- Non-corrosive liquids can be left in the pump and air must be kept out. Plug the ports or seal port connections.

In the case of conflicting instructions, always defer to the manufacturer's instructions for winterizing the sprayer. This is also an excellent opportunity to perform annual maintenance the sprayer wheels.

13.1 | Maintaining wheel assemblies

Airblast sprayer wheel assemblies should be cleaned and inspected as part of regular annual maintenance. Wheel bearing maintenance before long-term storage may prevent water from corroding the bearings. The exploded diagram (below) details the parts found in a typical wheel assembly.



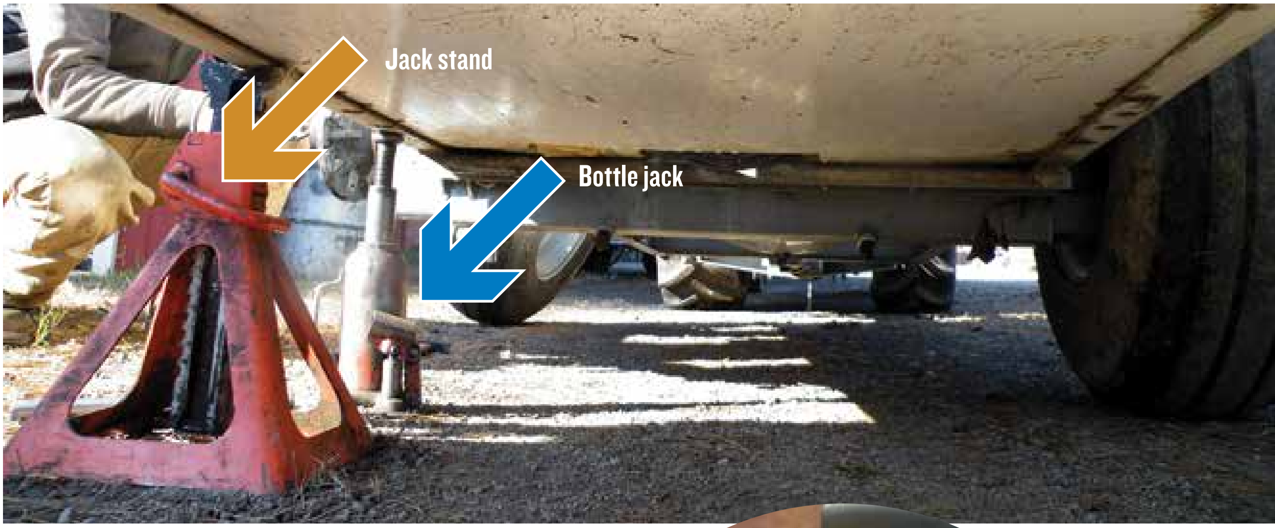
Exploded diagram of a typical airblast sprayer wheel assembly.

Some airblast sprayers (such as this Durand-Wayland) have wheel assemblies that can be rotated to four different positions in the chassis. This will raise or lower the sprayer to better align it with the tractor hitch and PTO shaft.

The following procedure was performed on a 2012 Durand-Wayland sprayer by Mr. M. Thiessen, Consulting Agricultural Mechanic, Ontario. The steps are applicable to most sprayer makes and models. The entire process should take approximately half an hour per wheel.

STEP 1

Empty the sprayer and park it in a well-lit, level spot. Unhitch the tractor and raise one side of the sprayer using a bottle or floor jack to clear the wheel. Secure the sprayer with a jack stand.



STEP 2

Remove the lug nuts and take the wheel off the hub. Do not remove the wheel and hub together because it is heavy and you might bang the delicate seal on the spindle. Check the wheel rim for signs of corrosion or distortion (often caused by either loose or over-tightened lug nuts). Check the tread for wear or cuts and check the tire pressure.

STEP 3

Remove the hub cap and pull out the cotter pin. Then remove the nut and washer that hold the hub on the spindle. Put all the small parts in a plastic container with some de-greaser (e.g. Varsol) to clean the parts and keep them from getting lost.

STEP 4

Knock out the seal and hub bearing and put them in the plastic container. There should be no need to remove the bearing cup (or race) from the hub unless it is damaged. The seal is designed to keep dirt out of the assembly, not to keep grease from escaping. Note which way it is facing. The seal is often ruined during disassembly – have a replacement on hand.

STEP 5

Clean the old grease out of the hub. This hub has too much and has filled much of the air space (or cavity) within the hub. The air space is provided so grease is not forced out as the hub heats up, and so dirt is not pulled in as the hub cools. Note the colour of the grease – if it is black and stains your hands, it has burned because too much grease has caused overheating. Look for evidence of dirt or water in the bearing, indicating seal failure.

STEP 6

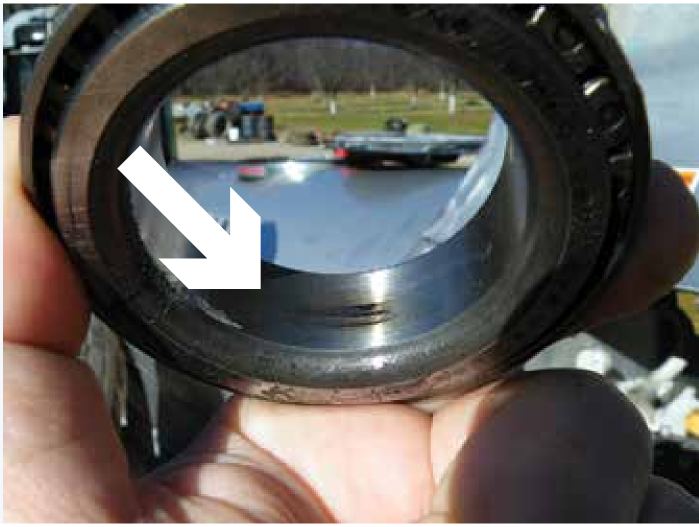
Wipe dirt from the spindle. Never pressure-wash wheels when they are on the spindles – the spray drives dirt and water past the seal and into the hub. Inspect the sealing surface of the spindle for damage or wear.

STEP 7

Clean the seal thoroughly. Seals are easily damaged and may need replacement.

STEP 8

Clean the hub bearing. Compressed air is a good way to get all the old grease out, but do not spin the bearing with the air.



STEP 9

Look for scratching, pitting or blue metal (indicating heat). This scorch mark indicates the bearing was moving on the spindle, and the friction created heat. Agricultural wheel bearings do not fit tight to the spindles. If there is too much clearance, the bearing race will turn on the spindle where it is not supposed to.

STEP 10

Repack the bearings, reassemble the hub and re-grease the hub. Bearings should only be ~40% full. Too much grease creates heat and does not let the bearing roll properly. Too little increases friction. No matter which grease you choose to use, never combine greases as they may not be chemically compatible.

STEP 11

Mount the hub on the spindle. Replace the washer, cotter pin, nut and cap. There is no need to bend the arms of a cotter pin all the way back – it weakens the metal. Just bend one arm to 90° and cut off the excess. Use anti-seize on the wheel pilot to make the rim easier to remove next time.

STEP 12

Replace the wheel and rim. Do not grease the lug nuts or they might loosen. Over- or under-torqueing lug nuts can cause damage. Look in the manual for your correct torque and consider using a torque wrench. Tighten the nuts in a star-shaped pattern – not sequentially.

Repeat process on the other wheel. **More information on bearings and bearing maintenance.**

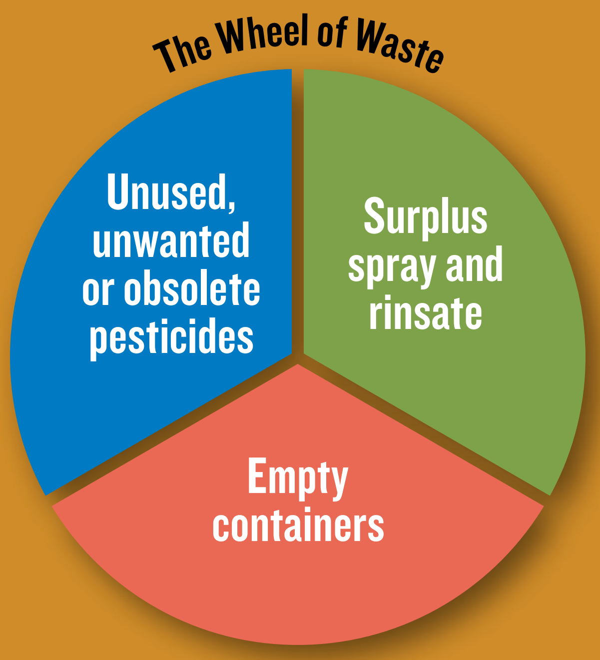
Pressure washers are handy tools on a farm, and they're fun to use, too. However, they can cause a great deal of damage if they are used to wash delicate things like engine parts, electronics housings or sealed bearings. Use caution!

14.0 Minimize waste

Minimize waste

Sprayer operators can generate three types of pesticide waste:

- surplus spray and rinsate
- empty containers
- unwanted pesticides



Here is some basic advice on disposal, but always refer to your local environmental authority.

14.1 | Surplus spray and rinsate

Spray surplus into the crop, diluting to a 1:10 ratio (1 part surplus or rinsate, 9 parts clean water). Spray out in an unsprayed or under-dosed portion of the crop. Never exceed the maximum labelled dose for the crop.

Another option is to drain spray washings to a storage tank, which is then sent for disposal. This isn't the preferred method because it introduces additional handling and raises the possibility of operator exposure. It also creates a "witches brew" of unknown products, and is very expensive to have disposed.

It's better to do some spray math to reduce the surplus as much as possible, and spray the diluted remainder onto the crops so it dissipates and breaks down the way the agrichemical company that developed it intended.

14.2 | Empty containers

Use returnable or refillable containers when possible. Recyclable containers should be triple-rinsed, perforated and taken to a pesticide container depot. Non-recyclable containers should be triple-rinsed (if appropriate) and taken to municipal landfill. Take empty paper or cardboard containers to a pesticide container depot or a municipal landfill – don't burn them.

14.3 Unused, unwanted or obsolete pesticides

Your local distributor may take back unopened containers with complete and current labels. In Canada, there are province-wide obsolete pesticide collections programs that run periodically. Empty Pesticide Container Recycling and Obsolete Pesticide Disposal (CleanFARMS) can be reached at 877.622.4460 or visit **www.cleanfarms.ca**.

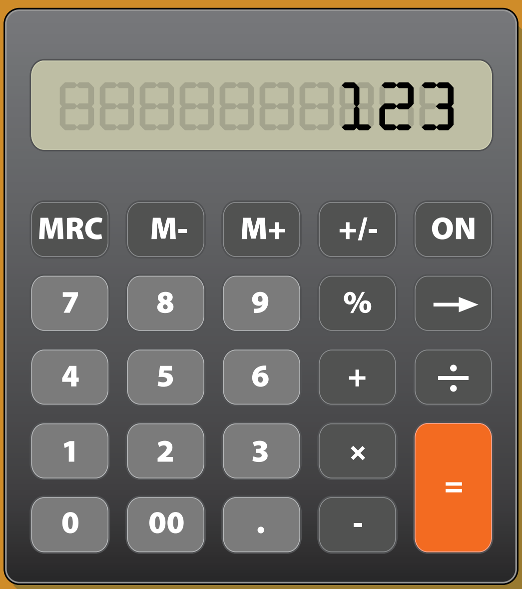
Safely dispose of unused, unwanted or obsolete pesticides and their containers.

15.0 Sprayer math

Sprayer math

Why is such an important topic at the end of the handbook? Why isn't it included with the sections on calibration?

Next to cleaning a sprayer, sprayer math can be onerous. I didn't want to derail the handbook by putting the math up front. If you got this far, I'm pretty sure you at least gleaned everything up to now – it's not like jumping ahead to find out "who dunnit" at the end of a mystery novel.



Sprayer math is already covered quite well in so many articles, safety courses, industrial catalogues and extension resource centres. Many operators already have equations they use frequently. Here's my version, but beware that mixing and matching methods can be confusing and sometimes yield the wrong answer if units and constants aren't handled correctly.

Airblast spraying and pesticide labels have something of a disconnect **(see Section 8.0)**. Many labels are cryptic with instructions to airblast sprayer operators, noting the product should be sprayed in "enough carrier to achieve adequate coverage, but not induce run-off". They describe the amount of product needed based on the planted area rather than the area-density of the crop canopy. That works well for grains and grasses, but not for highbush blueberries, grapes and orchards. The variability in crop size, shape, spacing and staging can amount to order-of-magnitude differences in canopy area-density from crop to crop. In the end, sprayer operators are often left to interpret the label as much as obey it, primarily ensuring they do not exceed the maximum dose.

This section may be at the end but it is still very important. Here are some common situations airblast sprayer operators face, and the formulae that will help them through.

15.1 | The formulae

QUESTION 1:

How large is the area I need to spray?

Multiply the length of the area you plan to spray times the width. If you are using metres, then divide the product by 10,000, which is the number of m^2 in a hectare (ha). For feet and acres, divide by 43,560 which is the number of ft^2 in an acre (ac.):

$$\text{ha} = \frac{\text{length (m) x width (m)}}{10{,}000\ \text{m}^2/\text{ha}} \qquad \text{ac.} = \frac{\text{length (ft.) x width (ft.)}}{43{,}560\ \text{ft}^2/\text{ha}}$$

QUESTION 2:

How much product is needed to spray the area?

If you measure your area in hectares, use the rate shown on the label. In Canada, it will often be written in litres or kilograms per hectare (L/ha or kg/ha). If you measure your area in acres, you'll have to convert by multiplying by a constant: 0.4. For those in the US, this step really doesn't apply to you. You will already have pounds or ounces per acre.

$$\begin{array}{c}\text{Rate for acres}\\ \text{(L/ha or kg/ha)}\end{array} = \begin{array}{c}\text{Metric rate}\\ \text{(L/ha or kg/ha)}\end{array} \text{ x } .04$$

Now multiply the area you want to spray (17.1) by the rate (label or 17.2).

$$\begin{array}{c}\text{L or kg of}\\ \text{product needed}\end{array} = \begin{array}{c}\text{Area to spray}\\ \text{(ha or ac.)}\end{array} \text{ x } \begin{array}{c}\text{Pesticide rate}\\ \text{(L or kg/ha) or (L or kg/ac.)}\end{array}$$

QUESTION 3:

How far can I go on a full tank?

You know your sprayer output (determined through calibration) so you divide that into your tank size. Watch your units.

$$\text{Number of ha or ac. per tank} = \frac{\text{Tank size (L or US gal.)}}{\text{Sprayer output (L/ha) or (L/ac.) or (US gal.)}}$$

QUESTION 4:

How much pesticide do I add per tank?

Multiply the area that can be sprayed per tank (17.3) by the pesticide rate (label or 17.2). For those in the US, just substitute pounds or ounces for kilograms or litres. Watch your units.

L or kg of pesticide per full tank = Area sprayed per tank (ha or ac.) x Pesticide rate (L/ha or kg/ha) or (L/ac. or kg/ac.)

QUESTION 5:

How much area is left to spray after I empty a tank?

Just subtract what you've already sprayed from the total area.

Area left to spray = Total area - Area already sprayed

QUESTION 6:

How much pesticide do I use in the last, partially-full tank to finish spraying the total area?

Multiply the area you have left to spray (17.5) by the pesticide rate (label or 17.2). For those in the US, just substitute pounds or ounces for kilograms or litres. Watch your units.

L or kg of pesticide to add to the last, partially full tank = Area left to spray (ha or ac.) x Pesticide rate (L/ha or kg/ha) or (L/ac. or kg/ac.)

QUESTION 7:

How much spray solution will I need for the partial tank to finish spraying the total area?

Multiply the area you have left to spray (17.5) by the sprayer output (determined through calibration). Watch your units.

Spray solution needed for the last, partially full tank = Area left to spray (ha or ac.) x Sprayer output (L/ha or US gal./ac.)

15.2 | Sample problem

Practice your sprayer math by answering these questions. This one is metric only, but it's still good practice.

> *Let's suppose you want to apply a product rate of 3 L/ha (~0.3 gal./ac.) to your blueberries. You calibrate your sprayer and determine your output to be 50 L/ha (~5.3 gal./ac.). Your tank holds 400 L (~105 gal.) of spray solution. Your planting is 500 m long (1,640 ft.) and 200 m (656 ft.) wide.*

QUESTION 1:

How large is the area I need to spray?

QUESTION 2:

How much product is needed to spray the area?

If you measure your area in hectares, use the rate shown on the label. In Canada, it will often be written in litres or kilograms per hectare (L/ha or kg/ha). If you measure your area in acres, you'll have to convert by multiplying by a constant: 0.4. For those in the US, this step really doesn't apply to you. You will already have pounds or ounces per acre.

ANSWERS

QUESTION 1:

$$ha = \frac{500\ m \times 200\ m}{10{,}000\ m^2/ha} = \boxed{10\ ha}$$

QUESTION 2:

$$3\ L/ha \times 10\ ha = \boxed{30\ L}$$

QUESTION 3:

How far can I go on a full tank?

You know your sprayer output (determined through calibration) so you divide that into your tank size. Watch your units.

QUESTION 4:

How much pesticide do I add per tank?

Multiply the area that can be sprayed per tank (17.3) by the pesticide rate (label or 17.2). For those in the US, just substitute pounds or ounces for kilograms or litres. Watch your units.

QUESTION 5:

How much area is left to spray after I empty a tank?

Just subtract what you've already sprayed from the total area.

QUESTION 3:

$$\frac{400\text{L tank}}{50\text{L/ha}} = \boxed{8\text{ ha}}$$

QUESTION 4:

$$8\text{ ha} \times 3\text{L/ha} = \boxed{24\text{L}}$$

QUESTION 5:

$$10\text{ ha} - 8\text{ ha} = \boxed{2\text{ ha}}$$

QUESTION 6:

How much pesticide do I use in the last, partially-full tank to finish spraying the total area?

Multiply the area you have left to spray (17.5) by the pesticide rate (label or 17.2). For those in the US, just substitute pounds or ounces for kilograms or litres. Watch your units.

QUESTION 7:

How much spray solution will I need for the partial tank to finish spraying the total area?

Multiply the area you have left to spray (17.5) by the sprayer output (determined through calibration). Watch your units.

QUESTION 6:

2ha x 3L/ha = 6L

QUESTION 7:

2ha x 50L/ha = 100L

Epilogue

If you're reading this then you've come a long way, or perhaps you've simply flipped to the end. I sincerely hope you've found some value in this handbook. It's been seven years in the making and wouldn't have been possible without information freely shared by colleagues, growers and industry.

As time goes on I'm sure I'll find things in this handbook I wish I'd written differently, or learn new techniques I would have liked to include. I can't change the printed book, but I can publish electronically. I invite you to explore **www.sprayers101.com** for the most up-to-date information on both horticultural and field crop spray application.

Thank you to Audra and Jane for bringing this handbook to life. And thanks to my parents for doing the same for me.

Happy spraying!
Jason Deveau

Growing Forward 2

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