

Airblast 101

Your Guide to Effective and Efficient Spraying

SECOND EDITION



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We are grateful to everyone that edited, contributed to, inspired or otherwise supported the research and development of this book. Airblast 101 represents the efforts of a global agricultural community. Special thanks to Dr. Tom Wolf for his critical review of the manuscript and for providing the Foreword.

“If I have seen further than others it is by standing upon the shoulders of giants.” – Sir Isaac Newton

We dedicate this edition to our unpredictable friend, Turbulent Eddy. While we hoped he'd go places, he always seemed to encounter obstacles. He is what he is today thanks to his paramour, Laminar Flo. She's never stopped trying to straighten him out.



Turbulent Eddy and Laminar Flo

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Foreword

If you're reading this you are likely an owner or operator of an airblast sprayer. Or perhaps you work in the industry as a manufacturer or sales rep, or an agronomist. You may be a regulator or an educator. No matter your background, you're in for a treat.

With this book, the authors have achieved that rarest of balances: broad scope, fine detail, and tremendous readability that appeals to all who are interested in spraying. Leafing through it, you'll see images and explanatory graphics that draw your eye and lower the intimidation level, and you quickly get a sense of the digestible content. But on reading it, you'll quickly see what really sets the work apart: the authors' ability to understand not only the subject matter, but their audience. This is no accident.

Deveau, Ledebuhr, and Manktelow have all paid their dues in the field, learning from applicators, actually doing and perfecting the work they describe. The understanding they lend to the subject clearly comes from experience. The value of this cannot be overstated because it allows them to speak the language of the applicators, and that's the magic. It makes the book understandable and effective.


But they don't stop there. They challenge the reader to think about the task, and provide the principles and tools to tailor the application to the target canopy. In the process, they unveil where they know the industry needs to head, with both equipment and label language, to assure better outcomes. Decision makers ought to pay heed to their observations, as these can shape a better future for airblast application.

For all those seeking Safe, Efficient, and Effective spray application, this is the definitive work on it.



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Glossary

Air angle: The net air direction.

Air energy: For a constant amount of air, air energy = air velocity × air volume.

Air velocity: The air speed.

Air volume: A measure of how much air is exiting the sprayer.

Air wash: The width of the spray plume as it contacts the canopy.

Application rate: The quantity of formulated product applied per planted area or row length.

Canopy: The collective structure containing all target plant surfaces.

Canopy density: The total surface area inside a canopy relative to its volume. Includes all foliar, fruit and wood surfaces.

Canopy indexing: A method for estimating relative spray distribution throughout a canopy.

Canopy phenology: Intrinsic to plant development, these characteristics describe crop growth and development in response to changes in season and climate.

Catch efficiency: Describes the target's potential to receive and retain droplets. Sometimes referred to as Retention Efficiency.

Cavitation (Suction): Drawing air into the pump, or the creation of vacuum bubbles in the spray liquid due to clogged pump suction. Affects the accuracy of spray delivery, can damage pump surfaces and may cause the pump to lose its prime.

Cleaning: Sprayer rinsing with additional steps to decontaminate sprayer components.

Concentration: The amount of formulated product contained within a volume of carrier (e.g. g/L or oz./gal.).

Coverage: Coverage describes the degree of contact between spray droplets and the target surface. It is a combination of the percent surface area covered and deposit density. Assuming proper timing and product choice, coverage can be used as an indirect indicator of a successful application.

Cracking force: The pressure where a valve first begins to bypass flow.

Deposit density: The total number of spray deposits, irrespective of their size, distributed evenly over a target area.

Dose: In the context of this book, dose is a measure of the active ingredient deposited per target area.

Drench: A spray application resulting in the complete saturation of target canopy surfaces with high levels of secondary spray movement (e.g. run off).

Droplet Size Distribution: The total number of droplets of every size produced by an atomizer.

Dwell time: The duration a target is exposed to the sprayer air wash.

DV_{0.1}: The droplet size where 10% of the spray volume is composed of finer droplets.

DV_{0.5}: The droplet size where half the spray volume is composed of finer droplets and the other half is composed of coarser droplets. (Same as Volume Median Diameter).

DV_{0.9}: The droplet size where 10% of the spray volume is composed of coarser droplets.

Effective: Defined as successfully producing the desired outcome. In the context of spraying, this is delivering the intended dose to a target area.

Effective Radial Distance (ERD): The radial distance from the center of a spray deposit that still creates the desired biological effect. The ERD can exceed the coverage radius of the original spray deposit when the active ingredient redistributes physically in precipitation, or systemically in plant tissue.

Efficient: In the context of spraying, defined as preventing the wasteful use of resources such as time, money or spray product.

Headland: A strip of land left unplowed at the end of a field, and/or the space available for turning on the row-ends.

Integrated Pest Management (IPM):
An ecosystem-based strategy combining biological control, habitat manipulation, modification of cultural practices, and the use of resistant varieties to control pests that are economically damaging to agriculture. Target organism-specific pesticides are used only after monitoring indicates they are needed.

Inverse square law: The work a sprayer must do increases inversely in proportion to the square of the distance from the target.

Leaf Area Index (LAI): The total one-sided green leaf area per unit ground surface area in broadleaf canopies.
 $LAI = \text{one-sided leaf area} / \text{ground area}$.

Lowest Effective Dose (LED): The minimum amount of active ingredient that must be deposited over a target area to produce the desired results. The LED may be achievable at a reduced application rate.

Non-drainable volume: The volume of spray liquid that remains in the sprayer's liquid handling system after normal draining methods are employed.

Operational capacity (Actual): This is the actual area (or row length) you can spray per hour.

Operational capacity (Hypothetical):
This is the potential maximum area (or row length) you can spray per hour.

Penetration: The distance (or depth) that spray infiltrates a canopy.

Percent coverage: A relative measure of the total target area that receives spray deposit. Usually expressed as percent area covered.

Plant canopy: The collective structure containing all plant surfaces. Referring to morphological height, depth, shape, and density.

Planting architecture: Refers to the geometric arrangement of canopies on a planted area, as described by row spacing, row length and plant spacing.

Pressure drop: The differential between the pressure at the point of measurement, usually near the pump outlet and the pressure at a given nozzle.

Relative Span (RS): The value determined by subtracting the $DV_{0.1}$ from the $DV_{0.9}$ and dividing by the $DV_{0.5}$. The smaller this number, the less variation in droplet size in the spray.

Residual volume: The volume of spray liquid that remains in the sprayer's liquid handling system when the pump begins to cavitate. When calculating the spray liquid requirements for the last, partially-full tank, non-drainable volume is subtracted from the residual volume, and that remainder is added to the calculated need to prevent running short.

Rinsing: The dilution of any remaining spray solution and exterior residue.

Run off: A coverage threshold where a surface becomes saturated and excess liquid drips off. At this point, the surface will not retain any additional spray deposits.

Spray (plume): The cloud of droplets and air generated by the sprayer.

Spray drift: The unintentional aerial movement of droplets, particles or vapour outside the treated area.

Spray height: The vertical distance spanned by spray. This is measured from the ground to the highest point reached by projected spray droplets. Note: droplets moving as spray drift are likely to achieve significantly greater heights.

Spray outlet: The mechanical structure where droplets and air merge to become spray. Sometimes referred to as a spray head, venturi, flute or jet.

Spray output: The rate of liquid flow from a sprayer, boom or nozzle (e.g. L/min or gal/min).

Spray volume: The volume of spray liquid per planted area (e.g. L/ha or gal/ac).

Sprayer configuration: Describes sprayer parameters that are either fixed as a function of sprayer design, or are rarely if ever adjusted. Examples of configuration parameters include fan size, tank size, pump type and volute type.

Sprayer use case or set up: Describes sprayer parameters that are regularly adjusted to reflect the changing needs of the application. For example, fan speed, travel speed, nozzle size, and operating pressure. Sometimes referred to as sprayer set-up, adjustment, or operation.

Spraying strategy: The overall management and operational plan for achieving safe, effective and efficient spray coverage of target crops.

Stiction: The threshold of static friction that must be overcome before a valve begins to move.

Swath: Swath is a theoretical application width intended to calculate product rates. It is typically from row center to row center (1 row), or row center to the middle of the target canopy ($\frac{1}{2}$ row).

Target area: Refers to the area of a specific plant surface intended to receive spray (e.g. cm^2 leaf, flower, fruit, bud, wood).

Throw: Where swath is the theoretical intent, throw is the actual distance spray travels.

Traffic pattern: The path the sprayer takes through the planting. It defines the swath.

Transfer efficiency: Describes the droplet's potential to arrive at the target.

Turbulence: Air dispersion and mixing.

Volume Median Diameter (VMD): The droplet size where half the spray volume is composed of finer droplets and the other half is composed of coarser droplets. Same as $DV_{0.5}$.

Waste: This is the ineffective use of resources. In the context of spraying, this could be time, money or any spray liquid not deposited on the target (e.g. spray drift, run off, leaks, spills, left-overs, etc.).

Wetting time: The duration a droplet remains in liquid form while in contact with the target surface. It is generally agreed that a longer wetting time means better product performance.

Prologue: Why “Airblast 101”?

This book began in 2010 as a classroom-based workshop for Ontario’s airblast sprayer operators. It was intended as a primer and decision-support tool for operators to become safer, more effective and more efficient.

The familiar “Airblast 101” title is, perhaps, no longer accurate. The original emphasis was on the classic, low profile radial design developed in the 1940s when it was recognized that pushing spray with air gave better coverage with less water. These sprayers continue to dominate in specialty crops around the world because they are simple, economical, and can operate effectively across a wide range of canopy forms and planting geometries.

But, air-assist sprayer design has evolved and diversified. With this new edition we’ve broadened the scope to include all air-assist sprayers. We hope to introduce you to equipment and practices you may never have personally encountered. We will also give you the tools to assess their relevance to your operation. This required a deeper dive into the physics of spraying, but we’ve kept the tone conversational and relied heavily on illustration to make concepts accessible.

We focus on three central themes:

1. Understanding the forces that influence air and spray droplet behaviour.
2. How to configure a sprayer to optimize coverage and minimize waste.
3. How to evaluate spray coverage.

So, perhaps you’re new to air-assist spraying and deciding which sprayer is right for your operation. Perhaps you’re an experienced operator re-evaluating your practices. Maybe you’re a farm manager, a government pesticide regulator, an agricultural extension specialist, an equipment manufacturer, a consultant, an agrichemical sales representative or a researcher. No matter your perspective, if you’re interested in air-assisted spraying there’s something here for you.



LAMINAR FLO SAYS...

Air-assist sprayers can have a lifespan of 25 years or more.
Consider your immediate and future needs and choose wisely.



The Eco Sprayer. A grower-designed and constructed orchard recycling sprayer.

Chapter 1

The six elements of spraying

A successful application relies on:

- knowing what and when to spray,
- knowing how the product works, and
- having the skill to apply it safely.

Pesticide handling certification programs and Integrated Pest Management (IPM) protocols provide guidance, but ultimately the operator must decide how best to run their sprayer.

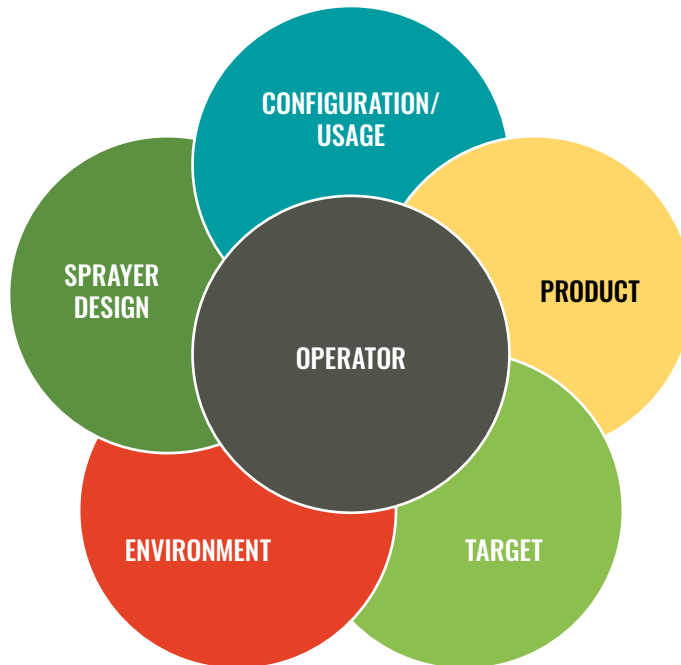
The right decisions result in the efficient delivery of an effective dose to a target area.

“Effective” means you are successful in producing the desired outcome. “Efficient” means you prevent the wasteful use of resources such as time, money or product. When we refer to wasted product we mean any spray liquid not deposited on the target (e.g. spray drift, run off, leaks, spills, left-overs, etc.).



This photo was taken during a calibration workshop. We sprayed water using the operator's typical configuration and asked attendees if the application was efficient and effective. Consensus was that it might be effective, but with so much wasted spray, it wasn't efficient.

There's a lot for the operator to consider, before and during an application. We've organized the contributing factors into six interdependent elements.



This Venn diagram illustrates the interdependence of the six elements that make up an effective and efficient spray application. Every respectable textbook should include a Venn diagram.

The elements overlap because they cannot be considered separately. Changes made in response to one element will have secondary impacts. For example, increasing droplet size (Configuration/Usage) to combat wind (Environment) at the top of a canopy (Target) also reduces the number of droplets sprayed. Reduced coverage might compromise efficacy (Product), so additional nozzles can be engaged to increase spray volume (Sprayer Design). But, is that the right decision (Operator)?

Notice that we have positioned the operator above all the other elements. An operator's skill, attentiveness and willingness to do a good job impacts every spray application. Technology can not compensate for an unwilling operator, or in the case of large corporate farms, a willing but unsupported sprayer operator. It is important to have all the decision-makers involved and in agreement when developing a spraying strategy ([see Chapter 8](#)).

Meet G.U.S.S.: The Global Unmanned Spray System developed by Crinklaw Farm Services, California. Even autonomous air-assist sprayers require an operator to make decisions about set-up and usage before and during an application.



Let's unpack the six elements to reveal their constituent factors. We reorganize this table every few years to reflect the state of horticultural spraying. Even now, there are valid arguments for swapping a few factors. But no matter how they are presented, they all contribute to the success of the spray application.

ENVIRONMENT	TARGET	PRODUCT	SPRAYER DESIGN	CONFIGURATION /USAGE	OPERATOR
WIND <ul style="list-style-type: none"> • Speed • Direction 	CANOPY STRUCTURE <ul style="list-style-type: none"> • Height • Density-area 	MODE OF ACTION <ul style="list-style-type: none"> • Timing 	AIR HANDLING <ul style="list-style-type: none"> • Volume • Velocity • Vector • Turbulence 	TRAVEL SPEED <ul style="list-style-type: none"> • Throw • Spray height 	OPERATION SCALE /COMPLEXITY
TEMPERATURE	<ul style="list-style-type: none"> • Planting architecture • Plant morphology 	TANK MIX <ul style="list-style-type: none"> • Water quality • Carrier volume 	LIQUID HANDLING <ul style="list-style-type: none"> • Pressure • Flow • Agitation 	SPRAYING STRATEGY <ul style="list-style-type: none"> • Traffic pattern and swath • Work rate • Coverage assessments • Filling process • Sanitization process • Maintenance schedule 	DECISION-MAKING AUTHORITY
RELATIVE HUMIDITY		<ul style="list-style-type: none"> • Product concentration • Application rate • Mix partners 			APTITUDE
THERMAL INVERSION	CANOPY MANAGEMENT				ATTITUDE
PROXIMITY TO SENSITIVE AREAS/SPECIES	TARGET <ul style="list-style-type: none"> • Size • Wettability • Location 		ATOMIZATION <ul style="list-style-type: none"> • Spray quality • Flow • Nozzle orientation 		

There are many factors involved in spraying. Some should be considered long before the application and others should be monitored (and acted on) during the application.

Much of this book is concerned with explaining how these factors affect spraying. When the operator understands their relevance, they can make informed decisions on how best to set-up and use their air-assist sprayer.



**TURBULENT
EDDY SAYS...**

Hey, if spraying was easy, anyone could do it.

1.1. | Perspective

Here is a thought exercise designed to give some perspective on what we are trying to achieve when spraying.

Suppose we want to apply the fungicide Captan to highbush blueberry. In Canada, the label rate is 2 kg of product per hectare of planted area (28.5 oz./ac.). This Captan product is 80% active ingredient, so a quick unit conversion tells us our objective is to apply 160 mg of active ingredient per m² of planted area. Let's decide to use a typical 500 L of carrier per hectare (53.5 gal./ac.), which converts to 50 mL/m².

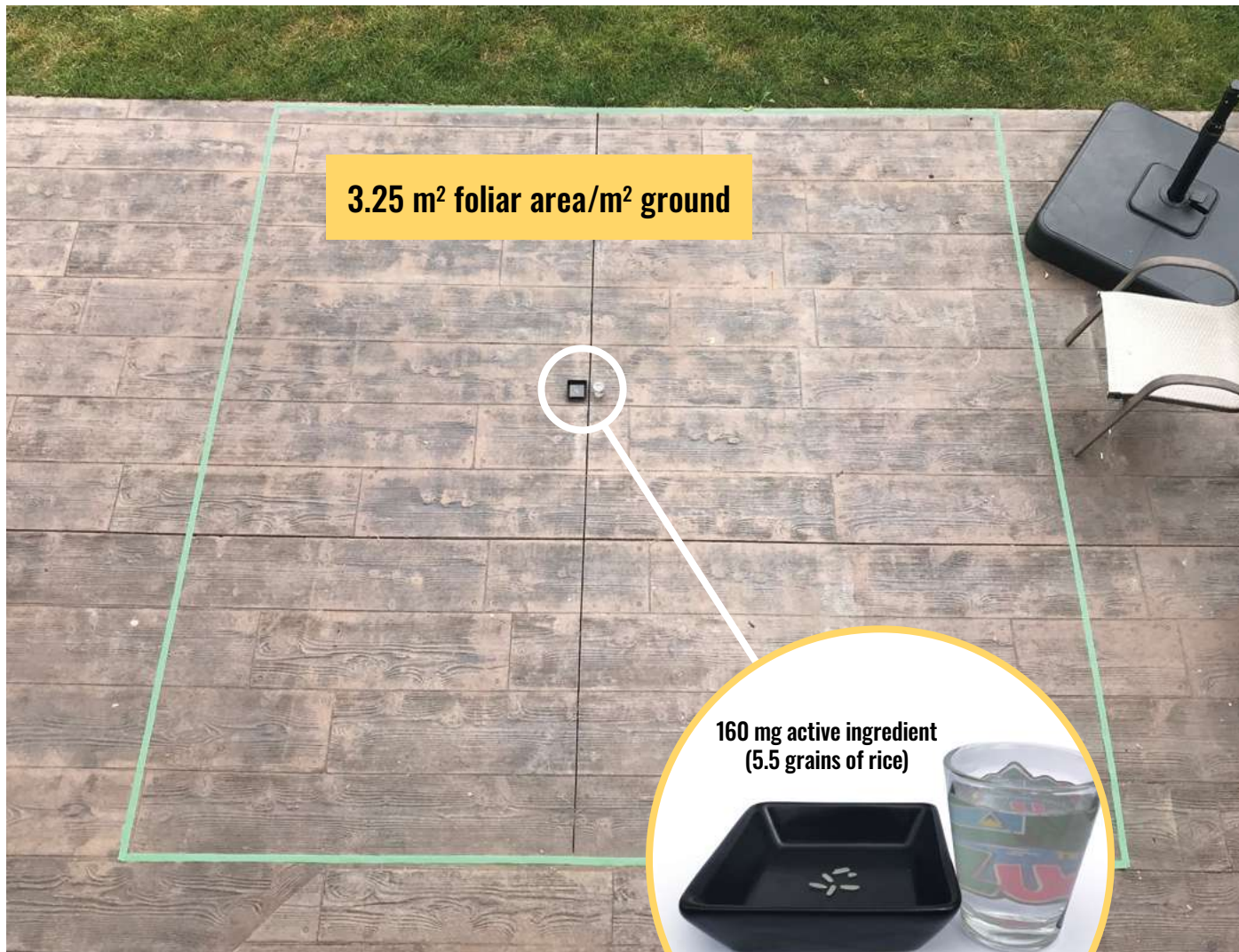
Now let's consider how much plant we want to cover. The Leaf Area Index (LAI) is the one-sided green leaf area per unit ground surface area. Think of this as plucking every single leaf from a broadleaf plant and laying them out like a quilt. Our blueberry patch is mature, well pruned and each plant is 1.8 m (6 ft.) high with a 1.2 m by 1.2 m (4 ft. by 4 ft.) footprint.

Assuming a conservative LAI of 2, that's 2.9 m² (31 ft.²) of foliar surface area per plant. We double that figure since we want to spray both sides of the leaves, and then assuming the bushes are planted on 3 m (10 ft.) alleys we arrive at a total foliar surface area of 3.25 m² per m² (3.25 ft.² per ft.²) planted area.

These figures are difficult to grasp, so let's convert them to something we can picture. Our objective is to dissolve 5.5 grains of rice in 3.5 tbsp of water and spray it over 3.25 m² (35 ft.²) of surface area ([see figure on the following page](#)). Now that's perspective!

1.2. | Review and consider

- As a sprayer operator, which factors do you pay attention to before and during spraying? Do you make changes to account for these factors? As a farm manager, do you instruct or encourage your operators to account for these factors?
- Will your new perspective on how little product must be distributed over such a large target area change how you plan to spray?



3.25 m² foliar area/m² ground

**160 mg active ingredient
(5.5 grains of rice)**

**50 mL carrier
(3.5 tbsp water)**

This photo shows the challenge of a 500 L/ha (53.5 gal./ac.) application. The green square represents the foliar surface area in a square meter of mature highbush blueberry. In the centre we have placed a bowl and a glass that contain the equivalent amount of active ingredient and water that must be distributed over that area. We zoomed in so you can see (inset image). It's amazing what we ask of an air-assist sprayer.



Chapter 2

What is an air-assist sprayer?

Let's save a few thousand words. From now on when we write "sprayer" assume we're referring to any air-assisted sprayer used in trellised and free-standing perennial tree, vine, cane, and bush crops. This represents significant structural and morphological variability, and in response, manufacturers seem to have produced a different sprayer (sometimes several) for each specialty crop.

The variability in sprayer design is why there is no single explanation of how best to operate one. But despite their differences all sprayers include three fundamental mechanical systems. These systems work together to meter a liquid solution in the form of droplets and generate air to convey those droplets to a target.



This collage depicts the massive variability in air-assist sprayer design. Believe it or not, there are many others.

1.

Air handling system
(Fans)

2.

Liquid handling system
(Plumbing)

3.

Atomization system
(Nozzles)

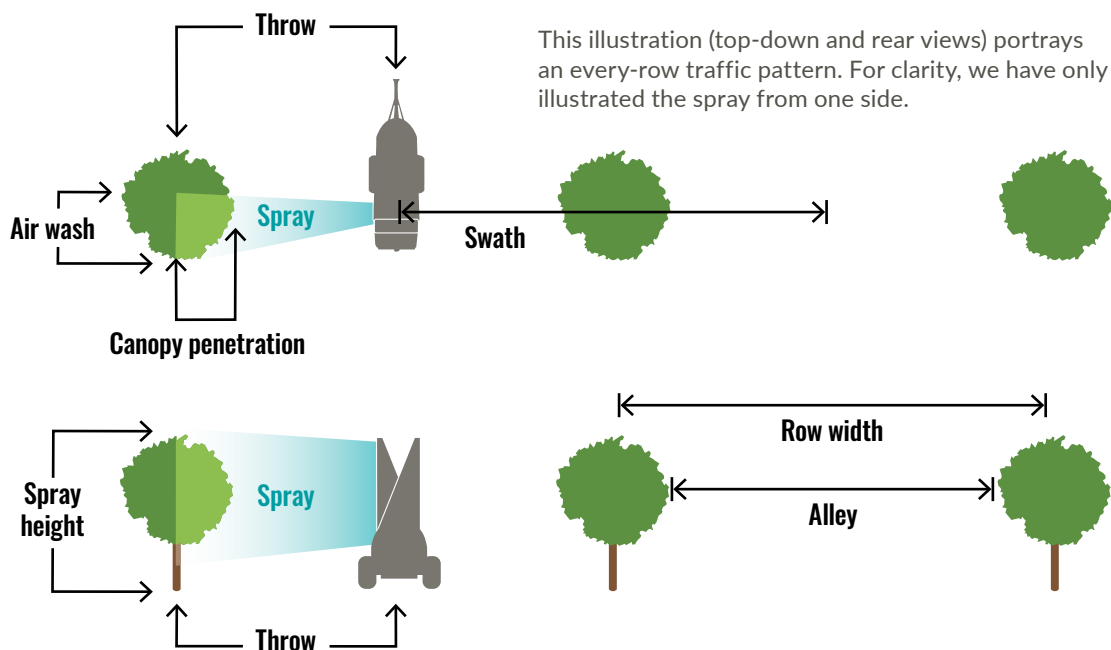
We'll define each mechanical system generically and then highlight significant design options. We'll use basic physics to explain how each design works and how they can be adjusted to optimize their performance. When you understand the benefits and limitations of each design you can make an informed sprayer purchase or feel more confident when configuring and adjusting your current sprayer.



2.1. | Describing spray geometry

We were about three months into writing this edition before we realized we were using different terms to describe spray geometry. We had to step back and develop a standard vocabulary. Take some time to familiarize yourself with these terms because you'll encounter them throughout the book.

- **Spray:** The cloud of droplets and air generated by the sprayer.
- **Air wash:** The width of the spray plume as it contacts the canopy. Typically intrinsic to sprayer design and a function of the distance between sprayer and target.
- **Spray height:** The distance from the ground to the spray's highest point. Influenced by the environment, travel speed, sprayer design and the resistance of intervening canopy.
- **Swath:** Swath is a theoretical application width intended to calculate product rates. It is typically from row center to row center (1 row), or row center to the middle of the target canopy (half row).
- **Throw:** Where swath is the theoretical intent, throw is the actual distance spray travels. It is influenced by the environment, travel speed, sprayer design and the resistance of intervening canopy.
- **Penetration:** The distance (or depth) that spray infiltrates a canopy.



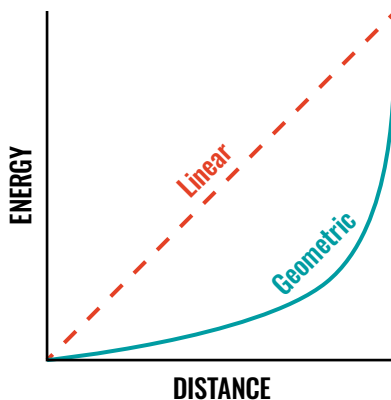
2.2. | The inverse square law

The inverse square law is an important concept in spraying. It is a physical law that governs the relationship between the sprayer and the target and defines the limits of what you can reasonably expect to accomplish. The Inverse Square Law states:

The farther away an object is from an effect, the less change can be observed in the object. That change is inversely proportional to the distance.

$$\text{Energy} = \frac{1}{\text{Distance}^2}$$

This may be easier to visualize as a graph (see figure below). Distance and energy do not have a linear relationship (i.e. one to one) but share a more complicated geometric relationship.



The geometric line (blue) represents the relationship between energy and distance. Unlike a linear relationship (broken red), this means that at a certain point, you can shovel a lot of power in, but only get a diminishing return.

The following examples show how the inverse square law applies in two real-world spraying scenarios:

1. **Pressure-based flow:** To double the flow through a hydraulic nozzle, you must quadruple the pressure (or close enough).

$$\text{Pressure}_{\text{original}} \times \text{Flow}_{\text{new}}^2 = \text{Pressure}_{\text{new}} \times \text{Flow}_{\text{original}}^2$$

Suppose you've just finished spraying a newly planted orchard and you're moving into an older block with bigger canopies that require twice the spray volume. The pressure required to increase the flow might exceed what your pump can handle. You may need a higher-capacity pump, or you could consider engaging more nozzle bodies or switching to nozzles that deliver a higher flow at a lower pressure.

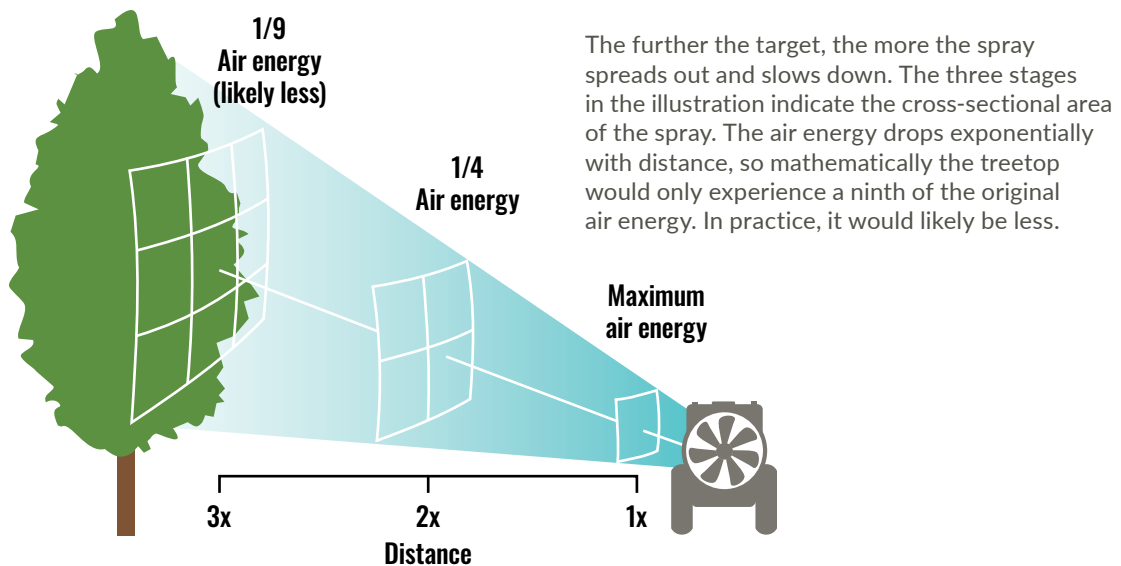
2.

Air energy: If you double the distance between your sprayer and your target, your air energy will drop to a quarter. Considered differently, if you half the distance between the sprayer and target, you may only need a quarter of the air energy.

$$\text{Air energy}_{\text{original}} \times \text{Distance}_{\text{new}}^2 = \text{Air energy}_{\text{new}} \times \text{Distance}_{\text{original}}^2$$

Suppose the afternoon wind picks up while you are spraying. You choose to combat the wind by doubling your airspeed (assuming your sprayer design permits it). To do so would require four times the energy. You may not have the horsepower, and even if you do, you'll likely over-extend your throw on the downwind side of the sprayer. Consider a sprayer design with towers or wraparound booms to bring the air and nozzles closer to the target.

Keep the inverse square law at the back of your mind as you explore this book. It comes up again and again.



2.3. | Review and consider

- The diversity in air-assist design gives operators a lot of choice when considering a new sprayer. Is your sprayer the best fit for your operation?
- How does the inverse square law affect your spraying strategy?
- Do you have issues reaching the tops or far sides of rows? How could you apply these concepts to improve matters?
- Is there sufficient capacity in your sprayer design to permit reasonable changes in your pressure or air handling settings, or are you operating at extremes?
- All things being equal, if a 100 hp fan drives spray to the top of a 3 m (10 ft.) tree, how much horsepower would be required to reach the top of a 6 m (20 ft.) tree? (Hint: It's a lot!)



The physics of spraying goes far deeper than our brief descriptions. If you're keen to learn more, Wikipedia is an excellent resource.



Chapter 3

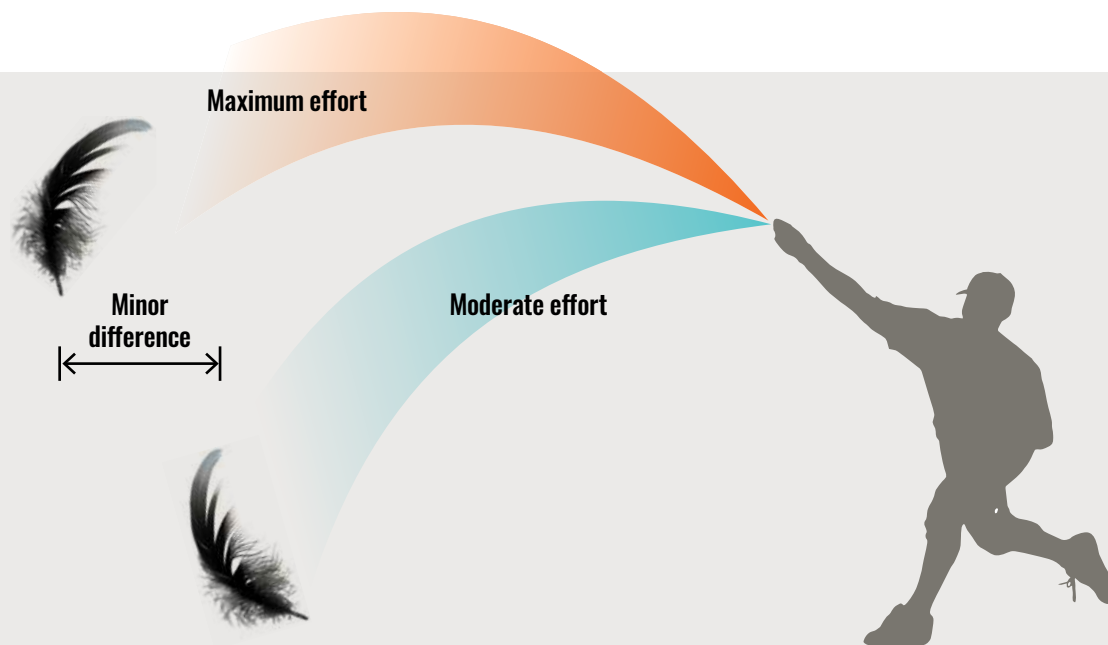
How air behaves

Air handling is the most important and least understood mechanical system on a sprayer. Small droplets have very little mass relative to their surface area, so they don't have much kinetic energy. Increasing hydraulic pressure results in only a marginal increase in how far a small droplet is propelled. Without air to impart speed and direction, most droplets would never go where we want them to. Air also opens and moves a canopy, exposing otherwise hidden surfaces to the droplets it's carrying.



**TURBULENT
EDDY SAYS...**

Sometimes, no amount of water can substitute for what air-assist can do to improve coverage.



Imagine throwing a feather. Now imagine throwing it as hard as you can. It may travel a little farther, but not much relative to the extra effort. Even then, an errant gust of wind might change its direction entirely. Similarly, we cannot rely on hydraulic pressure to propel small droplets. This is the primary reason for the “air” in air-assist spraying.

3.1. | Factors describing air behaviour

Air is generated by one or more fans and is channeled, deflected or otherwise aimed to carry spray droplets to the target. We can't describe air handling systems without first considering the nature of the air itself. The factors that define air behaviour are velocity, volume, angle and turbulence.

- **Velocity:** This is the air speed.
- **Volume:** This is how much air is exiting the sprayer.
- **Angle:** This is the net air direction.
- **Turbulence:** This is air dispersion and mixing.

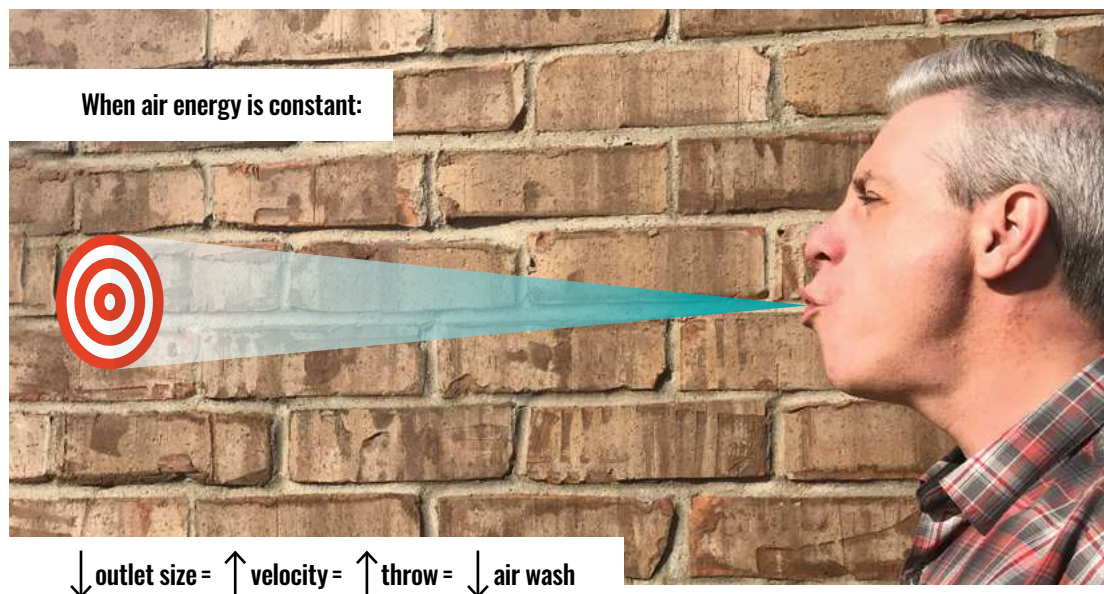
Velocity, volume and angle can be adjusted to improve spray coverage and reduce the potential for off-target drift. Turbulence is usually an intrinsic characteristic of sprayer design. Adjustable or not, understanding these factors will help you use your sprayer more effectively.

3.1.1. AIR VELOCITY AND VOLUME

Velocity and volume are different, but related. We used the term 'air energy' when we described the inverse square law, but it's only now that we can define it as the product of air velocity and air volume.

$$\text{Air energy} = \text{Velocity} \times \text{Volume}$$

From here on, when we refer to air velocity or volume, assume it's for a constant amount of air energy. It can be helpful to think of air energy as "penetrating power". Let's employ a well-known source of hot air to show what happens when we change air velocity using an adjustable air outlet ([see figures on the following page](#)).



We can use the same amount of air energy to accomplish very different things. In both pictures we generate the same volume of air: a lungful. We exhale for the same amount of time. When the mouth makes a small opening (top) that volume of air throws further at higher velocity to target a smaller area. When the mouth makes a large opening (bottom) that volume of air does not throw as far, travels at lower velocity and targets a larger area. PHOTO CREDIT: JODIE DEVEAU



3.1.2. AIR ANGLE

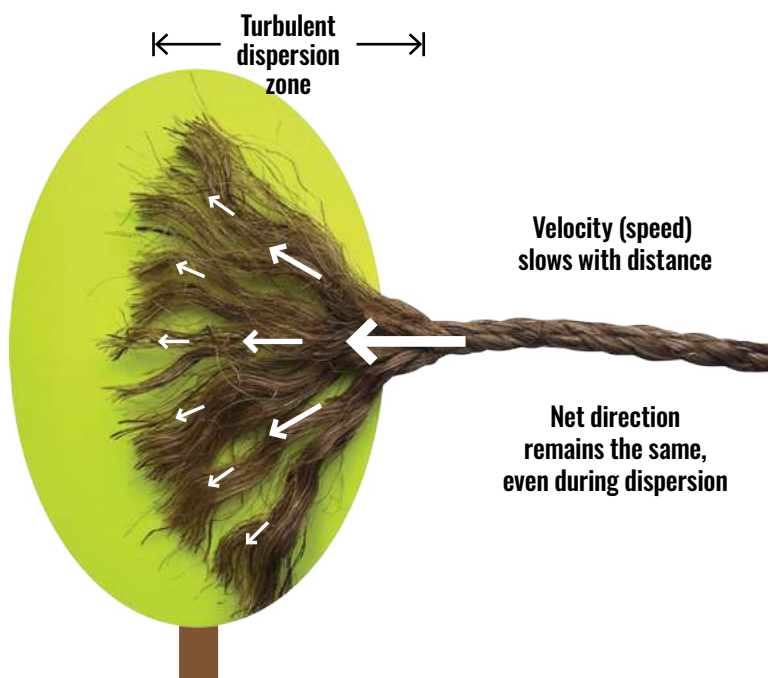
Angle describes where the air outlet(s) are aimed. Even when sprayer-generated air moves in many directions, the net angle describes the average direction of air exiting one side of the sprayer. When we focus or shape air energy to bear on a specific target, we are adjusting the air angle. This will be explored more in [Chapters 9, 10 and 11](#).

3.1.3. AIR TURBULENCE

Turbulence describes the degree of air mixing and instability. The initial level of turbulence depends on the sprayer design, but all air begins losing energy as soon as it is generated. The more laminar (i.e. less turbulent) the air is initially, the further it throws before dispersing in irregular paths and then stalling.

When air encounters a plant canopy, the irregular surfaces introduce additional resistance, increasing turbulence and reducing the throw as they interact with the spray. We like turbulence in the canopy! It rotates leaves to expose new target surfaces and carries droplets around obstacles into nooks and crannies that are not in the line-of-sight of the sprayer.

A frayed rope is a good metaphor for summarizing the four factors that define air behaviour. Sprayer-generated air begins as a concentrated but chaotic flow (the wound rope) and then slows and disperses in irregular paths (the frayed end) until there is no more air energy.



The four factors that define air behaviour can be illustrated using a frayed rope. The velocity is the length of the arrow. The volume is the width of the arrow. Net direction describes the average arrow direction. The fraying represents turbulent eddies where sprayer-generated air disperses, slows and mixes with surrounding air. Ideally, the dispersion zone begins outside of the target canopy and ends inside it.

3.2. | Travel speed

Travel speed can have a significant impact on work rate. However, the effect of travel speed on air behaviour (and ultimately coverage) should be the operator's primary concern. There will always be a trade-off between travel speed, coverage and work rate. The diagnostic methods described later in the book will help the operator find their travel speed "Goldilocks Zone".

Sprayer operators understand that travel speed affects how much liquid is applied to a canopy. If you slow down without adjusting flow, the canopy soon begins to drip. It's similar with air. Just as travel speed modifies the liquid rate per row, it also modifies air energy per row. This brings us to a discussion on Dwell Time and the Air Displacement Concept.

3.2.1. DWELL TIME

We've described how air behaves when it's generated from a stationary position, but what happens as a sprayer moves past a canopy? Let's leave the tractor cab to consider air from the target's perspective.

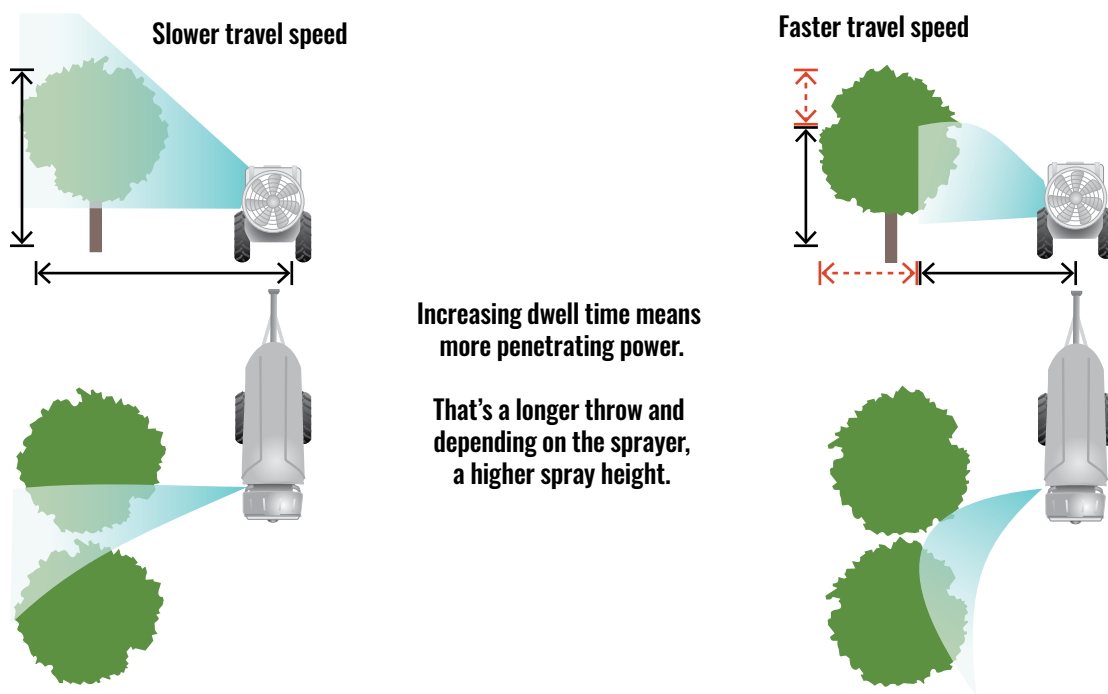
Dwell time is the duration a target is exposed to the air wash. If the sprayer design permits, you can change the dwell time by adjusting the width of the air wash. But, the easiest way to change the dwell time is to change the travel speed of the sprayer. If you halve your travel speed, you double your air energy (or penetrating power).



**LAMINAR
FLO SAYS...**

**It is critical to calibrate air energy
before calibrating liquid flow rate.
Remember, without air, small droplets
may never arrive.**

$$\text{Air energy}_{\text{original}} \times \text{Travel speed}_{\text{original}} = \text{Air energy}_{\text{new}} \times \text{Travel speed}_{\text{new}}$$



Travel speed can be used to change the duration a target is in the air wash. Slowing down increases throw and spray height. Speeding up decreases throw and spray height. Spray height is more sensitive to travel speed with low profile radial sprayers.)

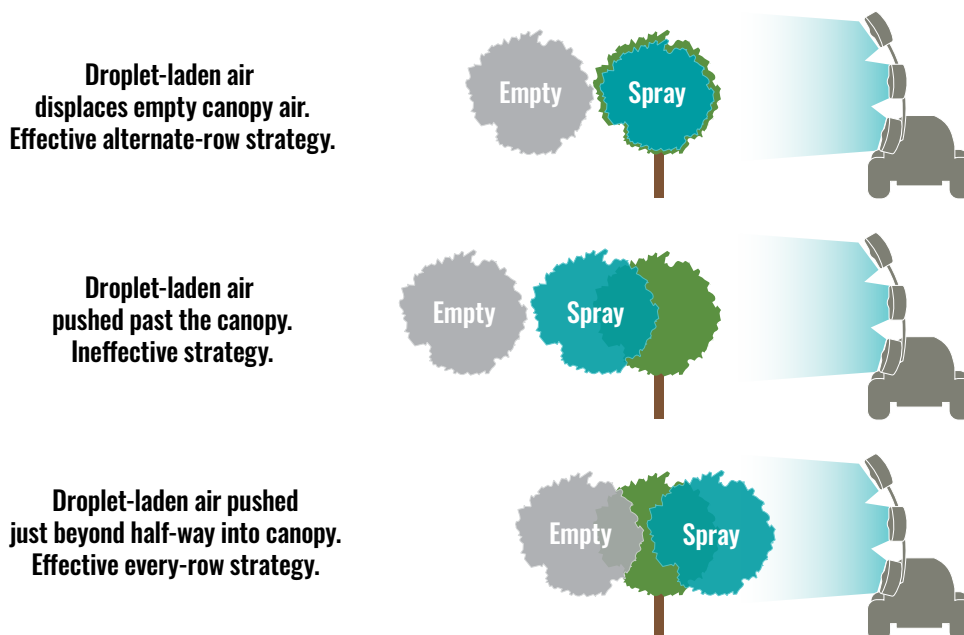
Air will tend to take the path of least resistance, moving around the outside of the target canopy. Decreasing dwell time (i.e. driving faster) reduces penetrating power and more spray will deposit in the outer portion of the canopy relative to the interior. This may or may not be desirable, depending on the product being applied.

If your sprayer is underpowered relative to the canopy size or wind conditions, increasing dwell time (i.e. driving slower) will concentrate air energy, increasing the throw and likely the spray height. But, driving too slowly can concentrate too much air energy, causing the leaves in some crops to shingle and close, or align with the air. We discuss these canopy/spray interactions in [Chapter 11](#).

3.2.2. THE AIR DISPLACEMENT CONCEPT

Air-assist spraying attempts to replace the empty air within a canopy with droplet-laden air (and then get it to stay there). Recall that the swath is the range in which all targets are intended to receive coverage. The throw is the distance spray actually travels.

If we don't have enough air energy, we won't displace enough empty air and the throw will fall short of the swath. We will miss our target. Likewise, if we have too much air energy, the throw will extend beyond the swath. This wastes spray and could compromise coverage. Ultimately, we want the air to expend all its energy, spreading, stalling and depositing droplets inside the target canopy.

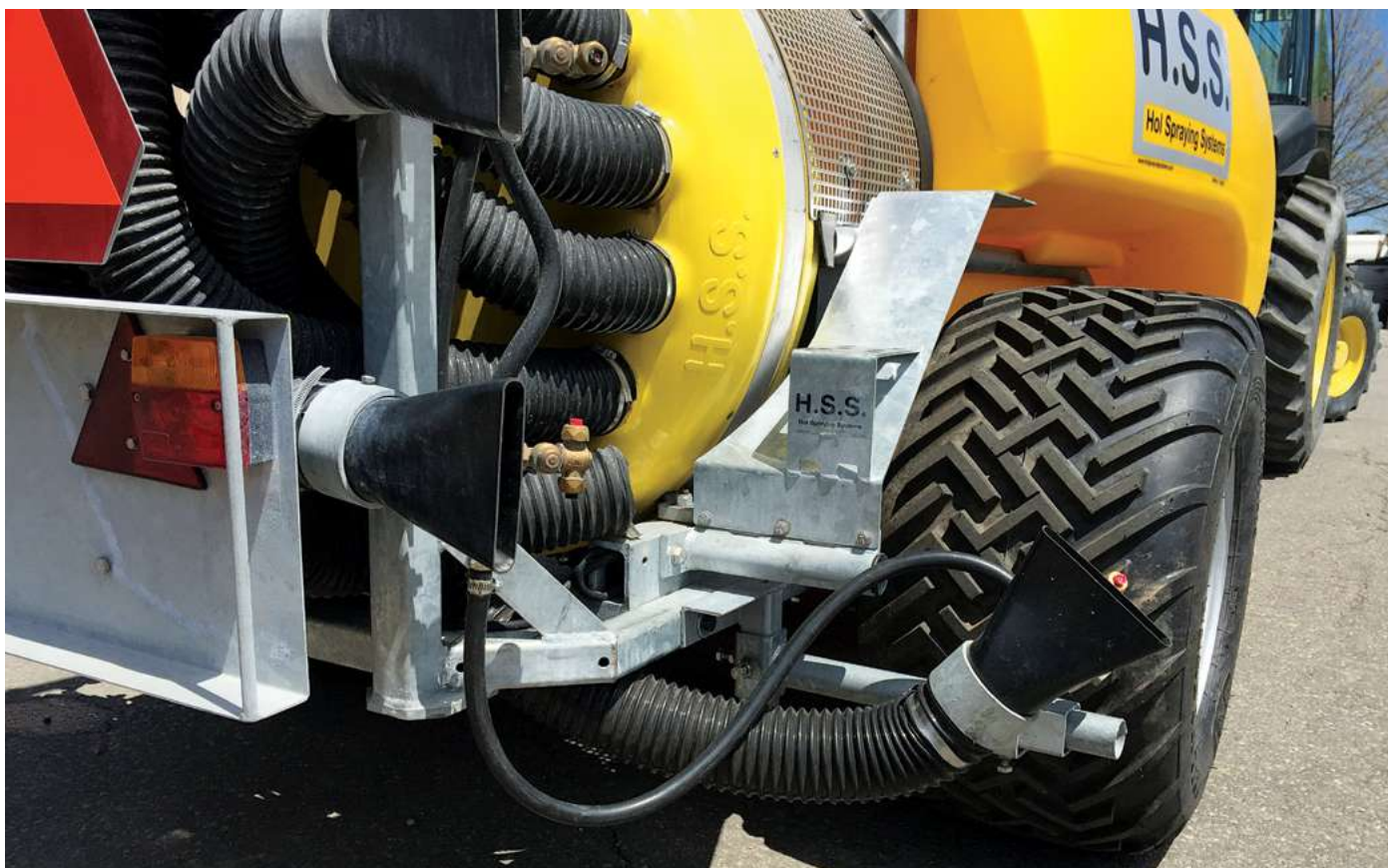


The air displacement concept requires a volume of empty air within a target canopy be replaced by a volume of droplet-laden air (i.e. spray). The throw should match the swath. This concept is, perhaps, oversimplified, but the important thing is to think about it.

Travel speed is the first and easiest adjustment to throw, spray height and canopy penetration. The second adjustment is to aim air energy where there is the most resistance. That might be the densest cross-section of a canopy, or perhaps it's the distant top of a tall canopy. This can be accomplished by redistributing air energy along a boom, or adjusting the air angle by aiming fans or deflectors. We will discuss how to measure and configure air in [Chapters 9, 10 and 11](#).

3.3. | Review and consider

- What can you do to adjust the air energy, angle and turbulence of your sprayer air?
- Have you considered the impact of your travel speed on air behaviour?
Would you be willing or able to drive faster? Slower?
- Do you change your air settings to adjust your throw?
Should you reconsider these changes throughout the spraying season?



Some sprayers can be adjusted to direct spray upwards from beneath tree canopies.



Chapter 4

Air handling systems

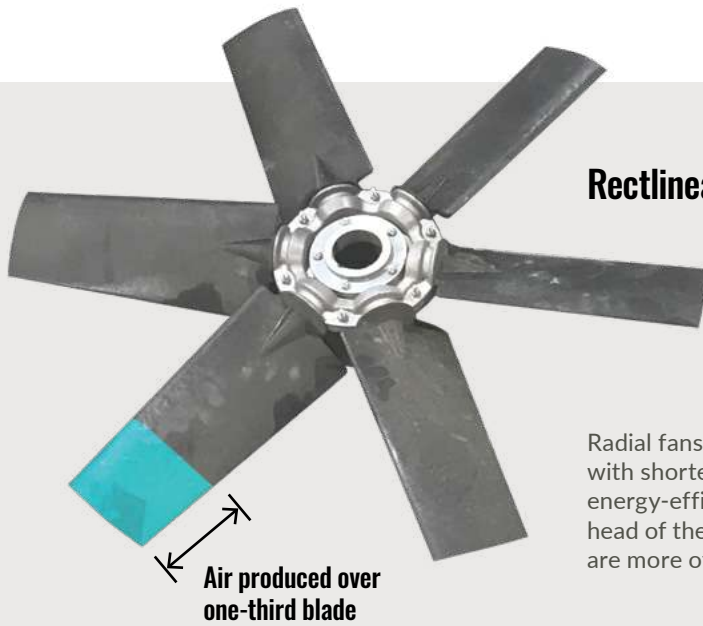
Air handling systems can be specialists or generalists; some are designed to do one thing very well while others are more adaptable but not as precise. Fan type plays a big role in determining a sprayer's abilities. A fan's native characteristics may make them better suited to certain scenarios, but there can also be a lot of crossover in capability.

Fan type is important, but what is done with the air at the outlets is more important. Fans operate within a larger, engineered air handling system and the operator has control over how that system is configured and used. This is why it is more important to consider how the air exits the sprayer; the fan is just a means to an end. That said, we do need to discuss fan types briefly.

4.1. | Fan types

- **Radial fans:** Radial fans produce high volumes of moderately turbulent air at relatively low static pressures. They are often associated with fixed vanes and straighteners inside the fan housing to reduce initial turbulence and create uniform air output.
- **Turbines:** Turbines may look like radial fans, but they spin faster and they have blades designed to compress air. They are used in sprayers that have ducts, such as towers and cannons.
- **Straight-through axial fans:** These small radial fans are typically arranged in arrays with no ducting. The air flows along the axis of the fan. They produce high volumes of the most turbulent air. With their comparatively short throw and wide air wash, they should be positioned close to the target.
- **Tangential (a.k.a. Cross-flow) fans:** Tangentials produce the most laminar air, forming a high volume, low velocity jet. The air outlet shapes the air wash into a narrow "curtain" or "knife". They have a comparatively long throw and rely on the canopy to induce turbulence.
- **Centrifugal (a.k.a. Squirrel cage) fans:** Centrifugal fans have a side-discharge arrangement that turns air 90°. They produce high static pressures and are nearly always paired with an air-shaping duct.

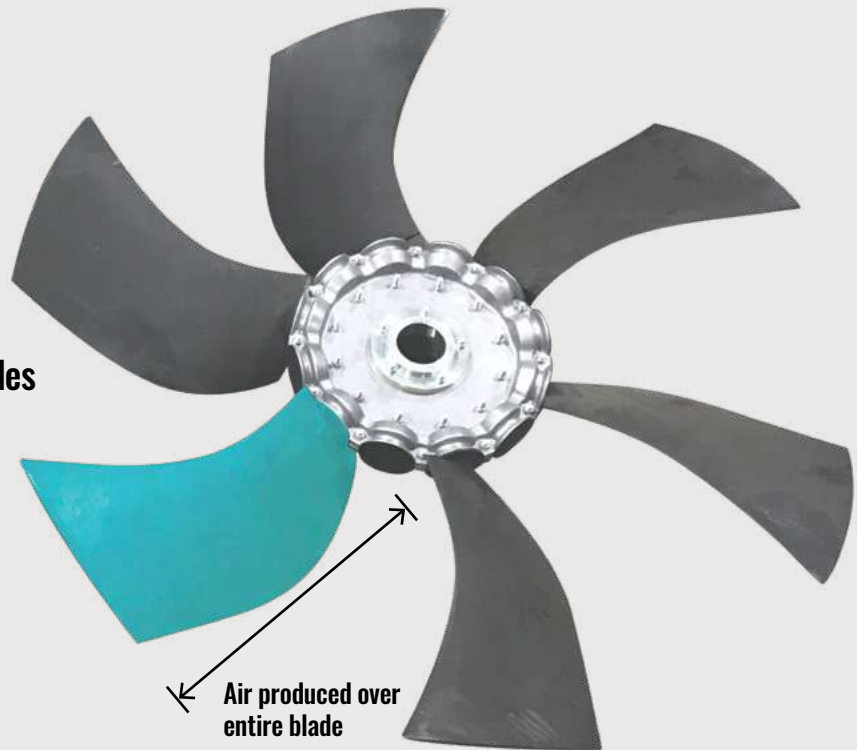
And with that, we now know enough about fans and air behaviour to define the five air handling system designs (and there was much rejoicing). Ultimately, the defining characteristic of each design is the net angle of the air they generate. We have included generic silhouettes for each air handling design, but they are not intended to imply a manufacturer.



Rectilinear fan blades

Radial fans with sickle-shaped/swept blades, or fans with shorter blades and large hubs, are quieter and more energy-efficient. The wider blade will increase the static head of the fan (i.e. create more pressure). Therefore they are more often found on ducted sprayers.

Sickle-shaped fan blades

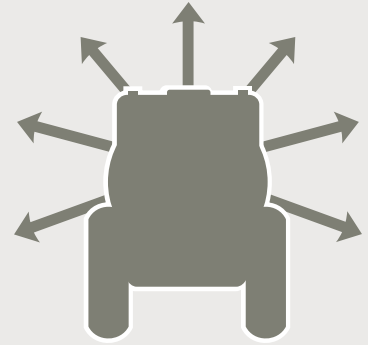


4.2. | Low Profile Radial

The oldest and perhaps most recognizable air handling design, the Low Profile Radial (LPR) sprayer generates air in a radial pattern from one or more axial fans or a duct connected to some other fan style. This is the classic airblast sprayer.

Defining characteristics:

- Wide range of adjustable air energies from virtually zero to high.
- Minor air angle adjustability via deflectors and moveable outlets.
- Net air movement is lateral and upward.



4.3. | Cannon

The Cannon (CN) sprayer generates and channels air through a single duct and delivers the spray as a compact, point-source jet.

Defining characteristics:

- High air energy characterized by high velocity and low volume.
- Extensive air angle adjustability via a vertical duct with positional outlet and deflector(s).
- Usually a single-sided sprayer used to spray over and through multiple rows.

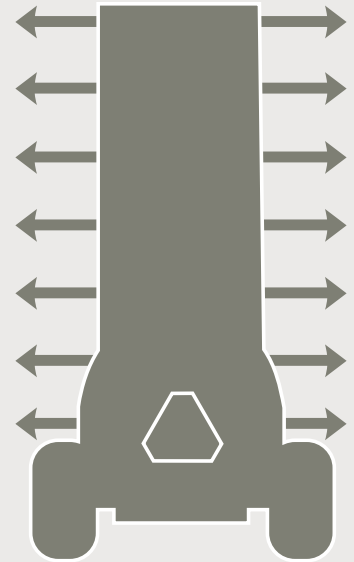


4.4. | Fixed Tower

The Fixed Tower (FT) sprayer generates air from one or more axial fans, multiple straight-through radial or tangential fans. It may employ flexible tubes, tapered bags or solid ducts to redirect air laterally from a fixed central tower. It may feature additional flexible ducts or adjustable deflectors at the top of the tower to spray over and beyond the adjacent rows.

Defining characteristics:

- Wide range of adjustable air energies from virtually zero to high.
- Minor air angle adjustability via deflectors and moveable outlets.
- Net air movement is lateral compared to LPR sprayers.

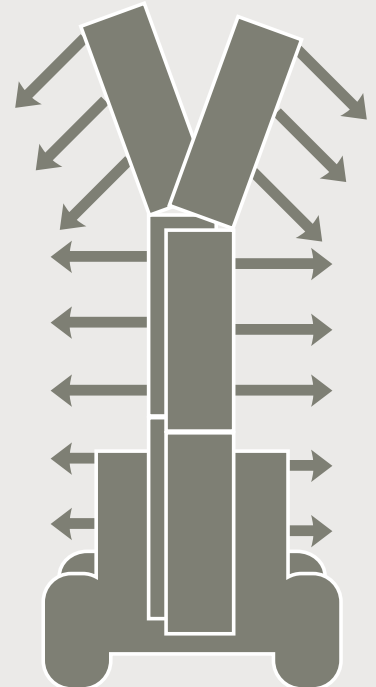


4.5. | Targeting Tower

Similar to the FT, the Targeting Tower (TT) sprayer can focus air angles with a wider range of adjustability, shaping the lateral air output more precisely to the canopy. TT's generate air from one or more radial fans or multiple tangential or straight-through axial fans. They may employ flexible tubes or solid ducts to redirect air generally laterally.

Defining characteristics:

- Medium to high air energy.
- Moderate to high air angle adjustability. Airflow can be subdivided into individually-adjustable sections.
- When the tower exceeds canopy height, net air movement is lateral to slightly downward.

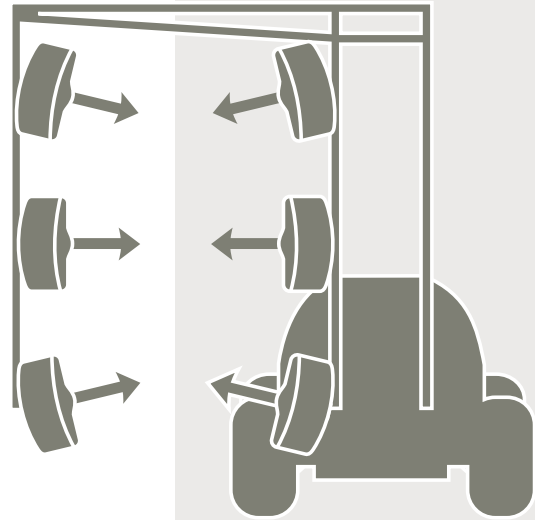


4.6. | Wrap-Around

The Wrap-Around (WA) surrounds the target rows with air outlets. WA's generate air from one or more radial fans or multiple tangential or straight-through axial fans. They may employ flexible tubes or solid ducts to redirect air generally laterally. This creates multiple converging and/or opposing airflows within the row.

Defining characteristics:

- Straight-through axial fan systems are either electric or hydraulic with a wide range of air energies.
- Low to high air angle adjustability via deflectors, moveable air outlets, or fan position adjustments. May also have an adjustable frame.
- Net air movement is ideally neutral to slightly downward.



FINAL THOUGHTS

We acknowledge that there are rare sprayer designs that don't quite fit these categories. But we can still use these designs to describe the anomalies. For example, there are commercially-available sprayers that combine LPR and FT features.

4.7 | Review and consider

- What style of fan does your sprayer use?
- Consider the distance to your target canopies, and the size of those canopies. What fan type and sprayer design would best fit your canopies?
- Does your sprayer have air handling adjustments you have never used?



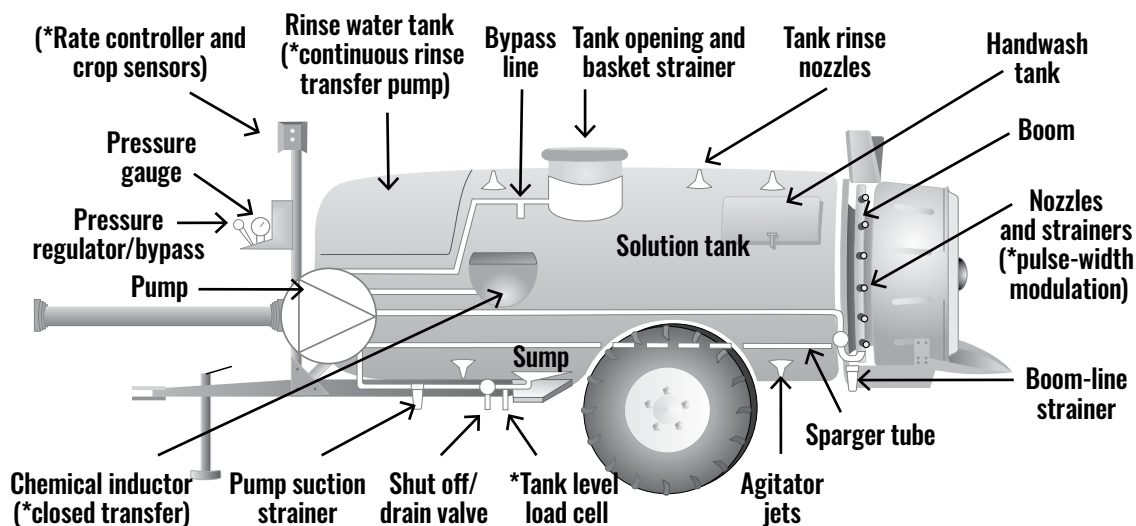
Homemade extensions for upper deflectors.



Chapter 5

Liquid handling systems

This chapter refers to spray liquid-related plumbing, not coolant systems or hydraulic fluid for powering machinery. The extent to which a liquid handling system can be adjusted is fairly limited and depends on its design. Let's begin with a conceptual diagram featuring every plumbing bell-and-whistle we could think of.



This conceptual diagram of an LPR sprayer illustrates the wide array of liquid-handling components available. Many of these rinsate management, loading, and operator safety features are globally accepted ISO standards that are, unfortunately, not widely adopted in North America. Progressive features are marked with an asterisk. For example, pulse-width modulating nozzles can be linked to canopy-sensing optics or prescription mapping for variable rate applications. There are exciting times ahead for air-assist sprayers.

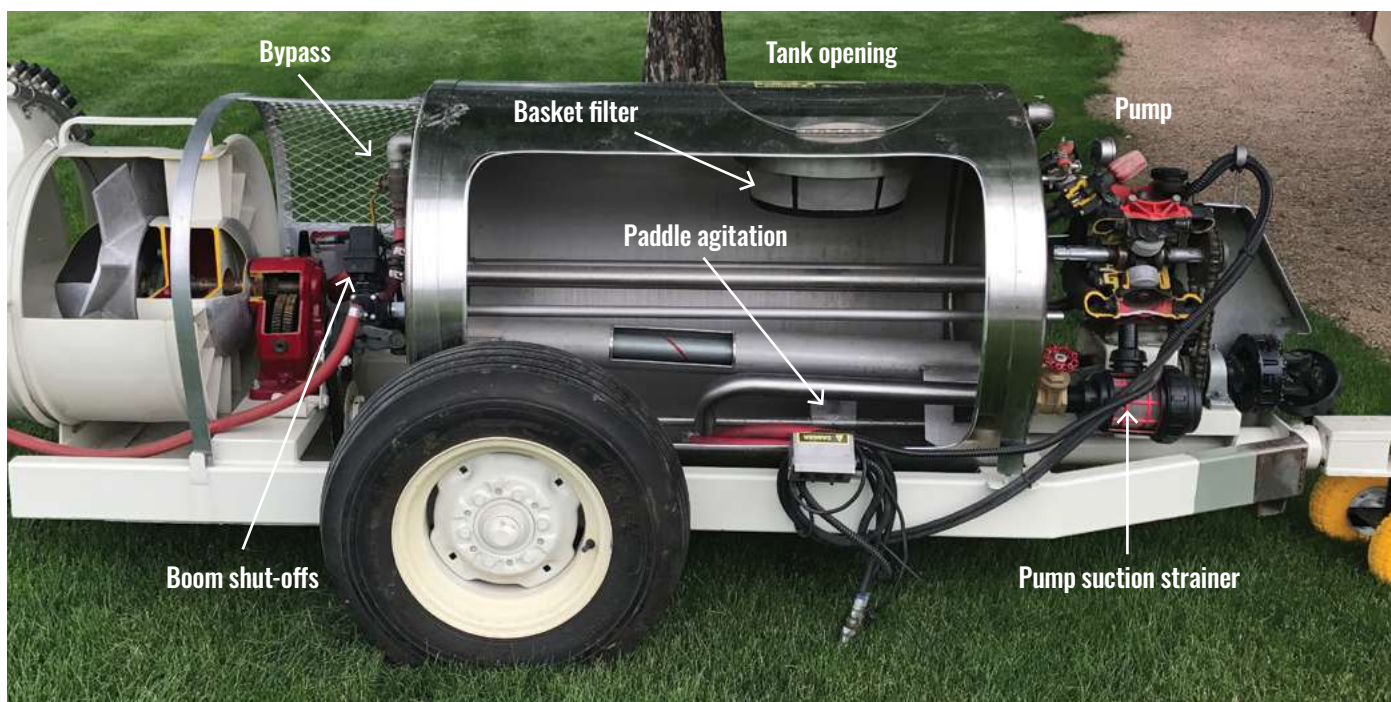


Solution tanks are generally constructed of one of three materials: stainless steel, fiberglass or polyethylene.

5.1. | Agitation

Sprayer agitation is an important function that doesn't get enough attention. It mixes products during loading, keeps them in suspension throughout the application and may be able to resuspend them if the job is delayed or interrupted. There are two agitation methods:

- **Mechanical agitation:** A rotating shaft with paddles. Due to the need for strong shaft support they are normally found in cylindrical stainless-steel solution tanks but are sometimes found in fiberglass. They pass through the wall of the solution tank, so seal or packing maintenance is periodically required. Generally the simplest to operate, with no adjustments required.
- **Hydraulic agitation:** A sparge bar and/or a series of venturi jets that sweep the bottom of the solution tank. They require less support structure from the solution tank and can accommodate the more complex shapes typical of molded solution tanks. They may require manual adjustments for filling, operating and during low tank conditions.



This clever cutaway of an LPR sprayer reveals some basic anatomy. Note the mechanical agitation system designed to sweep the length of the round-bottomed solution tank.

Problems arise when agitation is either inadequate or aggressive:

- **Inadequate agitation:** Emulsions can separate and suspensions can settle. When solids are discovered at the bottom of the solution tank, you can assume the rate applied was lower than intended and likely inconsistent. Adding insult to injury, the operator now has to deal with concentrated rinsate.

This is a condition more often associated with hydraulic agitation, which requires ~30% of the pump's total capacity (see [Appendix 1](#)). If your pump capacity is sufficient, and agitation is still underpowered, consider adding venturi agitators. Position them to sweep as much of the tank bottom as possible.

- **Aggressive agitation:** Foam is created when air and spray liquid mix. Once again, this is more often associated with hydraulic agitation. Air is entrained by the jets during filling or when the tank is low, and this can quickly create a runaway foam problem (a.k.a. foam-overs). More subtly, foaming inside the solution tank during spraying can break pump suction, create a non-uniform suspension that leads to an inconsistent application rate, or give inaccurate tank-level readings.

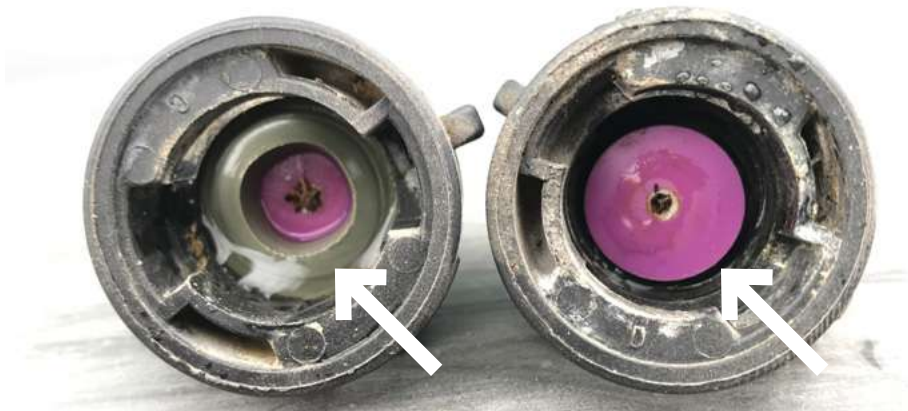
If you don't already have one, it is a relatively simple matter to add a manual valve to restrain agitation when required. If you are using a product that is prone to foaming, keep some defoamer adjuvant at the fill station.



Salespeople don't often demonstrate agitation while the sprayer is spraying. This may hide an insufficient pump diverting all the flow to nozzles. On the upside, everyone stays dry.

5.2. | Filtration

The water quality and materials sprayed should dictate the degree of filtration required on a sprayer. Insufficient filtration can lead to clogged nozzles and pump damage, which negatively impact work rate and efficacy.



An operator neglected to flush their sprayer and did not reinstall the nozzle filters following long-term storage. When we tried to spray, the pre-orifice of every nozzle plugged (repeatedly) until we were frustrated enough to flush the system properly and install the filters.

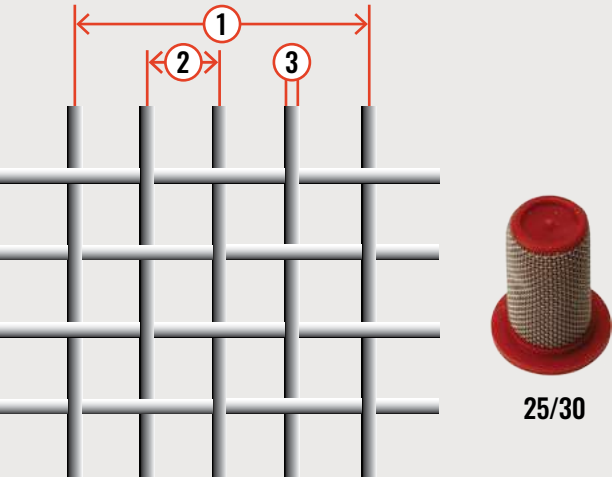


Typically, “strainers” are coarser and “filters” are finer, but the terms are used interchangeably.



If you have never opened your filter housing to rinse the filter, you may be facing a struggle. Always have spare parts on hand in case it doesn’t go well. Replace seals to prevent air leaks that cause cavitation. Clogged filters are a source of contamination and pressure drop.

There are positions for two filters on the suction side of the pump and for three on the pressure side. Each level of filtration between the solution tank opening and the nozzles should get progressively finer. The final filter should be finer than the nozzle orifice. Your nozzle catalog should recommend an appropriate filter mesh size (see figure below).



- ① Number of complete meshes (per 25.4 mm)
- ② Smallest distance between two adjacent wires (mm)
- ③ Thickness of filter wire (mm)

	①	② x ③
COLOUR	# OF MESHES	MESH WIDTH x WIRE WIDTH
Brown Red	16	1.2 x 0.32 to 1.40 x 0.25
Flame Red	25/30	0.45 x 0.32 to 0.63 x 0.16
Gentian Blue	50/60	0.28 x 0.22 to 0.35 x 0.18
Zinc Yellow	80	0.18 x 0.14 to 0.23 x 0.10
Traffic Green	100	0.14 x 0.11 to 0.18 x 0.08
Pure Orange	150	0.10 x 0.07
Light Pink	200	0.07 x 0.06 to 0.08 x 0.05

per ISO 19732:2007 (reviewed 2015)
www.sprayers101.com

This is how filter size is calculated. Colour codes officially changed in 2015 so beware old stock or non-compliant manufacturers.

Few sprayers employ all five levels of filtration, but there are good reasons for each of them:

FILTER LEVEL	PURPOSE AND MESH SIZE
1. Basket strainer	Catches foreign objects during loading (e.g. frogs, insects, leaves, glasses, phones...)
2. Pump strainer	Catches undissolved soluble bags and chunks of dry formulations that could clog the pump intake. Use 6 mesh or coarser (never so fine as to clog and cavitate the pump).
3. Pre-manifold or “main” filter	The heavy lifter, this filter on the pressure side of the pump catches any chunks that could clog a nozzle. Default is 40 mesh. If this is the last filter before nozzles, it should be the same rating as the nozzle chart recommendation.
4. In-line boom filter (a.k.a. T-strainer)	May be redundant with the pre-manifold. Should be at least as fine as the nozzle filter mesh size.
5. Nozzle (slotted strainer or mesh filter)	The last line of defense to ensure nozzle performance. Default is 50 mesh unless otherwise indicated by the nozzle manufacturer, pesticide label, or in very high flow situations. It may also be required to create a tight fit between a hydraulic nozzle and the nozzle body (see Chapter 17.3.5).

5.2.1. FILTRATION IMPROVEMENTS

Operators have a love-hate relationship with their filters. They balance the “nuisance factor” of maintenance and cleanout against the benefits of filtration. A few simple tweaks can greatly reduce the time and effort required.

Most filter casings have a pipe threaded drain plug on the bottom. Install a quarter turn valve to conveniently flush the main filter without removing it (this also drains residual spray). Consider a camlock cap in case the valve gets turned accidentally. Better still, if you route a line from that flush tap back to the tank, and leave the valve slightly open, you’ve re-invented the self-cleaning filter. Filters will still have to be removed and cleaned periodically, but this approach extends your cleaning intervals and helps break up any clumps of undissolved product.



TURBULENT EDDY SAYS...

Some filter casings have automatic shut-offs so you can remove the filter without accidentally draining the tank.

If you don't already have one, consider installing an inline T-strainer at the point where the line meets the boom (see figure right). The mesh size should be finer than the main filter, and at least as fine as the nozzle filters. The surface area of the T-strainer filter is larger than that of the nozzle filters. This will take the load off the nozzle filters so you should not have to clean them as often.

The operator installed this simple but effective T-filter (bottom left). It has more surface area than the collective tip filter area. As long as the mesh size is finer than the nozzle orifice, it's as or more effective than tip filters, and it's faster to clean.)



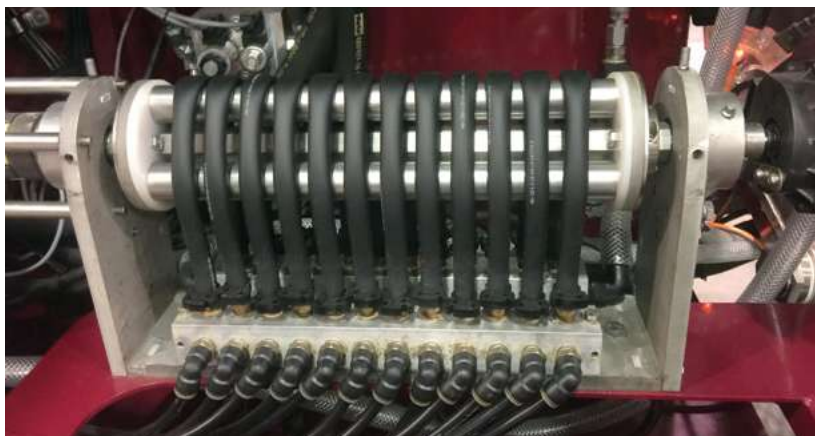
5.3. | Pump

The heart of the sprayer, the pump moves spray liquid from the solution tank to exit through the atomizers. Pump capacity must satisfy the highest possible demand (i.e. your highest-volume application), plus overcome back pressure and run any hydraulic agitation. We discuss sizing a pump in [Appendix 1](#).

Pumps are either positive displacement (diaphragm, piston or peristaltic pumps) or non-positive displacement (centrifugal pumps). Positive displacement means that for every turn of the pump shaft, liquid is pumped regardless of pressure. Fluid is not compressible, so unless it's relieved things could get a little... explody.

Centrifugal pumps, on the other hand, can be “dead-headed” where the flow is turned off entirely while running, with no immediate damage. The following table compares the four pumps commonly found on air-assist sprayers.

	CENTRIFUGAL	DIAPHRAGM	PISTON	PERISTALTIC
DISPLACEMENT / PRIMING / RELIEF	Non-positive. May need priming unless self-priming or gravity-fed. Does not require a relief valve.	Positive. Self-priming. Requires a relief valve.	Positive. Self-priming. Requires a relief valve.	Positive. Self-priming. Does not require a relief valve.
PRESSURE RANGE	<12.5 bar (180 psi) but generally best from 1.5-5.5 bar (20-80 psi).	<50 bar (725 psi) but generally best from 10.3-24 bar (150-350 psi).	10-525 bar (100-7,500 psi).	<3 bar (50 psi) depending on tubing.
OUTPUT VOLUME / FLOW	<700 L/min. (200 gpm). High volumes relative to pump size. Flow decreases quickly with back pressure.	10-250 L/min. (5-65 gpm). Flow proportional to pump speed and independent of pressure.	<40 L/min. (10 gpm). Flow proportional to pump speed and independent of pressure.	0-200 L/min. (0-50 gpm). Flow proportional to pump speed.
REVOLUTIONS PER MINUTE (RPM)	3,000-6,000 rpm. Best performance at higher speeds.	540 rpm.	540 rpm.	<540 rpm.
RUN DRY WITHOUT DAMAGE?	Not unless specifically designed with wet seals.	Yes.	Yes, for short periods.	Yes.
NOTES	Good for high flow, lower pressure requirements. If hydraulic-driven, no PTO is required. Good for abrasive materials, suspensions and slurries. Creates smooth flow that does not require pulse suppression.	Good for higher pressure requirements. Compact for the amount of flow and pressure developed.	Wide range of spraying applications. Highest pressure capabilities, low to mid-range flows. Construction similar to a car engine.	Very good for viscous and abrasive sprays. Linear flow rate over rated speed range also makes the pump a flowmeter. One channel per nozzle for precise flow distribution over boom.



While rare on air-assist sprayers, multi-channel peristaltic pumps have several benefits, such as dedicating one channel per nozzle for precise flow distribution over the boom.



We prefer pipe dope over PTFE tape. If you take plumbing apart, the shredded tape ends up in your system. Better yet, use flange fittings wherever possible.

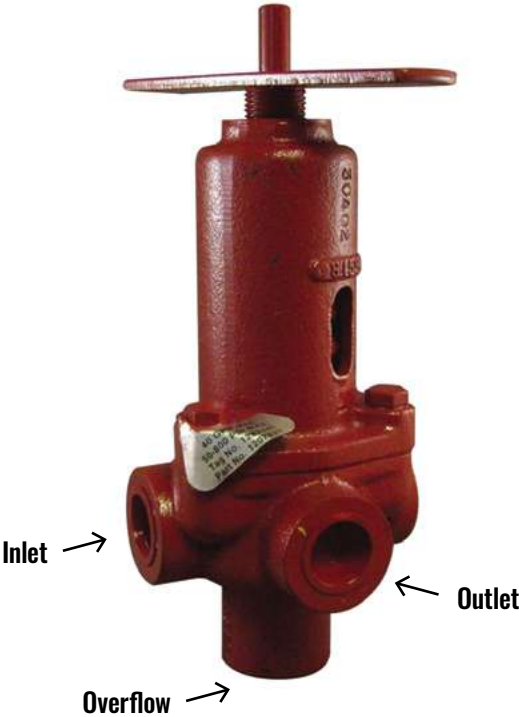
5.4. | Flow regulation and relief valves

The operator has to be able to control how much spray is applied. A properly-sized pump should produce more flow than is needed and work in conjunction with the atomizers to regulate that flow (see [Appendix 1](#)). Since atomizers are a mechanical system all their own, we discuss them in detail in [Chapter 6](#). That leaves two ways for an operator to address excess flow:

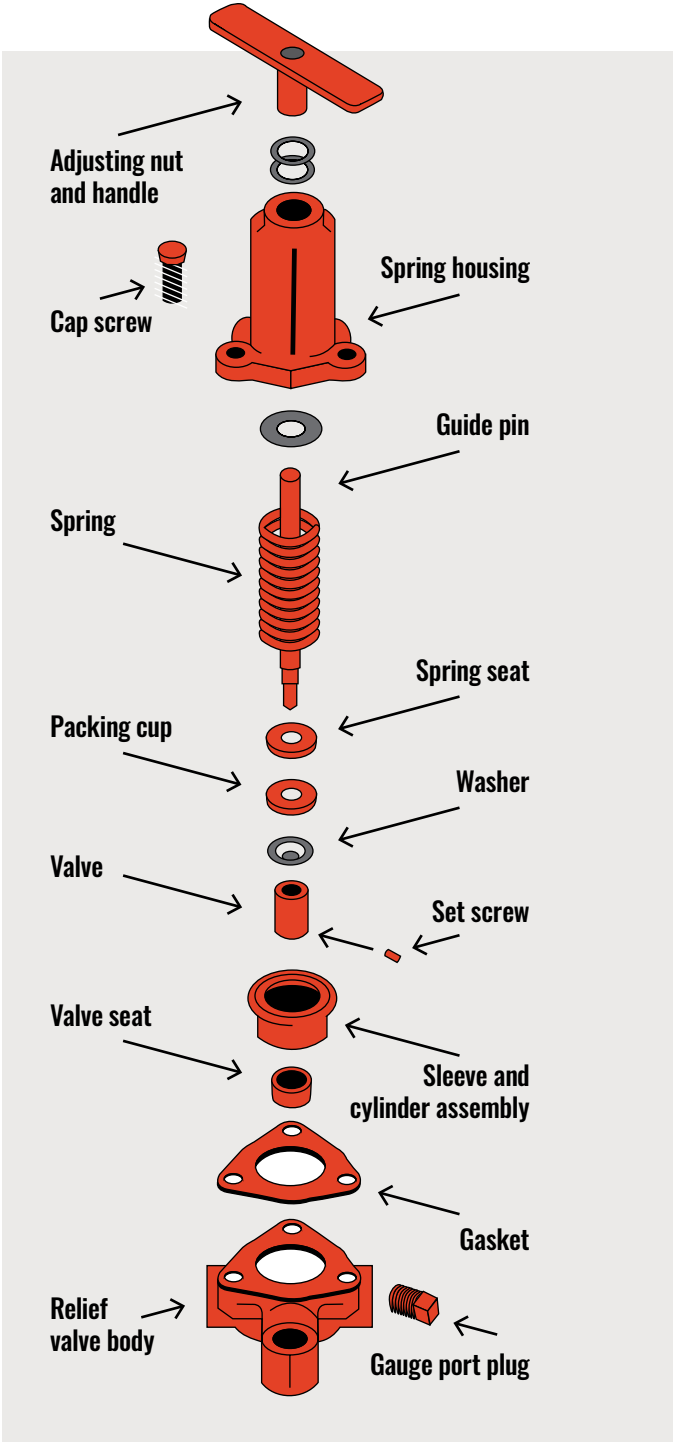
- Control the speed of the pump.
- Throttle or bypass a portion of the flow.

While common in modern field sprayers, it's uncommon for our sprayers to use pump speed to regulate flow. This is mostly due to the level of sophistication of the control systems and the relative size of the pumps. For positive displacement pumps, agitation must be controlled separately (e.g. use a second pump or mechanical agitation). It's possible, but generally impractical, to do this with hydraulically-driven centrifugal pumps because flow is inversely exponentially related to speed. That means a small reduction in centrifugal pump speed can cause a big drop in pressure.

Far more commonly, flow is controlled by a relief valve positioned between the pump and the nozzles. The valve is actuated by a spring-loaded piston or diaphragm, opening and closing in response to changes in pressure. The operator sets the desired operating pressure, and any additional pressure forces the valve open, diverting excess flow back to the solution tank via a bypass.



Exploded view of a classic piston relief valve. Manufacturers match spring tension to the maximum pressure of the pump for safety. If an operator attempts to make a low pressure application when the relief valve is designed for a high pressure pump, the spring may be too stiff to respond accurately. This can cause pressure spikes and poor regulation. Test the sprayers' ability to regulate low pressure flow by spraying from one and then both sides while observing a pressure gauge positioned at the boom.



Let's introduce two terms to describe how relief valves work: "Cracking Force" and "Stiction". Cracking force is the pressure where a valve first begins to bypass flow. Stiction is the threshold of static friction that must be overcome before that valve begins to move. The practical implication is that system pressure spikes briefly to open the valve before settling back to the set point. It takes a little extra effort to get things moving. There are exceptions and overlaps between piston and diaphragm relief valve designs, but generally:

- **Piston relief valves:** Better suited to high pressure pumps. Their design inherently has a higher cracking force, and since stiction is the same regardless of pressure, it's less noticeable at high operating pressures. Further, the pulsation of piston and diaphragm pumps provides extra force to overcome stiction without the operator even noticing.
- **Diaphragm relief valves:** Better suited to centrifugal pumps. They have low stiction and cracking force, so they are more responsive to small pressure changes. It's difficult to manufacture a diaphragm that is both sensitive to pressure change and resistant to high pressure, so most of the hardware available leans toward the latter. For their size, they have very high bypass flow capability.

The role of the relief valve changes if a rate controller system is installed, and we discuss rate controllers in [Appendix 2](#).



**LAMINAR
FLO SAYS...**

Relief valve cavities pack with dirt, springs and seats wear out, and assemblies can seize if they become caked with chemistry or rust. They require regular cleaning and maintenance.

5.5. | Pressure

Pressure influences nozzle flow, spray geometry and droplet size (see Chapter 6.2.). Most operators rely on a glycerin-filled gauge to monitor pressure, and yet have never tested or replaced it. Here are a few indications that your pressure gauge is ready for retirement:

- Gauge has an opaque or unreadable face.
- Fluid leaking (or mostly gone).
- Needle does not rest on zero pin when sprayer is not under pressure.

When replacing a worn gauge, choose a scale that is twice as high as your typical operating pressure. For example, if you spray at 10 bar (~150 psi), your gauge should read no higher than 20 bar (~300 psi). This better resolves pressure changes and allows a quick glance to confirm the needle is pointing straight up. We also suggest buying a gauge with a larger face to make it easier to read (something we may not have written 10 years ago).

Gauge accuracy should be checked periodically. Rather than investing in an expensive manometer, we suggest you copy this grower-inspired design (see figure below). It requires an air compressor, which most farms already have, and \$50.00 worth of plumbing materials. The suspect gauge is set in the tee and compared to an accurate gauge set in the elbow.



**TURBULENT
EDDY SAYS...**

If a pressure gauge experiences a physical impact, or a sudden pressure spike, it could be permanently damaged.



LEFT: Components required to construct a homemade manometer.

RIGHT: The assembled manometer requires an air compressor to test gauge accuracy.

Beware budget pressure gauges, which can vary by as much as 10% right off the shelf. How do you know if a new gauge is accurate? We recommend buying a few and testing different combinations using your homemade manometer. Keep the gauges that agree and return the faulty ones. We're sure the dealer won't put the inaccurate gauges back on the shelf...



A pressure-sender or transmitter can replace a gauge. They can be wired directly to a rate controller or purchased with a digital readout. It's more expensive, but more reliable than budget-level liquid filled gauges.

5.5.1. PRESSURE DROP

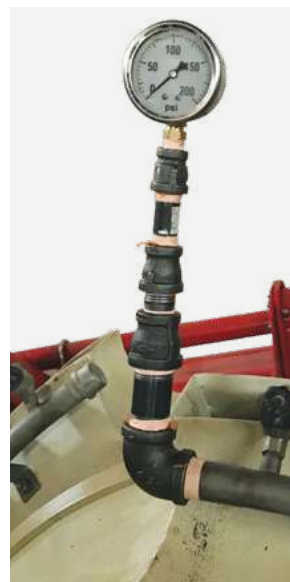
We've mentioned pressure drop a few times already. Pressure drop is the differential between the pressure at the pump outlet and the pressure at a given nozzle. The degree of pressure drop is contingent on:

- The cumulative impact of friction, which increases with distance.
- Any obstructions, such as reduced hose diameter, sharp bends, or clogged filters.
- Vertical height, which creates head pressure.

You may never notice pressure drop, but if it's significant it can cause liquid to divert to the bypass rather than flow out the highest nozzles on the boom. The impact depends on your typical operating pressure and sprayer design:

- **Pump type matters:** Pressure drop is less of an issue for positive displacement pumps. A positive displacement pump will draw more horsepower to compensate, pushing against back pressure to maintain flow. A centrifugal pump will lose flow to back pressure.
- **Operating pressure matters:** Pressure drop is relative, so it's less of an issue at higher operating pressures. For example, at 17 bar (250 psi) a 1 bar (15 psi) pressure drop reduces operating pressure by a tiny 0.06%. At 5.5 bar (80 psi), the same 1 bar (15 psi) pressure drop reduces pressure by 19%. According to our friend, the inverse square law, that's a flow reduction of 4.4%! Always operate a sprayer above 1.5 bar (20 psi).
- **Boom height matters:** Pressure drop is more of an issue with vertical booms. Vertical booms create a pressure drop of about 0.15 bar/m (0.75 psi/ft.) of height. This means the nozzles atop a 3 m (10 ft.) tower experience 0.5 bar (7.5 psi) less pressure than the bottom ones. Most hydraulic nozzles have anti-drip diaphragm check valves with actuator springs rated ~0.6 bar (10 psi) (see Chapter 17.5.1.). At lower operating pressures, the top nozzles may reduce flow or even shut down while the lower nozzles carry on spraying. This happens with surprising regularity at row-ends (unnoticed by the operator who is focused on negotiating the turn). It's a good reason for installing a rate controller with low pressure limits (see Appendix 2).

We can diagnose the differential by installing a second gauge temporarily at the furthest nozzle position or plumbing one permanently at the end of a boom (see figure below).



LEFT: Remove the nozzle cap, or the entire nozzle body, to temporarily install a gauge in the furthest nozzle position. Several fitting solutions are possible but contact your dealer because they may be hard to find. **RIGHT:** Alternately, permanently plumb a gauge at the end of a boom, oriented however it is easiest and safest to read.

When the second gauge is installed, follow these steps:

1. With the tractor parked, bring up the rpm to get the lines to the desired operating pressure.
2. While wearing PPE, engage your typical nozzle configuration and begin spraying.
3. Compare boom pressure (at the furthest nozzle position) to your desired pressure (usually read at the pump).
4. If the boom gauge reads lower than the main gauge, there is a pressure drop.



LAMINAR FLO SAYS...

To avoid problems inherent to pressure drop, always operate a sprayer above 1.5 bar (20 psi).

For positive displacement pumps, adjust the relief valve until the gauge on the boom reads the desired pressure. For centrifugal pumps, it is possible to make small changes to the pressure, but more important to note any pressure differential for later considerations regarding nozzle output and spray quality.

During operation, a temporary pressure increase instead of a drop is possible. 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, thereby increasing the boom output.

Pressure increase can also be caused by a sticky relief valve. Disassemble it and look for grit in the barrel of the valve. If it is damaged, replace it. If not, lubricate the parts. Sometimes, your relief valve may be mechanically sound, but the spring may not be sized to match a reduced operating pressure. Relief valve springs match the maximum pressure range of the pump. Sprayers operated at lower pressure may be unable to compress the spring. This is common when people switch from disc-core nozzles operated at higher pressure to molded nozzles operated at lower pressure. This would manifest when one boom is shut off for single-boom operation; there may not be enough pressure to open the bypass. As a result, flow increases over the remaining boom. Recognizing this problem, some operators have teed-in a second relief valve capable of finer adjustments at lower pressures. Make sure you know what you're doing if you're considering this option.



A classic homemade hop sprayer on display at Hopsteiner Farm.



Cousin to the sprayers described in this book, a stationary greenhouse fogger produces Fog to Very Fine droplets.

5.6. | Review and consider

- Can you trace the flow from tank to atomizer on your sprayer? Where would flow encounter restrictions or benefit from another level of filtration?
- What is the highest flow demand you place on your pump? Does it have sufficient capacity to satisfy that demand, plus account for agitation and back pressure?
- Consider watching the highest nozzle positions as you slow to take a turn. What will you see? Where could you install a second pressure gauge to monitor pressure drop?
- Have you ever disassembled and cleaned your relief valve? When was the last time you opened your filter housing(s) and cleaned the filter(s)?
- Which liquid handling parts are most likely to wear on your sprayer? Do you know where, and how long it would take, to get replacement parts?



This PTO-driven homemade berry sprayer was developed on a Hutterite farm in Manitoba, Canada.



Why get a big sprayer if you don't need one? Mow while you blow with a small-crop-appropriate, engine-driven tow-behind sprayer.


A person wearing a white protective suit is operating a red tractor with a large orange reel. The tractor is spraying a dense green vine-covered tree. The scene is outdoors, with a utility pole and power lines visible in the background. The tractor has a large black tire and a smaller front tire. The reel is orange with a black wire mesh. The person is sitting on the tractor, holding a spray wand. The tree is covered in thick green vines. The utility pole is made of wood and has some wires attached to it. The sky is clear and blue.

PHOTO CREDIT: DAN GROENENDALE

Chapter 6

Atomization systems and droplet size

Atomization is the conversion of liquid into droplets. A sprayer's air handling and liquid handling systems converge at the point of atomization, which is typically a hydraulic nozzle. The relative influence of air, liquid and/or mechanical energy can be used to define three atomization systems. Take a breath and we'll begin with a deep dive into the subject of atomizers and droplet size.



TURBULENT EDDY SAYS...

Sprayer enthusiasts are sometimes called “Nozzle Heads”, which we grumble about but secretly enjoy.

6.1. | Different game, different rules

Spray quality describes the size of the droplets produced by a nozzle. Droplet size is the biggest factor affecting droplet behaviour, so it gives us some sense of how a nozzle will perform. Most spray quality guidance pertains to herbicide applications in broad acre crops like grains and beans. This is motivated by the need to lay down a uniform swath and prevent drift. Coarse droplets make sense when gravity and droplet momentum are the dominant considerations. However, the rules for air-assist sprayers are different.

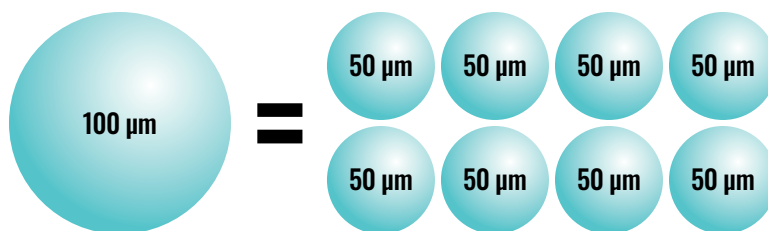
1. Coverage is king. Most of the products sprayed in our universe are not systemic. Therefore, as long as they arrive intact, finer droplets are preferred because they deliver a more consistent dose to every target surface ([see Chapter 14](#)).
2. Coarser droplets move faster and more predictably than finer droplets. But we don't often rely on the droplet's kinetic energy. Our primary tool for drift mitigation and coverage is air configuration relative to the target canopy.
3. Coarser droplets are harder to manipulate. They have more intrinsic energy (momentum) than finer droplets and don't respond well to air energy.
4. Our three-dimensional canopies are often deeper, denser and further away from the nozzles than most field crops. Finer droplets assisted by air do a better job of penetration and overall deposition ([see Chapter 12](#)).

6.1.1. DROPLET SIZE

Droplet diameter is measured in microns (a.k.a. micrometers or μm). A micron is 0.001 mm (a 25,400th of an inch). For reference, the thickness of a human hair ranges from 50 to 100 μm . Each droplet is a three-dimensional, or cubic, volume of liquid that can be described using geometry. Turns out your teacher was right – you do need geometry!

$$\text{Volume of a sphere} = \frac{4}{3} (\pi \text{ a radius}^3)$$

This formula tells us that there is enough volume in a single droplet to make eight droplets that are half as wide. We call this “The Rule of Eight”. Several factors complicate this relationship during spraying but suffice it to say as the average droplet size decreases, the number of droplets increase... a lot.



“The Rule of Eight”: A 100 μm diameter droplet has the same volume as eight 50 μm diameter droplets. This means a 500 μm diameter droplet has the same volume as 125,000 10 μm diameter droplets.

The spray from a single atomizer typically contains many different droplet sizes. There are no commercially available air-assisted sprayers that produce a monodisperse (i.e. single droplet size) spray. So how do we usefully and meaningfully describe the droplet sizes a nozzle produces?

In agriculture we describe a population of droplets using the Volume Median Diameter (VMD) or $DV_{0.5}$. This is the droplet size where half the spray volume is composed of finer droplets and the other half is composed of coarser droplets. Let's be clear: this does not mean half the droplets are smaller and half are larger. It represents volume, not the number of droplets.

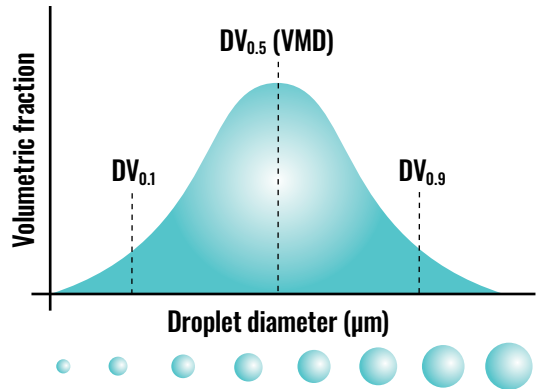
Two nozzles might have the same VMD, but the range of droplet sizes they produce can be radically different. We capture this by assigning two more values: $DV_{0.1}$ and $DV_{0.9}$ (see the figure right). $DV_{0.1}$ is the droplet size where 10% of the spray volume is composed of finer droplets. The smaller the $DV_{0.1}$, the more droplets are prone to drift and evaporation. $DV_{0.9}$ is the droplet size where 10% of the spray volume is composed of coarser droplets. The larger the $DV_{0.9}$, the more of the spray volume is tied up in Coarse droplets that are prone to dripping, bouncing or running off the target. The closer $DV_{0.1}$ and $DV_{0.9}$ are to the VMD, the more uniform the droplet sizes in the spray.

Relative Span (RS) can be used to describe droplet size variability. The value determined by subtracting the $DV_{0.1}$ from the $DV_{0.9}$ and dividing by the $DV_{0.5}$. The smaller this number, the less variation in droplet size in the spray.

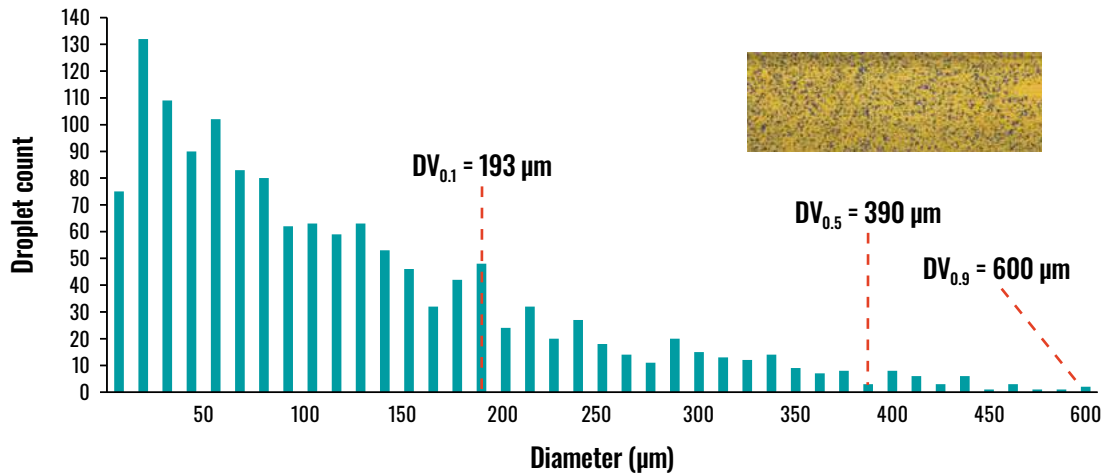
While it is helpful to describe spray using $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$, these are all statistical derivations based on volume. They don't tell you anything about the actual number of droplets. To learn more about the droplets an atomizer is producing, we turn to Droplet Size Distribution (DSD), which expresses a population of spray droplets by size and quantity.

For example, let's sample a volume of spray produced by a hollow cone nozzle. Then let's create a graph that shows the actual number of each droplet size (see [histogram on the following page](#)). DSD reveals the large population of finer droplets versus coarser droplets in a way that $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ do not.

The high number of finer droplets in this histogram can be good news for an air-assist sprayer operator. Operators should be concerned with keeping droplets large enough to remain viable (see [Chapter 12.1.](#)), but not so large that they waste volume and reduce droplet count. Somewhere between the $DV_{0.1}$ and the $DV_{0.5}$ in this histogram the droplets become large enough to behave ballistically, greatly reducing the potential to penetrate dense canopies (see [Chapter 12.2.](#)).



This hypothetical curve uses $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ to define an atomizer by the span of droplet sizes produced and their relative volume.



When a volume of spray produced by a hollow cone nozzle is organized by droplet count relative to droplet size, we can see there are far more small droplets than large. Inset is the water sensitive paper that was scanned and analyzed to produce this graph. This illustrates the impact a few large droplets have on the VMD.

6.1.2. NOZZLE CLASSIFICATION

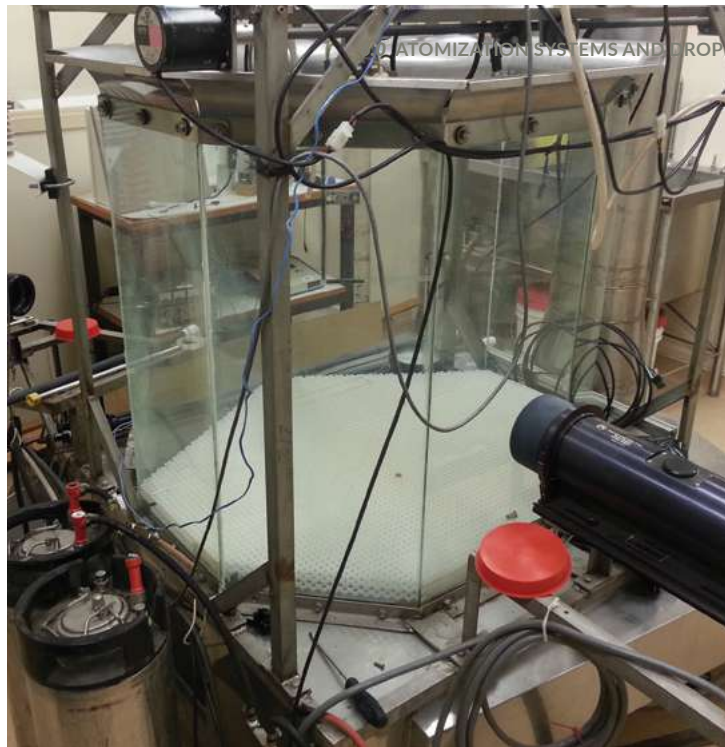
It can be difficult (or impossible) to access information about a nozzle's $DV_{0.1}$, $DV_{0.5}$, $DV_{0.9}$, or DSD. Instead, a hydraulic nozzle's spray quality is described in more general terms thanks to the American Society of Agricultural and Biological Engineers (ASABE) standard S572.3 and the similar ISO 10625:2018. The two standards were recently harmonized, but they are maintained separately because of their widespread use in regulatory activity.

The protocol classifies nozzles ranging from "Extremely Fine (XF)" to "Ultra Coarse (UC)" (see figure right). Most nozzle manufacturers voluntarily comply with this standard and provide the classifications for their nozzles. We'll discuss how to choose a nozzle using the manufacturer's nozzle tables in [Chapter 17](#).

CATEGORY	SYMBOL	$DV_{0.5} \mu\text{m}$	Air-Assist Droplet Range
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	EC	428 - 622	
Ultra Coarse	UC	>622	

S572.3 spray quality categories. $DV_{0.5}$ is provided here for relative comparison, but since its value depends on the measurement method, it is more accurate to focus on the symbols.

The classification protocol compares the test nozzle to a known reference nozzle. This largely negates any variation in instrument (typically laser diffraction) or lab setup when measuring droplet sizes. It doesn't matter what the actual $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ are for the nozzle in question; only how it stacks up against the reference nozzle under the same conditions. This means whatever the "Medium" reference nozzle does in that lab's test stand, a comparable nozzle will also rank as "Medium".



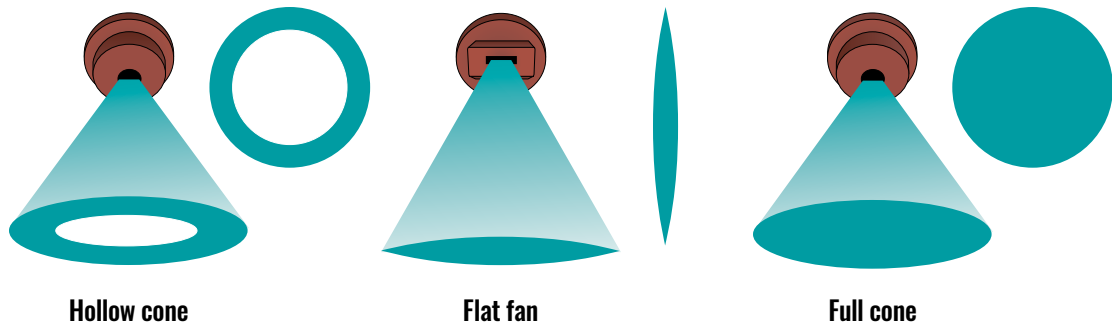
A phase doppler particle analyzer. A droplet passes through the intersection of two laser beams and scatters the light. The droplet's size and velocity are measured. PHOTO CREDIT: TOM WOLF

6.1.3. SPRAY QUALITY FOR AIR-ASSIST SPRAYERS

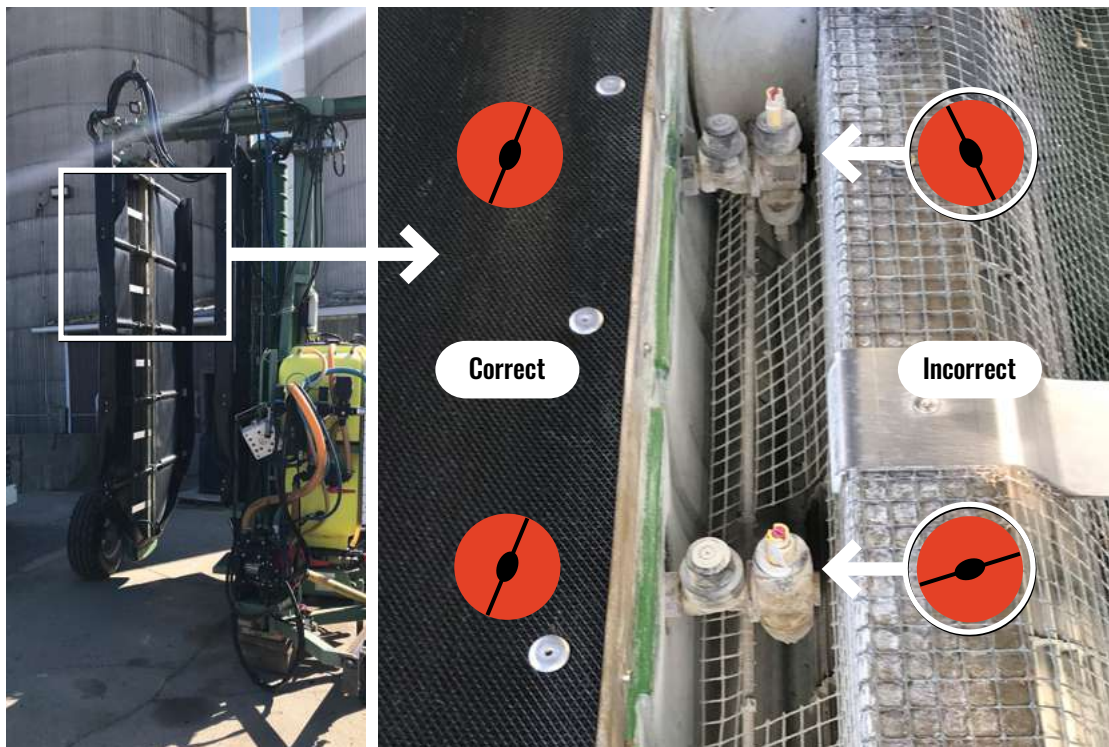
It was important to explain how droplet size is discussed in agriculture so you would know what is, and what is not, relevant to air-assist spraying. A nozzle's spray quality category implies a certain droplet behaviour, but the influence of air energy can reduce $DV_{0.5}$ considerably (see Chapter 6.5.1.). This means the nozzle choice and operating pressure may have an unpredictable impact on the size of the droplet that reaches the target.

6.2. | Hydraulic nozzles

Hydraulic nozzles rely on hydraulic energy in the form of liquid pressure. Pressure forces spray liquid out through the nozzle orifice at a rate described by the inverse square law (i.e. quadruple pressure gives double flow). Hydraulic nozzles produce a moderate range of flows and a wide range of droplet sizes. Nozzle size meters the flow while the orifice shape(s) define the spray geometry and spray quality. The air handling system can create secondary atomization, making the spray quality from a hydraulic nozzle finer. How much secondary atomization occurs depends on the liquid/air intercept angle and the relative velocities of air and liquid (see Chapter 6.5.1.).



The most common hydraulic nozzle spray geometries. On a horizontal boom, the spray from flat fan nozzles should overlap 100% at target height. On a horizontal boom, the spray from hollow cones should touch, but not overlap at target height. On air-assist sprayers with vertical booms, nozzle spacing is less relevant because droplets redistribute in the air. Nevertheless, it is still important to maintain some visible overlap between nozzle outputs to prevent gaps in coverage.



Be aware of orientation when using flat fan nozzles. Flat fans can sometimes turn inside round caps, reducing overlap and creating gaps in coverage.

6.3. | Twin-fluid nozzles

Twin-fluid nozzles include pneumatic and air-shear nozzles. Designs vary in this nozzle category (see figures below), but they all require air and liquid to interact either inside or just outside the nozzle. Pneumatic nozzles tend to be more restricted in their flow range and more precise in their droplet size (think of a painter's airbrush), but both produce a wide range of flows and create the finest droplet sizes.



Air-shear twin-fluid nozzles. A stream of spray liquid is propelled onto a teardrop-shaped deflector before being shorn into droplets by the entraining air. **INSET:** Air-shaping Venturi tube removed to expose the deflector.



Air-shear twin-fluid nozzles on a cannon sprayer. Spray liquid is released into fast-moving air that shears it into droplets as it flows to the edge of the plates.

Twin-fluid nozzles rely on the interaction of air energy and liquid energy to form the spray, and their impact on droplet size may not be intuitive. Regardless of the specific nozzle or flow rates, the higher the air energy relative to liquid energy, the finer the spray quality. This characteristic permits the manipulation of droplet size without changing liquid pressure.

The liquid flow is determined by a combination of hydraulic pressure, size-restriction (e.g. an in-line orifice plate) and the internal geometry of the nozzle itself. To further complicate things, air velocity can create suction from the Venturi effect, so the flow rate in many twin-fluid nozzles will vary with or without air (see Chapter 16.2.).

6.4. | Rotary atomizer nozzles

For rotary atomizer nozzles, spray quality is independent of air energy and liquid pressure. Instead, it relies on mechanical energy from the spinning atomizer. Spray liquid is released onto a spinning disc or into a spinning wire mesh basket. They are nearly always driven by an electric or hydraulic motor at constant speed. The speed is the primary means of determining droplet size. Both are capable of atomizing viscous and abrasive sprays into almost any droplet size desired. Flow is driven by a positive displacement pump (e.g. peristaltic) or introduced via an upstream calibrated orifice.

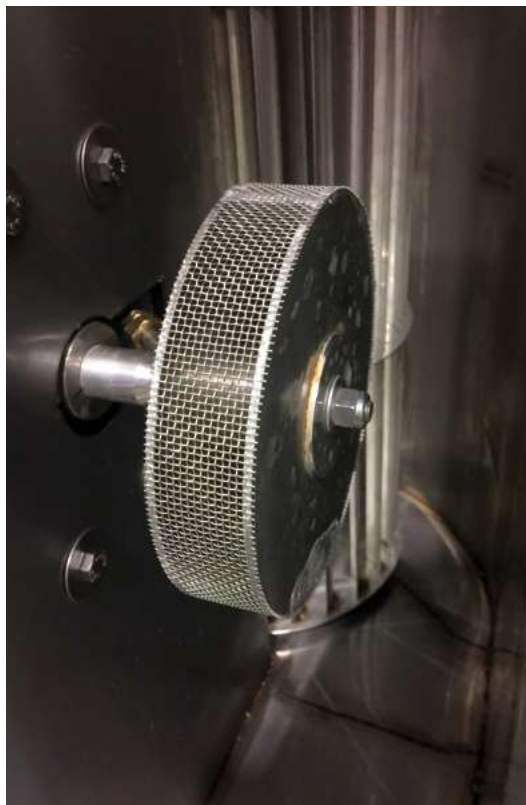
6.4.1. SPINNING DISC NOZZLE

This nozzle is highly uncommon on air-assist sprayers, but we'll mention it. Centrifugal force carries a sheet of liquid along the spinning disc to a serrated edge. The liquid then transitions from ligaments to droplets with a very uniform droplet size (i.e. a small relative span). It has a fairly narrow range of flows which correspond with precise droplet sizes.

6.4.2. WIRE MESH BASKET

Large droplets are slowly introduced to the center of the atomizer. The violent, high speed collision with the spinning wire mesh makes droplets. Imagine hitting a water balloon with a tennis racket. Flow ranges from a few mL/min (~0.1 oz./min.) to 16 L/min. (4.25 gpm) with no change in nozzle configuration, but droplet size distributions become less precise at high volumes.

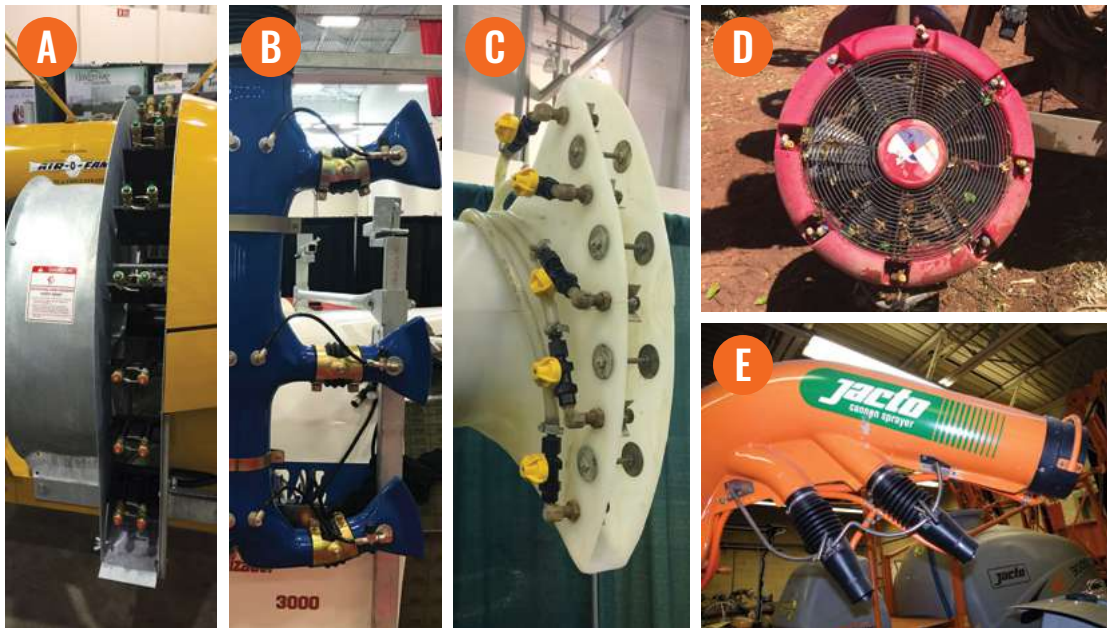
A wire-mesh basket rotary atomizer nozzle. Liquid is injected into a first-stage cup at the middle of the atomizer via a hollow shaft or injector. The cup distributes the fluid radially, and large, slow moving droplets are pulverized when they hit the spinning cage. The resultant finer droplets are flung out of the spinning cage and entrained by the air from the tangential fan (shown in the background).



6.5. | Spray outlets

A spray outlet is not the atomizer itself, but the mechanical structure where droplets and air merge to become spray. Regional and manufacturer-specific terms like spray heads, conveyors, venturis, flutes, jets or cannons could also be used, but we'll keep it simple.

Some sprayer designs have a series of independent spray outlets, permitting a range of air settings, spray qualities and liquid flows. Other designs are less flexible. Operators should learn which adjustments their sprayer is capable of in order to use it in a manner appropriate to its design.

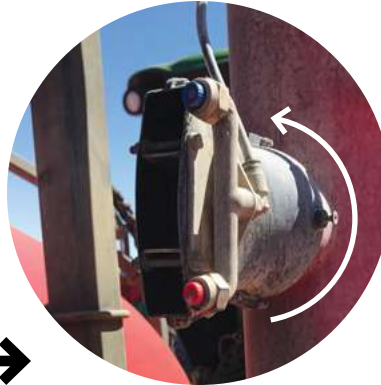


Spray outlet design is diverse. **A.** This outlet permits changes to liquid flow and spray quality by changing nozzles. Changes to air energy are limited to the entire boom. Vertical nozzle and air angles are simultaneously adjustable using an innovative deflector/nozzle assembly. **B.** This outlet permits changes to liquid flow and spray quality by changing hydraulic nozzles (located inside each air outlet). Changes to air energy are limited to the entire boom. Vertical nozzle and air angles are simultaneously adjustable. **C.** This outlet permits wide (albeit unpredictable) changes to spray quality by varying liquid flow. Vertical nozzle and air angles are simultaneously adjustable. Some variations permit adjustment to opening width, altering air energy. **D.** Spray quality and liquid flow can be adjusted by changing nozzles and nozzle body angle. Variable speed fans allow a wide range of air energy. The spray direction is adjusted by aiming the fan. **E.** This outlet permits minor changes to spray quality, and liquid flow can be adjusted for each outlet using in-line orifice plates. Air angles can be adjusted for each outlet, but air energy is fixed.

Before flip:
nozzles
behind air



After flip:
nozzles in front
of air



Direction of travel

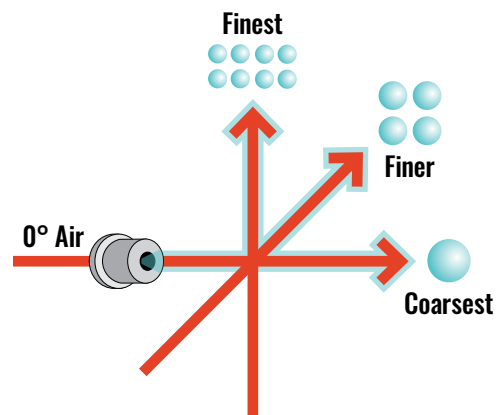
The air stream and spray liquid/droplets must intersect to become spray. **LEFT:** These hollow cones were trailing behind the air outlet. Only a portion of their droplets intersected the air, leaving the rest suspended behind the air stream as the sprayer passed.

RIGHT: We turned the spray outlet 180° so the nozzles preceded the air. This entrained more of the droplets and coverage was markedly improved in grape canopies.


6.5.1. SECONDARY ATOMIZATION

When droplets and air combine to form spray, the air energy can make droplets finer. How much finer depends on the relative air speed and the original droplet size. For example, sprayer generated air speeds over 200 km/h (125 mph) can make the VMD of an air induction hollow cone nozzle comparable to that of a conventional hollow cone. The relationship can be generalized as follows:


- The coarser the original VMD, the greater the impact of secondary atomization.
- The faster the air relative to liquid velocity, the finer the spray quality. However, air velocities below 100 km/h (60 mph) typically aren't fast enough to induce secondary atomization.
- The larger the angle between the nozzle and air angle, the finer the spray quality (see figure right).

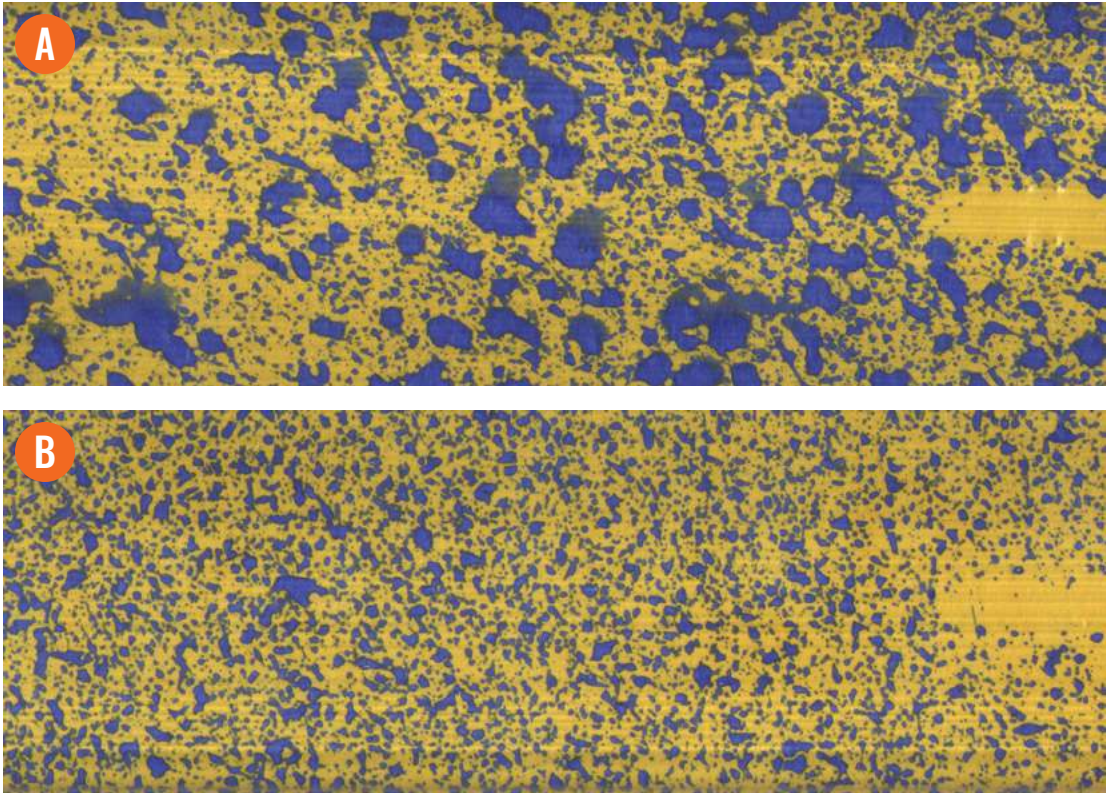


The interaction between spray liquid (blue outline) and air (red arrows) makes spray quality finer. The larger the angle of the air relative to the liquid stream from the nozzle, the finer the spray quality.



Molded hollow cone nozzles positioned outside the air outlet on a LPR sprayer. The nozzle in the foreground is conventional, producing a finer spray quality compared to the two air induction hollow cone nozzles at the top of the boom. Secondary atomization will make the spray quality finer (relatively more so for the air induction nozzles) because they are positioned outside of the air outlet, angled into the air.





Two water sensitive papers sprayed with the same air induction nozzle. **A.** The nozzle located in the air stream of an LPR sprayer does not experience as much shear and spray quality is coarser. **B.** The nozzle located outside the air stream of a different LPR sprayer, angled inward, experiences more shear and spray quality is finer.

6.6 | Review and consider

- What spray qualities do your atomizers produce?
- Does your sprayer design create secondary shear?
How much influence does that have on the spray quality?
- Can you change the spray quality that your atomizer produces?
Would there be any benefit in doing so?



Chapter 7

Canopy

Any discussion of a sprayer's capabilities or configuration is irrelevant without also considering the canopy. Canopy morphology (i.e. shape, size and density) has an enormous influence on the success of an application (see figure below). So much so, that it is sometimes wiser to invest in canopy management than to buy a different sprayer.



Consider an orchard of pears, or kiwis on pergolas, or this bay of container crops. Efficiency and efficacy are improved when the sprayer design and configuration reflect the canopy structure.

And yet, we do not have a generic protocol for categorizing and comparing horticultural canopy structures. Ideally, it would be simple and yield consistent direction for matching sprayers and canopies. It would also be robust, applying to any specialty crop irrespective of the geographic region. The potential benefits are compelling and include:

- Empowering operators to make adjustments to better match their sprayer to their target throughout the growing season.
- Permitting regulators and registrants to adapt product labels to standardized canopies, increasing the accuracy and consistency of pesticide use.
- As future cropping systems are engineered, the protocol would better integrate the spraying strategy with considerations of rootstock, variety, management practices and planting architecture.

While a grand unified theory of canopy structure is beyond the scope of this book, we can create meaningful linkages between the nature of the canopy and how best to spray it.

7.1. | Geometric characteristics

From a spraying perspective, a horticultural crop has two levels of organization: the plant canopy and the planting architecture. The Plant Canopy is the collective structure containing all plant surfaces. This could be the foliar portion of a single pecan tree, a panel of grapes, or a bay of container crops. The Planting Architecture is the physical arrangement of canopies on the planted area.

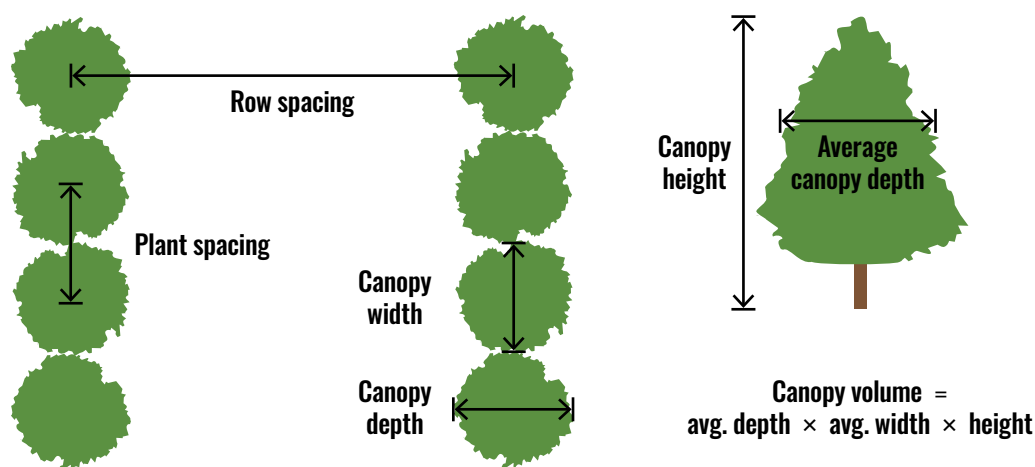
If we reduce the plant canopy and planting architecture to an arrangement of simple geometric shapes, we can begin to make assumptions about how each attribute responds to sprayer configuration:

- **Row spacing:** Sometimes called row width, this is the distance from row to row. Wider row spacings imply a greater distance from spray outlets, requiring higher air energy and more laminar air. Shorter spacings require lower air energy and more turbulent air.
- **Plant spacing:** The distance between plants within the row. Tighter spacing reduces gaps between canopies, making an application more efficient. Wider spacing creates gaps that waste spray, but also allow interaction with the canopy from multiple angles (see figure below).

Each tree in this young orchard requires a given amount of air energy and liquid flow to ensure sufficient coverage. The gaps between the canopies represent significant waste. One solution is to install canopy-sensing optics that permit sufficient lead and lag, but shut off flow to the boom sections where there is no canopy to spray.



- **Canopy height:** The average maintained height of the canopy. Higher canopies may require more air energy and liquid flow at the top of the sprayer boom. This is especially true when the canopy height exceeds sprayer height. The more uniform the canopy height, the more efficient and effective the application.
- **Canopy depth:** Sometimes called spread or dripline, this measures the canopy span perpendicular to the alleys. Many canopy profiles are not perfectly rectangular and are best defined by measuring the span at intervals along the height and taking the average. All other things being equal, deeper canopies will require more air energy.
- **Canopy width:** This measures the canopy span perpendicular to the row. In the case of canopies that grow to form a continuous wall, the canopy width can equal the plant spacing.
- **Canopy volume:** A three-dimensional value calculated by multiplying canopy height by average canopy depth by average canopy width. A higher canopy volume generally requires more spray liquid and air energy.



Six geometric characteristics of the plant canopy and planting architecture.

All of these attributes can be controlled at the time of planting and through crop management (e.g. pruning, topping, hedging). If an optimized sprayer is still unable to overcome the resistance created by some aspect of the canopy, the operator has two choices:

1. Reconsider the cost and merit of canopy management, or
2. Invest in a new sprayer better suited to the task.

Crop structure and management should always factor into an operation's overall spraying strategy (see [Chapter 8](#)).



Sprayer configuration and canopy management go together like interlaced fingers.

7.2. | Phenological characteristics

The phenological characteristics of a canopy are intrinsic to plant development. They describe the crop's growth and development in response to changes in season and climate. We can make generalizations about crop phenology that operators can use to adjust their spraying strategy and increase their likelihood for success. We will focus on three characteristics: canopy density, canopy stiffness and crop age/staging.

7.2.1. CANOPY DENSITY

With the possible exception of canopy height, canopy density has the greatest influence on sprayer settings. Density describes the amount of matter inside a canopy relative to the volume of space it occupies. Canopy density changes over the season, both as a function of growth and as a result of canopy management practices.

Density is not necessarily constant throughout a canopy. For example, citrus and cedar canopies could be very dense, or become hollow in their centres in response to poor light penetration. Peach trees are often pruned to form a hollow, goblet-like shape. Mature nut trees have a large canopy volume but contain plenums (areas of high density) and large open spaces.



Canopies are like presents. It's not the size of the box, but what's in the box that matters.

There are several ways to measure canopy density (see figure below), but for ease of discussion we will use a variation of the Leaf Area Index (LAI), which we referred to in [Chapter 1.1](#). The LAI is a measure for the total one-sided area of leaves per unit ground area and is used to describe the amount of light intercepted by plants. While this does not acknowledge the contribution of woody structures in the canopy, it is a good surrogate for describing how spray might penetrate.

$$\text{LAI} = \frac{\text{One-sided leaf area}}{\text{Ground area}}$$



Plant physiologists use terms like gap fraction analysis, surface area index or optical porosity when describing how “open” a canopy is. An open canopy will allow sprayer-generated air to penetrate more deeply, but also make it difficult to contain. Open canopies are also susceptible to wind deflecting spray. Look at the shadow under your trees at noon. If you see patches of light, your canopy is relatively open. Or, look through the canopy at someone standing on the other side. If you can tell what color shirt they are wearing, congratulations! Your canopy is relatively open and you're not colour-blind.



**LAMINAR
FLO SAYS...**

Sometimes the best sprayer adjustment you can make involves pruning shears or a chainsaw.

Generally, as density increases, so does the requirement for additional spray liquid and air energy. As the LAI approaches (and exceeds) a rating of “1”, it becomes more difficult to measure and less helpful. Nevertheless, we can use it in a conceptual framework to describe increasing levels of canopy density. These LAI numbers are not exact, but operators can reference this scale when relating sprayer configuration to canopy density:

- **Open, bare, or dormant (LAI of <0.1):**
The lowest canopy density, typical of early season dormancy and/or young crops.
- **Sparse (LAI of 0.1 to ~0.5):** All leaves and fruit receive direct sunlight. Some localized canopy density is possible, but overall the canopy is relatively open.
- **Clustered (LAI of 0.5 to ~1.5):**
>50% of leaves and fruit receive direct sunlight. Clustered foliage can have a higher LAI, causing air to flow around rather than through the denser pockets.
- **Full (LAI of 1 to 2):**
A mature foliated canopy that has been pruned to maximize light interception.
- **Dense (LAI of >2):**
Generally absorbs a lot of air energy to penetrate canopy, particularly stiff and unyielding morphologies.
- **Very dense (LAI of >3):**
Typical of a mature or unmanaged canopy and certain vines.

7.2.2. CANOPY STIFFNESS

Canopy stiffness describes the degree to which canopy structures resist being moved by air. Stiff canopies don't move easily, requiring a more focused air energy to displace them. Lithe canopies distort in the wind, moving with it and allowing spray to pass. Stiffness can be attributed to two things:

First, the physical qualities of the branches. The branches of some crops are naturally whippy and give easily in the wind, while others are stiff. We offer no scale or method for quantifying this, noting only that it is a modifier for spray penetration.

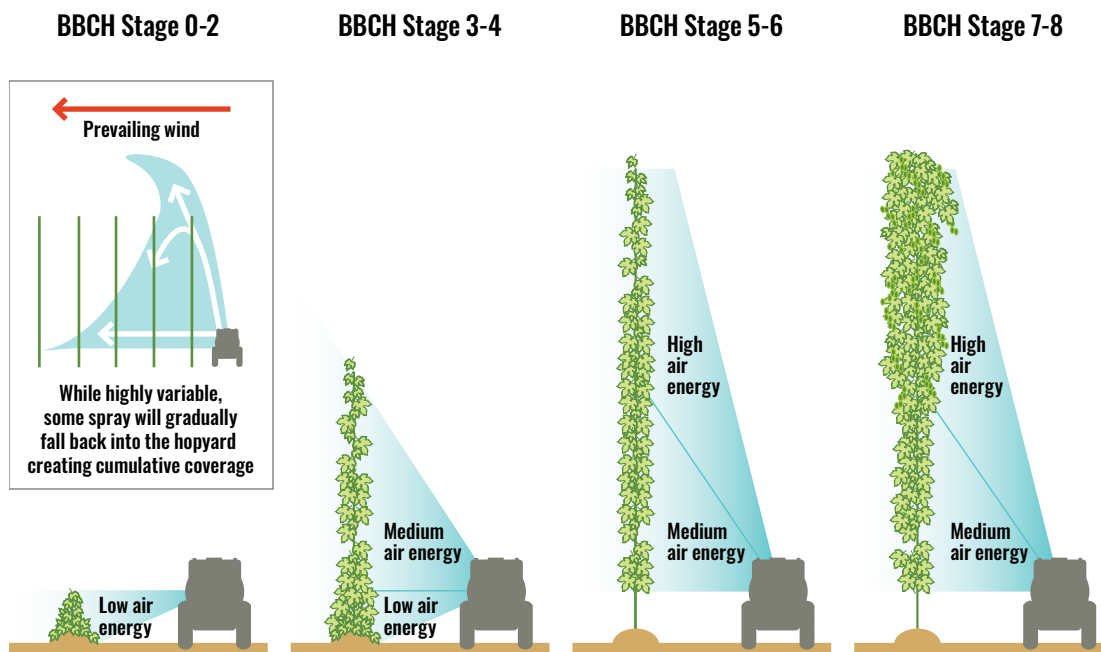
Second, the physical qualities of the leaves. Just as with canopy density, leaf size and shape are a helpful reference when describing canopy stiffness.

- Broad leaves (e.g. grapes, figs, papaya, pistachio) move easily but may shingle (see [Chapter 11.2.4.](#)). The larger they are, the more difficult it can be for air to move around them.
- Long and slender leaves (e.g. stone fruit, olives) align with air, and facilitate air penetration.
- Stiffer leaves (e.g. citrus or berry) do not move easily, requiring higher air energy and more turbulence to cover them.

7.2.3. CROP AGE/STAGING

The influence of age and staging on the canopy will depend on the crop variety, plant health, and canopy management practices. The practical implication is that mature and/or late season canopies are larger and closer to the sprayer than younger and/or early season canopies. As the canopy grows and fills it will require the operator to redistribute liquid flow (see Chapter 13.2.), and likely increase both spray volume and air energy.

The BBCH (**B**iologische **B**undesanstalt, **B**undessortenamt und **C**hemische Industrie) is one of many crop-specific scales used to identify a plant's phenological development. In horticulture, it can be used to describe pesticide application timing and risk assessment. While not intrinsic to the scale, systems like this are often adapted locally to extend the phenological stage to sprayer recommendations. We'll use hops as an example (see figure below).

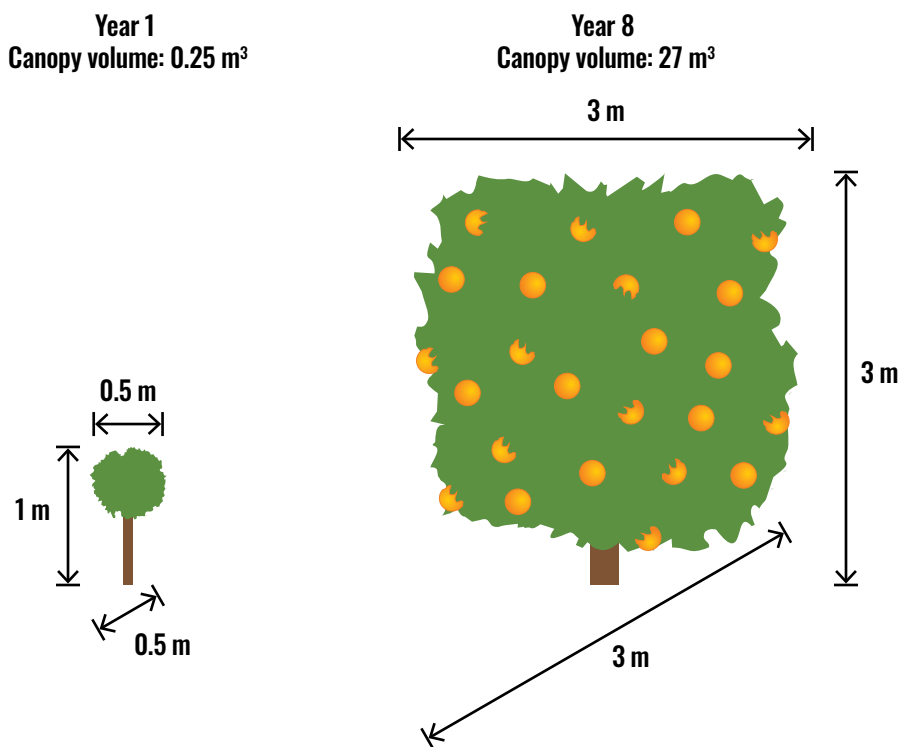


Sprayer settings should change throughout the season to reflect crop staging. In this example, an LPR sprayer is depicted spraying hops. **AT BBCH STAGE 0-2**, low air energy and the lowest nozzle positions are used. **AT STAGE 3-4**, additional nozzles are engaged and a medium air energy is required along the middle of the spray outlet. **AT STAGE 5-6** the lowest portion of leaves are stripped, so no more air or spray are required. However, additional crop height and density require more air energy and additional nozzles at the top of the spray boom. **STAGE 7-8** requires the most flow and air energy in the highest third of the spray outlet. **INSET:** In the later stages of development, each pass provides cumulative downwind coverage that should be accounted for.

7.3. | Catch efficiency

Within limits, canopy structure and planting architecture can form the basis for estimating an appropriate spray volume. The relationship is complicated. For example, two canopies with the same geometric volumes may require very different spray volumes (and air configurations) to achieve the same coverage. Likewise, changes in canopy volume over the season, or as a young canopy grows to maturity, may not directly scale to changes in spray volume.

We can demonstrate the complicated relationship between spray volume and canopy volume in an example. Let's consider a newly-planted citrus orchard (see figure below).



This image shows the volume of a citrus canopy in year 1 and year 8. The year 1 canopy represents 0.01% of its mature volume in year 8.

As the orchard grows to maturity, the average canopy volume per plant changes from 0.25 m^3 to 27 m^3 , representing a 108-fold increase. If a block of year 8 canopies was successfully sprayed using a volume of $1,000 \text{ L/ha}$ (107 gpa), simple math would suggest we only need 9.3 L/ha (1 gpa) to spray the year 1 canopies. Wow! So why don't we apply such small volumes?

In practice, trying to spray this extremely low volume would not be effective for two reasons:

- First, it's mechanically implausible to evenly distribute such a small volume. This degree of metering and targeting is a tall order. Even electronic eyes (Chapter 7.4.) are unable to turn the spray on or off exactly at the canopy edges; There is always some inefficiency. We are aware of operators spraying year 1 canopies with as little as 3% of the mature canopy rate, but math tells us this is still 300x more volume than should be needed.
- Second, small canopies are unable to catch the spray as efficiently as large canopies. Air follows the path of least resistance, flowing around them. What does penetrate has fewer opportunities to interact with the target before passing through.

The variables that create this complication are collectively referred to as Catch Efficiency. Catch efficiency is largely conceptual, describing a canopy's ability to intercept and retain spray. Generally, small, distant and spaced canopies are less able to capture and retain spray as large, proximal, continuous canopies.

7.3.1. ESTIMATING SPRAY VOLUME

Given the difficulty in characterizing a canopy, it is equally challenging to decide on an appropriate spray volume. Many operators resort to historical or regional practices and do not make adjustments to reflect their specific situation. Others refer to methods such as using the Tree Row Volume (a.k.a. Canopy Row Volume) which relates canopy volume per planted area to spray volume. In this case, catch efficiency is expressed as a coverage factor, which is determined through experimentation specific to the crop, environment and sprayer:

$$\text{Tree row volume} = \frac{\text{Canopy height} \times \text{Average canopy spread} \times \text{Planted area}}{\text{Row spacing}}$$

$$\text{Spray volume} = \text{Tree row volume} \times \text{Coverage factor}$$

In New Zealand, coverage factors for dilute applications to deciduous canopies range from 0.07 to 0.1 L/m³ (0.00052 to 0.00075 US gal./ft.³). The range captures variation in canopy density and any product-specific coverage requirements. Oil sprays, for example, require more surface coverage than most products. Evergreens such as citrus have very dense canopies, so their dilute coverage factors are higher, ranging from 0.1 to 0.33 L/m³ (0.00075 to 0.0025 US gal./ft.³).

While closer to “the truth”, the Tree Row Volume method is still only an estimate. To wit:

- It does not account for variations in canopy density or environmental conditions.
- It requires local experience to determine viable coverage factors.
- Concentrated applications require proportionally smaller coverage factors because they are intended to maintain the same product rate per planted area using less volume.

If the operator has no prior experience with the crop or the sprayer, and wants a sanity-check on their estimated spray volume, we propose the following guidelines for full canopy dilute applications to mature crops using every-row traffic patterns:

- Small canopies (e.g. bush, vine, cane, high-density fruiting wall): 500 L/ha (55 US gal./ac.) to 1,000 L/ha (110 US gal./ac.).
- Medium canopies (e.g. tender fruit, pome): 750 L/ha (80 gpa) to 1,250 L/ha (135 US gal./ac.).
- Large canopies (e.g. tree nut, citrus): >2,000 L/ha (214 US gal./ac.) and up to 7,000 L/ha (748 US gal./ac.).
- For operators that think in 100 m row lengths, consider 20 L volume per 100 m row length per 1 m canopy height.

No matter the approach to determining spray volume, it is imperative that the operator validate their decision by assessing spray coverage. We describe a few methods in [Chapter 15](#).



Operators have been known to link two engine-driven LPR sprayers, each spraying from alternate sides, to apply up to 7,000 L/ha (748 US gal./ac.) in mature pecan operations.

7.4 | Intelligent sprayers

As we write this, advances in canopy-sensing technology and sophisticated decision-making algorithms are ushering in a new generation of intelligent sprayers that perform real-time adjustments to liquid flow and air in response to crop structure (see below). Perhaps they will one day make the need for a canopy classification protocol (and indeed many of the manual adjustments recommended in this book) obsolete.



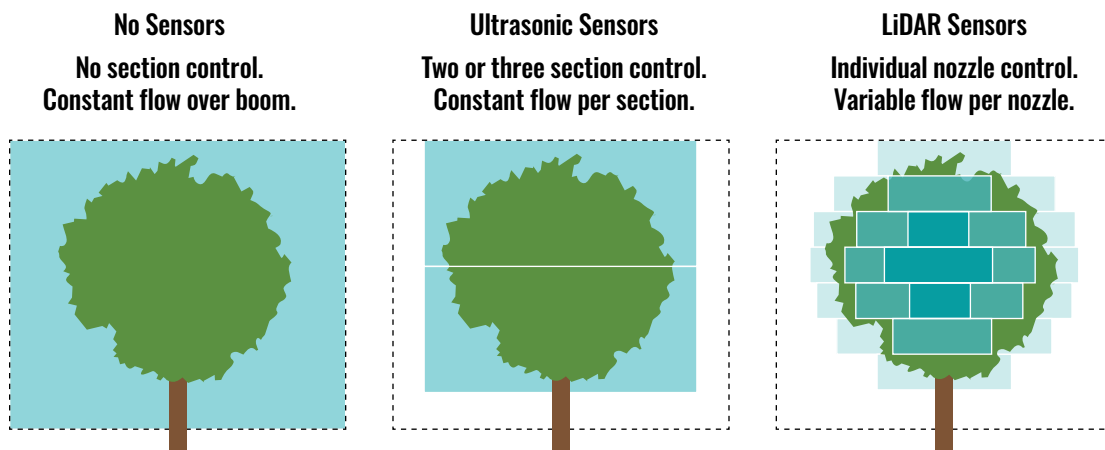
The Jacto Arbus 4000 JAV has intelligent section control that uses laser scanning to spray only where canopy is present. Electric fans adjust air energy according to the size of the plant. Several autonomous units can be interconnected and controlled by a fleet manager and they automatically return to the fill station.

PHOTO USED WITH PERMISSION FROM JACTO.

Machine vision sectional control has been available since the early 1980's. Collectively referred to as "electronic eyes", many sensor designs have been used, each meeting with varied success. Today, there are three relevant designs (see figure on the following page):

- **Ultrasonic sensors.** Economical, robust, and provide a relatively coarse but reliable signal. When combined with electronic valves, sectional flow control turns the boom off when there is no canopy.
- **Laser-based sensors.** Often LiDAR (Light Detection And Ranging) sensors, this design provides much more information than ultrasonics. When combined with pulse-width modulating nozzles, flow can be adjusted with nozzle-level resolution. This is made possible by an onboard computer that employs algorithms that relate flow to canopy structure.

- While it is not currently available, **Optical video machine vision** and artificial intelligence will challenge LiDAR in characterizing canopy structure. These systems currently exist in advanced vegetable operations, so perennial crops shouldn't be far behind. As we said in [Chapter 5](#), there are exciting times ahead for air-assist sprayers.



LEFT: A simple boom produces a steady flow and spray distribution (blue). A rate controller can adjust the flow to compensate for changes in travel speed, holding the rate constant. **MIDDLE:** Canopy-sensing technology will turn upper and lower boom sections on or off to correspond with the presence or absence of canopy. **RIGHT:** Intelligent sprayers adjust flow at each nozzle position, using proprietary coverage factors to reflect the volume and density of the corresponding target.

7.5. | Review and consider

- How diverse are the canopy sizes and planting architectures in your operation?
- Would canopy management make spraying more efficient? More effective?
- What changes do you make to your sprayer configuration to account for seasonal changes in canopy size and density?
- Are aftermarket crop-sensing technologies available for your sprayer?
When would such a system pay for itself?

Operators cannot see the spray that escapes above the canopy. Always adjust air settings to only just exceed canopy height.



Chapter 8

Spraying strategy

The Spraying Strategy documents a farm's overall management and operational plan for achieving safe, effective and efficient spray coverage of target crops. It reflects the operation's unique pressures and priorities, such as their size, spray equipment, crop varieties, geography, pest profiles, and any regional legal restrictions/requirements.

Developing a detailed strategy is a good business practice that informs traceability, insurance requirements and record keeping. While there is no standard format, it should address:

- The sprayer calibration and configuration process.
- The traffic pattern, swath and travel speeds.
- The acceptable environmental conditions for spraying.
- The loading and sprayer sanitization processes.
- The anticipated number of applications per season.
- How the preceding elements change relative to the crop developmental stage (e.g. early season spraying versus mid- to late-season).



TURBULENT EDDY SAYS...

A good spraying strategy should be flexible, but should also be efficient. Nobody sprays because they like to.

For example, specialty crop growers are facing an increase in invasive species, requiring an increased number of applications with a limited number of active ingredients. This has led to the strategy of dividing rates over multiple applications in order to remain below maximum residue limits (MRLs). We will not judge this practice but warn that it becomes absolutely critical to achieve the best coverage possible or risk a sub-lethal dose and a need for clean-up applications.

When pressures mount and time is short, operators may decide to abandon their spraying strategy, taking short-cuts or calculated risks. We agree that “a bad spray timed well beats the best spray timed poorly”, but this is an exception and not a rule. If a sprayer operator is always in crisis-mode, the spraying strategy should be reconsidered.



Hut-hut-hut! Watts describe the rate that energy is produced. 1992's "Tools for Agriculture" by Carruthers and Rodriguez states that a horse can deliver 500 watts of power over 10 hours. A camel can deliver 650 watts over six hours, a 30% increase in productivity! Understanding your sprayer's capabilities helps you develop an efficient spraying strategy.

DATE AND LOCATION OF THE PHOTOGRAPH ARE UNKNOWN. PHOTO PROVIDED BY RICHARD DERKSEN.

8.1. | Farm Management Systems

As we write this, large horticultural farms are enjoying a digital revolution that is changing how they operate. Farm Management Systems (FMS) use GPS Internet of Things (IoT) devices and other internet-connected data gathering devices to track the movement of farm assets and employees and to provide real-time management insights.

These systems are so powerful and easy to use that we have no doubt they will be widely adopted in horticulture. One particularly relevant benefit is providing real-time sprayer tracking and notification to both the operator and to off-site managers. Missed rows, speed variation, and other deviations are immediately flagged for corrective action.

Cumulative as-applied data makes for robust spray records, permits crop traceability and ultimately informs the farm's spraying strategy.

8.2. | Budgeting sprayer supply and demand

Do you have enough time to get the spray job done? To answer that question, you'll have to do a little accounting. The concept of supply and demand is central to any spraying strategy. Let's define a few concepts:

- **Time available:** The number of spray-friendly hours in a day depends on favourable environmental conditions and proximity restrictions from nearby sensitive species (e.g. neighbours, farm workers, pollinators, etc.).
- **Demand:** This is the planted area (or row length) that must be sprayed within the time available.
- **Hypothetical operational capacity:** This is the maximum planted area (or total row length) you can spray per hour.
- **Actual operational capacity:** This is the actual planted area (or total row length) you can spray per hour.

When demand changes, sprayer operators feel the crunch. The planted area doesn't change, but inclement weather and pest pressure can greatly compress the window of time available. Can your spraying strategy absorb those changes? Let's work through an example.

Suppose you have 50 ha on 3.3 m spacing (125 ac. on 11 ft. spacing). You have one sprayer and you drive an every-row traffic pattern at 5 km/h (3.1 mph). What is the hypothetical operational capacity? In other words, what is the maximum area you can spray in an hour?

$$\text{Operational capacity (ha/h)} = \frac{\text{Travel speed (km/h)} \times \text{Row spacing (m)}}{10}$$

$$\text{Hypothetical operational capacity (ha/h)} = \frac{5 \text{ km/h} \times 3.3 \text{ m}}{10} = 1.65 \text{ ha/h}$$

With that hypothetical operational capacity, how long would it take to spray the 50 hectares?

$$\text{Time required to spray (h)} = \frac{\text{Area (ha)}}{\text{Operational capacity (ha/h)}}$$

$$\text{Hypothetical time required to spray (h)} = \frac{50 \text{ ha}}{1.65 \text{ ha/h}} = 30.3 \text{ h}$$

Now, let's say the time available that is suitable for spraying is 8 hours per day. How many days would it take to complete the job?

$$\text{Days required to spray (d)} = \frac{\text{Time required to spray (h)}}{\text{Time available (h/d)}}$$

$$\text{Hypothetical days required to spray (d)} = \frac{30.3 \text{ h}}{8 \text{ h/d}} = 3.8 \text{ d}$$

The best-case scenario is that it will take 3.8 days. This figure is hypothetical because it does not account for all the time sinks, such as loading time or the turn time at row ends. Nor does it account for changes to the time available, which can be unpredictable depending on equipment gremlins and changeable weather. The hypothetical operational capacity gives us an estimate, but it isn't achievable.

We need a way to calculate the actual operational capacity. Moreover, we need a way to understand the relative impact of each variable on that capacity (e.g. is it more important to drive faster or spray multiple rows?). To this end, we have developed a handy work rate calculator. It allows you to enter all the variables and explore how they affect the actual operational capacity. To take full advantage of it, you'll need a stopwatch and a notepad to record how long your actions take on a typical spray day.

When you have your figures in hand, you can download the calculator from www.sprayers101.com using this link: www.sprayers101.com/airblast-workrate/. You must have Microsoft Excel and permit editing when prompted. You can build multiple scenarios to explore how changing a single variable affects the work rate. It may surprise you to discover which activities are consuming your time. Quite often, less than 60% of a spray day is actually spent spraying. Making small efficiency improvements to repeated tasks can add up quickly.



**LAMINAR
FLO SAYS...**

"If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it."

— H. JAMES HARRINGTON AND THOMAS MCNELLIS'
"MOBILIZING THE RIGHT LEAN METRICS FOR SUCCESS"

The work rate calculator also has the capacity to capture capital and some operational costs. For example, depending on the crop, a 40 ha (100 ac.) operation may have reached the point where it requires a third every-row sprayer to comfortably meet demand. An economic decision must be made to either purchase another tractor and sprayer (plus train an operator) or save drive time by investing in a multi-row system.

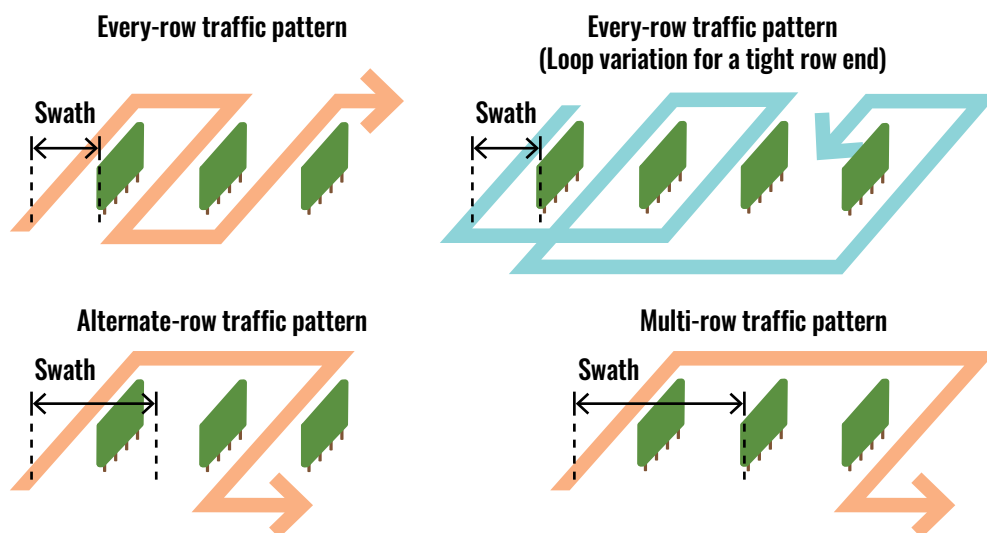
In the final analysis, the cost of spraying is always considered within the context of profit. Will better spraying practices result in better packout? If there is room for improvement, the only significant cost associated with increased packout is labour-related. When we compare the cost of a reduced operational capacity, or the costs associated with a hardware upgrade, against 5%, 10% or even 15% improved packout, the numbers will speak for themselves.



This huge, self-propelled WA orchard sprayer improves operational capacity by spraying three rows per pass and reducing the number of early-season fills by recycling over-spray. However, there is considerable capital expense and it may add turning-time and maintenance costs. Is it worth it? Download our work rate calculator and find out.

8.3. | Traffic pattern

The Traffic Pattern is the path driven through the planting. Planting infrastructure and architecture (e.g. trellises, support wires, netting, irrigation, no-drive alleys, tight row ends) can limit traffic pattern options. Driving fewer alleys and employing longer swaths is an attractive strategy for improving timeliness, but there are restrictions that must be considered. The following figure describes the three common traffic patterns: Every-row, Alternate-row and Multiple-row.



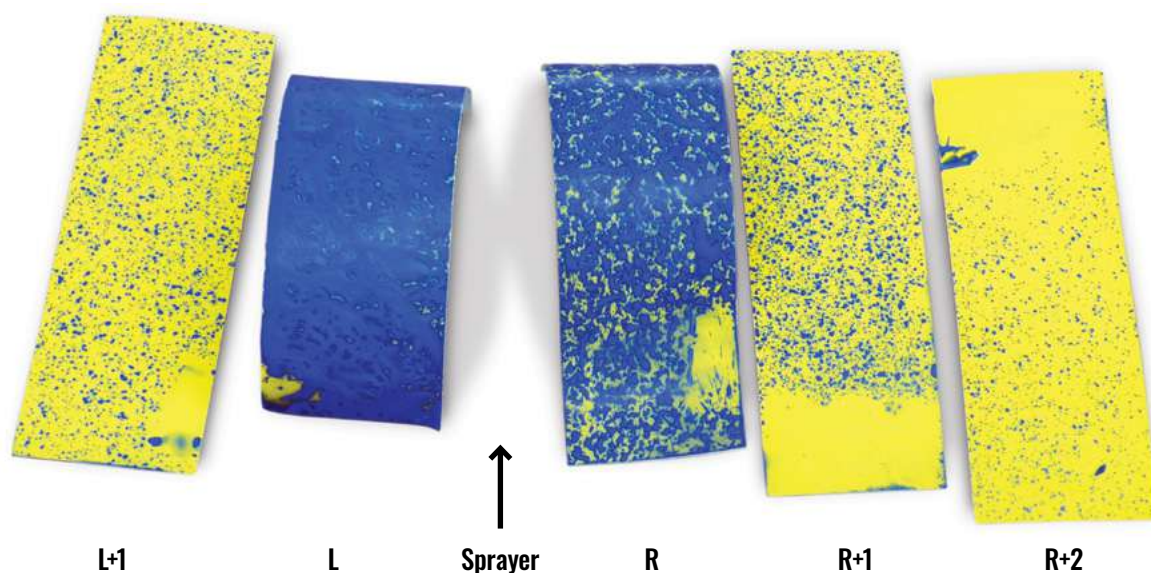
Traffic pattern and swath (illustrated for only one sprayer side) for three common spraying strategies. Top-right (blue) is a different version of an every-row traffic pattern. It is used when one headland is too tight to permit turning down each alley. There are other, more complicated patterns not illustrated here.

Any traffic pattern that minimizes the swath will give the best likelihood of successful coverage because it also minimizes the intervening distance and the time spray is in transit (see Chapter 12). LPR and FT sprayers are often used with an every-row pattern, representing the longest drive time. WA sprayers create the same minimal swath while driving every second or third alley, saving drive time.

LPR, cannon, FT and TT sprayers can sometimes be used to spray through multiple rows, saving drive time but increasing the swath. While this can be effective, control is always sacrificed. The inverse square law describes the loss of air energy with distance, plus each canopy impedes spray by filtering droplets and reducing air energy. The operator must carefully consider the inherent waste and be diligent about confirming coverage (see Chapter 15).

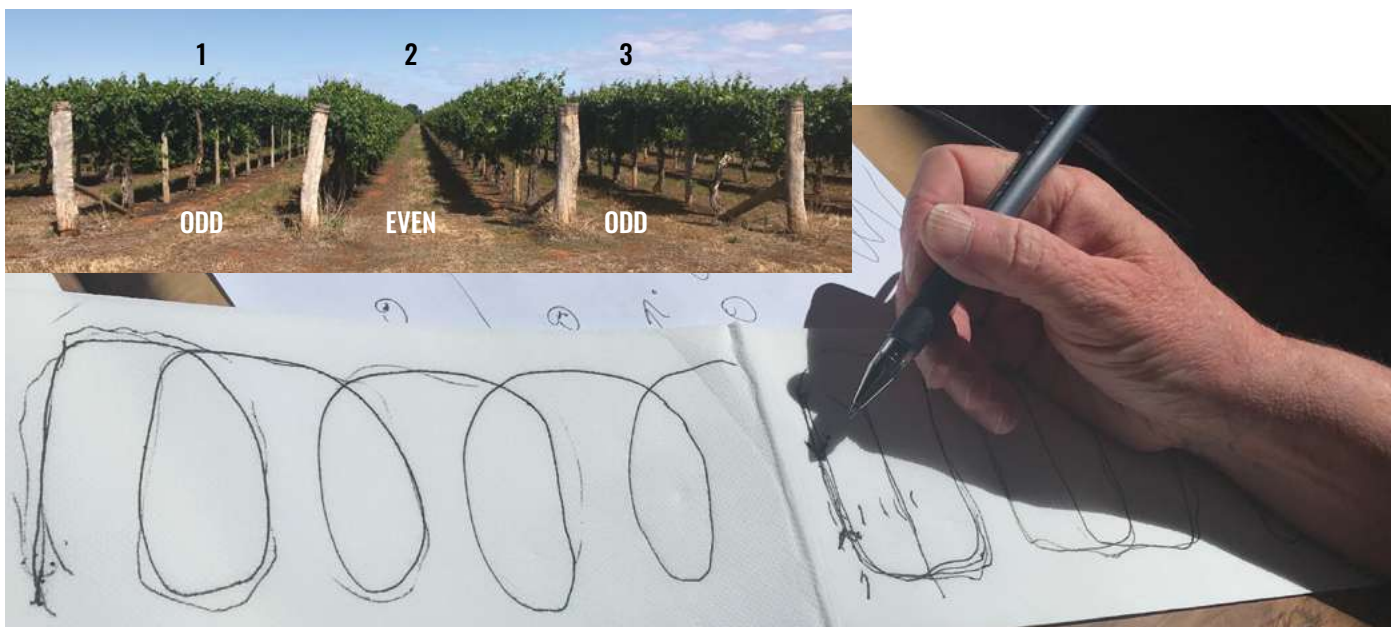
8.3.1. ALTERNATE THE TRAFFIC PATTERN

Alternating the traffic pattern reduces the chance of repeated sub-lethal doses. This means not driving the same alleys in the same direction on subsequent applications. Research in vineyards showed that a panel sprayed from both sides in the same direction received less coverage than one sprayed from opposite directions. Varying the direction of travel prevented repeated line-of-sight problems (see Chapter 10.1.1.). When sprayer agitation is suboptimal (see Chapter 5.1.), the product concentration can drop as the tank empties. Alternate traffic patterns prevent exposing the same rows to a reduced dose.



Water sensitive papers recovered during a workshop in highbush blueberry. The papers in the rows left (L) and right (R) of the sprayer were excessive. The papers in the next rows out (L+1 and R+1) were adequate. Downwind, two rows away, (R+2) spray coverage was inadequate, but still detectible. The operator could drive an alternate row traffic pattern, or better still, reduce the spray output and air energy considerably and drive every row.

It's easy to forget where you are while driving alternate patterns. Operators sometimes number alleys referring to them as "odds" and "evens" (see figure on the following page). As-applied maps and real-time GPS tracking can help operators and farm managers keep track.



Try sketching your traffic pattern. Number your alleys for easy reference. One strategy is to drive the same direction on odd-numbered alleys and switch that direction on the next application. When a headland will not permit a tight turn, the intricate loop-de-loop pattern solves the problem.

8.4. | Considerations for multi-row traffic patterns

Multi-row traffic patterns can work for non-WA sprayers. Conditions for success include small or sparse canopies, slower travel speeds, a sprayer design that creates a long throw, low-to-moderate pest pressure, and favourable weather. Risk of failure increases with longer swaths, high speed or gusting wind and when spraying products with contact-reliant modes of action. Coverage should be monitored closely when employing this traffic pattern (see Chapter 15). If coverage is insufficient, reconfigure for every-row or park the sprayer until conditions improve.

As lecturers, we often present on the perils of attempting too large a swath to save time. Invariably, someone will say it's always worked for them, or grouse about the pressures of their particular operation, claiming there's no way they can spray every row. But we can't give special dispensation to cut corners; you can't negotiate with physics.



"It ain't bragging if you can do it."

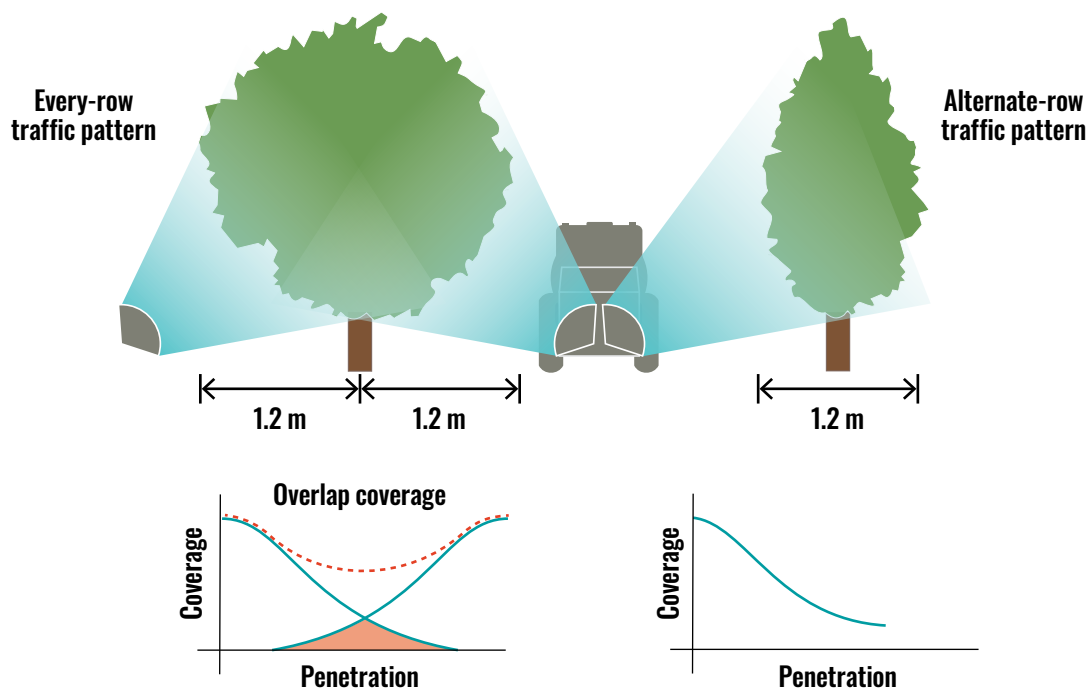
-DIZZY DEAN

Insufficient operational capacity is no excuse for adopting a multi-row traffic pattern with an inappropriate sprayer design in difficult-to-spray canopies and poor weather conditions. It may work a few times, but when conditions conspire to tip the balance, it will fail.

8.4.1. COVERAGE UNIFORMITY

A popular question in favour of alternate- and multi-row spraying comes from orchardists that are shifting from semi-dwarf root stock to high-density plantings. They ask: “If I can spray a 2.4 m (8 ft.) canopy from both sides, why can’t I spray a 1.2 m (4 ft.) wide tree from one side?” The answer is “Sometimes, you absolutely can.”

But spraying from one side only 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 from two vantage points. Coverage uniformity is always improved when spraying from both sides. This is discussed further in [Chapter 13](#).



Spraying from one side gives a single opportunity to cover the centre of the canopy. Spraying from both sides improves coverage uniformity. The coverage overlap is illustrated by the red-shaded area in the graph below the every-row pattern. The total resultant coverage is represented by the broken red line. In addition, spraying from a different vantage point hits targets that may have otherwise been out of the line-of-sight.



The most efficient application is the one you didn't have to make. Do it right the first time. Revenge spraying and clean-up sprays should never be required.

← Sporadic coverage

Excessive coverage →



The more rows attempted in a swath, the more likely you will lose control of the spray. Maintaining a lateral-downward angle helps to keep spray in the planting. Operators must also alter their traffic pattern to spray inward on the last few downwind rows. Coverage becomes increasingly inconsistent with distance, and interference from wind and intervening canopies exacerbates the situation. Mom was right... take smaller bites or you'll choke.

Wind speed and direction significantly impact coverage uniformity. Research performed in vineyards using a FT sprayer explored the coverage from alternate-row applications. The wind-facing side of the canopy always received more coverage, irrespective of which alley the sprayer drove. Work with cannon sprayers in nurseries and cane fruit showed that coverage becomes increasingly erratic with distance from the sprayer (hello again, inverse square law). The length of the throw was greatly affected by wind conditions.

8.4.2. MULTI-ROW VOLUMES AND PESTICIDE RATES

Multi-row traffic patterns with non-WA sprayers are sometimes promoted as a means to reduce pesticide use. This is incorrect. With the same amount of canopy to protect, there should be the same product rate requirement. In fact, every-row traffic patterns are more likely to reduce pesticide use because there is less waste and a greater opportunity for uniform coverage. Consider the following example:

**Top row: Every-row traffic pattern
250 L/ha (27 gal./ac.)**



**Bottom row: Alternate-row traffic pattern
1,000 L/ha (107 gal./ac.)**

The water sensitive papers in this image were folded and distributed throughout a high-density apple tree, oriented facing the alleys. They were sprayed with water using a FT sprayer applying 1,000 L/ha (107 gpa) on an alternate-row pattern, or 250 L/ha (27 gpa) on an every-row pattern. The every-row pattern improved coverage, even with the extreme reduction in carrier volume. The trade-off between fill time and drive time is an important consideration, but one that should be trumped by improved coverage uniformity and reduced waste.

8.4.3. CALIBRATION MATH FOR MULTI-ROW TRAFFIC PATTERNS

We discuss how to calculate pesticide rates in [Chapter 17](#). For now, be aware of these specific situations relating to mixing and loading non-WA sprayers for multi-row traffic patterns.

- **Situation 1:** The sprayer is configured to deliver twice the flow compared to an every-row traffic pattern, and the operator drives every second alley. The result is that the planted area receives the same carrier volume and pesticide rate as a typical every-row traffic pattern.
- **Situation 2:** The sprayer is set-up for an every-row traffic pattern but drives every second alley. This is effectively a half-rate application. Often, the intention is to spray the unsprayed rows soon after, but the operator risks missing the pest's efficacy window as well as having delivered a sub-lethal dose in the unsprayed rows. These decisions should be made with the close attention of an agronomist or local extension specialist.


- **Situation 3:** This is essentially a math error. Since the operator intends to drive alternate alleys, they erroneously set the sprayer to deliver half the flow compared to an every-row traffic pattern. The result is a quarter-dose application. Yes, this happens.

So, alternate- or multi-row traffic patterns with non-WA sprayers should be used with caution. Operators must be prepared to perform regular coverage checks and recognize when conditions change and can jeopardize coverage.

8.5. | Review and consider

- In your operation, are alternate-row spraying strategies a solution or a problem?
- Would a multi-row sprayer add value or flexibility to your operation?
Are there limitations that would make this style of spraying impractical?
- Have you found the balance between work rate, spray coverage and flexibility?
- Does your current work rate prevent timely applications? Are you forced to cut corners when time is short, or when conditions aren't ideal?





Measuring air speed with a pitot tube. Small changes to the sensor's position can create false readings, so a hot wire or propeller-driven anemometer is preferable.

Chapter 9

Measuring sprayer air

We discussed air handling and the air displacement concept in [Chapter 3](#). We can measure sprayer air and use math to estimate the fit between a sprayer and a planting. Measuring sprayer air has several benefits:

- It reveals non-uniform air speeds or gaps. This alerts you to the potential for poor coverage in the corresponding region of canopy.
- It determines if the sprayer can produce a volume of air suitable for the target canopy. It may be excessive or insufficient in certain scenarios.
- It can be used to estimate an ideal travel speed.

The following calculations establish whether a sprayer has the potential to provide suitable coverage. In practice, the nature of the sprayer-generated air, the environmental conditions, and the canopy itself will affect performance ([see Chapter 11](#)).

9.1 | Measuring air velocity

Air speed can be measured using a dedicated anemometer. However, we suggest buying a more versatile handheld weather meter like a Kestrel, Skymate or Ambient that is rated for high air speeds. This tool can be kept in the cab to take fast, local weather readings that inform your spray practices and help populate spray records.

Do not underestimate the hazards inherent to working with air-assist sprayers. Heed the following safety warnings when performing any adjustments or measurements:

- High-speed air is loud, can carry debris, and involves dangerous moving parts. Wear ear protection, eye protection, and be aware that long hair and loose clothing can be sucked into fan intakes or wrapped around spinning shafts. This can literally kill you.
- Hold the impeller no closer than 25 cm (10 in.) from the outlet. Some meters are not intended for such high speeds (you will hear a high-pitched whine). We have seen impellers damaged and become shrapnel. Quality anemometers are rated for 200 km/h (125 mph).

Don't assume the air along an outlet is uniform. Take a series of readings vertically and horizontally. A partner can record the speeds and relative locations as you yell them out over the noise of the fan. Calculate the sprayer's average air speed:

$$\frac{\text{Total air speed}}{\text{Number of measurements}} = \text{Average air speed}$$



LAMINAR FLO SAYS...

In-field readings from handheld weather meters are “C.Y.A.” insurance. If accused of off-target drift, you might otherwise be held accountable based on weather readings from a tower at the closest airport or weather station.

Use the meter to collect a series of air speed readings along each air outlet. The sprayer in this photo was not delivering sufficient air to the top of the trees in a citrus operation. We took 24 readings (six per air outlet) and found the overall speed was lower than expected. We traced the issue to the PTO shaft, which was spinning much slower than the assumed 540 rpm.

1.

2.

3.

4.

5.

6.

Anemometer



Handheld weather meter



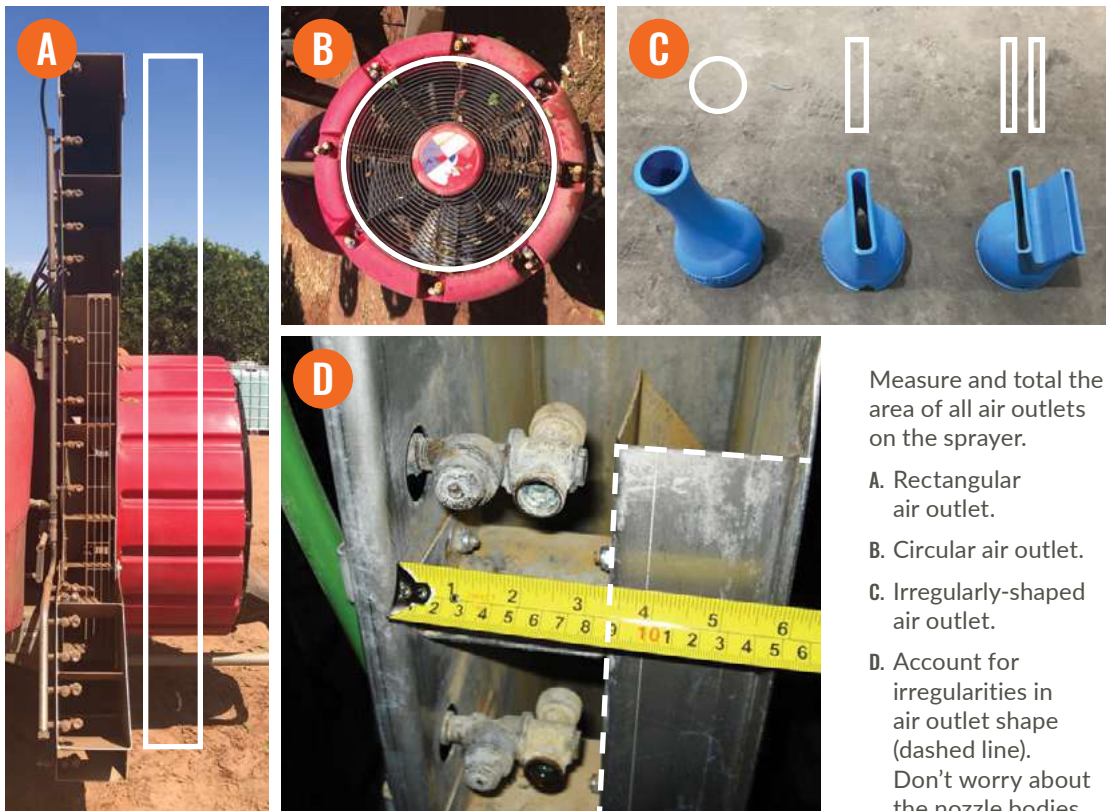


LAMINAR FLO SAYS...

You can use a handheld laser tachometer to measure a fan's rpm. Direct the laser at the spinning fan and take multiple readings. Divide the average by the number of fan blades.

9.2. | Measuring air outlet area

Next, work with a partner to measure the area of the air outlets, which might be simple rectangles, circles (e.g. straight-through axial fan) or irregularly-shaped (e.g. ovals or slots). Using a measuring tape, measure and total the area of all air outlets on both sides of the sprayer. Rectangles are **Length × Width**. Circles are **$3.14 \times \text{Radius}^2$** . You're on your own for the weird outlets. Be sure to account for irregularities in the air outlet shape, such as the dashed line in D.



Measure and total the area of all air outlets on the sprayer.

- A. Rectangular air outlet.
- B. Circular air outlet.
- C. Irregularly-shaped air outlet.
- D. Account for irregularities in air outlet shape (dashed line). Don't worry about the nozzle bodies.

9.3. | Volumetric flow and displacement rate

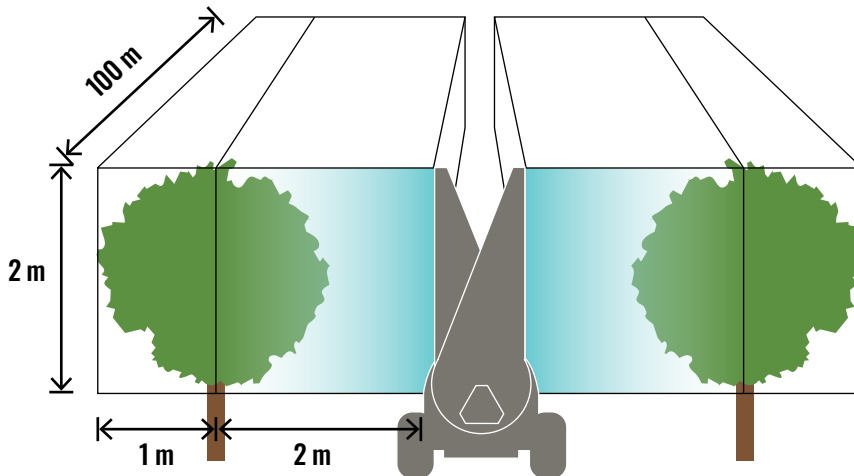
Let's use a real-world example to explain how the following calculations work. For simplicity, we'll do this in Metric.

Suppose we are considering buying a 2 m tall fixed tower sprayer to spray every row in a semi-dwarf orchard. We measure an average air speed of 160 km/h and a total outlet area of 0.25 m². We can now calculate the sprayer's volumetric flow, which is how long it takes for the sprayer to produce a given volume of air.

$$\text{Average air speed} \times \text{Total outlet area} = \text{Total volumetric flow}$$

$$160,000 \text{ m/h} \times 0.25 \text{ m}^2 = 40,000 \text{ m}^3/\text{h}$$

This is an important value. It allows us to estimate an ideal travel speed by comparing the volume of air generated by the sprayer to the volume of air we want to displace. Let's continue with our example.



In our example, a fixed tower sprayer must produce enough air to span the intervening distance and then displace half the volume of the adjacent canopies. (The closer the air outlet is to the canopy the less volume will be required.)

In the figure above we see that the sprayer must produce enough air to span 1 m of distance and then penetrate 1 m into each target canopy. The cross-sectional area is 2 m × 2 m = 4 m² for one side of the sprayer. The total area for both sides is 2 × 4 m² = 8 m². If the sprayer travels a 100 m row length, we find 8 m² × 100 m = 800 m³ of volume must be displaced.

Using this volume, we can calculate the displacement rate:

$$\frac{\text{Total volumetric flow}}{\text{Target volume}} = \text{Displacement rate}$$

$$\frac{40,000 \text{ m}^3/\text{h sprayer air}}{800 \text{ m}^3 \text{ target volume}} = 50 \text{ displacements/h}$$

Finally, we can use the displacement rate and row length to determine an ideal travel speed.

$$\text{Displacement rate} \times \text{Row length} = \text{Ideal travel speed}$$

$$50 \text{ displacements/h} \times 100 \text{ m row length} = 5 \text{ km/h travel speed}$$

Using this method, we see the sprayer has the potential to reach and displace the target volume while driving 5 km/h. These calculations are helpful when considering a significant change to your spraying strategy (e.g. purchasing a new sprayer or considering a new planting architecture). However, real-life factors will influence matters:

- Cross-winds will have an additive or deleterious effect depending on the direction, and that will imbalance the throw on one side versus the other.
- Canopy density creates resistance that will reduce penetration depth.
- Travel speed will affect dwell time, but it can also affect the fan's output depending on where the intake is located. When the intake is aimed into the wind and/or direction of travel, it acts like a turbocharger, increasing air energy. When the intake is in an area of lower pressure (e.g. located at the rear of the sprayer while driving into a headwind) the air energy is reduced.

It's almost impossible to use math to predict the collective impact of so many variables. In [Chapter 10](#) we'll discuss Ribbon Tests, which are a series of simple, qualitative procedures that detect these deficiencies and suggest corrections.



Did you find a “dead spot” along the air outlet? One trick is to try an air induction or full cone nozzle in that position. Their coarser droplets have more kinetic energy and travel further than finer droplets.

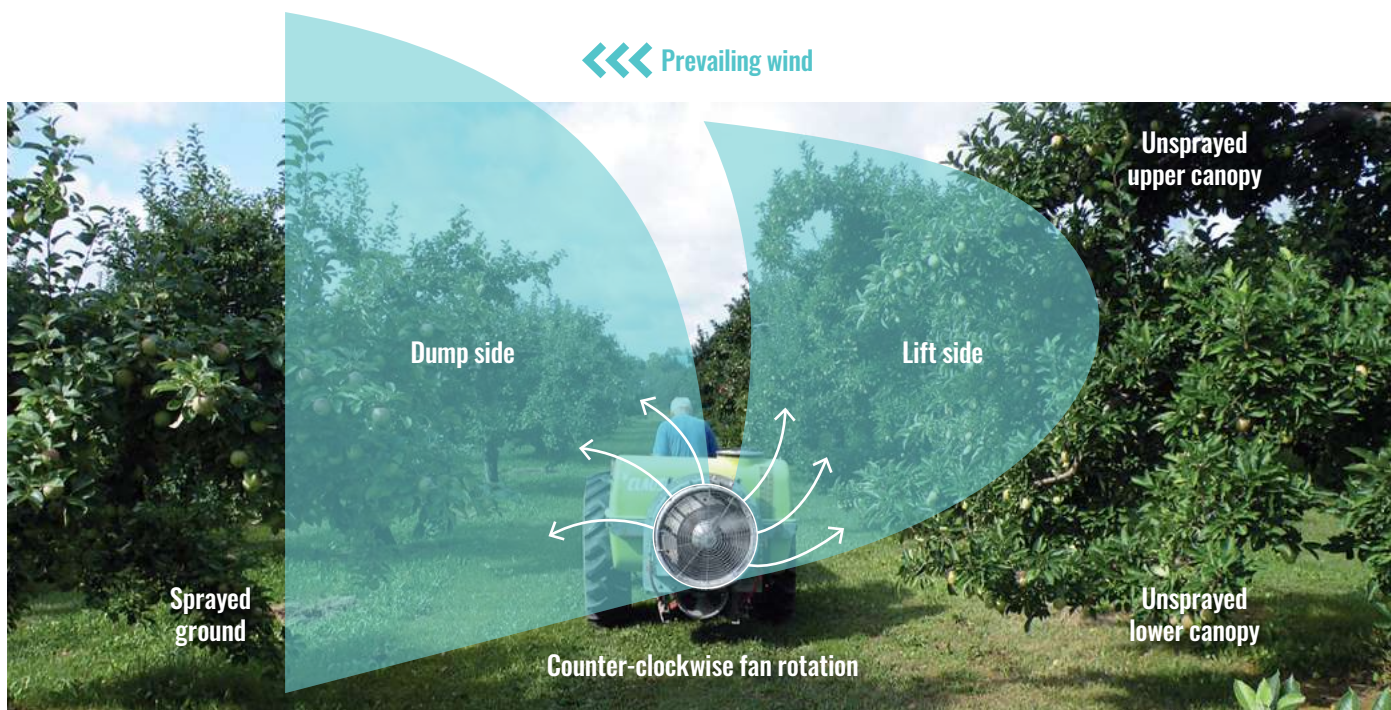
9.4. | Uneven air distribution

While evaluating the air speed and volume, you might notice imbalances or inconsistencies. If they are intentional, the operator can take advantage of them. If they are unintentional, the operator must compensate for them, or at least be aware of them.

9.4.1. LEFT-TO-RIGHT

Unless the sprayer is capable of automatically adjusting for cross-wind (commercially, this is still relatively new and rare), asymmetry between the left and right side is not desirable. It's hard to detect with an anemometer, but you can see the difference when you watch how the canopies move relative to the air, or when you use the ribbon tests we will describe in [Chapter 10](#).

This phenomenon is common to certain LPR sprayers. Looking from the rear, most LPR fans spin anti-clockwise, lifting air on the right and dumping it on the left. The left (or Dump Side), throws the air higher up than the right side (or Lift Side). This means the sprayer can't spray as high on the right. This is exacerbated when the lift side faces into the wind.



Single-fan LPR sprayers with inadequate straightening vanes or deflectors throw air and spray higher on the dump side. In extreme cases they may also miss the lower portion of nearby canopies on the lift side and spray the ground on the dump side. This is made worse when the lift side is into the wind.

Manufacturers often add straightening vanes to reduce turbulence as well as balance air angle and air energy. They can be on the intake and output sides of the fan. The best LPR sprayers have both. Adjustable deflectors along the air outlet (or at minimum, at the top and bottom) not only improve symmetry but enable the operator to focus air energy. Deflectors should be considered mandatory, not optional, for most LPR sprayers.

Commercially-available top-and-bottom deflectors are often just flat sheets. Air hits the surface and spills over the edges. Imagine pouring water onto a dinner plate; it just splashes off any which way. Better to replace those deflectors with a set that feature deep side-walls to channel the air. Anyone with access to a metal brake and some sheet metal can make their own. Longer is generally better if they do not stick out beyond the wheel of the sprayer where they could snag plants and trellises.



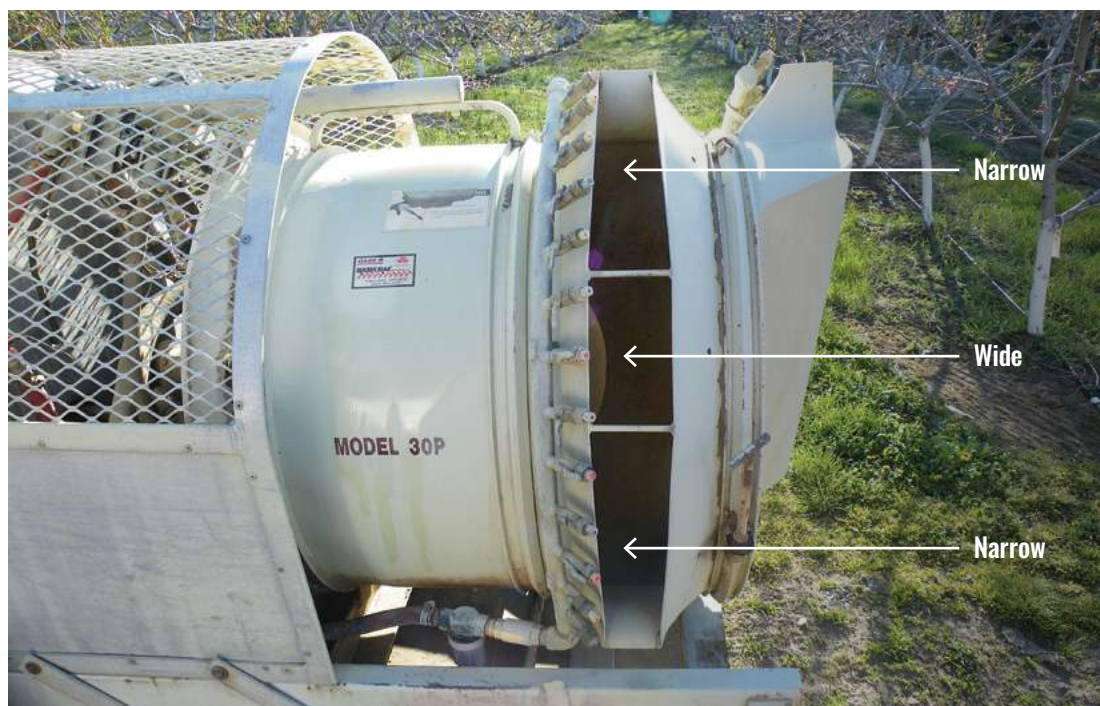
Installing homemade upper and lower deflectors on this engine-driven LPR made a big difference. The deep side walls compress and channel air. The top set was long and the bottom set did not extend beyond the wheels. Once installed, this sprayer easily reached the top of 6 m (20 ft.) McIntosh apple trees using lower rpm. This improved coverage while reducing waste, noise, fuel consumption and wear. Lower deflectors also prevent leaf litter and dirt from being stirred up. This helps to keep the fan blades and grill clean and reduces the potential for “sandblasting” grape and berry crops.



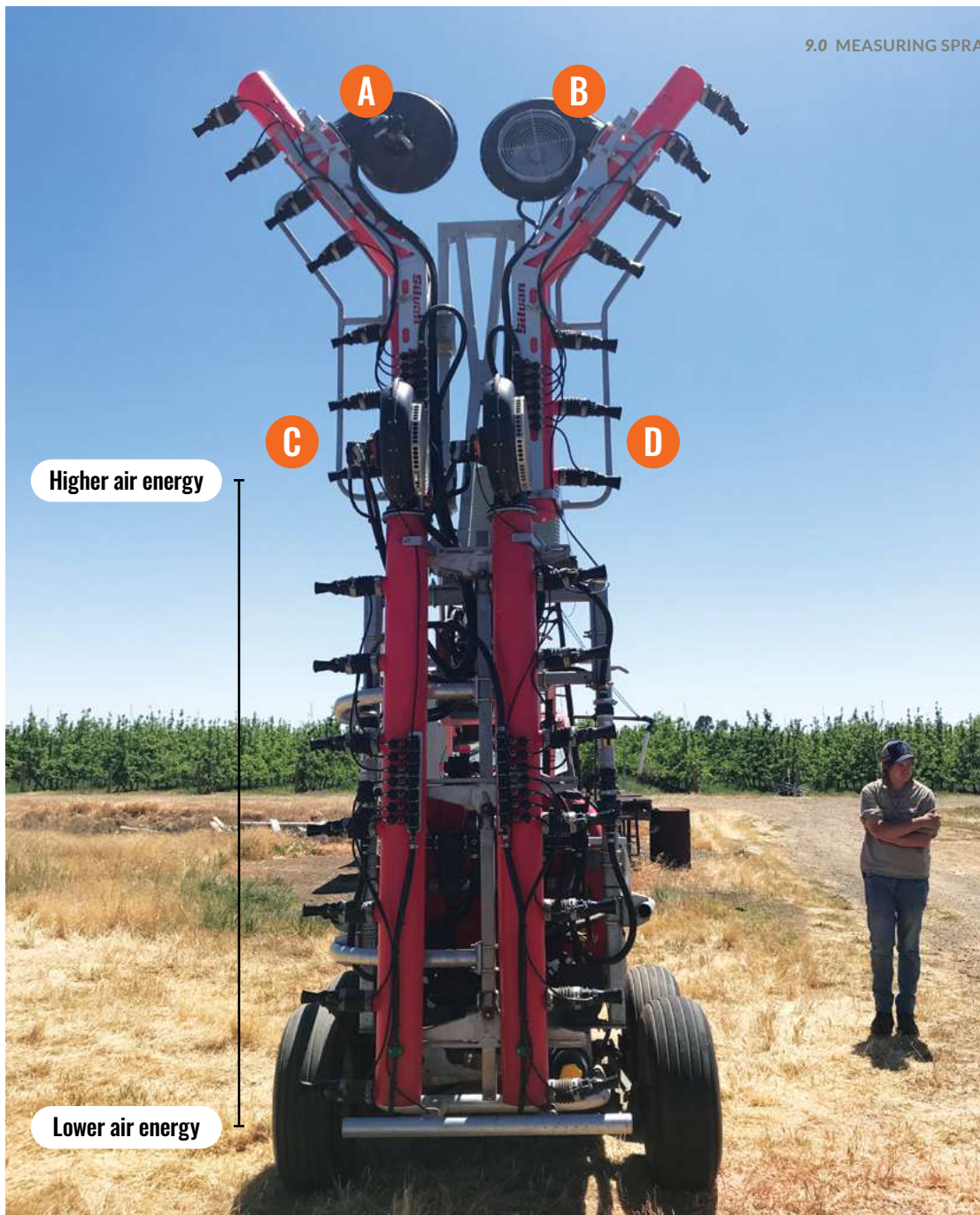
Adjustable deflectors along the entire air outlet give the operator a high level of control over the air angle.

9.4.2. TOP-TO-BOTTOM

Non-uniformity from the top to the bottom on an air outlet may or may not be deliberate. Some outlets are designed to direct more air energy at the widest portion of the canopy (see first figure below). Others suffer from design issues, such as obstructions in the outlet, or friction from tight bends in ducts or tubes (see figure on the following page). Non-uniformity may not be correctable, but the operator should be aware of the issue.



This LRP sprayer has an air outlet that is wider in the middle. During calibration, this duct should be turned to align the most air energy with the widest cross-section of the target canopy.



This unique sprayer was constructed for a research trial. We'll use it to point out some air handling issues. Wisely, the motors on these S.C.R.A.M. (Silvan Centrifugal Remote Air Module) fans sit opposite the intake and this keeps them clean. But, their orientation and relative positions have the potential to create air imbalances. The top fan intakes face in two different directions: Fan A is turbocharged by travel speed and Fan B struggles in the wake. Fans C and D are mounted at the top of their sectional ducts rather than the middle, so the air energy at the top nozzles (nearest the fans) will be higher than the bottom nozzles. Plus, Fan C is directly in the intake path of Fan D, creating a blockage.

9.5. | Review and consider

- Are there inconsistencies in your sprayer air? Do they correspond to portions of your target canopy where control has proved difficult?
- How would you sample and calculate your sprayer's air speed and volume? Would it help to create a form to make this process easier and to supplement your calibration records? (hint: yes.)
- When are conditions too windy to spray? Is your decision based on coverage, or drift? How does your sprayer's air energy affect that decision?





PHOTO CREDIT: STEVE SCHILLER

Chapter 10

The ribbon test

The measurements described in [Chapter 9](#) evaluate a sprayer's potential to satisfy the air requirements for a given swath. They do not, however, account for environmental factors, travel speed or the impact of intervening canopy. We need a way to assess their collective influence and confirm that the air is ultimately reaching the target.

Happily, this method is cheap and simple (and there's no math!). All you need is a roll of flagging tape, a partner wearing eye and ear protection, and the willingness to spend the time. The "Ribbon Test" can be divided into three consecutive steps that follow air from the point of generation to the end of the swath.

1.

Evaluate air angles
at the spray outlet.

2.

Evaluate air energy en route
to the target canopy.

3.

Evaluate air penetration
into the target canopy.



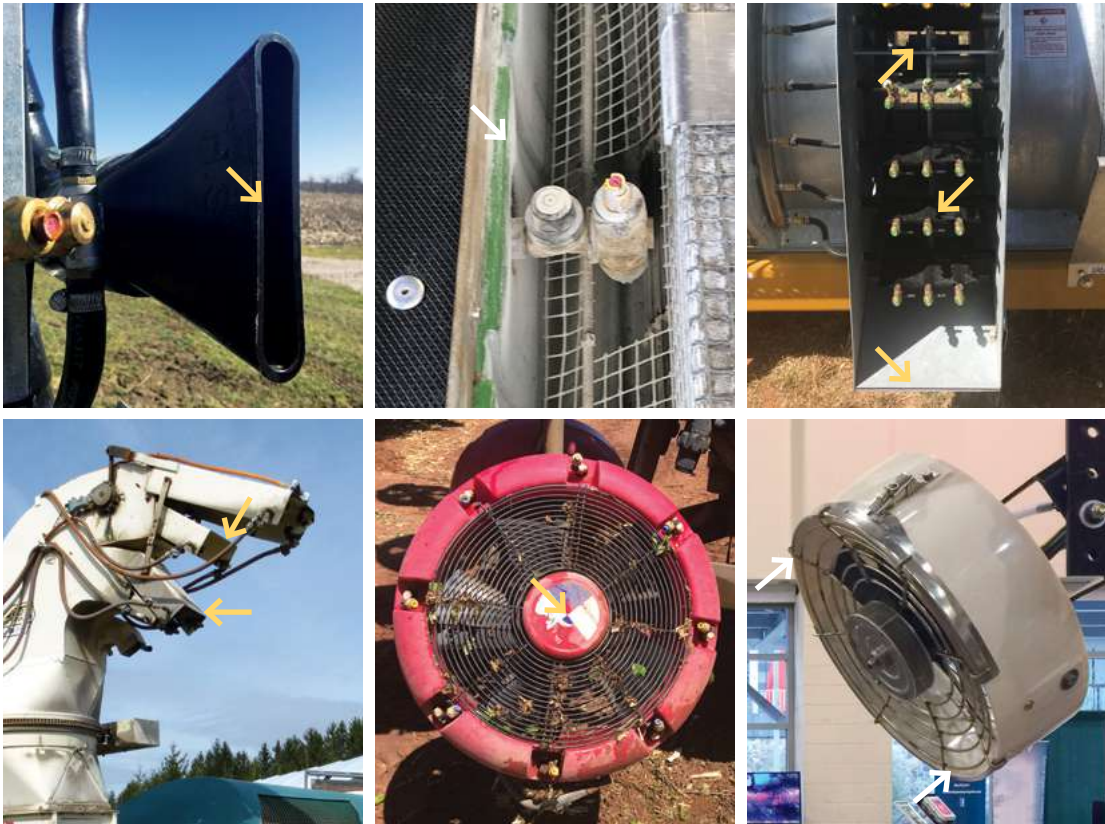
Next to water sensitive paper, a \$3.00 roll of flagging tape may be the most indispensable diagnostic tool in air-assist spraying.

But nothing's perfect. Straight-through axial fans and tangential fans used with shrouds (a.k.a. tunnels or curtains) are often positioned too close to the canopy to permit a ribbon test. If this is the case, the more practical approach is to configure these outlets as described in [Chapter 11.2.3](#). But don't skip ahead – the concepts described here are relevant to all air-assist designs.

10.1 | Ribbon test part 1: Evaluating vertical air angles

Whenever calibrating or adjusting a sprayer, it is critical to do so in the crop, in environmental conditions you would typically spray in. Perform the following steps to assess the air angle:

1. Park the sprayer in an alley between the rows.
2. Affix 25 cm (10 in.) lengths of tape along the air outlets. Tie them to nozzle bodies or use duct tape to position them so that they stand out in the sprayer-generated air. Locations are suggested in the following figure.



Suggested placements for flagging tape. The ribbons should be long enough to stand out in the air, but not so long as to sag or wrap around and get caught in the fan intake. Ribbons sucked into the fan become a spray of confetti, which is fun but not terribly informative.

3.

Bring the fans up to the desired speed but do not spray. Stand back behind the sprayer and use the ribbons to extrapolate the air angle relative to the target canopy. Look for asymmetries and wasted air (i.e. angled above the canopy or into the ground.)



The ribbons on the LPR sprayer in this photo are twice as long as they should be, but fortunately it was a calm day. Note the angles of the lower ribbons compared to the “ideal” broken white lines. The asymmetry corresponds to the misaligned bottom right deflector. Observe the ribbons while adjusting deflector positions. Any ribbons above the upper broken white lines indicate wasted air energy (and likely spray). Large upper deflectors, positioned horizontally, would reclaim wasted air and focus it into the crop.

PHOTO CREDIT: MADELINE WARING

10.1.1. LINE OF SIGHT

It's outside the scope of this book to describe best practices in canopy management, but there are a few concepts that relate to spraying. Canopy management (e.g. pruning, hedging, topping, leaf stripping, etc.) is an important consideration for perennial crops. It improves light penetration and air circulation, which improve the health of the plant and yield quality. From the perspective of a sprayer operator, it also makes it easier for spray to get into the canopy and exposes otherwise-hidden targets.



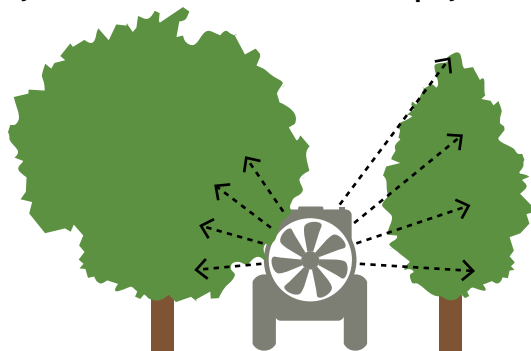
Consider your air angle from the nozzle's point of view. If you can't see your target, the spray may not be able to reach it.

In evaluating the air angles, you may notice obstructions, such as the trellis infrastructure, irrigation lines, netting, or even portions of the canopy itself. Large, unmanaged canopies that overhang alleys can block spray outlets and intercept spray before it reaches the intended depth or height. No portion of the canopy should be closer than 50 cm (20 in.) to an atomizer. If canopy management is not possible, coverage will be improved by:

- Travelling slower will increase dwell time and concentrate air energy for deeper canopy penetration.
- Varying traffic patterns to change air angle.
- Using turbulent air (determined by sprayer design).
- Using a wider air wash (determined by sprayer design).

Closed alley:
Top of tree
blocked
by lower limbs

Open alley:
Top of tree
in line of sight
of spray outlets



**Closed alleys reduce canopy penetration,
reduce spray height and prevent the use of towers**



Large, overgrown canopies may extend into the alleys. They create obstructions that prevent spray from reaching the intended depth and height. Canopies should be managed to keep the line-of-sight unobstructed and to maintain a minimum distance of 50 cm (20 in.) between the canopy exterior and the spray outlets.)



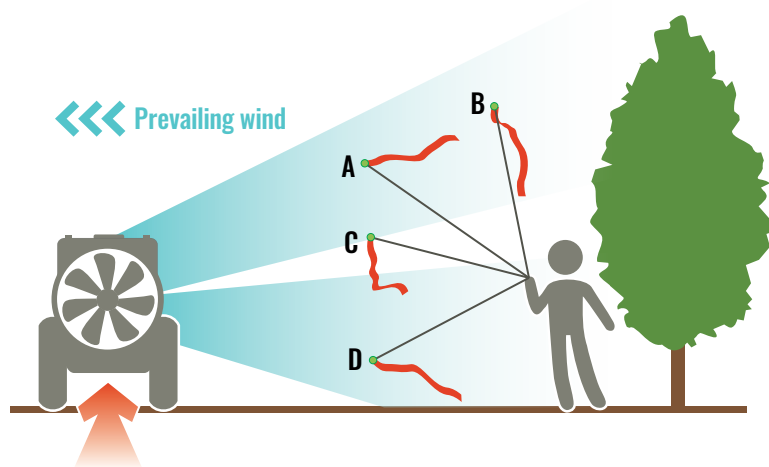
This medieval-looking cladding prevents almond-laden branches from damaging the tractor or snagging and de-seating the operator (we've been told this has happened more than once). If branches are hitting the tractor, they are likely creating a line-of-sight issue at the spray outlets as well.

10.2. | Ribbon test part 2: Evaluating air energy

Air behaviour can change radically between stationary operation and driving. We have learned that slower travel speeds increase the throw and the spray height, but the sprayer design also plays a role. Some air handling designs scavenge air from the sprayer's wake, reducing air energy. Others experience a boost when the intakes face into the wind and/or direction of travel.

The simplest way to track air is for a partner to watch the leaves in the target canopy. Leaves that are ruffling indicate that air is reaching them. A partner can record a smartphone video to show the operator, who couldn't otherwise see what was happening.

A more informative method, and one that works during dormancy, requires a length of flagging tape tied to the end of a long stick. The partner (wearing eye and ear protection) can move the ribbon around in the air wash, extending it into areas of interest. The ribbon's behaviour will indicate gaps, the air angle and relative air energy. The ribbon can be interpreted using the following figure.



Work on the lift side (if applicable) with the sprayer oriented to blow into any crosswind. Extend the ribbon into the sprayer air while the sprayer is stationary, or preferably, while driving. The ribbon's behaviour will show what you couldn't otherwise see. Here are a few possible outcomes: **A.** The angle and air energy are appropriate while the sprayer is stationary. **B.** The air energy is not sufficient to reach the tree top when the sprayer is driving. **C.** Obstructions or deflector misalignment can create gaps. **D.** Air is angled too low for the target canopy.

10.3. | Ribbon test part 3: Evaluating canopy penetration

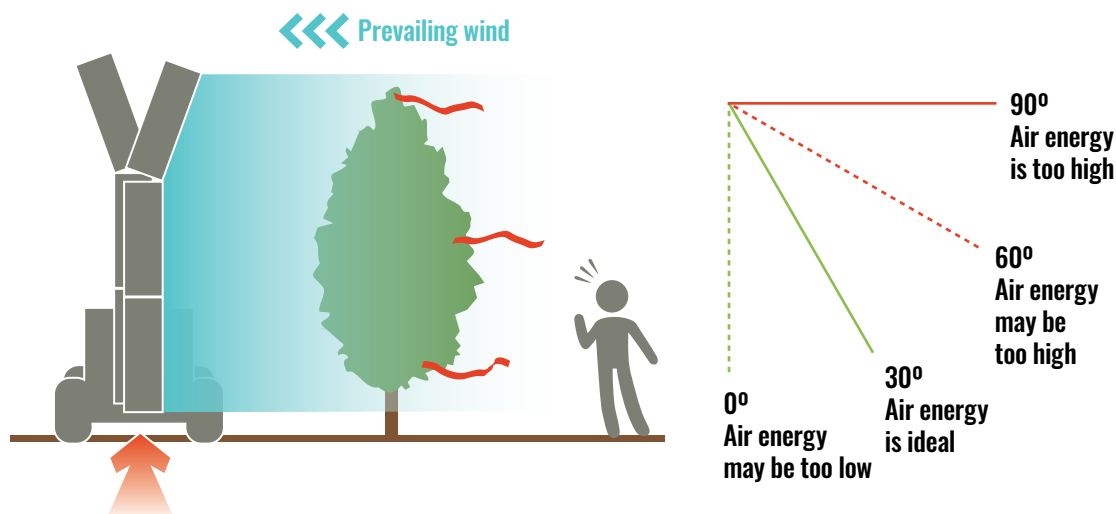
Part 3 accounts for the influence of any intervening canopy (or canopies for multiple-row strategies). It confirms that the air energy has the potential to carry droplets the full extent of the swath.



Evaluate sprayer configuration in the planting, in environmental conditions you would normally spray in.

1. Choose a canopy that is upwind and on the lift side of the sprayer (if applicable). Move a distance into the row to allow the sprayer to reach target speed and to avoid wind effects on the periphery.
2. Attach 25 cm (10 in.) lengths of flagging tape on the far side of the target canopy. Do this at the top, middle and bottom of the canopy. In tall canopies this might require a ladder, telescoping pole, or sections of galvanized pipe to raise the ribbons.
3. With deflectors/spray outlets adjusted and the desired fan gear (or fan speed) selected, start the air without spraying and bring the sprayer up to the target travel speed.
4. A partner wearing eye and ear protection will stand in the next alley and observe the ribbons as the sprayer passes (preferably recording a video for the operator). Interpret ribbon behaviour per the image on the [following page](#).

Evaluating at least one side will give you a lot of insight. If you've got the time, it's always good to do both sides. Since most sprayers have at least some imbalance in air handling, the results may surprise you ([see Chapter 9](#)).



Three ribbons are positioned on the far side of the upwind target canopy. In this case, an every-row traffic pattern is depicted. The observer watches or records the ribbons as the sprayer drives past with the air on (not the spray). For an every-row traffic pattern, the air energy is too high if the ribbon strains at 90°. It is ideal for the ribbon to briefly flutter (0°-60°). If the ribbon does not move (0°), the air energy may still be sufficient as long as it penetrates to the centre of the canopy. This is often the case with particularly dense/wide trees like nuts and citrus.

10.4. | Review and consider

- Does your sprayer produce equivalent air speeds and profiles on each side, or are they different?
- If there's an asymmetry, is it a problem or an advantage?
How could the applicator use this knowledge?
- Who would you work with to conduct the ribbon tests? Which planting/sprayer combination would benefit most from the test?
- Have you considered the economic impact of canopy management on your spray applications? Would more open canopies improve your disease control? What could that mean to your packout and harvest operations?
- How difficult would it be to perform a canopy modification trial in a single row? Test strip trials are a common practice in field crop operations.



PHOTO CREDIT: GWEN-ALYN HOHEISEL

Chapter 11

Configuring sprayer air

Interpreting the ribbons is not always straightforward. When they don't behave as anticipated they may be indicating one or more of the following problems:

1.

The air angle is incorrect.

2.

The air energy is too low.

3.

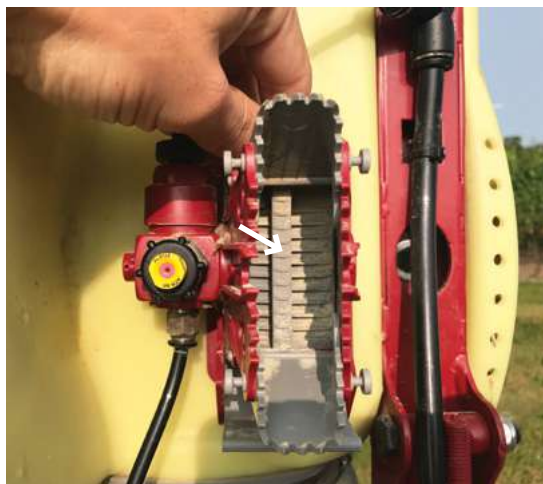
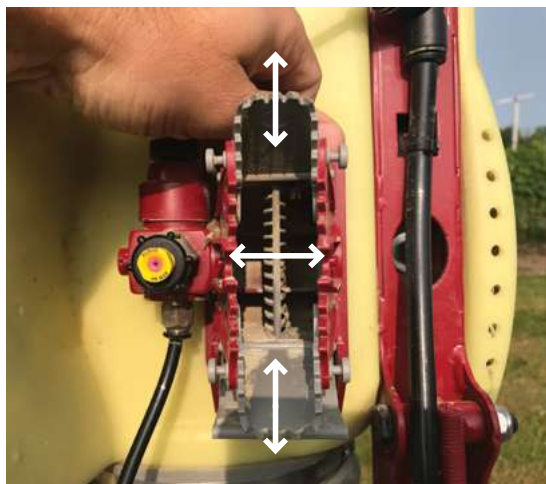
The air energy is too high.

There might be a single cause or several contributing factors. As you diagnose and attempt to correct these problems be aware that addressing one may create others (see figure below). If the problem cannot be corrected, the sprayer configuration (or design) may be inappropriate for the canopy or the environmental conditions.



LAMINAR FLO SAYS...

When reconfiguring a sprayer, do not make more than one change at a time before assessing the impact.

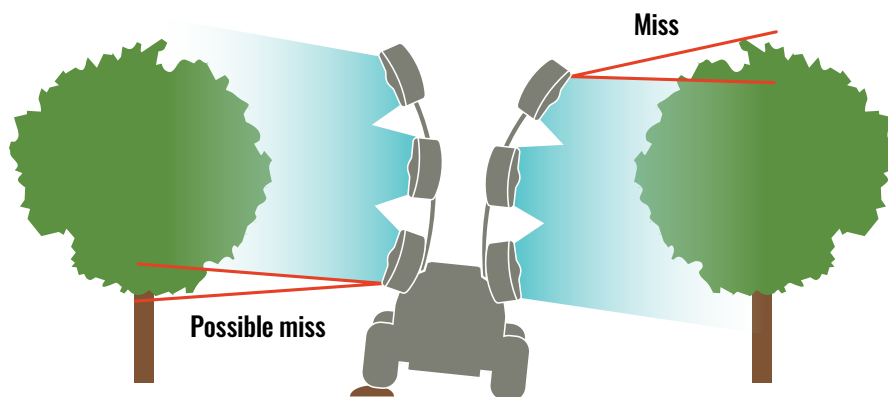


This ducted design features extensive adjustability similar to the air vents in the dash of a car.

LEFT: Upper and lower deflectors can be repositioned vertically. The entire outlet can also be angled horizontally. **RIGHT:** If air is not required in this position, a butterfly valve-style baffle can be closed, and the nozzle replaced with a cap to halt liquid flow.)

11.1. | Adjusting vertical alignment

Ribbons that don't point from the sprayer to the canopy may indicate a misalignment of spray outlets or deflectors. The bottom of the air should align with the bottom of the target. More critically, the top of the air should slightly overshoot the top of the target. We want to avoid spray drift, but we must account for wind speed increasing with height and vertical booms that rock on uneven alleys (gimbal systems are available to offset rock and sway). If the spray does not slightly overshoot the top of the target, it may miss it entirely.



When the canopy is higher than the highest spray outlet, it is preferable to have spray height slightly exceed the target height. This will help compensate for faster travel speeds, higher winds and uneven alleys that cause the sprayer to rock laterally.

In the case of a boom that extends over and under the target canopy, angling the top air outlet down and the bottom outlet up is a sensible practice. This is common for TT and WA designs. Doing so concentrates air energy and improves penetration. It also creates a desirable downward/lateral air angle to reduce spray drift.

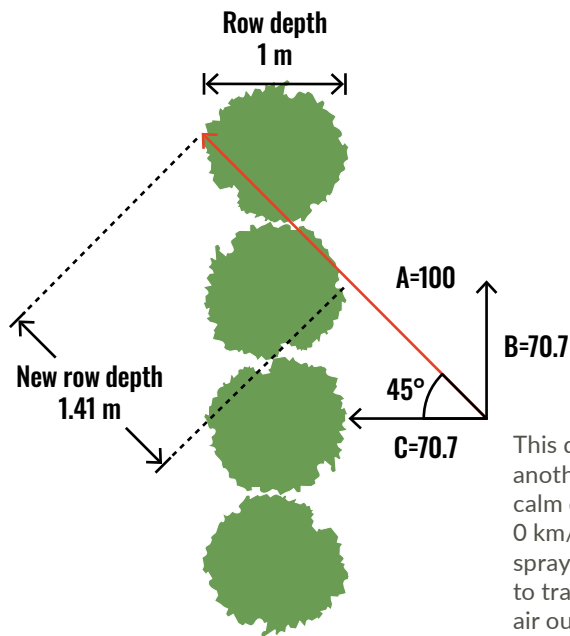
Note that in sparse canopies, there are a couple of positive and potentially negative consequences to this. Angling the top air outlet down pushes against the generally higher wind velocities in sparse canopies and controls upwards movement of drift. That's good. If there is nothing to catch that air, it may push dramatically further laterally. That's bad if you're spraying outward in the outside couple of rows. Understand the impact on throw using water sensitive papers (see [Chapter 15.4.](#)) and spray inward to mitigate the drift potential.

Adjusting vertical air alignment has a secondary benefit of indicating which nozzles should be on or off. Nozzles should span the canopy but not direct excessive spray below or above it (see [Chapter 13.2.](#)).

11.2. | Adjusting horizontal alignment

Adjusting horizontal alignment, when possible, can significantly impact sprayer performance. It can be tricky to optimize the angle because it represents the sum of several complicated interactions. We'll use trigonometry to show how the air angle affects air velocity and canopy depth (see figure below). Grab your protractors and meet the players:

- Travel speed
- Wind speed
- Sprayer air velocity
- Canopy depth
- and Pythagoras, who laid out the rules of the game.



Headwind: 0 km/h
 Travel speed: 0 km/h
 Air velocity: 100 km/h
 Air angle: 45° forward
 Change in row depth: +41%
 Change in air velocity: 0

$$A^2 = B^2 + C^2$$

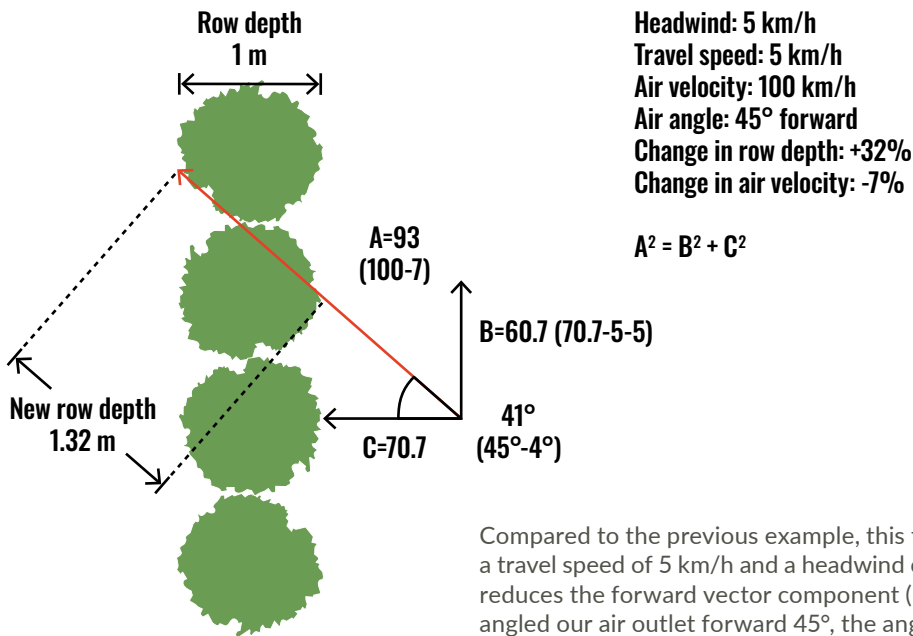
This diagram shows how all the factors relate to one another. Consider a sprayer parked in an orchard on a calm day. The travel speed is 0 km/h, the headwind is 0 km/h and the canopy is 1 m deep. If we angle the sprayer air directly at the canopy (i.e. 90°), it would have to travel 1 m to span the canopy depth. If we angle the air outlet forward 45° (the red arrow), trigonometry allows us to calculate the new distance it would have to travel to pass through the row. The effective canopy depth would increase 41% to 1.41 m.

While we don't illustrate it, air wash gets an honorable mention. Air outlets with a wide wash (e.g. straight-through axial fans) should only receive minor horizontal adjustments to maximize the air intercepting the canopy. We explain this further in [Chapter 11.2.3](#).

11.2.1. FORWARD-ANGLED AIR

Now let's consider a dynamic situation (see figure below). What happens to forward angled air while the sprayer is in motion with a moderate headwind? The wind created by the sprayer's travel speed opposes the forward motion of the sprayer air, which means we lose air velocity. It also reduces the angle, which reduces the relative canopy depth and the amount of resistance the air will encounter.

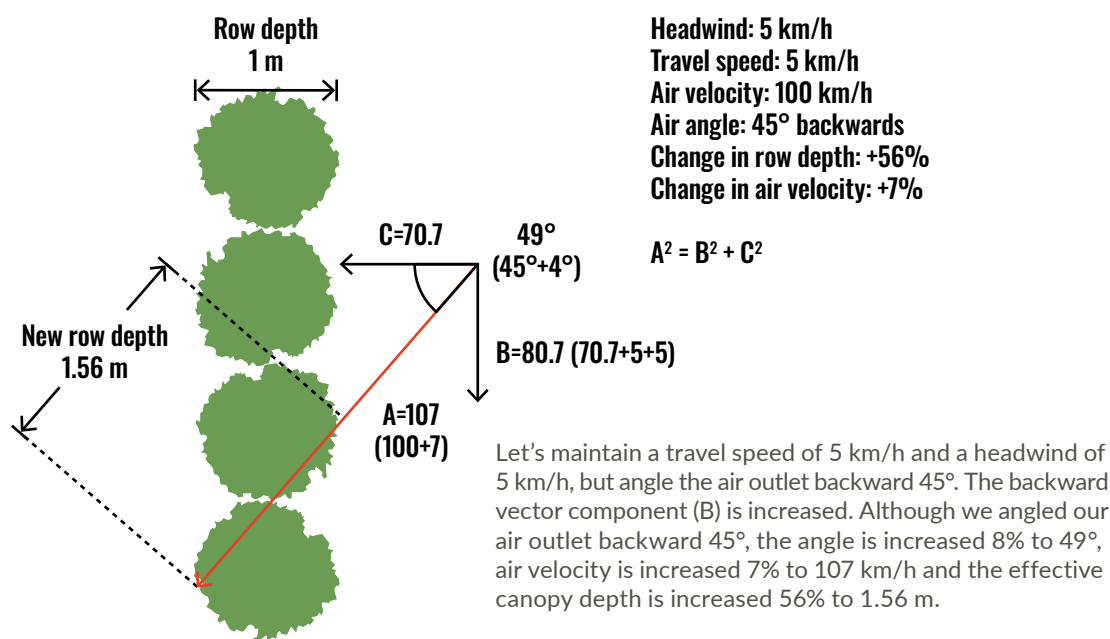
This might be good strategy for reducing excessive air energy. On the other hand, if the sprayer air is already limited, it could significantly reduce canopy penetration. Consider operator safety as well: if the spray is angled too far forward, it may needlessly increase operator exposure to spray.



Compared to the previous example, this figure factors in a travel speed of 5 km/h and a headwind of 5 km/h, which reduces the forward vector component (B). Although we angled our air outlet forward 45°, the angle is reduced 9% to 41°, air velocity is reduced 7% to 93 km/h and the effective canopy depth is only increased 32% to 1.32 m.

11.2.2. BACKWARD-ANGLED AIR

In the case of rear angled air, the wind created by the travel speed adds to the air velocity of the sprayer air. This can be difficult to perceive because the angle of the sprayer air is back beyond the operator's line of sight. While the canopy becomes deeper due to the diagonal attack, penetration is increased thanks to the added boost from the travel speed. As long as the sprayer has adequate air capacity, there is a benefit to some degree of backward angle (see figure below).



11.2.3. AIR IN OPPOSITION

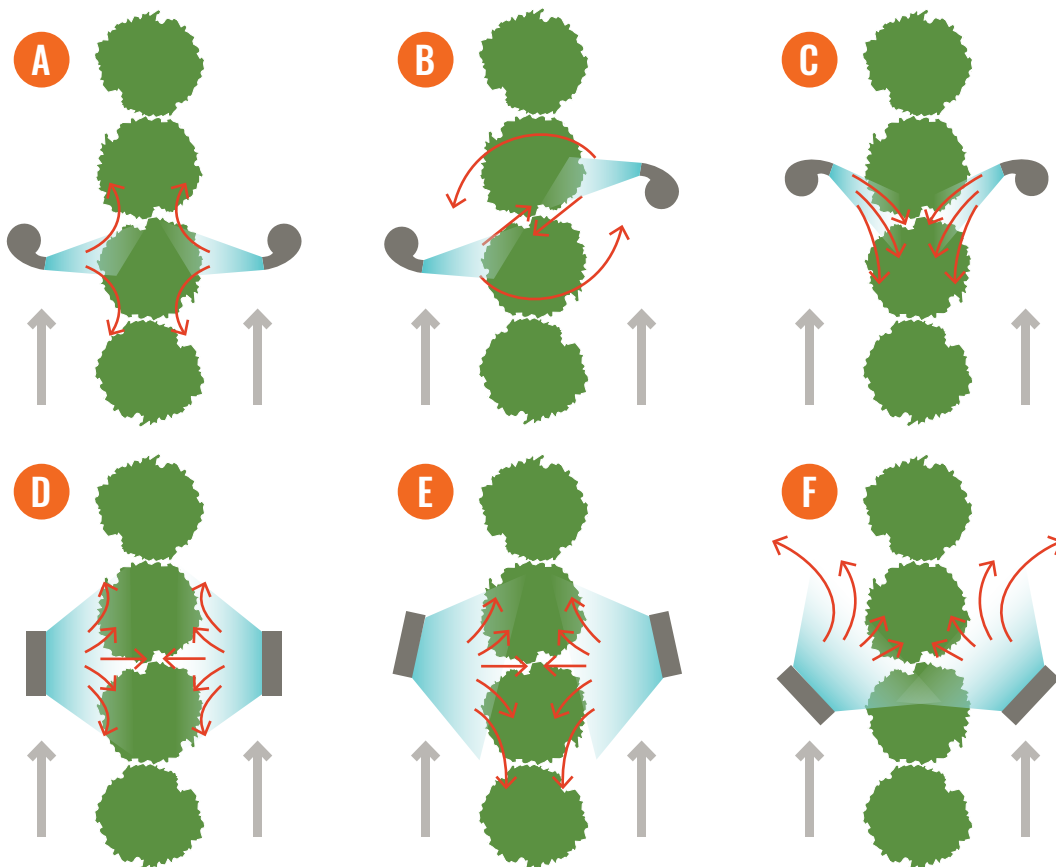
In [Chapter 10](#) we noted that the air outlets on WA sprayers may be positioned too close to the target canopy to permit a ribbon test. However, you can still use the ribbon-on-a-stick technique to visualize how the air is behaving. Consider these guidelines when positioning air outlets on either side of a canopy.

When possible, do not position laminar air outlets in direct opposition. The convergence creates a high pressure zone that reduces spray penetration. Laminar flows will deflect unpredictably around this pressurized area and carry droplets back out of the canopy. Unless the canopy is narrow and sparse, turbulent air handling systems do not typically create this problem. In both cases, canopy penetration is improved when fans are staggered and/or are angled slightly forward or backward ([see the following two figures](#)).



LAMINAR FLO SAYS...

When adjusting a WA sprayer, examine the plume by looking into the sun from behind the sprayer. Then turn off the upwind outlets in a crosswind to see if remaining fans are penetrating deeply enough.



Grey arrows indicate direction of travel. The air outlets of WA sprayers should be symmetrical when viewed from behind. **A.** Tangential fans in direct opposition: Poor coverage. **B.** Tangential fans angled forward/backward: Possible vortices and good coverage. **C.** Tangential fans angled backward: Good coverage, but if the angle is too steep, air will not penetrate the canopy. **D.** Straight-through axial fans in direct opposition: Good coverage in denser canopies. **E.** Straight-through axial fans angled slightly backward: Good coverage, but limit the angle to prevent the trailing edge of the air wash from missing the canopy entirely. **F.** Straight-through axial fans angled forward: Slight angles are acceptable, but too much in this image. Wind created by travel speed subtracts from air energy. This creates a risk of reduced coverage and increased operator exposure.



A. According to water sensitive paper, this WA recycling sprayer was not penetrating to the centre of this high-density apple canopy. The laminar air was in direct opposition. **B.** We turned the outer boom (which included the air outlet) about 10° backward by adjusting the four clamping screws. **C.** This minor change in configuration improved spray coverage significantly. Increasing the angle beyond 10° might have caused the air wash to trail along the canopy face and would have made sprayer turns difficult at the row ends.

11.2.4. LEAF SHINGLING

When too much air is vectored directly at the canopy face, it may close and compress that canopy rather than penetrate it. This is more likely when air is high energy, has a narrow air wash or is more laminar in nature. Consider the famous testudo (tortoise) defence of the Roman legions (see figure right).

The soldiers would overlap their shields to deflect a hail of arrows, protecting those inside the formation. Perhaps they were inspired by grape leaves moving in gusty winds and not a reclusive reptile. When air is angled directly at canopies with broad leaves that move freely the leaves can shingle like Roman shields.



A Roman Testudo.

PHOTO BY NEIL CAREY, VIA WIKIPEDIA.

When leaves shingle, the overlap blocks spray and creates resistance to sprayer air. Air will then take the path of least resistance and either deflect around the canopy or channel through any openings. When there is the potential for shingling the observer should watch the ribbons, but also note if the canopy appears to compress. It will look as if the canopy received a quick shove as the sprayer passes. We have watched grape canopies close as the sprayer passes using digital cameras placed inside.

Shingling can be corrected by angling air outlets slightly forward or backward. A little goes a long way as small changes can have big effects and too large a change can create other problems (see figure below). Recommendations for horizontal fan angle are crop and fan specific, but generally do not exceed 15°.



Air deflection and channeling may not move ribbons.

Problem: A narrow air wash angled directly at the canopy face (90° to the row) can sometimes cause shingling and close the canopy.

Solution: Angle air outlets slightly forward or backward, increase air turbulence or create a wider air wash. Multiple angles will twist leaves, exposing more surfaces to spray and improving canopy penetration.

When a narrow air wash is angled directly at the target row, large leaves may shingle and close the canopy. Air will deflect and channel along paths of least resistance. The lack of penetration may give the false impression that air energy is too low. The solution is to create multiple angles of attack which will ruffle the leaves and open the canopy to spray. This can be accomplished by angling air outlets slightly forward or backward or employing an air outlet with a wider air wash.

Turbulent air, or a wider air wash, will also reduce shingling by creating multiple angles relative to the leaf face. Multiple angles cause leaves to flutter and rotate rather than overlap one another. This will open the canopy and expose all surfaces to spray.

Coverage from a twin-fluid nozzle employing high air energy aimed directly at a canopy looks promising until we reveal the results of shingling. Reducing air energy was not possible with the atomizer design used to spray these grapes, but angling the air outlet relative to the canopy may have improved matters.

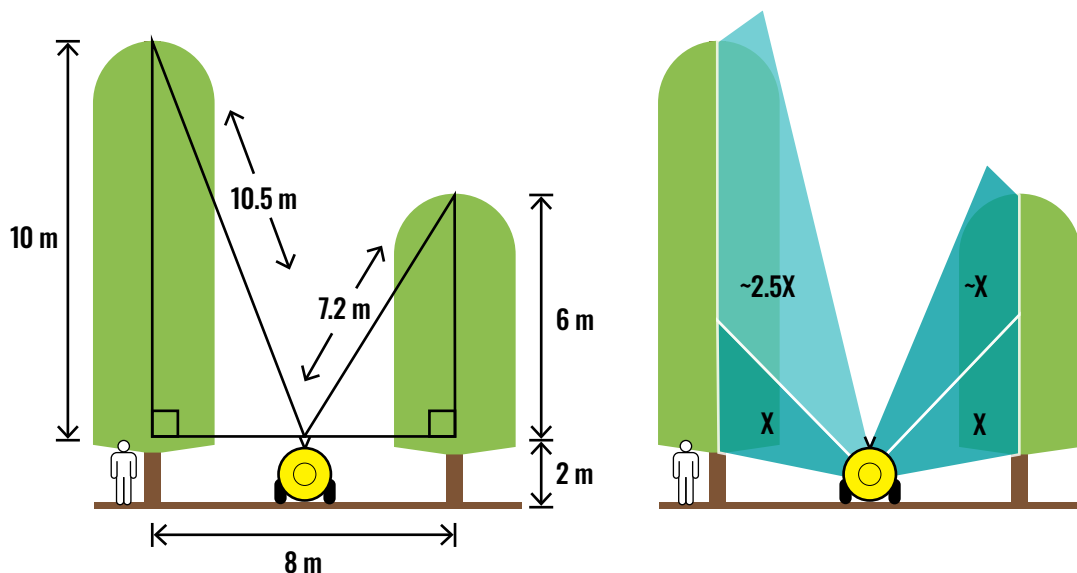


11.3. | Air energy: too low

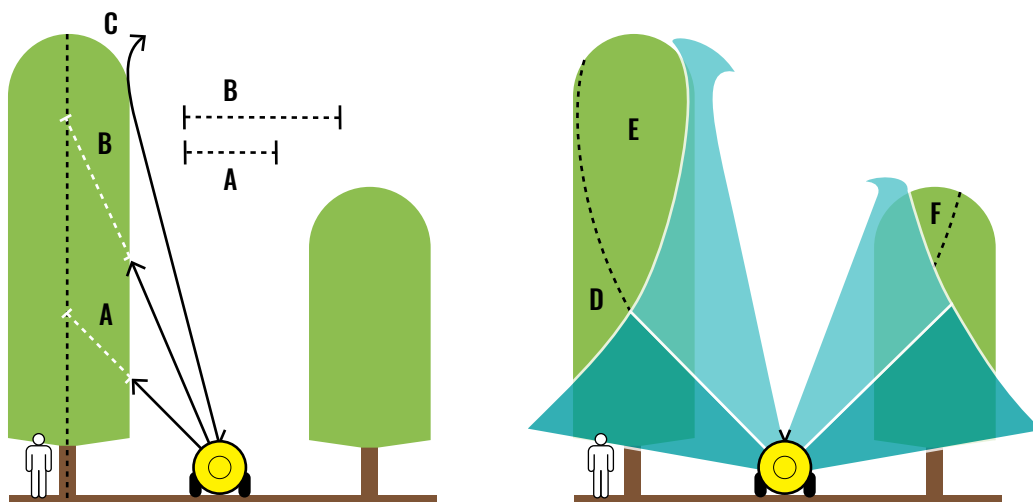
Unresponsive ribbons are often observed during a ribbon test. Depending on where the ribbon is located, this may or may not indicate a problem.

11.3.1. TOP RIBBON

Ideally, the top ribbon should always move in response to sprayer air. In larger canopies, this location represents the greatest distance sprayer air must travel and the highest wind speed it will encounter. For example, in the case of a canopy as large as macadamia, it is very difficult for a low profile radial sprayer to produce enough air energy to reach the top of the tree. Topping (i.e. reducing the height of the tree) may be required. Consider the following two figures:



LEFT: Spray must travel 10.5 m to reach the top of this mature macadamia tree and must pass through a cross section of canopy en route. Comparatively, it must only travel 7.2 m to reach the top of a managed canopy. Given the loss of air energy per the inverse square law and the higher wind speeds at the top of the larger tree, the shorter tree greatly improves the potential for coverage. **RIGHT:** If the air outlet is divided in half, the lower zone (dark blue) must produce enough air energy to satisfy cross sectional area "X". In the case of the larger tree, the upper zone of the outlet (light blue) must produce 2.5 times the air energy to cover its portion of the canopy. This is an underestimate given the increased distance it must travel. However, on a managed canopy, the air energy requirement is better balanced along the air outlet.



Canopies resist air penetration. Consider the path air must take to reach and then penetrate the canopy to the trunk. On the left, we see the air on angle (B) must pass through almost twice the canopy as angle (A). As air energy wanes with distance, we see it fail to penetrate on angle (C), deflecting along the path of least resistance. This is why canopy vulnerability increases with height. On the right we see the differential in canopy penetration with distance from the sprayer. The bottom (dark blue) zone passes the canopy at the midpoint, but penetration is greatly reduced with distance in the top (light blue) zone. The broken black line (D) indicates where penetration would end when sprayed from the alternate side. Unless the sprayer is calibrated to compensate, the lowest portion of the tree will receive a wasteful double-dose (those bugs aren't getting any deadier). The upper portion of the canopy (E) is the hardest region to cover with an LPR sprayer. Surface coverage may be acceptable but penetration is compromised. In contrast, the upper portion of the smaller canopy (F) receives better coverage in this region, but there is still room for improvement.

11.3.2. MIDDLE/BOTTOM RIBBON

The middle and bottom ribbons may or may not move in response to sprayer air. But in the immortal words of Douglas Adams, "Don't Panic!". Turbulent Eddy insists that a limp ribbon may not be a problem. When driving an every-row traffic pattern, air should penetrate the target canopy just beyond the midpoint (e.g. the trunk) and not blow out the far side. This is common in larger, denser canopies. To confirm this, an observer would have to stand at the trunk and watch the leaves rather than the ribbons. If the air is not moving the leaves at the centre (particularly half-way up the canopy) the following table suggests possible causes and corrective actions.

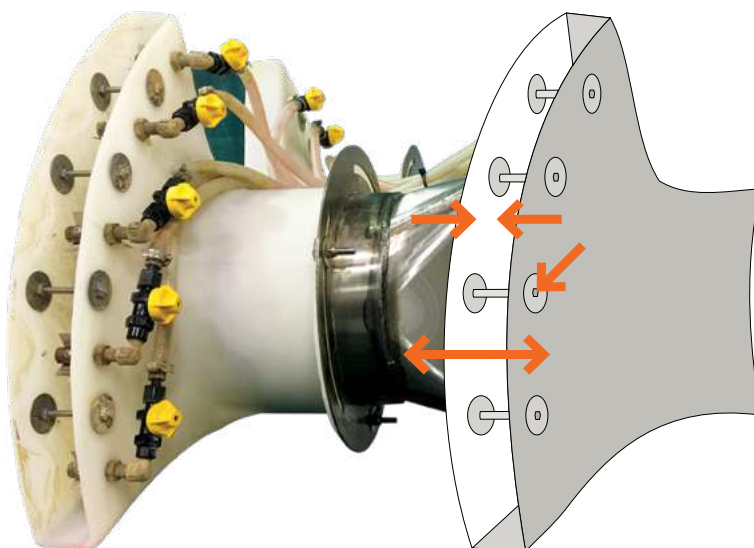


**LAMINAR
FLO SAYS...**

Focused, converging airstreams are like a magnifying glass. They intensify the sprayer's ability to penetrate a canopy and cheat the inverse square law.

CAUSE	CORRECTIVE ACTIONS
Fan speed is insufficient.	<ul style="list-style-type: none"> • Confirm fan(s) are not damaged (e.g. bearings, hydraulic fluid level). • Increase PTO speed to 540 rpm. • Increase fan gear. • Confirm the fan intake grill is clear of obstructions. • Increase straight-through axial fan speed or blade pitch to manufacturer's specifications.
The traffic pattern or sprayer configuration must be reconsidered.	<ul style="list-style-type: none"> • Confirm sprayer can produce sufficient volumetric flow to displace canopy volume. • Focus air energy using deflectors or adjust the air outlet size. • Reduce travel speed to increase dwell time. • Bring spray outlets closer to the canopy (important for turbulent air). • If spraying through multiple rows, consider a shorter swath. • Ensure canopy is not shingling, and in the case of WA sprayers, air outlets are appropriately angled.
Wind speed/direction are interfering.	<ul style="list-style-type: none"> • Park the sprayer until conditions improve. • Consider a sprayer design with more air energy or one that brings spray outlets closer to the target.
Canopy too wide/dense.	<ul style="list-style-type: none"> • Consider canopy management, particularly if spraying through multiple rows.

When this style of air outlet is made of plastic or fiberglass, you can make minor adjustments to the outlet size. Reducing the outlet size will reduce air volume and may increase air velocity. This adjustment can reduce the throw, which may improve coverage in adjacent canopies. Conversely, opening the outlet will increase air volume and throw. Be aware that opening the outlet can significantly increase the horsepower requirement. Confirm that your tractor has the capacity to handle this adjustment.



11.4. | Air energy: too high

When air energy is too high, the ribbons in the canopy will align with sprayer air and the throw will likely exceed the swath. This blow-through is wasteful, creating pesticide drift and reducing coverage. Blow-through is more likely when spraying sparse or dormant canopies.

11.4.1. CANOPY DISTORTION AND SLIPSTREAMING

Just as certain canopies will shingle, others will distort, which reduces the profile exposed to spray. In this case, leaves align with the air direction, exposing only their thin edge to the spray. The air will then slipstream along the face, reducing coverage as it carries droplets along with it.

When leaves align with the air it reduces the exposed surface area. Droplet-laden air then slipstreams along the face, reducing deposition.



Still conditions



10.8 km/h (6.7 mph)
~10% more canopy exposed
to air vs. still



18 km/h (11.2 mph)
~20% less canopy exposed
to air vs. still

Dr. Bernard Panneton performed a series of experiments exploring the relationship between canopies and wind. As wind speed increased, the leaves of these potato plants twisted and ruffled, increasing the amount of surface area exposed. However, the canopy distorted in high wind. Leaves aligned with the air, significantly reducing the surface area. Bernard's summary was succinct: "More air is not better."

PHOTO CREDIT: BERNARD PANNETON

11.4.2. STRATEGIES TO REDUCE AIR ENERGY

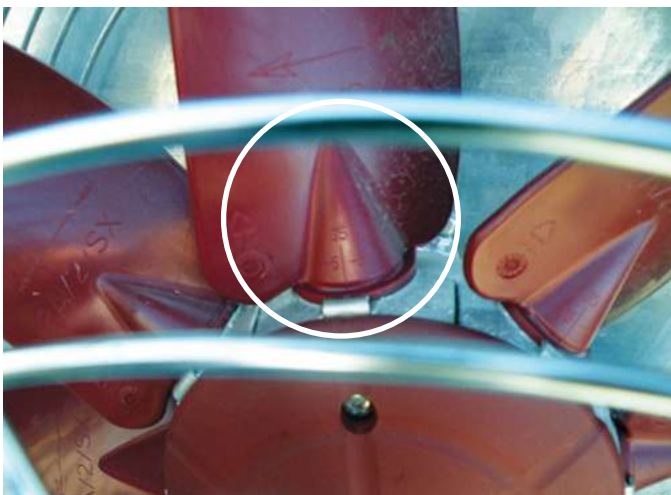
Operators may already be aware of some of the following methods to reduce air energy. Some are sprayer-specific and not all of them are recommended.

- **Increase travel speed:** The simplest approach, this method was explained in [Chapter 3.2](#). Basically, faster travel speeds shorten the throw (and in some cases the spray height).
- **Reduce fan gear/fan speed:** Some sprayer designs have a high or low gear, while others permit fan speed adjustment via hydraulics.
- **Block fan intake:** Once a popular approach, we do not recommend blocking a portion of the fan intake unless engineered specifically for the sprayer. We have been told stories of damage to fans and other potential dangers.
- **Block air output:** Unlike blocking the intake, blocking the output when needed (i.e. deadheading) is an acceptable strategy for reducing air energy. While uncommon, adjustable louvers or air dams can be installed to tailor air output, and if present have the added benefit of blocking one side when border spraying. Blocking air output will reduce the horsepower requirement of the sprayer.
- **Adjust fan blade pitch:** Some fans feature blades with adjustable pitch to increase or lower air energy. We do not recommend this method for axial fans on LPR sprayers because it is time-consuming and can potentially imbalance the fan if performed incorrectly. If your fan is designed for frequent adjustment this doesn't apply to you.
- **Reduce PTO rpm:** This method reduces the PTO speed to slow the fan. While effective, this method is only appropriate for a certain sprayer design. We explain his method in greater detail in [Chapter 11.4.3](#).



If you have never shifted your fan gear, be prepared for a struggle. Mr. Paul Splinter, shown here, has found a creative position to gain leverage using a heavy adjustable wrench. This, and a generous helping of lubricant, got the gear moving smoothly again. Pro tip: You may have to turn the fan manually to align the gears before it will shift.

Variable pitch angles are available on some welded fans, meaning you change the entire rotor to change the pitch. Others have an adjustable pitch to increase or lower air energy. Correctly adjusting blade pitch can be difficult and time-consuming. Most operators only try it once.



Mr. Kim Blagborne teaches the importance of focusing air energy into the canopy. He temporarily blocks a portion of the air outlet that extends above a grape canopy. What better way to block a duct than using duct tape?

11.4.3. REDUCE PTO SPEED

In 1977, David Shelton and Kenneth Von Bargaen (University of Nebraska) published an article called “10-1977 CC279 Gear Up – Throttle Down”. It described the merits of reducing tractor rpm for trailed implements that didn’t need the standard 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 didn’t need full tractor power, so why waste the fuel? He tested shifting to a higher tractor gear and slowing engine speed to maintain the desired ground speed. 700 diesel tractors were tested, and 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% of the diesel was saved.

For PTO-driven LPR sprayers with positive-displacement pumps, this strategy has a lot of merit. Increasing the tractor gear and throttling back can reduce the PTO speed from 540 rpm to somewhere between 350-375 rpm. This saves fuel and reduces noise levels, but more significantly it slows the fan speed without changing travel speed or nozzle pressure/calibration.

The following conditions must be met:

- The sprayer is PTO-driven and uses hydraulic nozzles.
- The pump must be positive displacement with sufficient surplus capacity to maintain pressure at lower rpm (see Chapter 5.3.).
- The tractor has sufficient horsepower (more than 25% in excess of minimal capacity) to permit a reduction in engine torque. Driving a tractor at full throttle with low engine rpm and the transmission in too high a gear is known as lugging. Black smoke and terrible sounds will follow.

11.5. | Review and consider

- Would a minor change to your air alignment improve your coverage?
Would it reduce waste?
- Which changes to your sprayer's air handling give the biggest benefit for the least effort?
- Does the air output of your current setup help or hurt you in relation to canopy slipstreaming or shingling? What could you do about it?
- Does changing travel speed make more sense than changing PTO speed or fan settings?
- Would changing the order in which plantings are sprayed reduce the number of changes required?



Chapter 12

Transfer efficiency

Once generated, droplets have three possible fates: the ground, the air, or the target. Transfer Efficiency is considered from the sprayer's perspective, describing the droplet's potential to arrive at the target. This is not to be confused with Catch Efficiency (a.k.a. Retention Efficiency) which is considered from the target's perspective and describes its potential to intercept and retain droplets (see Chapter 7). Transfer efficiency and catch efficiency are a spectrum where at some point one becomes the other. When an operator understands how droplet size influences droplet behaviour, they can make adjustments to improve transfer efficiency.



A baseball player with a good throwing arm has a high transfer efficiency. A baseball player with a good glove has a high catch efficiency.

12.1. | Droplet evaporation

Hot and dry conditions create significant evaporative losses which can reduce transfer efficiency and create drift issues. Consider that each droplet is a tiny portion of the original tank mix. When droplets evaporate, the water component disappears. Depending on the products in the solution tank, either a dust spec or a tiny oil droplet is left behind.

For example, a 100 μm droplet with a 3% non-volatile component evaporating to dryness would become a dust particle of around 30 μm . Under the right conditions, a few particles may adhere to the target due to electrostatic force (see Appendix 4), but they would have to rehydrate to become biologically active. Most will miss the target entirely, dispersing and drifting for a long time.

Coarser droplets survive longer (see table on the following page), so they can travel further and remain wet on the target surface. Wetting Time describes the duration a droplet remains in liquid form while in contact with the target surface. It is generally agreed that a longer wetting time means better product performance. In regions that get frequent re-wettings of dew or precipitation, this is less important.

ORIGINAL DROPLET DIAMETER (µm)	DROPLET DIAMETER AFTER WATER EVAPORATION (µm)	TIME TO EVAPORATE(S)
20	7	0.3
50	17	1.8
100	33	7
150	50	16

To be effective, a droplet should remain intact long enough to reach and wet the target. The coarser the droplet, the longer it will take to evaporate to dryness. This model assumes a temperature of 32°C (92°F), 36% relative humidity, and a 3.75% non-volatile pesticide solution. There is no air-assist factored into these figures.

The potential for evaporation is related to air temperature and relative humidity but is best described by Delta T (ΔT), which is dry bulb minus wet bulb temperature. Better hand-held weather meters will measure ΔT . This metric has become a standard indicator in Australia for acceptable field spraying conditions. It is a useful guideline for air-assist sprayer operators as well. When ΔT values are high, conditions are prone to evaporation. Wetting time is directly and inversely proportional to ΔT .

12.1.2. STRATEGIES TO MITIGATE EVAPORATION

There are several ways to reduce the impact of evaporation. Each of the following strategies require a compromise, but there should be viable options here for any spraying strategy.

- **Reduce the time between droplet release and impact:** Achieved by bringing the spray outlet(s) closer to target, or increasing droplet velocity. This is not an option for some sprayer designs.
- **Spray in the evening/night:** Environmental conditions are often cooler, calmer and more humid in the evening/night. Waiting to spray in these conditions may preserve droplet size, but can also increase drift potential if they correspond with thermal inversion conditions (see Chapter 21.2.1.).
- **Increase spray volume:** Increasing the amount of water used per planted area increases local humidity. The effect doesn't last long, but local evaporation is reduced, improving spray transfer and increasing wetting time. In hot, arid climates, operators may use 2-5 times as much water to achieve the same transfer efficiency as in more humid areas.

This may not be an option for so-called “low volume”, “concentrate”, or “mist blower” sprayers. These loose terms are region-specific, but generally refer to sprayers that use air-shear, rotary, or twin fluid atomizers and rely on high droplet counts and air (rather than water) to achieve coverage. When flow is increased, air energy remains constant and the relative span of the spray quality increases as droplets become coarser. An alternate approach is to reduce travel speed to increase the dwell time.

- **Increase droplet size:** Since volume is related to the cube of the diameter, small increases in droplet diameter give large increases in survivability. If the sprayer design permits, switching to a nozzle with a coarser spray quality at the same operating pressure will increase the VMD and resist evaporation. However, it will also reduce droplet count (see Chapter 6.1.1.). To compensate, we recommend increasing flow by moving to the next larger nozzle in the series. The result is both coarser droplets and an increased spray volume.
- **Use horticultural adjuvants:** Humectants reduce the evaporation rate, preserving droplet size and keeping them wet on the target surface longer. Spreaders increase the degree of contact between the droplet and the target by lowering surface tension and increasing spread. Stickers improve droplet retention on hard-to-wet targets such as waxy, glaucous (hairy) or vertical surfaces that tend to shed water.

Tank mixing adjuvants may not be an option, depending on regional label laws. If permitted, ensure the adjuvant is compatible with the tank mix and target crop. Responsible manufacturers will have tested for compatibility and should be able to provide the data. It is not confrontational or excessive to ask for recommendations in writing when a consultant or salesperson promotes an adjuvant. If something goes sideways you will be glad of the insurance.

12.2. | Droplet trajectory

Trajectory is the path a droplet follows once it leaves the spray outlet. The degree to which outside forces influence that path depends on the droplet size and velocity.

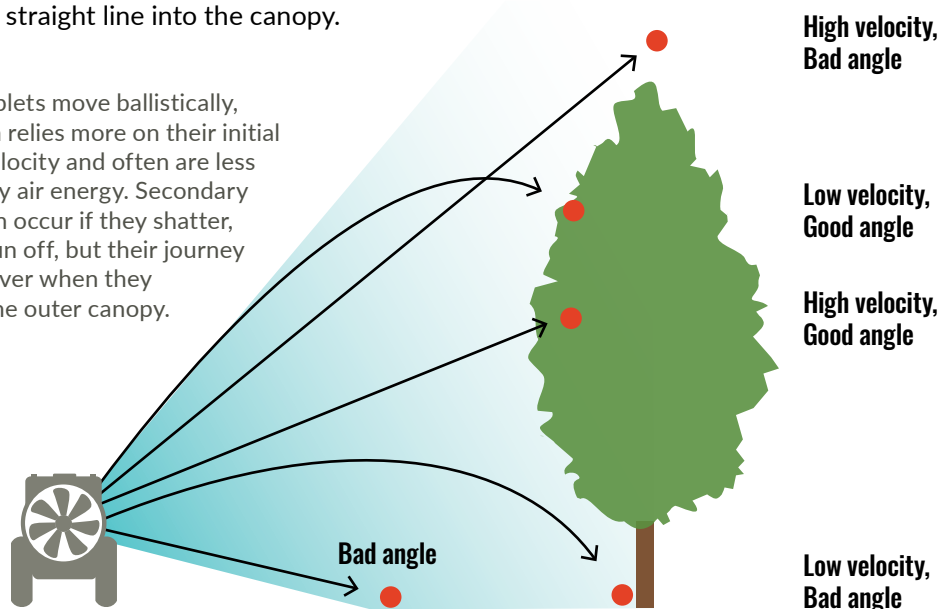
12.2.1. COARSER DROPLETS

Hydraulic atomization systems can use full-cone and air induction nozzles to produce coarser droplets. Coarser droplets behave ballistically: Their trajectory is like a cannon ball's arc. Their throw depends on the original angle (i.e. where the nozzle is pointed) and velocity (i.e. the pressure used to create the droplet). It is less influenced by the carrier air. While they travel further and straighter than finer droplets, they fall very quickly because of drag and gravity.

The figure below illustrates the possible trajectories and fates for coarser droplets:

- **Overshoot the target:** Droplet angle and velocity is too high, missing the target but falling soon after.
- **Lobbed into target:** Droplet angle is high and velocity moderate. Drag and gravity slow droplets, causing them to fall into the canopy.
- **Directed at target:** Angle and velocity are sufficient to propel droplets along a relatively straight line into the canopy.
- **Lobbed into ground:** Velocity is too low. Drag and gravity cause droplets to hit the ground prior to the target.
- **Directed into the ground:** Droplet angle is too low. Droplets are propelled into the ground prior to the target.

Coarser droplets move ballistically, so their path relies more on their initial angle and velocity and often are less influenced by air energy. Secondary coverage can occur if they shatter, bounce or run off, but their journey is typically over when they encounter the outer canopy.

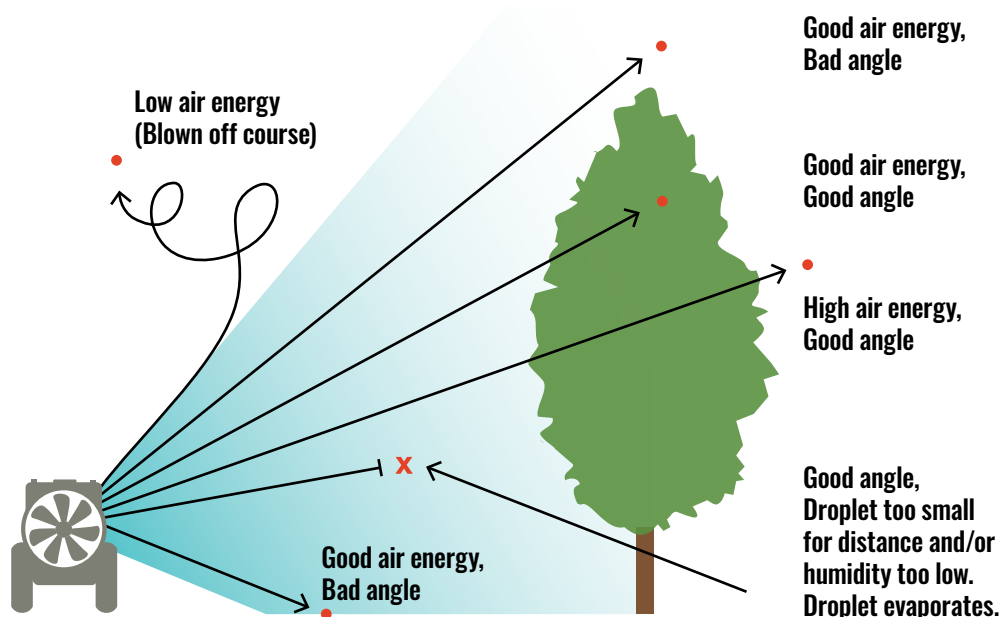


12.2.2. FINER DROPLETS

Most air-assist sprayers produce a finer spray quality. Hydraulic pressure does not tend to affect their throw or trajectory. They have very little mass and decelerate quickly, often within centimeters (or inches) upon leaving the nozzle. Finer droplets rely on the sprayer air energy and angle to deliver them to the target. In this sense, air is the surrogate for water as the carrier. As air energy wanes, finer droplets are increasingly affected by environmental forces such as wind and thermals, causing them to move erratically as they fall very slowly.

The figure below illustrates the possible trajectories and fates for finer droplets:

- **Droplets do not reach the target:**
Air energy is too low to carry droplets to the target and they are lost to the wind.
- **Overshoot the target:** Air angle is too high and droplets pass over the target.
- **Directed into target:** Air energy and angle sufficient to carry droplets into the target canopy and no further.
- **Directed through target:** Angle is correct, but air energy carries droplets through and beyond the target.
- **Droplets evaporate:** Angle and air energy are correct, but droplets evaporate before reaching target.
- **Directed into the ground:** Angle is too low.

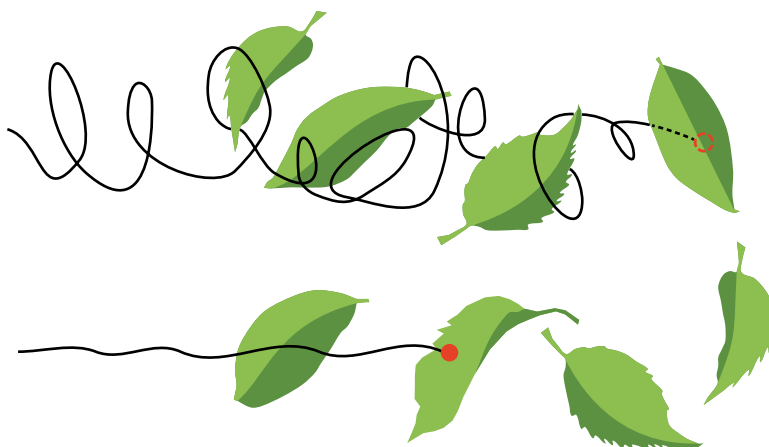


The path of finer droplets depends on sprayer-generated air. They can be blown over or under the target if the air angle is wrong. They can be blown through a canopy if the air energy is high. They can be blown off course if the air energy is too low for the situation. Even if the air energy and angle are correct, finer droplets may evaporate before reaching the target.

12.3. | Droplet velocity

If finer droplets remain entrained by sprayer air, they can travel with it to navigate twists and turns. This increases the odds they will avoid obstacles and penetrate more deeply into a canopy. As air energy wanes they can deposit on surfaces that are not line-of-sight. If, however, they are moving at too high a speed, droplets will leave the entraining air and deposit along their original path. The sprayer air may change direction, but the droplet will keep going (see figure below). This is called detrainment.

To better picture this phenomenon, imagine you are driving with your smartphone on the passenger seat. You take a sharp, high-speed turn but inertia carries your phone along the original vector. Had you driven the car (the air) more slowly, your phone (the droplet) would not now be under your passenger seat.



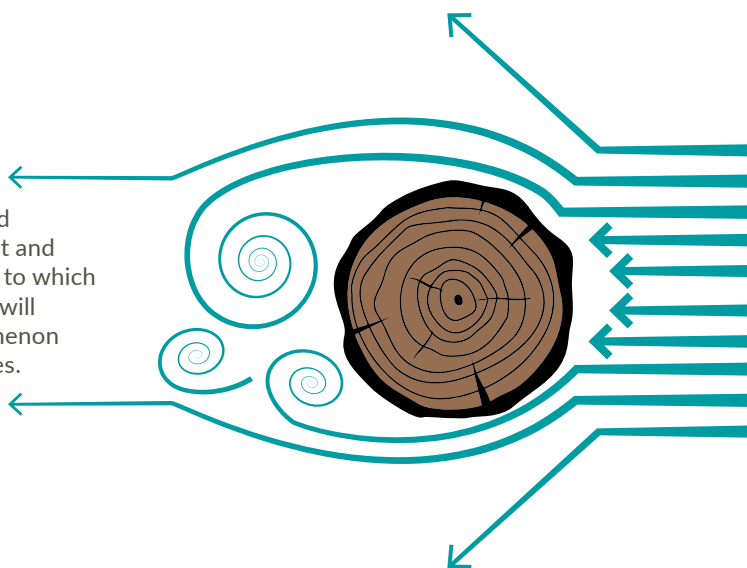
A tale of two droplets. **TOP:** Finer droplets in slow-moving and turbulent air follow a long and tortuous route. As they twist and turn in the canopy, finer droplets have the potential to encounter more surfaces. They might avoid them or deposit randomly (the leaf underside in this case). **BOTTOM:** Coarser droplets, or finer droplets carried by fast-moving air, will travel a shorter, more linear route. This reduces droplet penetration as they tend to deposit line-of-sight on the first object encountered.

We can see the impact of droplet velocity on coverage by observing how much wood is wetted during a dormant spray. Incidentally, establishing air settings for a dormant application can be challenging. Wind tends to be higher, leading some operators to combat it with increased air energy. On the other hand, some operators reduce air energy since empty canopies offer very little resistance. This is a good opportunity to try the ribbon test ([see Chapter 10](#)).

When sprayer air encounters an obstacle, such as twigs and branches, some of the air will deflect and some will wrap around and shed turbulent eddies in its wake. Once again, the degree to which droplets will follow the air and wet the circumference of the wood will depend on their velocity:

- No matter the air velocity, coarser droplets tend to deposit line-of-sight, wetting ~40% of the circumference. Coverage from coarser droplets may be improved by reducing their velocity and lobbing them into the target.
- Finer droplets in high speed air will detrain and deposit line-of-sight. Similar to coarser droplets, we can expect ~40% of the circumference (possibly more).
- Finer droplets in low speed air will ride the eddies around the target, wetting the wood over as much as 75% of its circumference. Low speed air also reduces the throw, permitting air energy to dissipate within the canopy and increasing the odds for random deposit.

Air encountering an obstacle, such as twigs and branches in a dormant canopy, will both deflect and wrap around behind that obstacle. The degree to which droplets will deposit around its circumference will depend on their size and velocity. This phenomenon holds true for any target, such as fruit or berries.



12.4. | Review and consider

- Would changing your spray quality improve the survivability of droplets?
What would this mean to droplet counts and flow in those nozzle positions?
- Small targets are often subjected to too much air energy from relatively over-powered sprayers. Does this describe your operation?
- Could you optimize your transfer efficiency with a combination of finer and coarser droplet atomizers in different zones on your sprayer?





Chapter 13

Canopy deposition and flow distribution

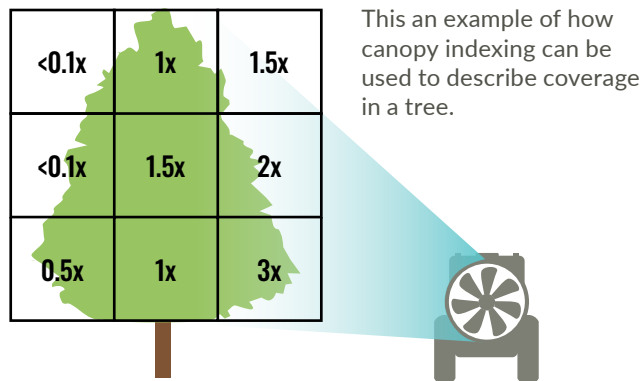
Spray droplet deposition occurs in two phases: Primary and Secondary. In the primary phase, droplets are projected directly into the target canopy through the direct action of the sprayer. Line-of-sight deposition occurs on any unobscured, sprayer-facing fruit, leaf and wood surfaces. In the secondary phase, droplets behave differently depending on their size. As air energy wanes, or as droplets begin to lose momentum, finer droplets will slowly deposit on random surfaces. Coarser droplets will quickly fall towards the bottom of the canopy, settling primarily on upward-facing surfaces.

13.1. | Canopy indexing

Drawing from previous chapters, we can now make assumptions about the relationship between the spraying strategy and spray deposition in a canopy:

- Spraying from both sides will improve coverage uniformity throughout a canopy.
- Smaller, or nearby canopies will require lower energy spraying strategies.
- Larger, or distant canopies will require higher energy spraying strategies to fill them with turbulent spray.
- Coverage will diminish as it penetrates and moves through the canopy.

Indexing allows us to describe the pattern of spray deposition in a canopy by comparing all coverage to the average on a simplified scale. It makes for very easy and relatable ways to interpret and compare coverage. A canopy is subdivided into equal zones and then sprayed. Coverage on all surfaces is measured and averaged. The degree that a zone deviates from the average is assigned an “x” factor. For example, if the average is 1x, 50% of that average is 0.5x and 300% of average is 3x (see figure below).



In late-season semi-dwarf apple canopies, an indexing experiment showed coverage was approximately halved for every 1 m (3 ft.) of penetration. The specific rate of decay will depend on the situation, but will always resemble the inverse square law in that coverage will get worse, at an increasing rate, the further out you go.

Canopy indexing provides valuable insight, but it's still only a crude metric. Averaging or totalling coverage for all surfaces within a zone masks important differences. For example, one sprayer might distribute finer deposits evenly over both sides of a leaf while another might deposit a single, Coarse droplet on the upper surface. When averaged, this insight is lost.

13.2. | Flow distribution

The flow from each atomizer position should reflect the size, density and distance from its corresponding portion of the canopy. Not every canopy is on a vertical plane. Cane fruit might be on rotating cross-arm trellises, some trees arch above the alleys and kiwi is typically overhead on pergolas (see figure below).

Not every target is on a vertical plane. Kiwi is grown on pergolas, shown here in its dormant state as it's sprayed with a tracer dye. No matter the relative position of sprayer and target canopy, coverage is improved and drift is reduced with careful consideration of the air configuration and flow distribution.



No matter the relative position of sprayer and target canopy, fine-tuning the flow profile can improve coverage uniformity, or focus spray on nearby target areas, such as trunks or defined fruit zones. This is accomplished by the strategic selection of hydraulic nozzle sizes, inline metering discs, or changing the number of active atomizers. For the sake of this discussion, we will assume the sprayer employs hydraulic nozzles.

Establishing flow distribution begins with determining your sprayer output, which in turn requires you to have decided on a spray volume for the planting ([see Chapter 7.3.1.](#)) and a travel speed ([see Chapter 16.1.](#)).

$$\text{Sprayer output (L/min. or US gal./min.)} = \frac{\text{Spray volume} \times \text{Travel speed} \times \text{Swath width}}{\text{a constant (depending on units)}}$$

Now you can determine how much flow should come from a single boom. For example, a TT sprayer has two sides and would therefore have two booms.

$$\text{Output from one boom (L/min. or gal./min.)} = \frac{\text{Sprayer output (L/min. or gal./min.)}}{\text{number of booms}}$$

Next you must decide how many nozzles will be required. The vertical ribbon test ([see Chapter 10.1.](#)) provides some guidance when deciding which nozzles are required to span the canopy height. Coverage in the upper canopy is always more challenging. Therefore it is more important to slightly overshoot the top than for active deposition to take place in the lowest portion of the canopy ([see Chapter 11.1.](#)). Remember that the lower threshold will change if the target bears heavy fruit that can weigh down boughs.



**TURBULENT
EDDY SAYS...**

"I got too much coverage in the top of the tree and missed the bottom entirely" said no LPR sprayer operator, ever.

If you intend to distribute the flow evenly over the number of active nozzles, simply divide the output from one boom by the number of nozzles.

$$\text{Average nozzle output (L/min. or US gal./min.)} = \frac{\text{Output from one boom (L/min. or gal./min.)}}{\text{Number of active nozzles on one boom}}$$

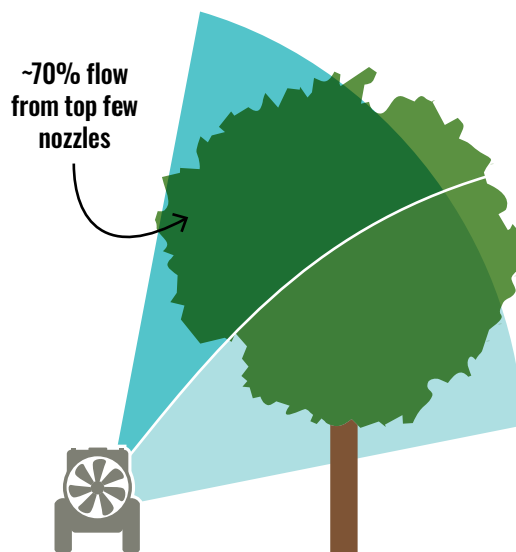
At this point you would select nozzles (or otherwise adjust flow) that match the desired average nozzle output ([see Chapter 17.](#)). However, as we stated earlier, the flow from each atomizer position should reflect the size, density and distance from its corresponding portion of the canopy. The canopy size may warrant an uneven flow distribution.

13.2.1. FLOW DISTRIBUTION FOR LARGE CANOPIES

It is more efficient and effective to maintain an equivalent distance between each spray outlet and its corresponding portion of canopy. Experiments have demonstrated that sprayers that employ a vertical boom that is at least as tall as the target (i.e. FT, TT or WA designs) will provide suitable coverage using a uniform flow distribution.

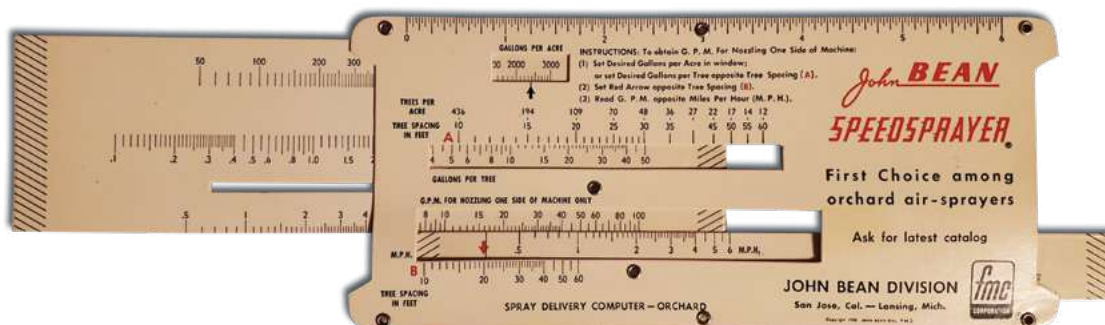
It is not always possible to use these sprayer designs with large canopies, which means LPR sprayers become the default. In [Chapter 11](#) we discussed the challenges inherent to configuring an LPR's air energy for large canopies. The same principles apply to liquid flow. The following three methods have been used in North America since the 1950s and to varying degrees are still used today in tree-nut, citrus and sour cherry.

- **The 70% method:** In North America in the 1950s, John Bean provided slide rule calculators and encouraged LPR operators to use full-cone disc-core nozzles to emit 70% of the output from the top few nozzles. In extreme cases, three times the flow was emitted from the highest nozzle versus any other (see figure right). Transfer efficiency is improved by using a coarser spray and higher flow to span the distance to the top of the canopy; sedimentation is a big part of this strategy. Drift and irregular coverage are unavoidable.



This 1955 John Bean slide rule calculator helped an operator nozzle one side of the sprayer based on row spacing and travel speed. In this case, the sprayer will emit a 2,500 gpa (~23,400 L/ha) spray volume. The scale goes to 3,000 gpa!

The 70% method of flow distribution for LPR sprayers and large canopies.

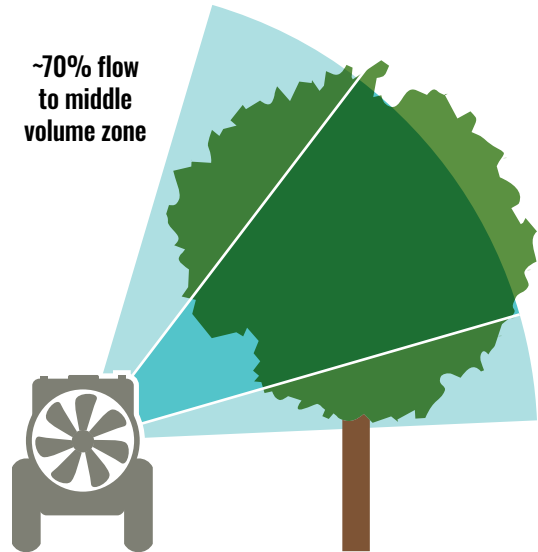


As semi-dwarf began to replace standard orchards in the 1970s, two new approaches emerged to better match flow to the smaller canopies and narrower alleys.

- **The Middle Volume Zone method:**

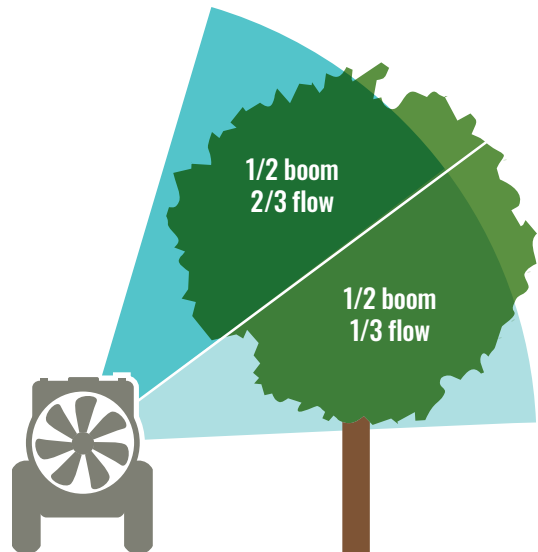
Described in a 1976 Ontario Ministry of Agriculture and Food publication entitled “Orchard Sprayers” (see figure right). Here are their instructions:

1. Choose a tree size and shape that is typical of your orchard and park the sprayer at the normal spraying distance from it.
2. Find one or two middle nozzle positions and air deflector or vane settings that direct the spray up through the greatest volume of canopy towards the top-inside of the tree (a.k.a. the middle volume zone).
3. Find rates that will give a large output in this middle volume zone, and smaller outputs for positions above and below.
4. The total output must still add up to the target volume.



The Middle Volume Zone method of flow distribution for LPR sprayers and large canopies.

- **The Two-Thirds Boom method:** Described in a 1977 Agriculture Canada publication entitled “Air-Blast Orchard Sprayers – A Operation and Maintenance Manual”. It advocated emitting two-thirds of the flow from the top half of the boom to ensure good distribution throughout the tree (see figure right).



The Two-Thirds Boom method of flow distribution for LPR sprayers and large canopies.

All three methods place the largest proportion of flow in line with the greatest portion of canopy, with preference at the top of the boom to span the greatest distance. There is no perfect method, which is why there are calibration devices called Vertical Patternators to help visualize and evaluate a sprayer's flow profile (see figures below). They are a great starting point, but patternators can't replicate the complicated relationship between canopy and a moving sprayer. We prefer that operators use a coverage indicator such as water sensitive paper to assess the fit between the flow profile and canopy ([see Chapter 15](#)).



The AAMS-Salvarani vertical patternator. The mast moves back and forth through the spray from a parked sprayer. Each black collector intercepts droplets at different heights. The corresponding volumes are collected in a series of graduated cylinders to show the flow distribution.

PHOTO CREDIT: JAN LANGENAKENS



Our homemade vertical patternator on display at a conference. Window screens with gutters are attached to a telescoping ladder affixed to a weighted base. The sprayer parks in front of the screens, and sprays for a period of time. Lines channel the volume intercepted by each screen to a series of graduated cylinders to show the flow distribution.

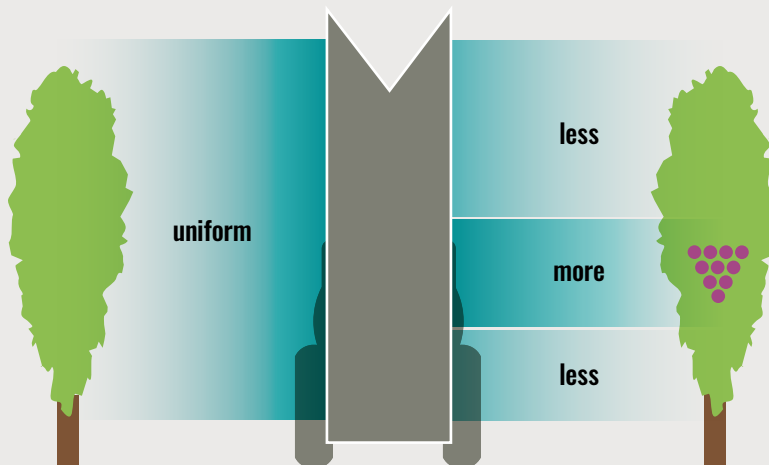
13.2.2. FLOW DISTRIBUTION FOR MEDIUM AND SMALL CANOPIES

Flow distribution is easier to manage with small and medium sized canopies (e.g. grape, berry, high-density orchard). Generally, a uniform flow distribution is adequate for foliar applications, no matter the sprayer design. This changes when targeting trunks, or a defined fruit zone (e.g. VSP grapes).

Fruit and wood are often under-dosed compared to leaves. This is due in part to their surface structure but also their rigid nature in relation to sprayer air ([see Chapter 7.2.2.](#)). To increase coverage in these areas it is important to focus air on them, as well as leverage as much turbulence and as many angles of attack as possible. Also consider using a finer spray quality to maximize wrap-around coverage ([see Chapter 12.3.](#))

When the spray is specifically intended to protect fruit, and the fruiting zone is distinct, direct the majority of liquid flow to that area (see figure below). If the fruit is all you care about, why spray the entire canopy? This is a form of crop-adapted spraying, which we discuss in [Chapter 14](#). The relatively recent introduction of 60° hollow cone nozzles may permit operators to focus spray more accurately. The narrow spray geometry also better matches the narrow profile air outlets on certain WA sprayers.

When a canopy has a defined fruiting zone, flow should be redistributed to focus more on the fruit and less on the canopy. Fruit is the critical and hardest-to-wet spraying target.



TURBULENT EDDY SAYS...

Fruit surfaces are difficult-to-wet targets. For a given application, spray deposits on fruit are typically ~half that found on leaves.

Where possible, consider using a coarser spray quality (e.g. air induction hydraulic nozzles) in the top one or two nozzle positions. This will reduce the volume of spray lost to drift, as larger droplets follow a ballistic path and will fall back into the planting. Doing so may require the operator to move up to the next-highest nozzle rate to account for the reduction in droplet count. It is important to assess coverage when making changes to flow distribution (see Chapter 15).

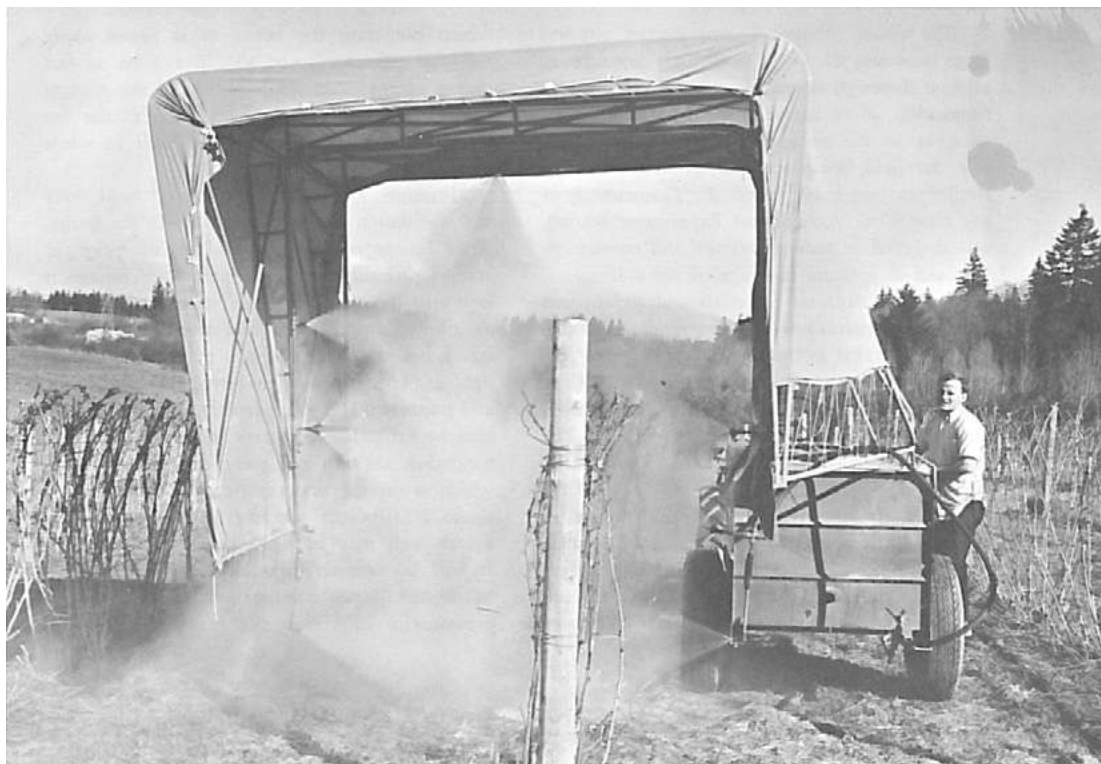
13.2.3. SHROUDED SPRAYERS IN SMALL AND MEDIUM CANOPIES

As noted in Chapter 7, catch efficiency is poor for low profile targets, such as young or early-season canopies. The great majority of spray will miss the target. As canopies grow and fill, there will be more surface area to intercept the spray and catch efficiency will increase. In viniferous crops, for example, typical catch efficiency values are as follows:

- Dormant, bare canes: ~5%
- Flowering: ~50%
- Four weeks after bud break: ~20%
- Bunch closure: ~80%

Some WA sprayers use hoods or shrouds to mitigate drift by intercepting spray that passes through small or sparse canopies. This concept has been around since the 1940s, and while our grainy photos weren't good enough for print we have included one from the 1970s (see figure below).

This hooded sprayer employed hydraulic pressure to spray from the sides and the top, but had no air-assist feature. Photographed in Ontario, Canada c.1979.



Many of today's shrouded sprayers also reduce waste by recovering and recycling the overspray back to the solution tank. As with any sprayer, it has the potential to work very well, but we must be aware of the advantages and the disadvantages inherent to the recycling design:

- Work rate is increased by spraying multiple rows, but travel speed may have to be reduced to allow sufficient dwell time to intercept overspray, avoid hitting the rows, and permit turns.
- Shrouds create a shelter that improves transfer efficiency in cross winds, but a head or tail wind will channel and deflect spray, pulling it out of the shrouded area.
- Reports of pesticide savings and ease-of-use are appealing, but lead many operators to falsely assume they do not have to optimize air or liquid handling systems to match the canopy. As we stated in the first chapter, no equipment can replace the operator's good sense and judgement.
- Shrouds obscure the booms from the public, and this is often promoted as a way to make crop protection practices more socially acceptable. However they also obscure them from the operator, making it difficult to identify problems such as blocked nozzles.



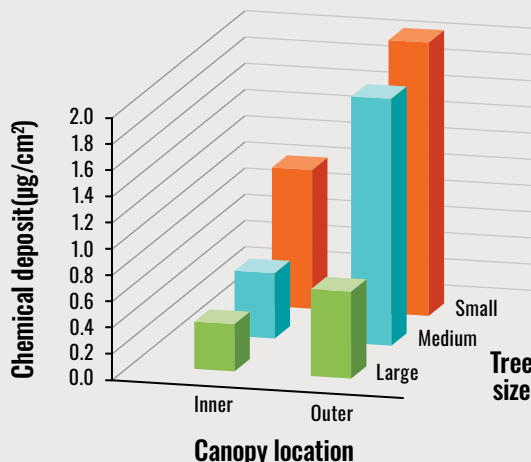
Recycling sprayers collect spray that passes through sparse canopies. These WA sprayers apply from both sides, but for clarity we have only illustrated the liquid circuit for one boom. **LEFT:** Spray liquid (blue arrows) travels from the tank to the outer boom and into the canopy. Overspray (broken red arrows) impacts the opposite shroud. **BOTTOM RIGHT:** Spray liquid runs down the shroud into a collector, where it is filtered and circulated back to the solution tank. **TOP RIGHT:** Some manufacturers make the fans optional. While a non-air assist design can work in early season applications, we recommend them for the entire season for reasons we have previously described.

13.3. | Run off

The canopy exterior is subjected to the highest concentration of spray droplets. When these surfaces become saturated, the excess runs off. At this point, the canopy exterior has reached the maximum level of deposit. Imagine placing marbles one at a time on a table top. When the surface is completely covered, every additional marble added will push one (or likely more than one) off the edge. You can't stack marbles in the same way you can't stack liquid.

Studies in dense canopies (e.g. citrus) have shown that when the canopy exterior begins to drip, the interior will have received about half the relative dose. Dose is a measure of the active ingredient deposited over a target area and we discuss it further in [Chapter 14](#). Increasing dwell time and/or spray volume will increase coverage in the canopy interior, but once again the saturated outer canopy will receive no additional deposit.

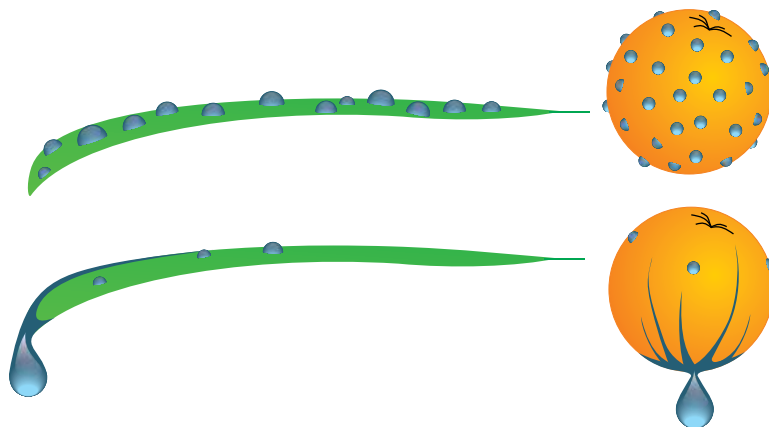
Canopy coverage experiments were performed in citrus orchards. A high-pressure boom sprayer applied the same volume of tracer dye to three tree sizes. The small canopies were 2.0 m (6.5 ft.) tall mandarins with a 2.8 m (9 ft.) spread. The medium canopies were 3.2 m (10.5 ft.) tall navels with a 3.1 m (10 ft.) spread. The large canopies were 4.0 m (13 ft.) tall valencias with a 3.9 m (13 ft.) spread. In all canopies, researchers observed a two-fold variation of foliar deposit of dye deposited between the inner and outer canopy. The large canopy in this example was not sprayed to drip. The medium and small canopies reflect the maximum retention in the outer canopy.



LAMINAR FLO SAYS...

Spraying to run off is an effective but wasteful practice. Measurements have shown that when a canopy begins to drip, dosage losses of 15% or more have already been incurred.

The spray volume required to incur run off can vary by >30% depending on spray quality, target surface (i.e. wettability) and product formulation. A finer spray quality is less likely to incur run off. This was clearly demonstrated in an Australian study where grape bunches were dipped in a solution to saturate their surfaces. This was intended to emulate a drenching spray. This was compared to the same targets sprayed with finer droplets. The finer spray resulted in a higher dose and more uniform distribution over the grape surfaces.



TOP: In practice, finer spray quality tends to deliver a higher dose and more uniform coverage than coarser droplets, which tend to run off. **BOTTOM:** Run off creates an inconsistent distribution on a target surface and a lower overall dose. Liquid will channel and pool, creating the potential for concentrated residues at the drip point.

When spray liquid runs, it will pool and collect at the lowest edge of each target surface. This can create phytotoxicity issues at the drip-points where residues concentrate as they dry. Spreader adjuvants such as organosilicones can almost magically pull a drip back from the brink and spread it along the target surface via capillary action. As long as it remains wet, the active ingredient redistributes over the surface and can even wrap around to the back side of leaves. However, the surface saturates far sooner, incurring greater overall losses to run off. The ability of adjuvants to improve coverage is appealing, but should only be considered after sprayer configuration has been explored, and only when there is evidence that they are safe and effective on the crop.

13.4. | Review and consider

- Does your sprayer support flow adjustments along the boom?
Does it matter for your operation?
- How much spray is lost to run off on your canopies?
How much is necessary for sufficient spray to reach the canopy interior?
- Would it be possible to use less water but still achieve sufficient coverage?
- What are the advantages of a shrouded sprayer? What are the disadvantages?



Sprayers with two axles distribute weight over a larger area, reducing compaction.



Chapter 14

Reconciling rate and coverage

If sparse coverage is not enough and saturation is typically too much, what does good coverage look like? This simple question strikes fear into the heart of the bravest consultant. It's tremendously complicated.

This is why workshops and demonstrations (including ours) often end with the attendees deciding whether they like the coverage they see, rather than having it prescribed. The best workshops follow a before-and-after format, where a base level of coverage is established, and then compared to coverage following sprayer adjustments. If concentration is maintained and coverage uniformity is improved (i.e. fewer misses, fewer drenches) then everyone is satisfied.

This chapter will explore the relationship between rate, concentration, dose and coverage. We will begin with a macro focus of what happens in a planting, then shift to a micro focus of what happens on plant surfaces before exploring rate adjustment methods. Implicit to this discussion is the primary and overriding mandate of risk management (i.e. minimizing residues and the potential for non-target environmental, operator or bystander exposure).



Never miss the rare opportunity to attend a workshop or demonstration on air-assist spraying. Both the demonstrator and the attendees represent a wealth of knowledge and local experience. Even when the event is focused on a crop you don't grow, the information is transferable.

14.1 | Application rate

Regulators and product manufacturers (a.k.a. registrants) use Application Rates to communicate how much product is required. The application rate is the maximum amount of formulated product permitted per planted area or row length. This rate can never be exceeded, and local authorities can reduce it further by imposing restrictions.

Application rates are found on product labels, which are legal documents whose content and format vary between countries. Many labels describe the application rate as a two-dimensional value that relates the amount of product to the planted area (e.g. 1 kg/ha or 0.9 lb/ac.). While suitable for broad acre or row crops, this format is less appropriate for three-dimensional perennial crops. It does not reflect the variation in crop morphology (e.g. growth stage, rootstock, time of season) or canopy management which, collectively, can represent order-of-magnitude differences in the amount of target surface area.

Nor does it reflect row spacing, which has a direct impact on the amount of crop canopy per planted area. For example, decreasing row spacing by 15% represents 15% more canopy per planted area. This is why many Australasian countries have based rates on 100 m row length (and height) rather than planted area.

Some labels describe rates in terms of Concentration. The concentration is the amount of formulated product contained within a volume of carrier (e.g. g/L or oz./gal.). The carrier volume must be high enough to suspend or dissolve the formulated product and to deliver and distribute that product over the target surfaces. A dilute application describes a carrier volume that drenches a canopy (typically just to the point of run off) while satisfying the prescribed application rate.

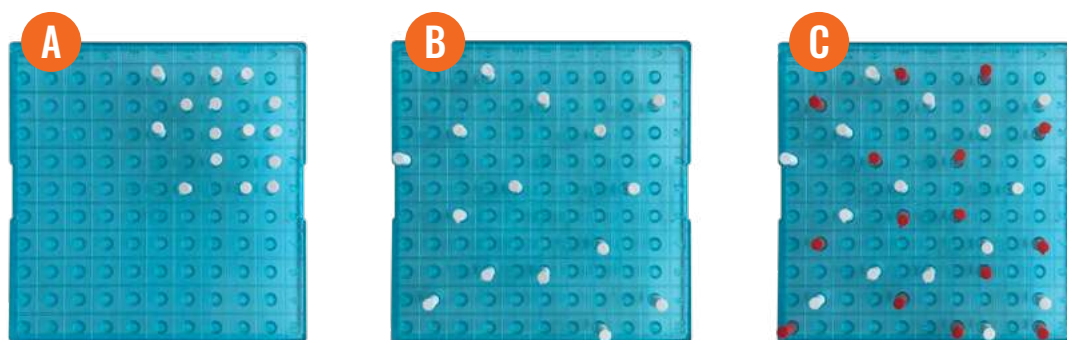
Skilled operators can improve their operational capacity (i.e. work rate) by concentrating the tank mix and thereby reducing the number of refills. The volume sprayed is reduced while the application rate is maintained. The degree of concentration is traditionally described using an X-factor. A dilute application is always defined as 1X. An concentrated application may only use one-quarter of the carrier volume and is therefore described as 4X. The degree to which spray liquid can be concentrated will depend on the sprayer design and mixing limitations (see Chapter 18) and should never compromise coverage.

And so, label rates must be high enough to ensure effective, consistent and sustainable results while accommodating diverse crops, sprayer designs, application methods and operator abilities. If they account for all this variability, it must be concluded that they include redundancy. The maximum rate is clear and inviolate, but efficiencies are possible with a better understanding of the relationship between rate and coverage.

14.2. | Deposit density

Assuming proper timing and product choice, coverage can be used to gauge the success of a spray application. Coverage describes the degree of contact between spray droplets and the Target Area. The target area refers to the specific plant surface intended to receive spray (e.g. cm^2 leaf, flower, fruit, bud, wood). We can quantify coverage as the percent area covered, but a related and more important descriptor is Deposit Density. Deposit density is the deposit count relative to the area and it gives more information about how deposits are distributed.

For example, suppose you are spraying a fungicide. The objective is to cover all susceptible plant parts because most fungicides are weakly systemic and their deposits must contact the fungal pathogen to be effective. The odds of contacting the pathogen go up when the deposits are evenly distributed instead of concentrated in a small area (see figure below). Efficacy also depends on any chemical influence that extends beyond the physical spread of each deposit. This Effective Radial Distance (ERD) will depend on the nature of the target surface, any redistribution in rain or heavy dew and the product's mode of action.



We'll use a popular board game to describe the importance of deposit density. **A.** The 15 white pegs on a grid of 100 spaces represent 15% of the target area covered. But the clustered distribution leaves a lot of empty surface uninterrupted by deposits. This is not good coverage. **B.** Here is the same 15% coverage, but deposits are distributed uniformly over the surface. We have improved coverage by reducing the extent of the unsprayed areas. **C.** In the case of protective products, a second application should be made when there is new tissue to protect, or when time or precipitation reduces residual activity. As protection from the first application wanes (white pegs) it is supplemented and eventually replaced by that of the second application (red pegs).

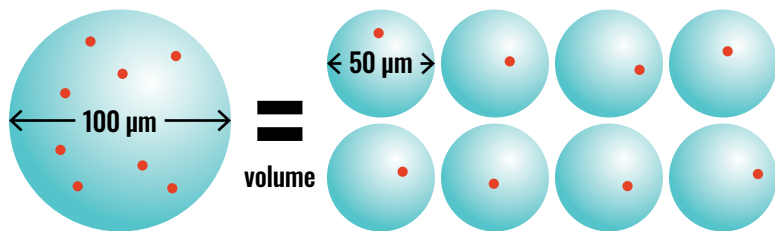
There are research methods to quantify deposit density. Artificial targets are sprayed, digitized and subjected to counts by area. A Voronoi analysis can produce an even more informative measure of deposit density. This method gives perspective on the relative area each deposit can influence by calculating the shortest intervening distances between deposits. The shorter the distances, the more uniform the distribution. But how does deposit density on a plant surface relate to the application rate? To answer that question we have to discuss dose.

14.3. | Dose

Where rate is the amount formulated product per unit land area, we will express dose as a measure of the active ingredient per unit plant surface area. The Lowest Effective Dose (LED) is the minimum amount of active ingredient that must be deposited over a target area to produce the desired results. If an application satisfies the LED, it should be successful. Ideally, the product label would supply this critical information, but it doesn't. This is because dose represents a complicated relationship between concentration and droplet size. Once again, we'll use an example to illustrate the relationship between concentration, droplet size and dose.

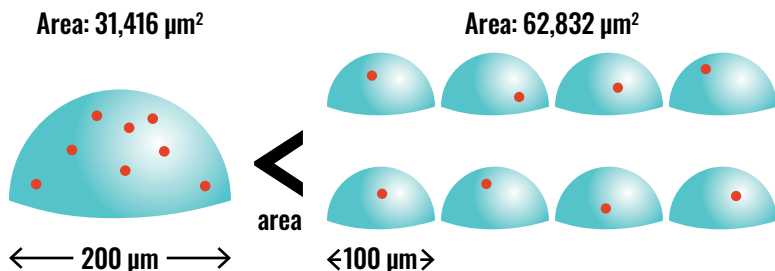
Suppose we mix a solution of pesticide in a solution tank. We use pipettes to extract a 100 μm diameter droplet, and eight 50 μm droplets. From Chapter 6.1.1, we know they have an equal volume, but they also have the same concentration. This is illustrated in the following figure, which uses red dots to represent the ratio of water and dissolved product.

A 100 μm diameter droplet has the same volume as eight 50 μm diameter droplets. If extracted from the same solution, they will have the same concentration, and therefore contain the same relative amount of dissolved active ingredient (red dots).



Now we'll deposit the large droplet on a target surface. Assuming a spread factor of 2, geometry tells us it would cover a cross-sectional area of 31,416 μm^2 . Collectively, the eight droplets would cover twice that area: 62,832 μm^2 (see figure below). Therefore, compared to the large droplet, the smaller droplets distribute the same amount of active ingredient over twice the area, which results in half the dose.

Mathematically, the finer the droplet, the greater the potential for area covered. However, assuming a constant concentration, finer droplets distribute a finite amount of active ingredient (red dots) thereby reducing the dose.





TURBULENT EDDY SAYS...

For a given concentration, reducing the droplet diameter by half will double the area covered and half the dose.

As the droplets dry, the residues left behind will be different. The larger droplet with the higher dose would leave a thicker, longer-lasting residue than the smaller droplets with the lower dose (see following figure). Either result could be acceptable, depending on the intent of the application. For example, longer-lasting residues may be desirable to extend the effectiveness of foliar protectants, but create unacceptable levels on harvestable fruit.



Assuming a constant concentration and spread factor, larger droplets will deposit thicker residues than smaller droplets. In our example, the larger droplet will leave twice the film thickness on half the area.

This example is sound, but oversimplified. In practice, dose and residue are influenced by the wettability of the target surface, adjuvants, the product's mode of action and the environment's relative impact on residual activity. Recall that when coarser droplets incur run off, the finer droplets tend to produce the higher dose (see Chapter 13.3.). Incidentally, this example also illustrates why low volume sprayers that employ finer droplets tend to use concentrated spray mixes. The increase in concentration offsets the dose-reduction effect inherent to finer sprays.

If the droplets in our example were drawn from two different solution tanks with unknown concentrations, it would be impossible to use coverage to imply relative dose. This is why research trials do not typically rely on coverage as an indicator of dose. Some will spray a canopy to run off and then use the concentration to assume dose. This approach has limitations, because as we know, canopy coverage is non-uniform and the volume required to incur run off is variable. Moreover it does not reflect the sprayer operator's typical usage pattern.

Preferably, trials calculate dose by recovering residue from the target surface. In this situation the active ingredient, or some other detectable substance (e.g. copper sulfate, fluorescent dyes), is applied in a known concentration. Once dry, the residue is rinsed from the target surface and the indicator recovered is quantified. This is then normalized by measuring the area of the target or its dry weight. This method allows researchers to apply products in a conventional manner and then say how much "active ingredient" was deposited per surface area (e.g. dye/leaf as $\mu\text{g}/\text{cm}^2$).

14.4. | Can coverage determine rate?

Operators that recognize the redundancy inherent to product label rates for three-dimensional perennial crops (see Chapter 14.1.) may choose to employ rate adjustment methods. Many formal methods have been developed to improve the fit between rate and canopy coverage (e.g. Tree-Row Volume, PACE+, DOSAVIÑA). Each has value, but their adoption has been slow because they are region- or crop-specific and they can sometimes be quite complicated.

Simpler, informal rate adjustments are more common, such as making a pro rata change by engaging/disengaging nozzles in response to canopy height, or by altering speed in response to canopy density. These approaches yield inconsistent results because they are based on subjective criteria and do not employ a feedback mechanism.

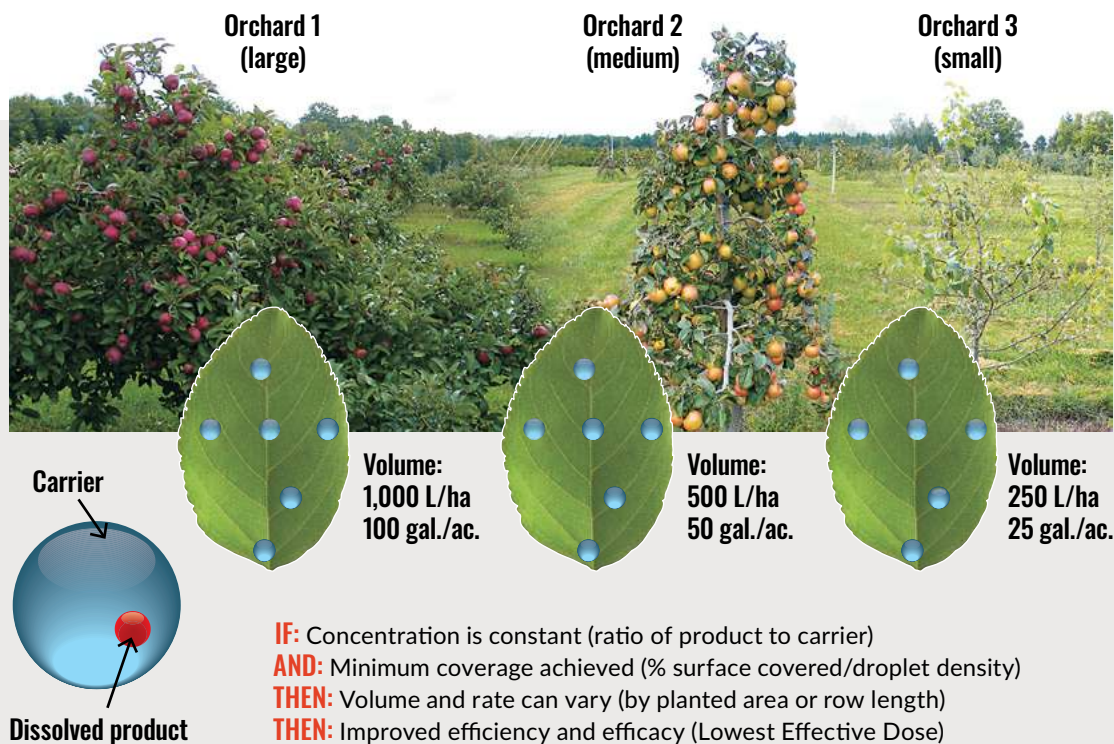
Rate adjustment may also be inherent to the sprayer design. Recycling and intelligent sprayers adjust rates in real time as they recover or modify flow based on crop morphology. These sprayers may or may not be compatible with existing crop architecture and can represent significant capital expense.

Common to each of these approaches is the need to interpret label rates in order to apply a rational, sustainable and precise dose. This would be greatly facilitated if product labels for three-dimensional perennial crops communicated the following four pieces of information:

1. The lowest effective dose (for efficacy).
2. The lowest effective product concentration (for residual activity).
3. The minimum coverage threshold (for a specific target area and/or region within a canopy).
4. A maximum rate per planted area (for safety).

Points 1, 2 and 3 would establish how a product should be applied. If this could be consistently achieved, over and underdosing would be reduced, addressing concerns of resistance, improving packout, and rewarding efficient applicators with a better work rate. Point 4 would mitigate risk, establishing residue levels, restricted entry intervals and post harvest intervals. This less prescriptive label would empower sprayer operators to select the safest and most appropriate strategy for their given equipment and conditions ([see figure on the following page](#)).

Seeing as the most powerful force in the world is the status quo, we don't foresee label language changing in the near future. In the meantime, we will throw our hat into the ring and describe our method for rate adjustment. We wish to be clear that our objective is not to save money by "cutting rates". Any savings in water or product is welcome, but incidental and certainly not assured. The intent of this method is to improve coverage uniformity and reduce waste.



Provided with a product concentration and minimum coverage threshold, an operator could improve coverage uniformity and ensure the LED. The minimal required deposit would be satisfied for all canopies, irrespective of their size or spacing, the sprayer design, or how much spray mix was used per planted area. A maximum rate per planted area would mitigate exposure and environmental risk.

While we recognize the complicated relationship between coverage and dose, we still feel a minimum coverage threshold can be used to adjust the application rate. Experiments with rate adjustment, and our collective experience, lead us to propose a robust, minimum coverage threshold of both **85 deposits/cm²** and **10-15% target area covered**. This provides the applicator with a clear goal and the operational freedom to consistently succeed, irrespective of their unique situation.



A minimum threshold of 85 deposits/cm² and 10-15% target area covered is adequate coverage for most applications.

As an operator gains experience and confidence, they can refine this coverage threshold. It has proven adequate for conventional products, but biorational (e.g. pheromones), organic and plant growth modifying products may have more stringent coverage requirements. When coverage recommendations differ, always defer to the highest degree of coverage.


We begin by establishing a starting point for adjusting the application rate. Operators may use a range of rates to reflect pest pressure, or to account for multiple modes of action from tank mix partners. They may use a concentrated or a dilute spray mix. There's no way to know which approach is best, so our method retains the operator's typical mixing practices. Stated differently, the operator will continue to use the same ratio of formulated product to carrier volume. The appropriateness of this assumption is evidenced by a history of satisfactory pest control in the operation.

Using water to make iterative test sprays, the operator determines which portions of the canopy receive coverage above or below the coverage threshold, and optimizes the sprayer configuration to meet or exceed that threshold. Coverage is evaluated using a water sensitive paper protocol that we describe in detail in [Chapter 15](#). In our experience, minimum coverage can often be achieved using less spray mix than is typically used. Once the sprayer is properly adjusted, the operator can continue to mix each tankload per usual, but will require fewer tanks to complete the job.

This crop-adapted approach to adjusting rates is promoted, and has proved effective, in Ontario orchards and highbush berry operations for many years.

14.5. | Review and consider

- What changes do you already make to your sprayer output to account for changes in canopy size and row spacing? Are these changes made consistently, or ad hoc?
- If using a low, or ultra low volume application, how do you decide on a concentration? Do you assess coverage and efficacy to validate your choices?
- Do you have a test row in your operation for monitoring experimental changes to sprayer configuration or rates?

A man wearing a dark green t-shirt, blue jeans, a dark hat, and blue gloves is standing on a wooden A-frame ladder. He is reaching into the branches of a large, leafy tree, placing small white papers and ribbons. The tree has many green leaves and some bare branches. The ground is covered in green grass. In the background, there are more trees and a clear blue sky. A small white paper with a yellow ribbon is lying on the grass near the base of the ladder.

Placing water sensitive papers,
and ribbons, in an apple tree.

Chapter 15

Assessing coverage

Too much time elapses between spraying and observing the biological results for operators to evaluate sprayer adjustments. Timely feedback is required to assess the fit between the sprayer configuration and the canopy. This is why we assess spray coverage. Assessing coverage as soon as possible can alert the operator to correctable problems. We will discuss four methods:

1.

The shoulder-check

2.

Dripping (Run off)

3.

Wetting and residue

4.

Water sensitive paper

The first three methods are quick and dirty, offering limited information but better than nothing. The fourth method requires more time and is the most informative approach.



LAMINAR FLO SAYS...

Be aware of restricted entry intervals and PPE requirements when confirming coverage. It is always preferable to evaluate coverage using water and not active ingredients.

15.1. | The shoulder-check

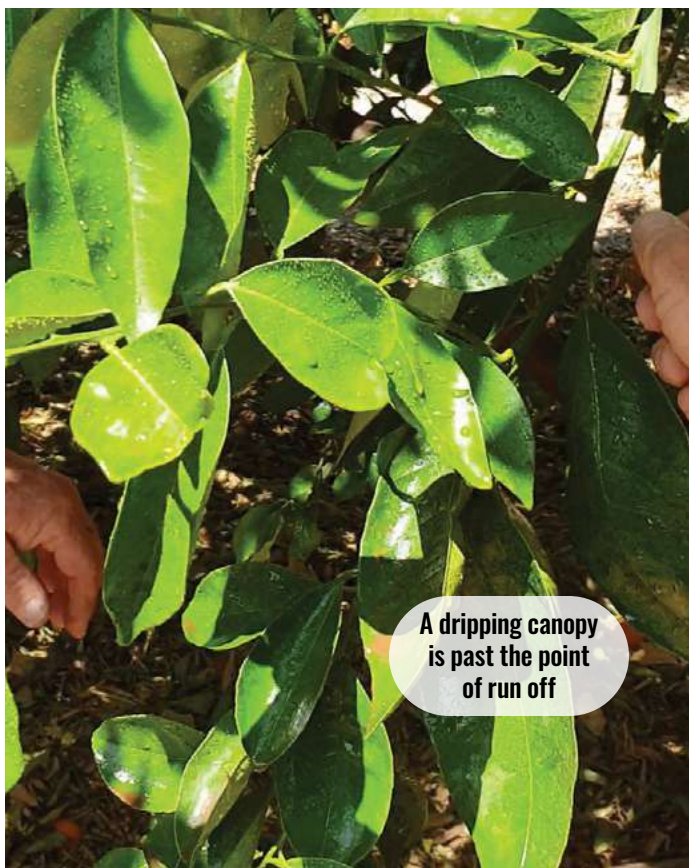
Shoulder-checks can identify leaking or plugged hydraulic nozzles, but observers cannot reliably detect variation in flow from nozzle to nozzle (even when it's over 50%). The vantage point also makes it difficult to determine if spray is passing under, over or through the adjacent rows. It is better to perform an inspection with the help of a partner outside the sprayer per the ribbon test ([see Chapter 10](#)).



Shoulder-checks are fine for detecting plugged or leaking nozzles, but the vantage point makes it hard to discern much else.

15.2. | Dripping (Run off)

Listening or watching for dripping is an unreliable coverage criterion. As we learned in [Chapter 13.3.](#), the threshold for run off depends on the nature of the target surface (e.g. waxy, hairy, vertical), the product formulation (e.g. oils, stickers, spreaders) and droplet size. Further, the canopy exterior can drip before the canopy interior receives sufficient coverage.



Inspecting for run off is not a reliable indicator of good coverage.

15.3. | Wetting and residue

Inspecting surfaces for wetting or residue can give a broad indication of whether a canopy has received sufficient coverage, but it can be hard to discern on some plant surfaces. Residue on high-contrast black irrigation lines may be a tempting indicator, but make sure it's not the cumulative result of an earlier application. In hot, dry environments the water can flash very quickly and this residue may be your only evidence.

When using low or ultra low carrier volumes, the deposit residue from small droplets appears as a haze, so look closely. Dry fluorescent tracers and kaolin clay can help operators visualize deposits on actual plant surfaces, but they are messy and hard to quantify or record. If you are interested in trying fluorescing dye in your sprayer, contact one of the authors.

Children's non-toxic, water-soluble fluorescent face paint can be diluted in water and sprayed. The level of dilution will depend on the colour you choose (yellow is best), so mix a small volume in a squirt bottle to determine a good ratio. When you shine a 51 LED ultraviolet blacklight on the target surface you have a safe and relatively cheap method for exploring coverage on actual target surfaces. These items are available online and are both fun and informative.



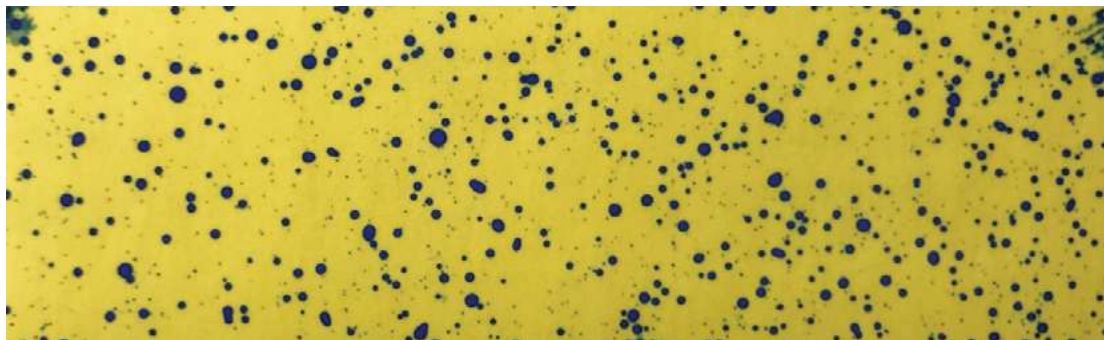
15.4. | Water sensitive paper

Water sensitive paper allows an operator to visualize, quantify and record spray coverage. Given the low cost and simplicity, this is our preferred method. Packages of 50, 26x76 mm (1x3 in.) papers are available online or from local agrichemical retailers for about \$60.00. Each paper has a yellow side that turns blue when it contacts moisture, resolving deposits from droplets >50 μm . Once dry, sprayed papers can be labeled, sealed and stored for up to a year, or photographed for permanent spray records. They are a versatile tool, but they do have limitations:

- Water sensitive paper underestimates the spreading effect that can occur on plant surfaces (especially where surfactants are used).
- They are rigid, which means they do not move like leaves.
- They will not reliably resolve deposits from droplets <50 μm in diameter, underestimating coverage from twin-fluid and rotary atomizer systems.
- Water sensitive papers are a relative index, meaning papers should only be compared to other papers. They are most effective when you use them to evaluate changes within your own spray program, such as comparing coverage before and after sprayer adjustments.

Smartphone apps and portable scanners are available for diagnosing water sensitive paper. Most only quantify the percent coverage. Those that do measure deposit density are reliable up to about 30% coverage (which is when deposits begin to overlap). With experience, deposit density can be satisfactorily judged by eye.

Each package includes a laminated card with a 1 cm^2 cut-out. By placing the window randomly over a sprayed paper you can manually count the deposits to determine deposit density. Every deposit should be counted, but the human eye cannot resolve stains less than 100 μm , so many viable deposits are missed. It is entirely fair to use a hand lens to ensure you count every drop.



Water sensitive paper. Simple and immediate feedback on the quality of the spray application. Large or small, every deposit counts.

15.5. | How to use water sensitive paper

When, and how often, an operator performs this assessment will depend on their experience with the sprayer and the crop in question. Perhaps they will only assess a known trouble zone where there is historically bad control. Perhaps they are using a new sprayer and looking to build confidence by assessing coverage throughout the season.

We suggest that coverage should be assessed at least twice per season, in weather conditions typical to the operation. For deciduous crops, assess coverage at bloom when the canopy is sparse and there are flowers to protect, and late season when the canopy is at its fullest and there is fruit to protect. For evergreen crops, consider assessing coverage pre- and post-pruning/hedging, which changes the canopy significantly.



The race is on to develop wireless spray deposition sensors. The prototypes detect mass, not just coverage, and are so sensitive we can watch spray evaporate in real time.

This is an iterative process requiring a few attempts before coverage is improved. Try to identify the most limiting factor, make a single adjustment, and then reassess. Consider factors such as travel speed, sprayer air output, nozzle rates and overall spray volume. Also consider canopy management and weather conditions.

When water sensitive papers are prepared in advance, each assessment should take two people less than half an hour. Compare assessments side-by-side. This small investment of time and money can return better crop protection, greater efficiency, and the confidence that the sprayer is doing the job.

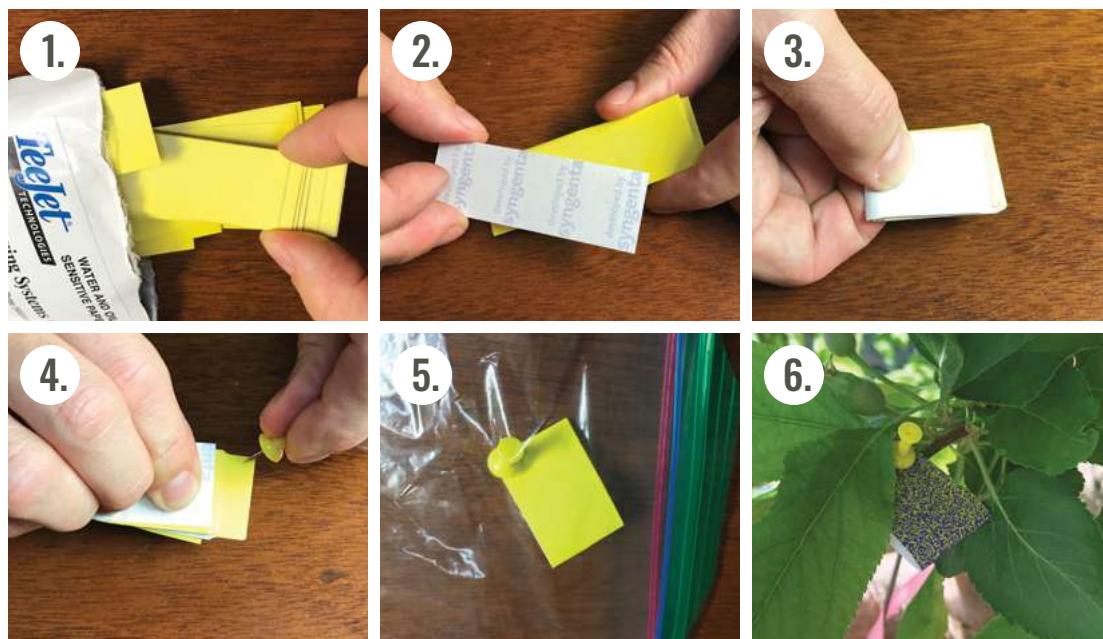


Four growers volunteered to place and recover water sensitive papers during a sprayer workshop. We watched as the spray blew through the target canopy (and the next four downwind rows). The growers were shocked when such an impressive plume left very little deposit on the papers. Slipstreaming and an excessive throw were the culprits, and reduced air energy was the solution.

15.5.1. PREPARING AND PLACING PAPERS

To avoid fingerprints, wear gloves or handle papers by the back and edges. Papers will slowly turn blue in humid conditions, so keep them sealed in their foil package when not in use. You will need ten pushpins (five dark coloured, five light coloured), eleven papers and a resealable plastic bag. The following process may seem like close-up magic but with practice you can quickly prepare multiple sets of papers (see figure below).

1. Remove eleven papers from the foil package.
2. Stack them yellow-side-up and flip the top paper over.
3. Using the flipped paper, carefully fold the stack in half. Now ten are folded yellow-side-out.
4. Expose one-quarter of the middle paper. Pinching the stack firmly will flex it and give support as you pierce the corner with a pushpin (twist as you push).
5. Use the pushpin as a handle to slide it from the stack and drop it into a resealable bag. Repeat the process for the remaining nine papers (return the outside one to the package for later use).
6. They will remain viable in the sealed bag for several days before they are used in the target canopy. Once placed in the canopy, ten folded papers provide 20 target surfaces.



To avoid boundary effects, don't place papers in the periphery of the planting. Also, go a short distance into the target row and pick a representative tree, bush or vine. This ensures the sprayer is up-to-speed and the canopy is not overly exposed to wind. The pins will hold the papers to stems, twigs and leaf petioles. Shadowing from leaves is inevitable, but try to avoid placing them up against fruit, leaves or wood. Distribution within the canopy depends on canopy size:

- **Small Canopies:** Using grape as an example, pin five dark pins into stems next to inner bunches deep in the canopy. Pin the five light pins around the outer bunches, oriented with one side of the paper exposed to the sprayer. When you stand back, it should be hard to see the inner papers.

Similar positioning can be used for berry canes and bushes. Pin five dark pins in the inner canopy, spanning the height but oriented randomly. Pin five light pins in the outer canopy, spanning the height but oriented with one side exposed to the sprayer.

- **Medium canopies:** For high-density orchards and larger trellised canopies, a ladder might be required. Pin five dark pins in the inner canopy, spanning the height but oriented randomly. Pin five light pins in the outer canopy, spanning the height but oriented randomly.
- **Large canopies:** For hops or large trees (e.g. tree nut, citrus, sour cherry), a creative approach is required to span the canopy height. Instead of dark pins, use sections of plastic or galvanized conduit. Note the wire clips developed to affix papers to the conduit in the figure below. You won't have these, so any method of firmly affixing the papers is acceptable. Alligator clips or spring-back paperclips work very well.



Use lengths of metal or plastic conduit to create a mast that can span the height of large canopies. Distribute papers evenly along the length as it is assembled and erected from inside the canopy.

Stand at the trunk and raise the conduit section by section to reach the full height of the canopy. Attach the five papers as you erect the mast, ensuring one at the top, one at the bottom and evenly distributing the other three. A wrap of electrical tape may be required to help hold sections together. Then, pin five light pins in the outer canopy, oriented randomly and spanning as high as can be conveniently reached (see figure right).



**TURBULENT
EDDY SAYS...**

Don't play hide-and-seek with water sensitive papers. Tie flagging tape around stems to mark their locations. You can find them and replace them for the next trial.



Larger trees, like nuts, citrus and sour cherry make it harder to assess all canopy positions. It helps when you're as tall as David.

15.5.2. SPRAYING PAPERS

Spray the target row as you normally would in weather you would normally spray in. It is preferable to spray clean water from a rinsed sprayer, but you can sometimes assess coverage following a chemical spray as long as label restrictions permit re-entry and you leave time for spray to settle. If papers can be inspected without removing them, consider driving the upwind alley, then inspect the papers in place, and then spray from the other side. This reveals the cumulative impact of spraying from each side, or the influence of wind on the application. Retrieve the papers when they are dry enough to handle. Pay attention to where they were in the canopy (or pre-label them). You'll need to know this for the assessment.



LAMINAR FLO SAYS...

Do not put wet water sensitive papers in a plastic bag. The trapped humidity will turn them entirely blue. Leave them in place and allow them to dry before harvesting.

15.5.3. ASSESSING CANOPY COVERAGE

Print or reproduce the coverage assessment form shown below. Complete the top section, being sure to describe the sprayer set-up, spray volume and weather conditions at the time of spraying. Either staple or glue the recovered papers to the form. Try to arrange them relative to their original positions in the canopy. Glue sticks work but use your finger to smooth out lumps before adhering the papers (otherwise they show through).

WATER SENSITIVE PAPER CANOPY COVERAGE ASSESSMENT									
Location			Date			Run #			
Block			Trial Notes and Sketches (Sprayer Setup, Wind direction, Travel Direction)						
Sprayer									
Volume									
Travel Speed									
Wind Speed									
Temperature			www.sprayers101.com						
Outer Canopy (circle rating for each side) Inner Canopy (circle rating for each side)									
E	Sprayer-Facing Side (Small Canopies)		E	E			E		
A			A	A			A		
I			I	I			I		
E	Sprayer-Facing Side (Small Canopies)		E	E			E		
A			A	A			A		
I			I	I			I		
E	Sprayer-Facing Side (Small Canopies)		E	E			E		
A			A	A			A		
I			I	I			I		
E	Sprayer-Facing Side (Small Canopies)		E	E			E		
A			A	A			A		
I			I	I			I		
E	Sprayer-Facing Side (Small Canopies)		E	E			E		
A			A	A			A		
I			I	I			I		
COUNT (E)xcessive <input type="text"/> (A)dequate <input type="text"/> (I)nadequate <input type="text"/> Total <input type="text"/>									
PERCENTAGE (count/total x 100) (E)xcessive <input type="text"/> (A)dequate <input type="text"/> (I)nadequate (Goal: <20%) <input type="text"/>									

Download a copy of this form from <https://sprayers101.com/assess-airblast/>.
 Print copies for use in your coverage assessments.

15.5.4. ASSESSING EACH PAPER

Coverage assessments are most effective when you use them to evaluate changes within your own spray program, such as comparing coverage before and after sprayer adjustments. When observers judge one paper to be visibly “bluer” than another, subsequent measurements have shown it represents >20% difference in actual canopy deposits. If you can perceive a difference, it’s very likely to represent a biological impact.

As we stated in Chapter 14.4., research and experience suggest that a minimum coverage threshold of both 85 deposits/cm² and 10-15% area covered is adequate for most foliar insecticides and fungicides. Experience, or label-indicated coverage requirements, may warrant a different coverage threshold. Remember: **Every. Deposit. Counts.**

Grade each of the 20 surfaces as (E) Excessive, (A) Adequate or (I) Inadequate by circling the corresponding letter on the form.

E

Excessive:

Provides crop protection, but may indicate unnecessary waste

A

Adequate:

Satisfies minimal coverage

I

Inadequate:

Includes non-uniform and insufficient coverage

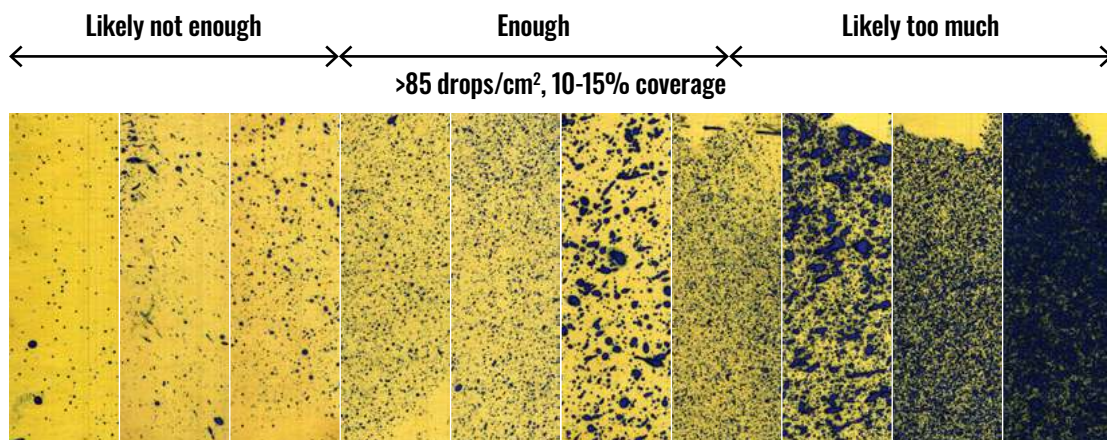


Count	(E) Excellent	(A) Adequate	(I) Inadequate	Total
Percentage	Excellent = 35%	Adequate = 50%	Inadequate = 15%	(Percentage = count ÷ total x 100)
Targets	Excellent or Adequate = 85%	Inadequate = less than 20%		

What do you think of the coverage shown on the 20 surfaces in this example? Seven of the 20 surfaces (35%) show almost no deposit, and 10 (50%) have visibly low numbers of relatively large deposits – that is usually an indication of inadequate coverage. This coverage assessment indicates more spray is needed.

When assessing coverage, be aware of the following exceptions. Consult the following figure and consider the following:

- Make allowances for a paper where adequate coverage was prevented by an obstacle. You often see the silhouette of the obstacle.
- Finer sprays will have higher deposit counts and may or may not cover less surface. If percent coverage seems low, focus more on deposit counts and distribution.
- Coarser sprays have lower deposit counts and may coalesce into blobs. When deposit counts are not possible, focus more on even distribution and consider how much paper is uncovered rather than how much is covered.
- Spray must pass through the canopy exterior to reach the interior. Drenched targets may be unavoidable in the outer region of large and/or dense canopies.



Unless using a scanner, visually assessing papers is subjective. Consider the sprayer design, product concentration and mode of action when making a determination.



Want to learn more about assessing deposits?
Theory, resources and practical techniques are
available at www.smalldropsprays.info.

15.5.5. ASSESSING CANOPY DISTRIBUTION

Spray coverage is highly variable. This method employs 20 surfaces and semi-random orientation to mimic some of that variability, but if you suspect your results don't represent reality, consider trying it again. Minimal coverage (i.e. Adequate and Excessive) should be achieved on 80% of the papers.

Complete canopy coverage is not required, but there is a limit. Studies in New Zealand wine grapes showed a direct correlation between the percentage of Inadequate papers and levels of bunch botrytis. Disease levels increased only when the number of Inadequate papers increased over 20%. We have observed similar results in many crops, but it also matters how coverage is distributed throughout the canopy.

Be wary of the following patterns and refer to the prior chapters on how to correct the issues.

1.

Clustered gaps in coverage

2.

Uneven coverage

3.

Run off

15.6. | Review and consider

- Which method of coverage assessment do you rely on?
- Have you ever counted deposits on a water sensitive paper?
Did you use a hand lens?
- Where can you buy water sensitive paper in your area?
- Are there known trouble spots in your canopy?
Would assessing coverage in those areas be worthwhile?
- Who is your trusted partner for assessing spray coverage?



Workshops don't have to be fancy to be impactful. We used some scrap wood with a ribbon affixed to the end to demonstrate the benefit of deflectors.

Chapter 16

Calibration

Any discussion of sprayers must include calibration. When we ask stakeholders to define sprayer calibration, their responses cover a wide range of activities that can be rolled up into three related, but different, tasks. All three tasks should be performed regularly as part of a successful spraying strategy. They improve accuracy and safety as well as prevent costly and inconvenient failures.

1. **Confirming sprayer output:** A series of diagnostics and calculations intended to verify that the sprayer is performing as intended. This is the commonly accepted description of calibration.
2. **Adjusting sprayer configuration:** A sprayer optimized to match the canopy may require recalibration. Conversely, when a sprayer is recalibrated, don't assume you are still optimized to match the canopy.
3. **Sprayer inspection:** A series of high-level safety and operational checks, more often associated with a preventative maintenance program.



Ask a group of stakeholders to define sprayer calibration. Be prepared for a variety of answers.

Calibration ensures the crop will receive the intended product rate with no unexpected left-overs or shortages. The operator should calibrate the sprayer at the beginning of the season and after any significant change to the sprayer set-up. Examples include new tractor tires, using a different tractor, or after replacing any liquid-handling component (e.g. nozzles, filters, lines).

16.1. | Measuring travel speed

As speed increases, the amount of spray volume applied per unit area decreases at an equivalent rate. For example, doubling your travel speed will half your spray volume.

$$\text{Spray volume}_{\text{new}} = \frac{\text{Spray volume}_{\text{original}} \times \text{Speed}_{\text{original}}}{\text{Speed}_{\text{new}}}$$

This is why any assessment of sprayer travel speed should be performed with the solution tank half-full of water. This approximates the average weight of the sprayer during an application.

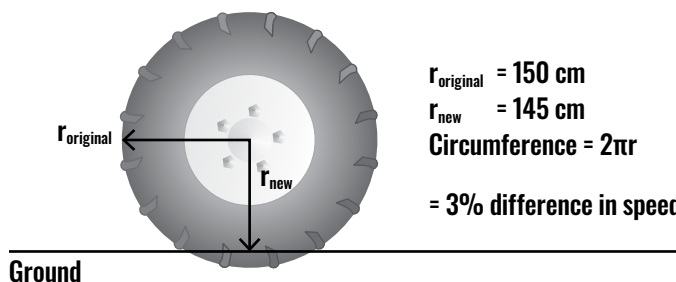
Travel speed should be slow enough to allow the spray-laden air to reach and displace the air in the target canopy (see Chapter 3.2.), but fast enough to get the job done in a timely manner. While there is no specific target speed, an average of 5 km/h (3.1 mph) is a common starting point. Operators must know their average travel speed to calculate how much spray liquid and time is required to complete the job. Notice that it's an average and not a constant. Speed changes on hills, when ground conditions change, as the sprayer gets lighter, and when the operator responds to weather or canopy size.

You may be tempted to consult the tractor speedometer, but it can be fooled by changes in wheel size. This can be due to tire wear, or ground softness (see figure below). Slippage on hilly or wet ground also affects travel speed. If you rely on a rate controller, know that monitoring wheel rotations is less accurate than employing RTK satellite navigation or a radar speed monitor for similar reasons.



**TURBULENT
EDDY SAYS...**

**Spraying on slopes? Be sure to average
your uphill and downhill speeds.**



Anything that affects tire radius will affect travel speed. This includes switching tires, tire pressure, tank level, or the ground conditions. A tractor with 150 cm (5 ft.) diameter tires reduced by only 5 cm (2 in.) loses 3% of the distance it travels per rotation, which means it drives 3% slower.

Consider downloading a smartphone speedometer app. The refresh rate can be slow, so you may have to drive several rows to get a reliable average. You could even use a fitness watch (and cheat to get your steps in for the day). Take a screenshot and email it to yourself as a time-stamped component of your spray records.

Smartphone speedometers are a reliable way to determine average travel speed. Depending on the sampling speed, you may have to drive a few rows to get an accurate representation.



Those that prefer a manual method can follow this time-honoured protocol for determining average travel speed:

1. Go to a row that is representative of the terrain in your planting. Measure out a distance and mark the start and finish positions with wire marker flags.
2. Fill the solution tank half full of water.
3. Select the gear and engine speed in which you intend to spray. If using a towed sprayer, ensure the PTO is running or you could introduce errors.
4. Bring the sprayer up to speed for a running start and begin timing as the front wheel passes the first flag. This is easier and more accurate with a partner.
5. Stop the timer as the front wheel passes the second flag.
6. Stay out of any ruts and run the course two more times.
7. Determine the average drive time for the three runs (i.e. the sum of all three times in seconds, divided by three). Note: if you see a large discrepancy between drive times, run them again.
8. Finally, calculate travel speed using one of the following formulae, depending on preferred units:

$$\text{Speed (km/h)} = \frac{\text{Distance travelled (m)}}{\text{time (s)}} \times 3.6 \text{ (a constant)}$$

$$\text{Speed (mph)} = \frac{\text{Distance travelled (ft.)}}{\text{time (s)}} \times 0.682 \text{ (a constant)}$$

16.2. | Measuring sprayer output

Once travel speed has been determined, use one of the following methods to assess sprayer output. There are pros and cons to each method.

16.2.1. AREA/LENGTH METHOD

Operators that draw comfort from the sprayer emptying in the same place each time are essentially assessing output using the area/length method. The sprayer is filled through a flow meter with enough water to spray a known area or row length. The area or distance is sprayed and if the tank empties where expected, it confirms the anticipated output (volume/planted area or volume/row length). But, there are potential problems with this method.

Most operators don't have an accurate test area marked off, and even when they think they know the area, measurements often prove otherwise. Row lengths are less difficult to measure. More importantly, this method reveals the total sprayer output but does not assess individual atomizers. For example, partially-blocked nozzles and worn nozzles average out (yes, this actually happens). This method will not expose these problems.

16.2.2. DIPSTICK METHOD

The sprayer is filled to a known volume through a flow meter while observing a sight gauge or a graduated dipstick. Then, while parked, the operator sprays for a given amount of time and refers to the dipstick or gauge to measure the volume remaining in the tank. This gives an output in volume/time.



Consider putting a small float or colourful fishing bobber inside your sight gauge tube. It makes it easier to see the spray liquid level.



Sight gauges are not an accurate means for determining tank volume. They are difficult to read and can become opaque (see middle image). Consider calibrating them on a level surface with a hose-end flow meter.

But this method can be fooled if the volume is misread. It's an easy error to make if the sprayer is parked on a grade, or the dipstick shifts in a tank with a rounded bottom. It would be preferable to refill the sprayer to the original level and note how much water it took to achieve it. In either case, this method also masks issues with individual atomizers.

16.2.3. TIMED-OUTPUT METHOD

Our preferred method is to measure the output of each nozzle individually. This timed-output method can be messy and time consuming, but it's accurate. Appropriate personal protective equipment is required to perform the timed-output method.

1. Fill the rinsed sprayer with clean water and park it on a level surface. You may need more than one tankful for larger sprayers with more nozzles.
2. With the fan(s) off, bring the sprayer up to operating pressure. Start spraying with your typical flow distribution (closing nozzles to save water may change the pressure).
3. You will need ~1 m (3 ft.) of 2.5 cm (1 in.) diameter braided hose. A second, longer hose is helpful for reaching the top of tall sprayers. It should be stiff enough that you can slip it over a nozzle body while holding the other end. Use it to guide flow into a collection vessel. The hose not only redirects flow downward, but allows any foam to dissipate.
4. When flow from the hose is steady, direct it into the collection vessel for 30 seconds (a partner with a stopwatch is very helpful). It is preferable to collect for a minute because it improves the accuracy.



Performing a timed-output test for each nozzle is an important part of sprayer operation, no matter how many nozzles there are. On this sprayer, it simply isn't feasible. It may be simpler to just replace all the nozzles after a given period of use. It would be helpful if someone would design a table-top nozzle tester... hint hint, industry.

5.

Assess and record nozzle output. Unless you have access to a scientific-grade graduated cylinder, graduations on plastic collection vessels are often unreliable. It's preferable to weigh the output using a digital kitchen scale. 1 mL of clean water weighs 1 g. Don't forget to subtract the weight of the vessel (this is called taring) and if liquid is only collected for 30 seconds, double the weight to convert it to minutes:

$$\text{Nozzle output (L/min.)} = \text{Weight (g/min.)} \times 1,000 \text{ (a constant)}$$

We provide a handy list of liquid unit conversions in [Appendix 4](#), but to convert to US gallons:

$$\text{Nozzle output (US gal./min.)} = \text{Rate (L/min.)} \times 0.264 \text{ (a constant)}$$

Once you have recorded the output of each nozzle, they can be added for the total sprayer output (volume/time). You can also assess flow-based nozzle wear using the nozzle manufacturer's rate tables ([see Chapter 17.2.](#)).

The SpotOn SC-4 calibration vessel is a quick and easy method for performing a timed output test. It calculates output in L/min., US gal./min. or oz./min. However, be sure to wet the sponge and hold it at a constant level during collection. Also be aware that foam can interfere with the readings, so only use clean water.



**TURBULENT
EDDY SAYS...**

Don't assume new hydraulic nozzles are accurate. New nozzles can have damage and defects. We've seen +/- 10% flow variation right off the shelf. Keep your receipts.

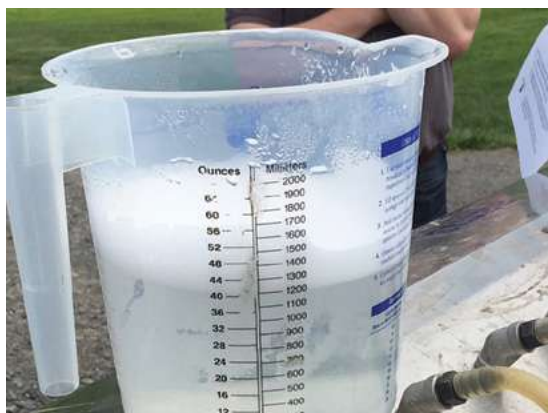
ABOVE: Twin-fluid (particularly air shear) atomizers pose a challenge for the timed-output method of calibration. Manufacturers propose removing the feed lines prior to the manifold and collecting the output. However, this does not capture potential differences between atomizers and will always underestimate flow because it removes the influence of air. Operators often resort to monitoring overall flow using the Area or Dipstick method or through a rate controller.

Rather than use a single braided hose, some operations save time and water by hose-clamping multiple lines around the nozzle bodies and collecting in multiple containers simultaneously (see first figure below). However, flow must be constant before collection begins and it can sometimes be difficult to get a tight seal. Further, clamping may cause problems with air induction (AI) nozzles. If the air inlets on AI nozzles are blocked, they will produce a falsely high flow reading (see second figure below).



Flow measurements systems (such as this one from AAMS-Salvarani) might make economic sense for large operations, or when grower groups buy and communally share the equipment. They are accurate and can read the output for multiple nozzles at once.

1,200 mL (0.317 US gal.) collected from an air induction flat fan nozzle with unobstructed air inlets.



1,350 mL (0.357 US gal.) collected from the same nozzle with plugged air inlets. This is a 10% increase in flow.



Plugging the air inlets on air induction nozzles when collecting flow will produce a falsely high reading.

Another alternative is nozzle body clamps. The pincers are designed to latch behind the nut of the nozzle body (see figure left), but they don't always fit and their weight can turn nozzle bodies into a partially-off position. Passive flow meters (see figure right) are sometimes used because they remove the need for a collection vessel. They are difficult to source in North America and their accuracy is questionable, but they are fine for comparing relative flow from nozzle to nozzle. They're really a better fit for horizontal boom sprayers since they have to be held in place manually.



AAMS-salvarani clamp
secured behind nozzle cap.
Hose barb directs flow to
calibration vessel.



Passive flow meter
directs flow past a float ball.
3-10% absolute precision,
1.5% relative precision.

16.3. | Nozzling a sprayer from scratch

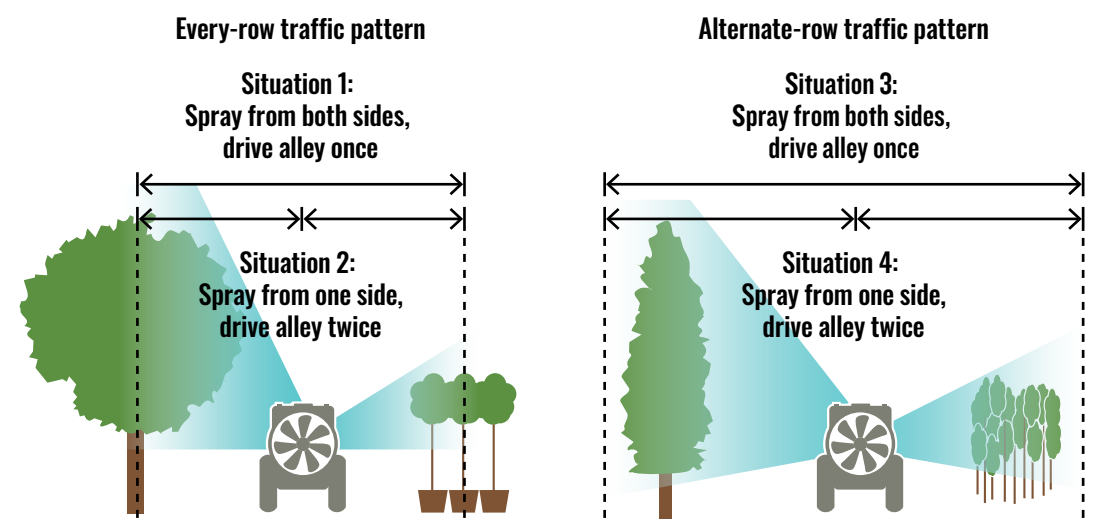
Until now we have described validating the calibration of a sprayer that has already been configured. What do you do if you are setting up a brand new sprayer? Or if your sprayer is coming out of long-term storage and was last nozzled for a full canopy? You may have to nozzle it from scratch before you can calibrate it.

As we discussed in [Chapter 13.2](#), when we considered flow distribution, we need a few pieces of information before we can continue. Perhaps these are derived from your spraying strategy, or advice from someone with prior experience. We've discussed these variables previously, so look back for guidance to help you decide:

- Travel speed ([see Chapter 3.2.](#))
- Sprayer output (per planted area or row length) ([see Chapter 7.3.1.](#))
- Traffic pattern ([see Chapter 8.3.](#))

The following formulae are a concise derivation of the approach presented in Chapter 13.2. We have provided Metric, US units and a hybrid option for four common situations (see table and figure below). The key difference in each situation is the combination of traffic pattern and sprayer design. Multi-row applications and WA sprayers are not specified in these scenarios, so consider them carefully.

SITUATION	TRAFFIC PATTERN	ALLEYS DRIVEN	SPRAYING FROM	SWATH EXTENDS TO
1	Every-row	Once	Both sides	Middle of adjacent rows
2	Every-row	Twice	One side	Middle of adjacent rows
3	Alternate-row	Once	Both sides	Middle of adjacent alleys
4	Alternate-row	Twice	One side	Middle of adjacent alleys



This figure illustrates the four spraying situations. Several canopy structures are depicted as examples. LEFT: Illustrating the swath for situations 1 and 2. RIGHT: Illustrating the swath for situations 3 and 4.

$$\text{Output from one boom (L/min.)} = \frac{\text{Spray volume (L/ha)} \times \text{Travel speed (km/h)} \times \text{Swath width (m)}}{600 \text{ (a constant)}}$$

$$\text{Output from one boom (L/min.)} = \frac{\text{Spray volume (L/ac.)} \times \text{Travel speed (km/h)} \times \text{Swath width (m)}}{243 \text{ (a constant)}}$$

$$\text{Output from one boom (US gal./min.)} = \frac{\text{Spray volume (US gal./ac.)} \times \text{Travel speed (mph)} \times \text{Swath width (ft.)}}{495 \text{ (a constant)}}$$

When you have calculated the output for a single boom you can choose to distribute the flow evenly, or unevenly, as discussed in [Chapter 13.2](#). Then you can select the actual nozzles as described in [Chapter 17](#).

16.4. | Sprayer inspection

The daily sprayer inspection is part of preventative maintenance, which identifies small problems before they become big ones. It's easier for operators (and farm managers) to justify the time required when they accept that the inspection should be part of a regular spray day.

It's a good practice to keep a few spare parts on the shelf. Swapping out a damaged component for a working one usually means less downtime than a trip to the dealer (assuming they are open). Perhaps you can repair the component later on when time isn't pressing.



An LPR pump makes a cozy place for a robin's nest. Perform regular sprayer inspections because you never know what has changed since you last used it.

What follows is a generic 15 step sprayer inspection. Always defer to the sprayer manufacturer or corporate policies where steps differ. Much of the inspection can be performed at the filling station, so it's fairly convenient. It assumes the sprayer was rinsed and stored properly after its last use (see Chapter 19), but always wear appropriate personal protective equipment, including hearing protection. Since you're loading, you should be wearing PPE anyway.

BEFORE FILLING

1. Park the rinsed sprayer on level ground (e.g. the fill pad).
2. Check lines/hoses and fittings for signs of wear or cracking. Leaks or bulging may only become apparent under pressure.
3. Strainers and nozzles should be clean and unbroken. Leaks may only become apparent under pressure.
4. Engage each nozzle shut-off valve or nozzle body flip position. They can seize or loosen with time.
5. Confirm adequate oil levels in the pump and gearbox.

BEGIN FILLING

6. Begin filling the sprayer half full with water (do not add product).
7. For PTO-driven sprayers, confirm universal joint(s), sprayer-tractor hitch and all connections are clean, lubricated and secure.
8. Check that all guards (e.g. PTO shaft shield) are in place and intact.
9. Ensure fan blades are unbroken and scraped clean. Intake grille(s) must also be clean and unbroken.
10. When half full, stop filling and check tire pressure (tractor and sprayer).



Plastic suction filter casings can warp or become brittle, preventing the O-ring from forming a seal. This can create pressure fluctuations as air is drawn into the lines. Clean and inspect filters when the sprayer is rinsed and empty at the end of the day.

TEST SPRAY

For WA and multi-boom sprayers, you may have to move the sprayer off the fill pad for the test spray. Perform these steps with the air off, if possible:

11. Bring up the tractor rpm, set the relief valve to the desired operating pressure and open the manifold valves to fill the lines and begin spraying clean water.
12. Ensure each nozzle sprays correctly. Get out of the cab to inspect from the rear. This gives the opportunity to double-check for line-bulges and leaks (see steps 1 and 2).
13. Ensure the agitation/bypass system is functioning properly.
14. Check that the solution tank is secure on the chassis and both crack and leak-free.
15. Turn off the spray and return the sprayer to the fill pad to complete the filling and product loading process.




Consider regular sprayer servicing by a professional agricultural mechanic.

Sprayer inspections are repetitive, so it's easy to accidentally miss things. Have you ever driven home while preoccupied, only to discover you don't remember how you got there? We suggest operators modify our generic checklist to suit their specific needs and then print and laminate it. Keep it at the filling station where it can be used repeatedly with a dry erase marker. This will keep you engaged and attentive during the inspection.

16.5. | Review and consider

- Is there a reputable agricultural mechanic in your area that does house calls?
- How much does an hour of downtime cost your operation?
How long does it take to perform a sprayer inspection?
- When did you last replace your nozzles? The entire set – not just the broken one.
- Do you have a spare set of nozzles and filter screens? Where would you get them?



Color-coded nozzles make it easy to
confirm the flow rate in each position...
as long as you can see them.
This nozzle is actually blue.

Chapter 17

About hydraulic nozzles

We introduced hydraulic nozzles, the atomizer most commonly used on air assist sprayers, in [Chapter 6.2](#). Don't be intimidated by the array of designs, sizes and materials (see figure below). Many are not relevant to directed applications.



Somehow, no matter how many nozzles you have, you never seem to have the one you need. Tackle boxes are a great way to organize your inventory.

17.1. | Disc-core nozzles

Many LPR sprayers use combination disc and core nozzles. Cores are sometimes called whirl or swirl plates. In combination, discs and cores produce a hollow or a full cone pattern with spray angles ranging from 15° to 115°, depending on the combination and hydraulic pressure. A disc is sometimes used alone if a jet of spray liquid is required.

Most discs are numbered according to their orifice diameter in 64ths of an inch. This is stamped in the face of the plate. The higher the disc plate number, the higher the flow and larger the VMD. The core accelerates the liquid and shapes the pattern. Core numbers are stamped along the edge of the plate, most commonly 13, 23, 25 and 45. The first digit signifies the number of diagonal holes and the second digit indicates their size relative to other cores. Cores with a hole drilled in the centre of the plate change the hollow cone pattern to a full cone pattern.

Disc-cores are made of several materials, spanning from soft nylon to hard-but-brittle ceramic (see figure below). Brass tips should not be used for day-to-day operation, but they are ideal for exploring sprayer outputs and flow distributions. Owning a library of brass discs and cores will allow you to experiment to find the best nozzle configuration for your sprayer (see Chapter 13.2.). Once you've determined the best rate for each nozzle position, purchase the more expensive equivalent rates in ceramic.



LAMINAR FLO SAYS...

When assembling disc-cores, note that metal cores have a raised “nib” on one side that must be oriented toward the sprayer.



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.

Working with disc-core nozzles can be aggravating. Here are a few common issues:

- It's hard to read the numbers stamped into the plates, especially when they are covered with fungicide.
- In the case of non-ceramic cores, installing them backwards changes the spray quality.
- Disc-cores that require gaskets can cause leaks or affect spray quality if they are assembled 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. Operators often resort to using a dental pick that can damage the nozzle orifice.

- If you've ever over-tightened a cap you know the terrible sound of accidentally crushing ceramics. A little more than finger-tight is sufficient (see figure below) as long as sprayer vibration doesn't loosen them.
- It's easy to lose a disc or core if you drop it while cleaning out a clogged tip in low light. Many are never seen again.

Before calibrating a sprayer we 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 we remove the caps we 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.



17.2. | Molded hollow cone nozzles

Ceramic discs and cores are available in a single, convenient, polyacetal nozzle. There many advantages to molded nozzles:

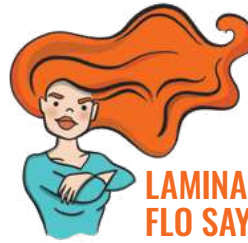
- It takes less than a minute to swap out a molded nozzle and they cannot be mounted backwards.
- Molded nozzles are brightly coloured and easier to find if accidentally dropped.
- The nozzle colour indicates the flow rate (discussed in [Chapter 17.4.](#)), which is very useful when switching between blocks that require different nozzle arrangements. Creating and keeping a pictorial key in the tractor cab avoids communication errors when matching nozzle arrangements and blocks.
- There is evidence that molded tips with pre-orifices outlast ceramic disc-core assemblies.
- Conventional hollow-cone molded tips are about the same price as ceramic disc-core.

Of course, nothing is perfect. There are also a few drawbacks to molded nozzles:

- Molded nozzle sizes are not as large as disc-cores, so they may not be suitable for higher-volume applications.
- Molded nozzles are not available in full cone patterns.
- Some operators report they are difficult to clean, but this only applies to older, non-ISO threaded TeeJet tips where the core must be unscrewed from the body. Newer tips are compression-fitted and pop apart easily.
- Converting from disc-core to molded nozzle might require new nozzle bodies ([see Chapter 17.5.](#)).

17.2.1. AIR INDUCTION

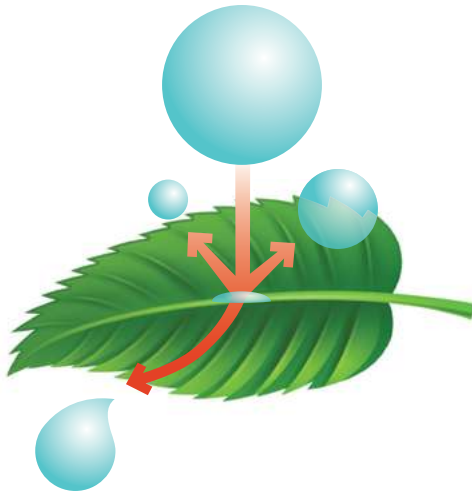
Sometimes called air inclusion or venturi nozzles, molded nozzles are available with an internal venturi that creates negative pressure to draw air into the spray liquid through one or two external ports. Droplets form around the air and the resultant air pockets behave like shock-absorbers, preventing coarser droplets from bouncing when they land (see figure below).



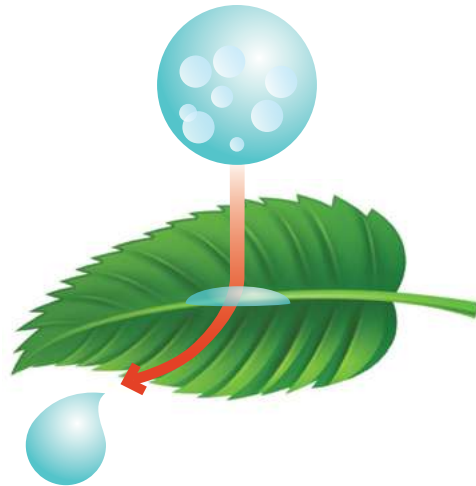
**LAMINAR
FLO SAYS...**

The inner edges of nozzle orifices are extremely delicate. Don't clean them with wires or toothpicks. Use a can of compressed air or soft-bristled brush. Better still, carry spares so you can replace them quickly and clean them later.

**Coarser droplets
bounce, shatter or run off**



**AI droplets
are less likely to bounce or shatter,
but can still run off**



Droplets with air inclusions are less dense than a solid droplet with an equivalent diameter. This has two consequences: they travel slower due to drag, and the inclusions act as shock-absorbers on impact. They are less likely to bounce or shatter when they impinge on a surface but compared to finer droplets, they are still prone to run off.

Air induction nozzles create coarser droplets than conventional nozzles, even when secondary atomization (see Chapter 6.5.1.) reduces their native VMD. They can be used in place of conventional nozzles in the following scenarios:

- Used along the entire boom when spraying sparse canopies to reduce off target drift.
- Previously mentioned in Chapter 13.2.2., AI nozzles can be used in the top few nozzle positions because coarser droplets will fall back into the planting if they miss the canopy. However, in the case of distant targets, there have been instances where coarser droplets fall out of the air stream before arrival.
- Used in boom positions where there is insufficient air energy, usually owing to design flaw creating a blockage in the air outlet. The mass of coarser droplets will help maintain their direction over short distances in lieu of air assist.

17.3. | Nozzle wear

The rate of nozzle wear depends on hydraulic pressure, product sprayed, hours used and the nozzle material. For example, spraying copper for ten hours at 10 bar (145 psi) through a brass nozzle will wear it by about 10%. Upgrading to a harder, more durable tip costs more initially, but reduces maintenance costs.

All nozzles wear out eventually – even ceramic. Replace any nozzles that are 10% more than the rated output. This not only indicates a problem with flow, but likely a problem with spray quality and geometry as well. Unless you are replacing a broken nozzle, they should go on as a set and come off as a set.



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.



**TURBULENT
EDDY SAYS...**

When determining nozzle wear, it is just as important to consider spray quality and spray geometry. A flow-based diagnostic may not indicate a problem.

17.4. | Reading nozzle tables

All operators should know how to read a nozzle table, no matter the atomization system on their sprayer. Tables are found on dealer and manufacturer websites as well as in their catalogs. The table layout varies slightly with brand, but they all relate a nozzle's flow to operating pressure. The better tables also provide the spray angle and in the case of molded nozzles, the spray quality.

Operators can use tables to complete calibration calculations and when deciding how to distribute nozzle rates, angles and spray quality along a boom relative to the target canopy. The rates also serve as validation criteria when an operator is determining nozzle wear.



Hollow and full cone nozzles are most commonly used on air-assist sprayers, but sprayers with narrow air outlets may benefit from flat fan nozzles. If the operating pressure exceeds the range in the manufacturer's nozzle table, you can extrapolate using the inverse square law, which describes the relationship between pressure and flow.

PHOTO CREDIT: WILL SMART.



Generally, the smaller the hydraulic nozzle size, the finer the VMD. Recognize that both flow and spray quality might change when you switch nozzles.

Suppose you have a red 60° ATR hollow cone nozzle and you operate the sprayer at 9 bar. What is the nozzle's flow rate? Using the table below, follow these three steps:

1. Find the red nozzle along the top row.
2. Find the 9 bar operating pressure in the left-most column.
3. Trace along the row and column to find 1.83 L/min. indicated in the cell at the intersection.

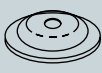

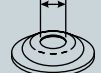

Perhaps you already have a rate in mind and you want a nozzle that will achieve it. Find the rate in the body of the table and trace the column and row to determine the nozzle/pressure combination. For example, suppose we want a flow rate of ~1.00 L/min. Using the same table, we can use a Yellow at 10 bar or an Orange at 5 bar. Yellow is the better choice since the Orange would have to be operated at the bottom of its pressure range (more on that later).

ALBUZ 60° AND 80° ATR HOLLOW CONE NOZZLE CHART

BAR	L/MIN.										
	WHITE	LILAC	BROWN	YELLOW	ORANGE	RED	GREY	GREEN	BLACK	BLUE	PURPLE
5	0.27	0.36	0.48	0.73	0.99	1.38	1.5	1.78	2	2.45	3.05
6	0.29	0.39	0.52	0.8	1.08	1.51	1.63	1.94	2.18	2.67	3.32
7	0.32	0.42	0.56	0.86	1.17	1.62	1.76	2.09	2.35	2.87	3.57
8	0.34	0.45	0.6	0.92	1.24	1.73	1.87	2.22	2.5	3.06	3.81
9	0.36	0.48	0.64	0.97	1.32	1.83	1.98	2.35	2.64	3.24	4.03
10	0.38	0.50	0.67	1.03	1.39	1.92	2.08	2.47	2.78	3.4	4.23
11	0.39	0.52	0.7	1.07	1.45	2.01	2.17	2.58	2.9	3.56	4.43
12	0.41	0.55	0.73	1.12	1.51	2.09	2.26	2.69	3.03	3.71	4.61
13	0.43	0.57	0.76	1.17	1.57	2.17	2.35	2.79	3.14	3.85	4.79
14	0.44	0.59	0.79	1.21	1.63	2.25	2.43	2.89	3.26	3.99	4.96
15	0.46	0.61	0.81	1.25	1.69	2.33	2.51	2.99	3.36	4.12	5.12
16	0.47	0.63	0.84	1.29	1.74	2.4	2.59	3.08	3.47	4.25	5.28
17	0.48	0.64	0.86	1.33	1.79	2.47	2.67	3.17	3.57	4.37	5.43
18	0.50	0.66	0.89	1.37	1.84	2.54	2.74	3.25	3.67	4.49	5.58
19	0.51	0.68	0.91	1.4	1.89	2.6	2.81	3.34	3.76	4.61	5.73
20	0.52	0.70	0.93	1.44	1.94	2.67	2.88	3.42	3.85	4.72	5.87

Nozzle table for Albus 60° and 80° ATR nozzles.

A disc-core table is slightly different from a molded nozzle table. Using the table below, we see that a D2 disc (left-most column) and a DC35 core (second left-most column) will emit 0.34 gpm at 80 psi. By continuing along the row, we see that the spray angle for this combination at 80 psi will be 47° (right-most column). Unlike molded nozzles, disc-core tables do not include information on droplet size. That said, they generally fall in the Medium to Fine categories.

			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 TeeJet nozzle table lists rates for a disc (D#) and core (DC#) full cone combination nozzles in US gallons per minute.



TURBULENT EDDY SAYS...

Do not confuse TeeJet's ISO-standardized TXA or TXB nozzles with TXVK or Conejet nozzles. They may be the same colour, but their rates are very different. Refer to the tables.

17.4.1. PRESSURE RANGE

Do not operate a nozzle at the extreme of their flow or pressure range. A trailed PTO sprayer will experience pressure changes from driving on hills, or rate controllers will create pressure changes in response to changes in travel speed ([see Appendix 2](#)). In either situation, coverage may be compromised if the nozzle is pushed outside its optimal range.

Use pressure to achieve small changes in flow, but for more extreme changes, switch nozzles. Remember, the Inverse Square Law: it takes four times the pressure to get two times the flow. Stated differently, it takes one-quarter the pressure to get half the flow. For example, if operating at 5 km/h and 6 bar, slowing the travel speed to 2.5 km/h will half the required flow rate. To achieve this, you would have to lower the pressure to 2.45 bar (the square root of 6), coarsening the spray and possibly compromising coverage.

You may not find a nozzle/pressure combination that creates the rate you are looking for. When your desired rate or pressure falls between the figures listed in the table, you have a choice. When the increment is small (e.g. 20 psi) it's reasonable to average the output. When the increment is larger (e.g. 50 psi), use the inverse square law. When nozzling an entire boom with different nozzle flows, get each position as close as you can to achieve the overall boom flow for a given pressure.

Nozzling is always a compromise – don't stress over it.

17.4.2. NOZZLE SPRAY ANGLE

We are referring to the shape of the spray produced by a nozzle, and not how the nozzle is positioned. Different disc-core combinations, or molded nozzles at different pressures, can produce similar rates. However, their spray quality and the angle of the fan or cone can be very different ([see last three columns in the earlier TeeJet table figure](#)).

Creating a full, overlapping spray swath that spans the entire canopy is a function of nozzle spacing, distance-to-target, and sprayer air-settings. It can also be affected by humidity, wind speed and wind direction at the time of spraying.

When the target is far away from the corresponding nozzle (e.g. the tops of nut trees), or the canopy is very dense (e.g. citrus canopies), consider tight-angled full cones under high pressure ([see figure on the following page](#)). This is inefficient and can give variable coverage, but it is sometimes the only option in extreme situations. When the target is very close to the sprayer (e.g. cane fruit) wide angled hollow cones or fans will overlap sooner, reducing the potential for undesirable striping or banded coverage.

Confirm your spray has sufficient overlap by parking the sprayer in the alley between crops. With the air on, spray clean water while a partner stands a safe distance behind the sprayer to look for gaps in the swath. The partner will see things the operator's shoulder check will not reveal.



In this staged photo the two nozzles on the top-left of the tower are either full-cone nozzles or discs without cores. They have a higher flow, coarser spray quality and tighter pattern than the hollow cones on the top-right. This strategy is intended to increase the throw, but coverage can become erratic.

PHOTO CREDIT: JEREMY BRIGHT.

Conversely, watch for places where the spray cone or fan is too wide and does not properly join the airstream. When spray extends beyond the influence of the air generated by the sprayer it won't reach the target and will likely become spray drift. If this is happening, consider a nozzle style with a narrower spray angle, or reposition the nozzle body to better intersect the air.

17.4.3. NOZZLE TABLES CAN BE WRONG

Sometimes nozzles do not perform as advertised. We have discovered errors in published tables, worldwide. Here are the big four:

- **Conversion errors.** Manufacturers publish catalogs in Metric and in US units, but we have found errors in the conversions.
- **Spray angle errors.** When nozzles are operated at the extremes of their pressure ranges, spray angles deviate from those listed in the tables.
- **Flow rate errors.** When tables are not updated to reflect changes in nozzle design, or the manufacturing process, actual flow rates deviate from those listed in the tables.
- **Nozzle tables are generated using clean water.** Product formulations and concentrations change the physical qualities of the spray liquid. This can lead to significant differences in flow compared to the published tables.

Perhaps it's not the table, but the nozzle itself that's out of order. Most nozzle manufacturers accept a flow variability up to $\pm 2.5\%$ for new nozzles, but we have seen higher. It depends how they are made (machined, stamped, printed) and the material they are made of.

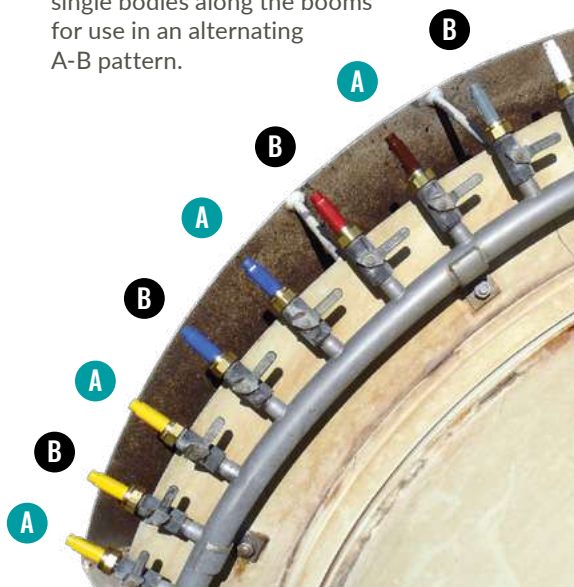
When errors are discovered and reported, the manufacturers can be slow to issue corrections and the errors will persist in print. Yes, even apps (which are often based on tables) can be wrong. So, predicted flow rates can prove unreliable. This is why it is important to double check by observing nozzle overlap and validating flow when you replace nozzles, even when they are brand new.

17.5. | Nozzle bodies

Nozzle bodies permit the operator to mount hydraulic nozzles along the boom. Nozzle caps compress and seal the nozzle against the body to force the spray mix through the nozzle orifice. There are several configurations:

- **Multi-outlet or roll-over bodies:** These bodies allow the operator to quickly switch between two or sometimes three nozzles in each position. This is convenient when alternating between dilute and concentrated applications, or changing the spray distribution from block to block. The roll-over feature can act as a shut-off or allow the operator to adjust the angle $\pm 15^\circ$ from centre. When roll-overs are new there is an audible 'click' when they reach 15° to alert the operator that turning them any further will interfere with flow. This feature fails as bodies wear.
- **Single nozzle bodies:** Some sprayers employ single nozzle bodies featuring screw or lever-style shut-offs. Some sprayers double the density of the bodies along the boom, arranged in an alternating A-B pattern. The operator shuts off each alternate nozzle, perhaps using the A's for dilute and the B's for concentrate applications. This design gives the operator the ability to "double up" in positions along the boom if more flow is required.
- **Deflector-mounted nozzle bodies:** These are nozzle bodies that are integrated into the deflectors, permitting the operator to orient the air and nozzles at the same time.

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



This design combines two single nozzle bodies with each air deflector. The operator angles air and liquid simultaneously and has considerable freedom to modify flow and spray quality in each position.

17.5.1. CHECK VALVES

When no flow is required, nozzles should be able to close quickly and completely. This can be accomplished through electric valves, spring-attenuated ball valves in the strainer, or most commonly, anti-drip diaphragm check valves with actuator springs.

For example, when an operator turns off an outside boom on a turn, the spray liquid in that boom will drain out the lowest nozzles. When the boom is turned back on there's a lag as it fills and repressurizes. Check valves will open or shut around 0.6 bar (10 psi), making the booms more responsive and less wasteful (see figure below).



The nozzle bodies on this older LPR sprayer do not have check valves. When the boom is shut off, it will drain through the lowest nozzle. This is wasteful and unnecessary environmental contamination.



This is a creative example of retrofitting diaphragm check valves on single nozzle bodies. The nozzles protrude into the air stream, and the check valve must be oriented to avoid the shut-off valve, but the operator has been successful for six years and counting.

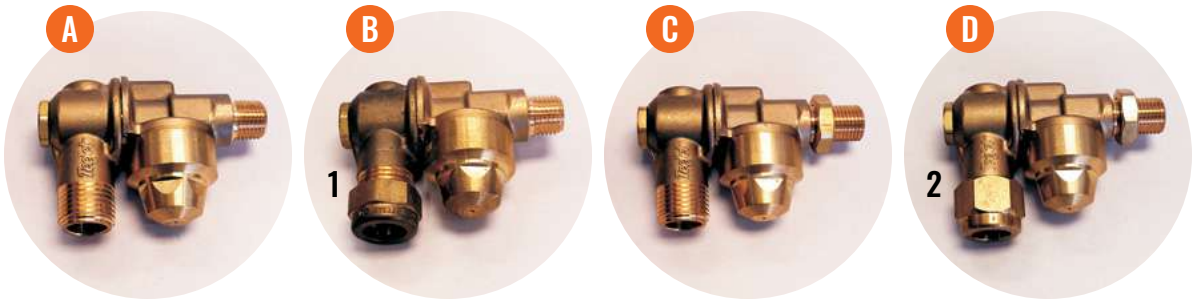


TURBULENT EDDY SAYS...

Nozzle body diaphragm check valves are preferred over ball-valve nozzle strainers, which create a minor pressure drop of ~5 psi and plug with irritating regularity.

17.5.2. THREAD TYPES

In North America, nozzle bodies are available with four inlet thread types (see first figure below). If you are replacing your nozzle bodies, be sure the thread type is compatible with your boom (see second and third figures below).



A. British Standard, Pipe Tapered (BSPT). B. National, Pipe Tapered (NPT) 1. Shallow cap. C. British Standard, Pipe Straight (BSPS). D. National Pipe Straight (NPS) 2. Deep cap.



ABOVE: Old roll-over bodies without check-valves. These were removed to make way for better bodies.

BELOW: Older nozzle bodies can seize in the boom, requiring a more aggressive approach for removing them. In this case, the mechanic is heating and loosening the fittings using “the blue wrench”. We included this particular image to point out a few notable PPE issues. Don’t try this unless operating in an open space using gloves, eye protection and a respirator (the filter-tip pictured doesn’t count). Years of residue build-up should be anticipated and respected.



17.5.3. NOZZLE COMPATIBILITY

If you are considering converting from disc-core nozzles to single-piece, molded nozzles, be aware they may not fit your existing nozzle bodies (see figure below). Check the diameter of the body outlet (where the nozzle rests) and the outlet cap (which compresses the nozzle against the body outlet). If your sprayer currently uses an unusual-diameter nozzle, like older FMC disc-whirls or European large-diameter pink ceramic disc-cores, today's ISO molded nozzles won't fit.

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



Hipro 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.



LAMINAR FLO SAYS...

Molded nozzles protrude, so ensure the roll-over nozzle body still has the clearance to turn freely.

17.5.4. NOZZLE BODY CAPS

Nozzle bodies do not come with the nozzle caps. This can be an unpleasant surprise when you take delivery of a new set of bodies. Caps have different depths specific to the nozzle type so they must be purchased separately.

Standard caps are threaded brass hex nuts but there are also plastic bayonet-style caps that can be installed with a simple quarter-turn and a push, no tools needed. Beware converting to quarter-turn systems for air-assist sprayers. It can work, but nozzles may require additional gaskets and O-rings that can lead to complications. Even then they have been known to leak if the cap diameter is too large (see below).



Incompatible caps and nozzles will leak. High pressure systems can also force the O-ring off the molded nozzle.

Regarding the cap depths, sprayer operators must consider how much “stuff” is between the nozzle body and cap. Gaskets, spacers, O-rings and strainers take up room that may warrant a deeper cap. Perhaps most critical is the nozzle itself. For example, brass disc-core are quite thin, but ceramic are much thicker. They require different cap depths.

TeeJet’s molded cone nozzles come with an ‘A’ (Thinner) or ‘B’ (Thicker) shoulder. The shoulder is the lip around the nozzle base that is compressed against the nozzle body outlet. The B-shoulder is the ISO standard, and is preferred (see below). Shallow caps may not thread onto a nozzle body using a nozzle with a B-shoulder. Deep caps may bottom-out before compressing a nozzle with an A-shoulder, creating leaks. Be sure to note in the nozzle catalog which caps are recommended for the nozzle.



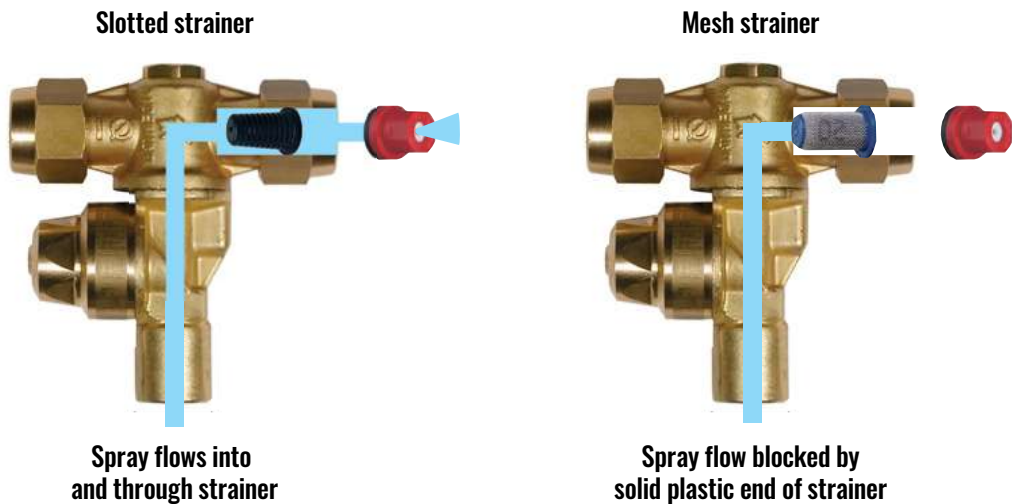
Molded cone nozzles come in the thin shoulder (A-style, nozzles 1 and 3) or thick shoulder (B-style, nozzles 2 and 4) varieties. The B-style is the ISO standard and is preferred. Nozzle 4 is designed to be easily separated into its component disc and core sections to facilitate cleaning.

17.5.5. NOZZLE STRAINERS/FILTERS

As mentioned, the nozzle strainer shoulder takes up some room between nozzle body and cap. Here's a real world example of why that matters.

A hop grower installed new nozzle bodies on his sprayer. He'd accounted for the shoulder when he selected his caps. Why were his nozzles not spraying? And why when he loosened the cap to finger-tight did they spray, but leak?

We tried gaskets, O-rings, different cap depths and new nozzles – but no change. That's when we noticed one side of the roll-over body had a plastic slotted strainer and the other had newer mesh strainer. The mesh strainers were longer and terminated in a disk of solid plastic. When we swapped the two strainers, we had flow! We realized the longer mesh strainers were being compressed against the orifice in the nozzle body, acting like a cork in a wine bottle.



Make sure your strainer/filter fits the cavity. Incompatibility is a common problem with sprayer parts. Some nozzle strainers are long and terminate in a plastic disc that will block flow in the nozzle body when the cap is tightened.

17.6. | Putting it all together

Armed with your new understanding of the components that make up a hydraulic atomizer, you may choose to upgrade your sprayer. If you have always used the same nozzle, don't assume your new configuration will be compatible. Pay particular attention to the following:

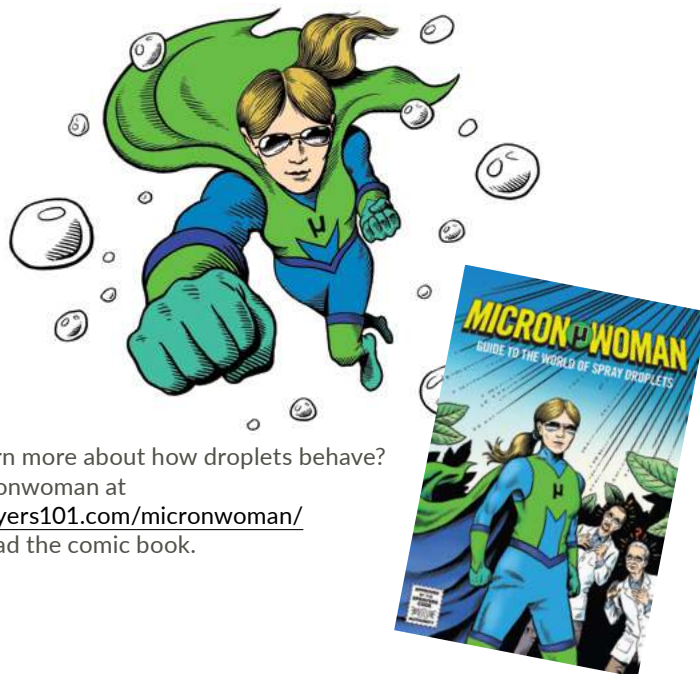
- The nozzle bodies: Will they fit your new nozzle and the thread in the sprayer manifold? Will they fit in the space provided in the sprayer?
- The seal: Is it the right thickness, diameter and material (viton is always the right choice). Do you have enough room to accommodate the tip filter?
- The cap: Does it have the right diameter and geometry to fit the nozzle? Is there enough thread to ensure it's a tight seal? If you choose a quarter turn cap, will it fit your strainer, seal and nozzle?
- The nozzle design: Beyond the size, spray angle and spray quality, does the shoulder and diameter fit with all the other components?



We happened upon this opportunity at the side of the road while lecturing in Australia. Secondhand sprayers may be economical, but look closely, ask questions, and consider the cost and availability of replacement parts.

17.7. | Review and consider

- Are you considering changing your nozzles and bodies?
Have you planned ahead to ensure components are both available and compatible?
- Did you order enough to have some spares?
- If your nozzles are worn by 5%, how much water and product is being wasted annually in your operation? How much would it cost to replace the nozzles?
- Would molded nozzles produce enough flow to work in your operation?
Are they compatible with your current nozzle bodies?
- Do you keep spare nozzles, a wrench and nitrile gloves in your tractor cab?
- Would it be worth having two or maybe even three different sets of nozzles ready so you can change your sprayer configuration as orchard conditions change?



Want to learn more about how droplets behave?
Watch Micronwoman at
<https://sprayers101.com/micronwoman/>
and download the comic book.



STORAGE FOR USED
CHEMICAL DRUMS FOR
DRUM MUSTER
MUST BE LOCKED AT ALL TIMES!!!

STING

MEGAFOL

Chapter 18

Loading and mixing

Adding products to the solution tank requires an understanding of how they dissolve or suspend in water and how they react to one another. We provide calculations to determine how much product is required in [Appendix 3](#). The generally-acceptable order is as follows:

- | | | | |
|--|--|---|--|
| <div style="background-color: #4CAF50; color: white; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">1.</div> <p>Fill the solution tank half to two-thirds full with water.</p> | <div style="background-color: #4CAF50; color: white; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">2.</div> <p>Turn on agitation.</p> | <div style="background-color: #4CAF50; color: white; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">3.</div> <p>Add products in the correct order, leaving sufficient time for dissolution/dissipation.</p> | <div style="background-color: #4CAF50; color: white; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center; margin: 0 auto 10px auto;">4.</div> <p>Add remaining water.</p> |
|--|--|---|--|

We will discuss each step in detail.

18.1 | The carrier

In the world of air-assist sprayers, the carrier is almost always water. Water quality plays a very important (and often unappreciated) role in tank mixing. Begin with a qualified laboratory test to establish an accurate baseline for:

- pH
- Total hardness
- Bicarbonate (HCO^-)
- Salinity (electrical conductivity) or Total Dissolved Salts (TDS)

Colorimetric test strips can be used to quickly check water quality before the addition of pesticides and for monitoring changes in water quality between laboratory tests. We prefer handheld digital monitors because they are more reliable (and readable) after pesticide additions.

Water quality can vary over time depending on its source. Municipal water quality tends to vary very little, but water from surface sources such as dams, storage tanks, holding ponds and rivers will vary depending on rainfall and other factors. Depending where you live, groundwater can also vary over time. It's a function of how much is being pumped and the recharge rates of the aquifer.

If your water requires correction, do so before loading the tank (see [Chapter 18.3](#)). Products dissolve better in higher volumes. The solution tank (vat, inductor, etc.) should be at least half full of water before adding the first product. The incomplete dissolution of products can leave hard-to-clean residues, plug fluid lines, and result in a non-uniform application that reduces efficacy. The risk is greater with low carrier volumes and high product rates (especially dry formulations), such as in ULV sprayers.

18.2. | Agitation and pace

As we learned in [Chapter 5.1.](#), agitation should be on-going during mixing and spraying. When agitation is too low, products may not disperse or suspend and can settle out. In the case of leaving a sprayer overnight without agitation, settled product may or may not resuspend. When agitation is too aggressive (e.g. full agitation when the tank is less than half full) product can foam, causing overflows or breaking pump suction during spraying. Over agitation can also cause dispersed products (e.g. emulsifiable concentrates) to separate and cause clumping that looks like curds.

While efficient sprayer loading is an excellent opportunity to improve your work rate (see [Chapter 8.2.](#)), some dry products can require as long as five minutes to dissolve completely. Pace is especially important when the carrier or product is cold. Imagine mixing sugar in hot tea versus iced tea – more sugar dissolves more quickly in hot liquid. To save some time, operators sometimes pre-hydrate dry products in a smaller tank (often called a slurry) or use an extra tank to pre-mix whole loads and simply transfer them over.



If you collect rainwater or store groundwater, use an opaque or covered tank to reduce algal growth. The Stones had it right: Paint it black.



Adding pesticide to the sprayer may not be straight-forward. For example, many operators place water-soluble packages 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 pouches can “puff” open, releasing product into the air. This creates unnecessary contamination and operator exposure. If the pouch is dropped into the half-full sprayer, it can be sucked into the pump intake, which prevents dissolution. Yet another reason for maintaining a clean and effective suction strainer ahead of the pump. Others take the time to mix a pre-slurry, but the soluble packages are often used as a mitigation strategy to reduce operator exposure and product labels will specify that they must be added to the product tank unopened. Choose the safest method for your situation.

PHOTO CREDIT: MARIO LANTHIER.



LAMINAR FLO SAYS...

Even when products appear to be dissolved, they might not be. Labels will indicate when products need time to hydrate. Be patient.

18.3. | Tank mixing

Each country and region has their own set of rules and regulations regarding mixing multiple products in a single solution tank. In Canada, for example, users of commercial class pest control products for crop protection or vegetation management are permitted to mix multiple products as long as:

- Each partner is registered for use on the crop.
- The tank mix only includes an adjuvant when specifically required by one of the mix partners.
- The 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.

Tank mixing multiple products has several advantages:

- **Efficiency:** If the timing makes sense, a single pass saves time, reduces compaction and possible crop damage (usually an issue with berries on tight alleys).
- **Resistance management:** Multiple effective modes of action help prevent resistance development and combat existing problems.
- **Improved performance:** Labels may require adjuvants to improve spray quality and potency, which can enhance performance.

Rushing a tank mix can cause physical incompatibilities that lead to prolonged delays and create unnecessary waste.



18.4. | Mixing order

After the carrier has been tested and corrected (if necessary) we have to decide on the mixing order. There are several acronyms around to help you decide on the sequence. The oldest and most recognizable is W.A.L.E.S. This stands for Wettable powders, Agitate, Liquid flowables, Emulsifiable concentrates, Surfactants.

There are other acronyms, but W.A.L.E.S. is still relevant. In fact, formulation chemists expect it to work ~95% of time. Generally, soluble liquids are forgiving and can be added early or late. It's the dry formulations and emulsifiable concentrates that require more care. When there are exceptions to the order, they are clearly indicated on the pesticide label.

W.A.L.E.S. is, perhaps, a bit simplistic. Products that fall within each "letter" have their own preferred mixing order that isn't specified by the acronym. Here is our expanded generic mixing order. Some of it is specific to herbicide applications from horizontal booms, but we include them for completeness:

1. Water-Soluble Packages (WSP): Allow them to fully dissolve and disperse.
2. Wettable Powders (WP)
3. Water Dispersible Granules (WDG, WG, SG)
4. Agitation to allow dry products to mix and disperse.
5. Liquid Flowables (F, FL): Including, in order, Suspension Concentrates (SC), Suspo-emulsions (SE), Capsule Suspensions (CS/ZC), Dispersible Concentrates (DC), Emulsions in water (EW).
6. In order: Emulsifiable Concentrates (EC): Microemulsifiable Concentrates (MEC) and Oil Dispersions (OD).
7. In order: Solutions (SN), Soluble Liquids (SL), Liquid Fertilizers and Micronutrients (when not already premixed with fertilizer).

NOTE: Compatibility agents and anti-foamers should be added before pesticides. Adjuvants like Non-Ionic Surfactants (NIS), Crop Oil Concentrates (COC), Drift Retardants (DR), and spreader/stickers should be added based on specific label direction or based on their formulation, just like pesticides.

Tank mixing requires caution and careful investigation. Should tank mix partners prove to be incompatible, the consequences can be subtle or dramatic, but are always negative. There are two kinds of incompatibility: Biological/chemical and physical.

Water-soluble packaging is sometimes used for dry flowable and wettable powder formulations. In most cases, the packaging material is PVA (polyvinyl alcohol), which dissolves completely when added to the carrier according to instructions. Read labels carefully:

- Keep pouches dry (do not handle with hands or wet gloves).
- Keep pouches in the outer package until just before use and reseal it afterwards.
- Oils, certain adjuvants and EC formulations, as well as residues of these products, can interfere with the dissolution of water-soluble packages.
- Dissolution is improved when the carrier is not cold, the product tank is at least half full and sufficient time is allotted between additions.

18.4.1. BIOLOGICAL OR CHEMICAL INCOMPATIBILITY

This form of incompatibility may not be immediately apparent following an application. Some level of crop damage or impaired efficacy occurs, which may impact yield or warrant an additional “clean-up” application. This is the result of product synergism or antagonism.

When products synergize, the application becomes too potent. For example, an adjuvant could affect crop retention or uptake, exposing it to more active ingredients or overwhelming crop metabolism. The result is damage to the crop we are trying to protect. For example, do not mix sulfur with products that contain oil.

When products antagonize, the application becomes less potent. Many operators are already aware of the risks of tank mixing biofungicides, but there are several other examples:

- pH adjusters in one product may reduce the half-life of certain insecticides. For example, the half-life of Captan (an insecticide) drops from 32 h at pH 5 to 10 min at pH 8. The half-life of mancozeb (a fungicide) is virtually unaffected (32-34 h) over a similar pH range.
- Active ingredients may get tied-up on the clay-based adjuvants in other products (more often a herbicide concern).
- One product changes the uptake/retention of another. For example, acids such as phosphorus can make copper phytotoxic.

18.4.2. PHYSICAL INCOMPATIBILITY

Physical incompatibility affects work rate and efficacy. Products form solids that interfere with or halt spraying. It can also make sprayer clean-up more difficult. There are many forms of physical incompatibility:

- Liquids can curdle into pastes and gels that clog plumbing to such an extent that flushing cannot clear it and a manual tear down is required.
- Dry formulations don't hydrate or disperse, becoming sediment that clogs screens and nozzles. Even if they are small enough to spray, they reduce coverage uniformity. For example, a dry product added behind an oil gets coated, preventing it from hydrating.
- Certain product combinations may cause settling, or one partner is more prone to settling. If the sprayer sits without agitation, settled products may or may not resuspend. Even if they do resuspend in the tank, they may remain as sediment in lines.
- Certain product combinations may cause foaming, or one partner may be prone to foaming, causing overflows or breaking pump suction. When products foam, dry products added through the foam may swell, preventing hydration.
- Phase separation occurs when products layer in the tank. Consider oil and water. Even with agitation, the active ingredients may not be uniformly suspended in the tank and coverage uniformity will be reduced during spraying.
- Even the packaging itself should be considered. Water-soluble packaging is incompatible with spray oils and boron-containing fertilizers.



Salad dressing is a good metaphor for separation. **LEFT:** Separation can occur when agitation is too low, or products are left for prolonged periods. **RIGHT:** Sufficient agitation will suspend or emulsify a tank mix for a consistent application.

PHOTO CREDIT: MIKE COWBROUGH.

18.5. | Successful mixing

Product formulation is a complicated science. In the 1950s a formulation might have three active ingredients and an inert filler. Today, certain field crop products can include ~40 ingredients with formulation testing lasting two to four years!

Incompatibility is often a function of the inert ingredients in pesticide formulations (e.g. thickeners, adjuvants, defoamers, stabilizers, solvents, etc.) and not the active ingredients. The more products you add to the solution tank, the more likely you'll encounter an issue. Do not decide on a new tank mix during loading. Even if you've used these products successfully in the past, formulations change without notice. Be sure to do the following:

18.5.1. CONSULT PESTICIDE LABELS

Pesticide labels are always the first point of reference. They should be obeyed even if they contradict conventional practices. Booklet-style labels that come with the products are long, difficult to search and may not be up-to-date. It is often faster and easier to consult a trusted online source.

For example, Canada's PMRA Label Search website allows users to search labels in PDF format. In other countries, consult the manufacturer's website for label information. When searching a label in PDF form, use <CTRL>+F to find the following keywords for each tank mix partner:

“Do Not Mix” “Mix” “Hours” “Agitation” “Fertilizers”



Do not decide on a new tank mix during loading.

18.5.2. CONSULT MANUFACTURER AND CROP ADVISORS

It's likely you are not the first to consider a certain tank mix. You can learn lessons from others:

- Consult your chemical sales representative. They know their products best and want to see you succeed. They may have insight that is not found on the product label.
- Consult local government or academic extension programs for an unbiased opinion.
- Enlist the help of a professional crop advisor.



**LAMINAR
FLO SAYS...**

Be wary of advice obtained from other growers at coffee shops.

It is a good practice to get tank mix recommendations in writing. If something should go wrong, liability is an important concern. If you are considering mixing partners not listed on the label, beware that local regulations may or may not permit you to do so. When there is no information available, or when labels contradict or are silent, it is best to perform a jar test for physical compatibility.

18.5.3. THE JAR TEST

Performing a jar test is like filling a sprayer in miniature; everything is held in the same ratio. You'll need a disposable syringe and a cheap digital scale (available online, or at your local drug store/chemist). Follow all the same rules as filling your sprayer, using your actual water source and temperature. Always wear personal protective equipment and work in a safe and ventilated area. A jar test will only reveal physical incompatibility between products. It will not reveal any other form of antagonism.

- 1. Read all product labels:** Know the product formulation (which affects mixing method and order). Look for information about the influence of carrier pH, hardness and any requirement for adjuvants. Defer to label instructions should they differ from these mixing steps.
- 2. Shake any liquid products:** This ensures the active ingredient and inert ingredients are thoroughly mixed.
- 3. Add 250 mL to a 1 L glass jar.**
- 4. Agitate (stir) between additions:** In a sprayer, agitation should continue throughout the mixing process.

5. **Add products in order:** Scale back the weights/volumes used to match the concentration intended for an actual solution tank (e.g. 1 kg product in a 1,000 L solution tank is 0.5 g product in a 500 mL jar test). In a sprayer, you would flush an inductor with water between additions.
6. **Wait and check:** Dry products and water-soluble packets must fully disperse and/or dissolve before adding the next product. Several factors affect the duration, but 3-5 minutes is typical. If testing water-soluble packets, include a $\sim 1 \text{ cm}^2$ cutting of the PVA packaging.
7. **Top up the carrier to 500 mL.**
8. **Measure pH** using a digital meter (test strips may not be readable). This is best done after all products are added to account for their impact on pH and buffering capacity. If required, pH adjusters can be added at the end of mixing to ensure the solution is in the range required by the label.
9. **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.

Keep detailed records of what you mixed and how you mixed it. This is important for traceability and for tracking successes and failures for next year. The jar test itself can become a valuable record if it's labelled and left in the chemical shed. You will see if products separate, precipitate or form residues. This may indicate if you can let a tank mix sit overnight or if it will require special attention during rinsing.

18.6. | The reverse jar test

Accidents happen, so what do you do if you've made a mess? We'll use this real-world situation from a herbicide application as an example:

Problem: "I mixed up a batch of MCPA 500 A and Glyphosate at three-quarters recommended label rate, but then got delayed on application with a stuck drill. I came back to the sprayer and found a nasty chemical precipitate – like waxy chunks. Agitation didn't break them down. I dumped the tank out as I didn't want to pump it through the booms. How do I clean up the chunks in the system?"

Solution: "Wearing appropriate personal protective equipment, physically remove the "chunky" material. A lot of time can be wasted (and rinsate water created) by experimenting with various concoctions, but if you do choose to try a compatibility agent, first try it in a mason jar. If it works to dissolve the material, it can be added to the tank with water and agitated. If not, you are down to manual cleaning: hot water under pressure."

We dubbed this process "The Reverse Jar Test". Do not add hot water, cleaners or compatibility agents until the reverse jar test confirms success. You may create a larger problem. Of course, the best advice is to not put yourself in this position to begin with. Don't make mixing decisions at the inductor bowl – make them before ordering products.



If you experience physical incompatibility during loading, don't blame the last product you put in the tank.

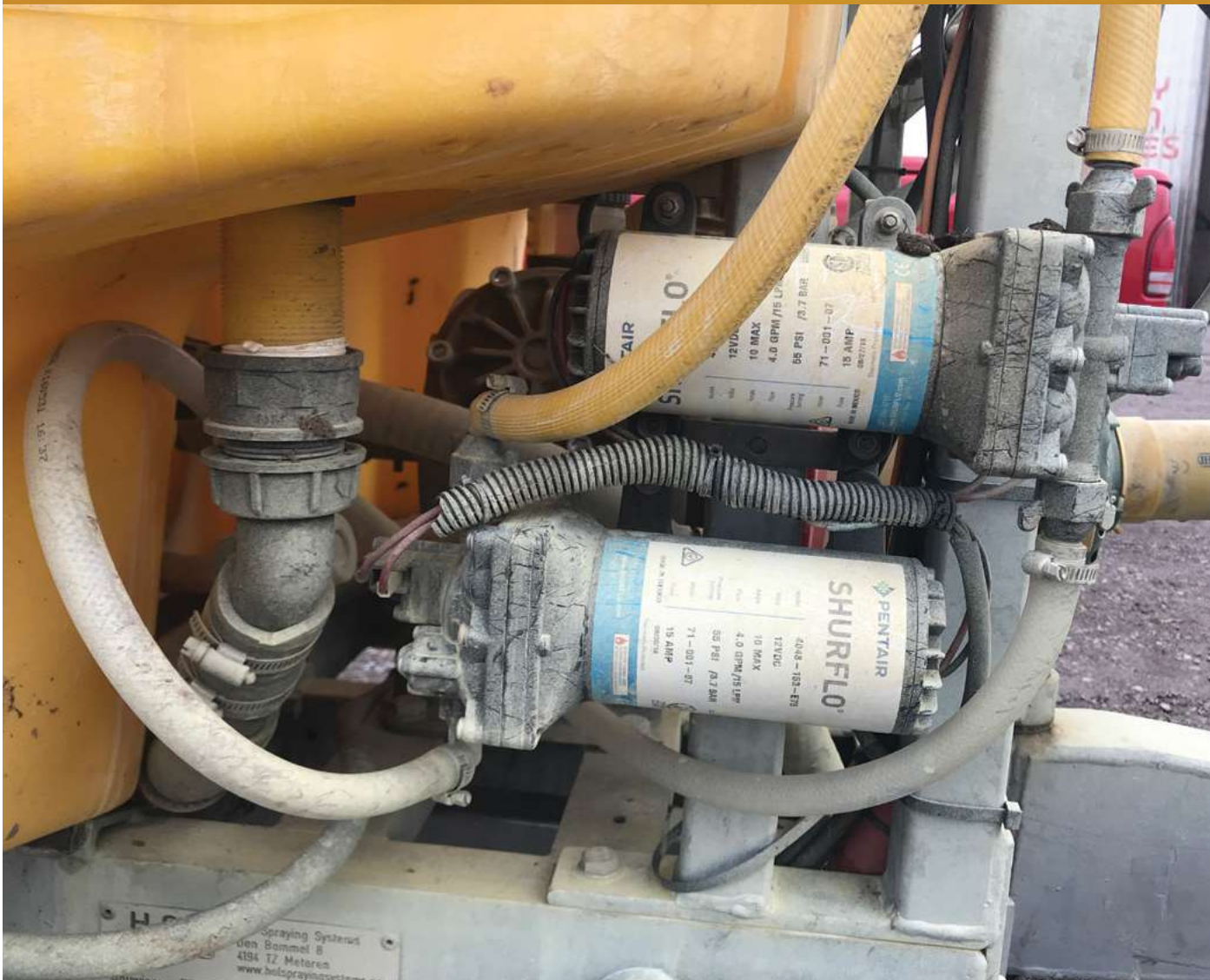
18.7 | Review and consider

- Have you ever performed a jar test?
- Do you have access to the most recent product labels? Do you know how to search your regional or national label database for loading and handling warnings?
- How long do you wait after adding dry products? It may feel like forever, but it's worth it.
- What is the temperature of your carrier?
- Which products are problem products for you? Would changing the mixing order, adding adjuvants, or pre-mixing help with these?
- Who might you ask for loading and mixing guidance?



Spraying in wet conditions is challenging. Avoid spraying unless you absolutely must and consider reducing the tire pressure and only half-filling the tank. We found these ruts in a sour cherry orchard and once dry they were there all season long.

An experimental continuous rinse system was installed on a tower sprayer. Two pumps drawing 9 amps supply clean water to the tank via through two modified rinse nozzles. The operator simultaneously sprays the rinsate in the planting at an equivalent flow rate. The sprayer is rinsed to a degree comparable to three serial rinses, but in a fraction of the time, with no operator exposure, and the dilute rinsate is distributed in the field.



Chapter 19

Sprayer sanitization

Next to sprayer math, cleaning the sprayer may be the most unpopular aspect of spraying. It's time-consuming, you never really know when you're finished, and sprayer manufacturers and pesticide labels offer only limited guidance.



LAMINAR FLO SAYS...

Clean sprayer rinsate looks and smells exactly like contaminated sprayer rinsate. Don't leave product in the lines and rinse as soon as possible after spraying.

When sprayers are not cleaned as often or as thoroughly as they should be, it creates problems:

- Unnecessary operator and environmental exposure.
- Residue in (or on) the equipment can damage sprayer components.
- Residue can cause physical or chemical incompatibility issues with future spray mixes.
- Carry-over can deposit damaging or unlabelled residues on crops.

It helps to think of sprayer sanitation as two processes. Rinsing is a precursor to cleaning, and depending on your situation, you may not have to go all the way.

- **Rinsing:** The dilution of any remaining spray solution and exterior residue.
- **Cleaning:** Rinsing with additional steps to decontaminate sprayer components.

19.1 | Rinsing

Nowadays, all air-assist sprayers should include an onboard tank-rinse system consisting of a clean water tank and tank-rinse nozzles inside the solution tank. They may even include a pressure wand to rinse the exterior. Sadly, most sprayers do not have these features. But, aftermarket rinse kits are available.



LEFT: Product-pump-powered water tank. **RIGHT:** External-pump-powered water tanks. Images from Paolo Balsari's (DiSAFA) "Sprayer Cleaning: Importance and Phases" at AAB Sprayer Cleaning Workshop, Oberbozen, Italy. October 2019.

We'll walk through a generic rinsing process step by step. If your operation (or the pesticide label, or the sprayer manufacturer) requires additional or different steps, be sure to follow them.

1.

Rinse as soon as possible

2.

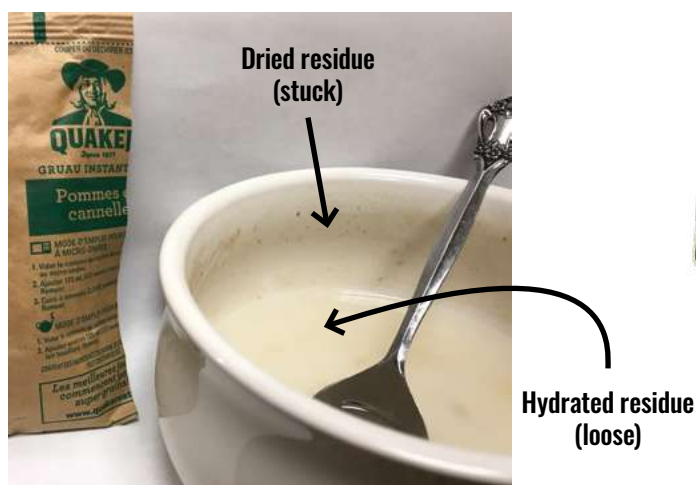
Minimize the remainder

3.

Dilute the remnant
(the triple rinse)

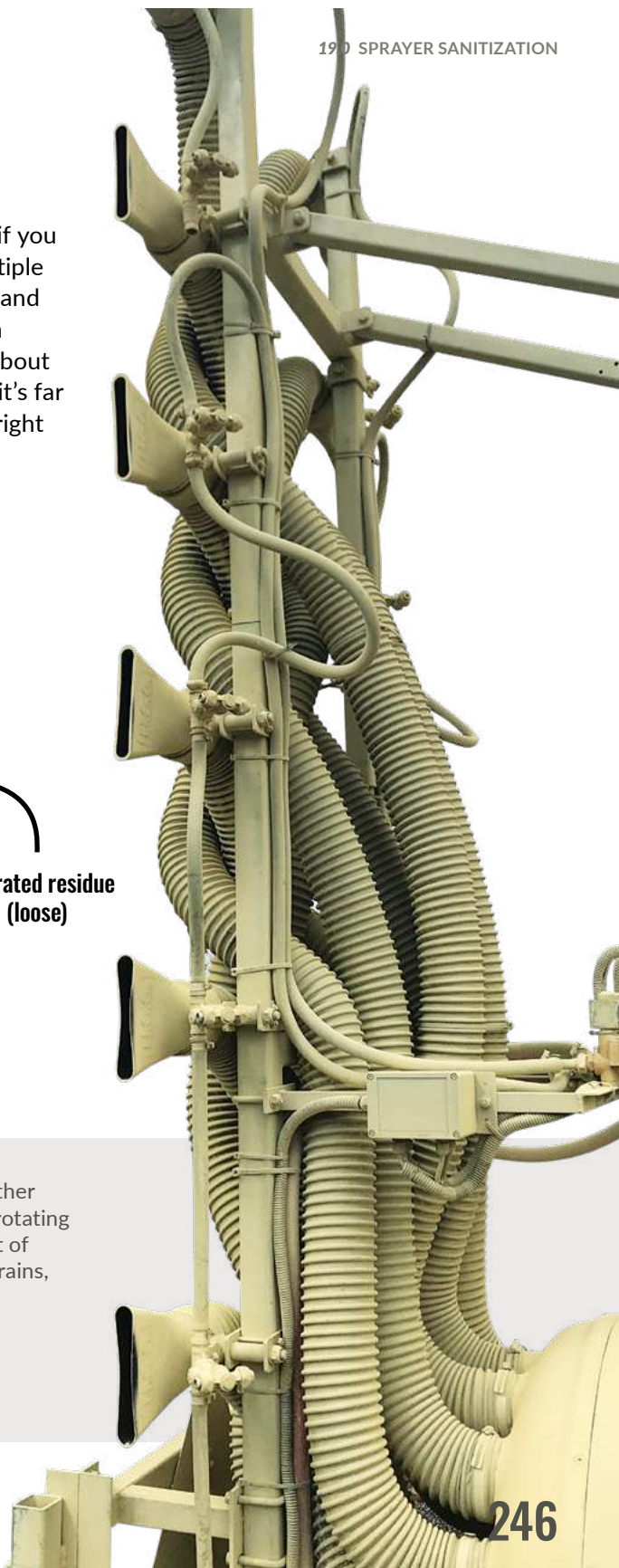
19.1.1. RINSE ASAP

Don't let residue sit in (or on) the sprayer, even if you plan to use the same product the next day. Multiple studies have shown that products adsorb onto, and absorb into, plastic and rubber parts. They form hard-to-clean residues when left to dry. Think about chipping dried oatmeal or egg yolk off dishes – it's far easier if you clean them before they dry. Rinse right away, while the sprayer is still wet.



Never let residue sit and dry in or on a sprayer. As long as it is hydrated, it is much easier to dislodge and rinse away. It's the same as soaking dirty dishes.

Sprayer towers accumulate residue more than any other part of the sprayer. It is best to power wash them in rotating locations in the crop. Sadly, we have all seen the part of the farm where the gravel is always yellow. When it rains, residue may find its way into waterways.



19.1.2. MINIMIZE THE REMAINDER

Minimizing any remaining volume makes rinsing far more effective. Experience, sprayer math, and load cell transducer-based volume monitoring systems (e.g. Simon Innovations' Accu-Volume or the ARAG VISIO) help minimize the left-over remnant. Even an "empty" sprayer can still retain several litres of standing volume in the sump and lines. This Residual Volume is the volume of spray liquid that remains in the sprayer's liquid handling system when the pump begins to cavitate. Operators should know this volume. Never "Drive-and-Drain" to empty a remainder or residual volume onto the ground.



Standing volume from the booms allowed to drain to a holding tank via the bottom nozzles.

19.1.3. DILUTE THE REMNANT: THE TRIPLE RINSE

Rinsing the system multiple times with low volumes (a.k.a. the Triple Rinse) is more effective at reducing pesticide concentration than a single, high-volume rinse. Once the sprayer is "empty", use clean water to fill the solution tank to 10% of its capacity (or add 10 parts water to one part residual volume) for the first rinse. Agitate and circulate it through the entire sprayer for a few minutes. Spray out the rinsate and repeat the process two more times.

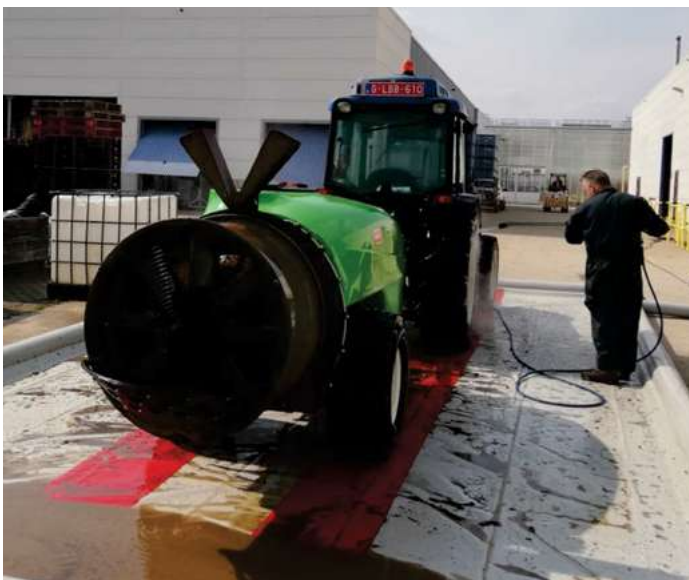
The use of such low volumes may not be possible with centrifugal systems where the solution tank must be filled above the top of the pump for priming. Know your sprayer design.

19.1.4. DEALING WITH RINSATE

As regulatory agencies concerned with environmental contamination re-evaluate chemistries critical to horticulture, it becomes even more important for sprayer operators to manage rinsate responsibly.

Precautions must be taken to ensure rinsing is performed away from wells or open water. It is best to perform the triple rinse in the crop that was just sprayed. The dilute rinsate can 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 and regional restrictions permitting), or use a hedgerow or target row that has been set aside for this purpose.

In Europe, horizontal boom sprayers increasingly use continuous rinsing systems to make this process fast and simple. When the sprayer reaches its residual volume, the operator engages a dedicated pump to transfer clean water to the solution tank through tank-rinse nozzles. Simultaneously, the sprayer continues to drive and spray with bypass circuits engaged. This quickly dilutes and displaces any residual product and sprays the rinsate into the crop.



Cleaning an airblast sprayer on an inflatable pad. Images from Victoria Nelissen's (pcfruit, Belgium) "On-farm systems to avoid point pollution" at AAB Sprayer Cleaning Workshop, Oberbozen, Italy. October 2019. These systems are still uncommon in North America.

Continuous rinsing is as effective as a series of three low-volume rinses, takes a fraction of the time, there is no operator exposure and the residue is eliminated responsibly. The key is to balance the flows so the main pump is marginally starved and sucks a few bubbles (which act to physically scrub the lines). There are after-market continuous rinsing kits available, but operators can DIY with the following tools:

- Two electric pumps plumbed in parallel will draw negligible amperage and produce sufficient flow from an aftermarket clean-water saddle tank.
- A pressure-based rate controller can be set to a pre-determined flow rate to ensure the sprayer output slightly exceeds the introduction of clean water.
- While we have successfully modified existing tank rinse nozzles, Lechler recently introduced its ContiCleaner tank cleaning nozzle line developed specifically for continuous rinse. Operators can choose from a range of four nozzles that operate at lower pressures (2-5 bar or 29-73 psi) and reduced flow (4.1-32.3 L/min. or 1.1-8.5 gpm).

While it is best to rinse the sprayer exterior in the planting as well, most return to the farm. Too often, the entire rinsing procedure takes place on-farm, on crushed gravel. This creates point-source contamination: a leading source of off-target pesticide movement. Washings should be secured (e.g. on an inflatable or permanent loading/mixing pad).

Operators are encouraged to collect contaminated rinsate for safe disposal. Best practice is to reduce residue as much as possible in the planting. A power washer, clean water tank with tank-rinse nozzles, or a continuous rinse system make this possible. Then, the operator can return to add the remainder to one of five rinsate-remediation options:

- **Bioremediation** – Employs a bio-active matrix (e.g. Biobed).
- **Evaporation/Dehydration** – Residue following evaporation is collected and disposed of (e.g. Heliosec).
- **Physico-chemical** – A combination of filtration and active carbon.
- **Photocatalytic** – Photo degradation (e.g. Phytocat).
- **Holding tank** – Must be pumped out periodically for safe disposal.

19.2. | Cleaning

A complete cleaning (sometimes called a decontamination) is required prior to long-term storage, or when residues from previous applications are known to cause physical or chemical antagonism with scheduled applications. Perform the following steps after a continuous or triple rinse:

1. Remove the suction and in-line screens. Remove nozzle strainers and nozzle tips. These will be inspected and cleaned shortly.
2. Fill the solution tank about half full of water and add an appropriate tank cleaning adjuvant. For example, 1 L of household ammonia (3% concentration) / 100 L (25 gal.) water will raise the pH and helps remove those products whose solubility benefits from this. A detergent or surfactant will remove the oily layer formed by EC formulations. Commercial cleaners conveniently combine these properties in one jug. Be aware that adding a surfactant or a commercial cleaner can generate a lot of foam, so have a defoamer handy.

Ammonia cleaner products do not neutralize pesticides; they raise the pH, improving the solubility of some products. 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.
3. Collect a bucket-full of cleaner solution from the tank. Using a brush, clean the suction and in-line screens, and the nozzle strainers and tips.
4. Meanwhile, agitate and circulate the cleaner solution 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.

5. 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.
6. Clean the exterior of the sprayer. High pressure washers and scrubbing with a push broom works well. Studies in Europe have shown the vast majority of residue is found on the sprayer head (i.e. fan outlet and boom area).
7. Rinse it all off. Replace all parts unless preparing for long-term storage ([see Chapter 20](#)).



LAMINAR FLO SAYS...

While not all created equal, there are sprayer coatings available to make exterior rinsing easier.

19.3. | Exterior treatments

Historically, some operators coated their sprayers with diesel or used engine oil as a preservative. It was intended for winter storage or to make it easier to clean the sprayer following the next application. Obviously this is an environmentally unacceptable practice, but the principle has merit.

If you are considering an exterior treatment, be sure to use the right product. For example, don't wax your sprayer with car wax. Many pesticide formulations are designed to stick to waxy leaves. So rather than repel residue, your sprayer will accumulate it.

There are commercially-available products designed for both for storage and in-season use. For example, anti-corrosion surface-treatment oils that are formulated to creep and not oxidize (unlike used motor oil) will get into nooks and crannies while coating the surface. They have an added advantage of preventing fastener threads from seizing, making servicing easier over the long term.


They can be purchased in bulk and should be applied to sprayer after it's thoroughly cleaned. A thin film works in most cases. A sprayer covered with these oily formulations does tend to pick up a lot of dirt and trash, but they power wash easily afterwards and reapplication may not be needed every time.

19.4. | Review and consider

- Where do you typically rinse and clean your sprayer?
How difficult would it be to spray rinsate in the planting?
- Where could you fit a rinse tank refit on your existing sprayer?
What could you do to make in-field rinsing practical? Is continuous rinse an option?
- How much spray mix do you have left at the end of a job? What do you do with it?
- Would it make sense to consider a nurse truck to bring clean water to the sprayer?
What about permanent holding tanks at strategic locations?
- Are there any local government programs that might assist you in creating a contained sprayer cleaning area?



Originally designed for standard orchards, this 50-year-old LPR sprayer was being used in highbush blueberry. Switching to a new, efficient and appropriately-sized sprayer saved the operator 20% of their annual spray volume.



Still the best way to repack grease in wheel bearings.

Chapter 20

Start-up and storage

Any description of sprayer start-up must, contextually, make assumptions on how it was winterized for long-term storage. The inability to describe one process without the other is further complicated by the possibility that the sprayer might be brand new and therefore never winterized. So, what follows is an attempt at a logical sequence of pre-season maintenance activities to initiate a new sprayer, restore a winterized sprayer, and to winterize a sprayer for long-term storage.

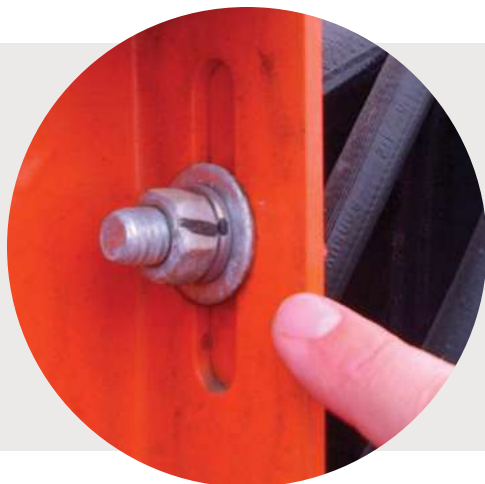
Many operators are guilty of neglecting their air-assist sprayers and babying their tractors. Sprayers are precision tools that must be kept in good operating order to prevent costly breakdowns, improve their performance, and increase their lifespan. Your car is serviced based on distance travelled. Your sprayer should receive regular maintenance based on working hours, per the manufacturer's recommendations. Daily sprayer inspections (see Chapter 16.4.) are part of regular maintenance since the operator will (hopefully) find small problems before they become big problems.

If any of the following steps conflict with those of the manufacturer's, always follow the manufacturer's. Do this for reasons of safety and to preserve any warranty.

20.1. | New sprayer start-up

If this is a new sprayer, you have an opportunity to upgrade base systems (e.g. install a rate controller) and perform some preventative maintenance while the sprayer is still clean. This is also an opportunity for you to get to know your new sprayer and its design quirks.

- Loosen, lubricate and re-tighten clamps. Always back gears off before tightening to avoid stretching them. Use double clamps on pressurized lines for added safety. Wider clamps are better and T-bolt clamps are better than worm-gear.
- Put thread release on bolts and re-tighten with a torque wrench (not an impact tool). Use a paint pen to mark the nut, washer and bolt for future visual checks.
- Protect hoses and wires at rub points. Follow hoses and with a paint pen, number the hose-ends and connections for future reference. Old garden hose or innertubes wrapped around lines make great protective shields.
- Using a new tractor? You may have to re-calibrate to account for different gear ratios. Don't exceed maximum working angles for PTO shafts (usually <25°).
- Find your grease points. Know which grease is required and follow the recommended schedule for lubrication. Grease is cheaper than metal.
- Familiarize yourself with the pump. Download the pump manual if one did not come with the sprayer. Find your pump seal(s) and be sure to have spares on hand.



When all nuts are correctly tightened, use a paint pen to draw a line across the bolt, nut, washers and chassis. Now you can do a visual check to ensure nothing is coming loose.

20.2. | Winterized sprayer start-up

When planning spring start-up, never assume the winterized sprayer is ready for immediate hook-up. Parts seize, scale breaks away from surfaces, and small beasts sometimes choose to eat, or make their homes in, cozy sprayers. Expect a minimum half day per sprayer. We touch on the key points in this chapter, but refer to your ag mechanic or sprayer manufacturer/dealer for a more fulsome list of maintenance activities.

Attempting to loosen or shift something that hasn't moved in several months is risky. Pressure gauges snap off, fittings crack, welds break. Expect the unexpected and either have spare parts on hand, or a plan to get them quickly. Parts are most likely to seize during the first spray (especially bearings and PTO universal joints).

- Start-up is a good time to lubricate parts. Repack wheel bearings, grease the PTO universal joint cross. Separate, clean and lubricate the PTO shaft. This is also a good time to check any shear bolts.
- Insects, birds and rodents eat, or make homes in, sprayers. Professional rodent bait/traps, steel wool and peppermint oil/gel are possible solutions.
- Check belt tension, alignment and wear.
- Pump specific maintenance is beyond the scope of this book. Most gearboxes will have a short break-in period, after which the oil should be changed. Pump diaphragms typically should be replaced every 1,000 h. Use a paint pen to write on the pump what type of oil it requires, and then date the filters, seals, and diaphragms.



Use a paint pen to write on the pump what type of oil it requires, and then date the filters. You can even note when it was winterized.

- At minimum, check the tire pressure. Hard tires can increase compaction and soft tires disperse weight better but may wear faster. It's a trade-off. Ensure tire pressure matches the ideal stamped on the tire or at least ensure both tires have the same pressure. Sprayer wheel assemblies should be cleaned and inspected as part of regular annual maintenance. Consider installing "bearing buddies" and the optional dust cover if you can find sizes that fit your axle. They will keep water and/or chemicals from being sucked into the bearings during thermal cycles.
- If your LPR sprayer has a relief valve, it should always be in the bypass position during start-up. If your gauge spikes even once then the gauge may always read high afterwards and should be replaced. You'll know this happened because the gauge will not return to zero – it's ruined.
- Replacing leaking, opaque or inaccurate gauges improves sprayer performance. Be sure to use the liquid-filled variety of gauge to eliminate a bouncing needle. You can also get suppressors that fit between the gauge and sprayer to prevent pulsing and protect the gauge from the chemicals. Use a wrench to turn gauges at the nut; Don't twist them by hand holding the face.
- 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 half a turn, but if that doesn't work you may have to remove and repack (or replace) it.

- Minerals chelate (i.e. scale) more readily on stainless steel than plastic tanks. In either case, the first tank of water and leftover antifreeze should be sprayed from the nozzle bodies with no line or nozzle strainers, and no nozzles. Replace them once the tank is sprayed out.
- Examine the sprayer for leaks while under pressure and replace worn or damaged hoses. Be careful when pressurizing the sprayer for the first time in the spring; this is when lines are likely to come loose or burst. Check and tighten clamps as needed.
- The last step to start up is calibrating the sprayer (see Chapter 16).



Repacking the gland on this mechanical agitator shaft stopped this persistent leak. Something of a dying art, there are lots of online tutorials that explain how.

20.3. | Winterizing a sprayer

If you are preparing the sprayer for long-term storage, follow the normal rinsing process (see Chapter 19.1.), but don't reinstall strainers and nozzles. Instead:

- Look in the nozzle bodies for debris. Discard worn or broken nozzles. Soak, scrub, rinse and store nozzles and nozzle strainers. You may replace them once the sprayer is clean, but we prefer to store them separately since they have to come back off during start-up.
- With the agitation on, circulate undiluted plumbing antifreeze (the sprayer already has 5-10 L (2-3 gal.) of water in the system from the decontamination process) for five minutes and drain it through the plumbing system (not the booms).
- Disconnect hoses where they attach to the booms and drain as much liquid from the sprayer as possible.
- Clean the sprayer (triple rinse and use a detergent in the second rinse, per Chapter 19.2.) and scrub the exterior. Do not use pressure washers on bearings, fittings, pumps or any lubricated or moving parts.




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

- Examine fan blades for cracks, build-up or nicks that can cause imbalance. Replace (not just repair) punctured intake grills.
- Don't ignore tank damage. Poly tanks are prone to sun damage and cracks. Never climb into a tank to repair it. Quite often, replacement is the best option.
- Clean and inspect wheel assemblies. It's best to do this during winterization to prevent bearing corrosion as the sprayer sits all winter.
- Remove any rust and repaint (or just touch up). Paint not only looks good, it protects.
- If in cold climates, add RV antifreeze, which is a 50% solution of antifreeze and water with a rust inhibitor. It should not cause phytotoxicity if sprayed or dumped but be sure to dispose of it away from water sources during start-up. Consider removing the pressure gauge and storing it in a warm place when winterizing the sprayer. It's dead-headed so it does not get flushed with antifreeze. Turn the pump manually to get antifreeze throughout the system. Close the nozzle bodies, loosely fit the tank lid and store indoors.

20.4. | Review and consider

- Where are the filters located on your sprayer?
- Can your sprayer be completely drained? Could you add valves to the pump or some other low point in the plumbing to help make this easier?
- When was the last time you checked or changed gearbox oil in the fans and pumps? Do you mark the date for reference?
- Is now the time to address that leak? Replace the broken grill? Strip and paint the rusting chassis?
- Do you have a spare pump seal/diaphragms, wheel bearing, PTO shaft cross, and other common service items on the shelf or available close by? Do you know what the part numbers are for these things and where you could get them?

An aerial photograph of an experimental farm. The landscape is divided into numerous rectangular plots of varying colors, including vibrant green, dark brown, and reddish-brown. These plots are separated by narrow, winding paths and lines of trees, which serve as windbreaks. In the upper left corner, a small cluster of farm buildings, including a white house and several red-roofed structures, is visible. The overall scene illustrates a diverse agricultural experiment, likely testing different crop varieties or land management techniques under varying conditions.

Experimental farm for testing windbreaks.
PHOTO CREDIT: ANDRÉ VÉZINA

Chapter 21

Stewardship

Pesticide use and misuse is a public concern and has often been a central political theme of agricultural sustainability. A grower's right to farm is contingent on public trust. This implies a social contract wherein the sprayer operator promises to make every reasonable effort to reduce environmental impact. It's almost an environmental Hippocratic Oath. Growers take this responsibility seriously.

Note that we wrote "reasonable effort". Growers must often make difficult decisions that require them to choose the lesser of two evils. We are not referring to considerations of convenience (e.g. extra money, time or effort) but actions that represent the difference between having a crop or not.

Inclement weather often necessitates these decisions. This can be exacerbated when label language includes contradicting restrictions or unrealistic limitations that force growers into a position of non-compliance. So what can a grower do when trapped between a rock and a hard place?

True stewardship is planning for bad spray situations years in advance. It may not be enough to spray inward from the outside row, or switch to a few AI nozzles. A robust spraying strategy may require an entirely different sprayer design, maintaining excess spraying capacity, modifying planting architecture, or installing features such as windbreaks and set-backs. It is not a last-minute consideration.

To regulators, neighbours, equipment manufacturers and anyone that interfaces with agriculture: stewardship is a partnership. You play a role as well. Many of the things a grower needs to succeed are out of their direct control, such as appropriate regulations, well-designed equipment, actionable information and the economic support to help them succeed as both a business person and a steward. This may seem like a departure from the rest of this book, but these conditions set the context for every recommendation we've made so far.

We'll climb down from our soapbox now - it's not all dire news. This is the last chapter in the book for good reason. Growers that adopt the best practices we have described will greatly reduce the potential for environmental contamination. It is entirely possible to be an environmental steward and improve spray efficacy and efficiency at the same time ([see table on the following page](#)).

ACTION	PRODUCTIVITY	STEWARDSHIP
Adjust air and nozzle configuration to match spray to canopy height.	<ul style="list-style-type: none"> • All spray is focussed on the canopy, improving coverage and likely permitting a reduction in spray volume. 	<ul style="list-style-type: none"> • Less spray escapes above the operation. • Less spray is directed into the ground below the canopy. • Less spray volume represents a direct reduction in pesticide use.
Assess coverage with water sensitive paper and adjust sprayer configuration accordingly.	<ul style="list-style-type: none"> • Flow is reduced where corresponding canopy receives excessive coverage, or redistributed to areas of reduced coverage. • Improved coverage uniformity better protects the crop. 	<ul style="list-style-type: none"> • Reduced flow represents reduced pesticide use. • Sublethal doses, which encourage resistance, are eliminated. • Run off onto the ground (and into the water table) is reduced. • When applications are successful, clean-up applications are unnecessary, reducing pesticide, water and fuel usage.
Perform sprayer math and regular calibrations.	<ul style="list-style-type: none"> • The sprayer operates correctly and consistently, not running short and left with minimal spray liquid following the application. • The potential for time-consuming breakdowns is reduced. 	<ul style="list-style-type: none"> • Leaks, unnecessary waste due to worn nozzles, and excess leftover spray liquid are minimized.
Follow a schedule of sprayer sanitation.	<ul style="list-style-type: none"> • Equipment functions reliably and lasts longer when product buildup is prevented. • Residues that may cause compatibility issues, or carry over onto other crops, are removed. 	<ul style="list-style-type: none"> • A clean sprayer exterior reduces unnecessary operator exposure. • Cleaning the sprayer in rotating locations reduces point source contamination. • Spraying left-over product back into the crop reduces left over spray liquid.

21.1. | Spray drift

A good steward is one who can identify the environmental factors that may negatively impact an application and increase the potential for off target spray drift. Spray drift is the aerial movement, and unintentional deposit, of pesticide outside the target area. There are a lot of compelling reasons for avoiding it:

- Every droplet that drifts means there is less spray being 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 that deposits on an off-target crop may create problems with maximum residue limits (MRLs) of that crop.
- Certainly not least, 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.



Temporary signs or written/verbal notification may be required when you are spraying. Find out if this applies to you.

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, but for our purposes:

- **Particle Drift:** is the off-target movement of pesticide droplets (or solid particles). This occurs at, or shortly after, the time of application, and while it is generally on a scale of tens-of-metres, temperature inversions can carry it much farther.
- **Vapour Drift:** is the off-target movement of pesticide vapours and it is typically associated with herbicides. This occurs for volatile products only and can occur for hours to days after application. Vapour losses are higher with higher temperatures. If vapour gets caught up in a light breeze, moves downhill during a temperature inversion, or is redistributed in precipitation, movement can be on a scale of kilometres.



LAMINAR FLO SAYS...

If possible, and especially if nozzles point upward, use a coarser spray quality in the top nozzle positions when spraying small or medium sized canopies. Consider moving up to the next-highest nozzle size to account for reduced droplet count.

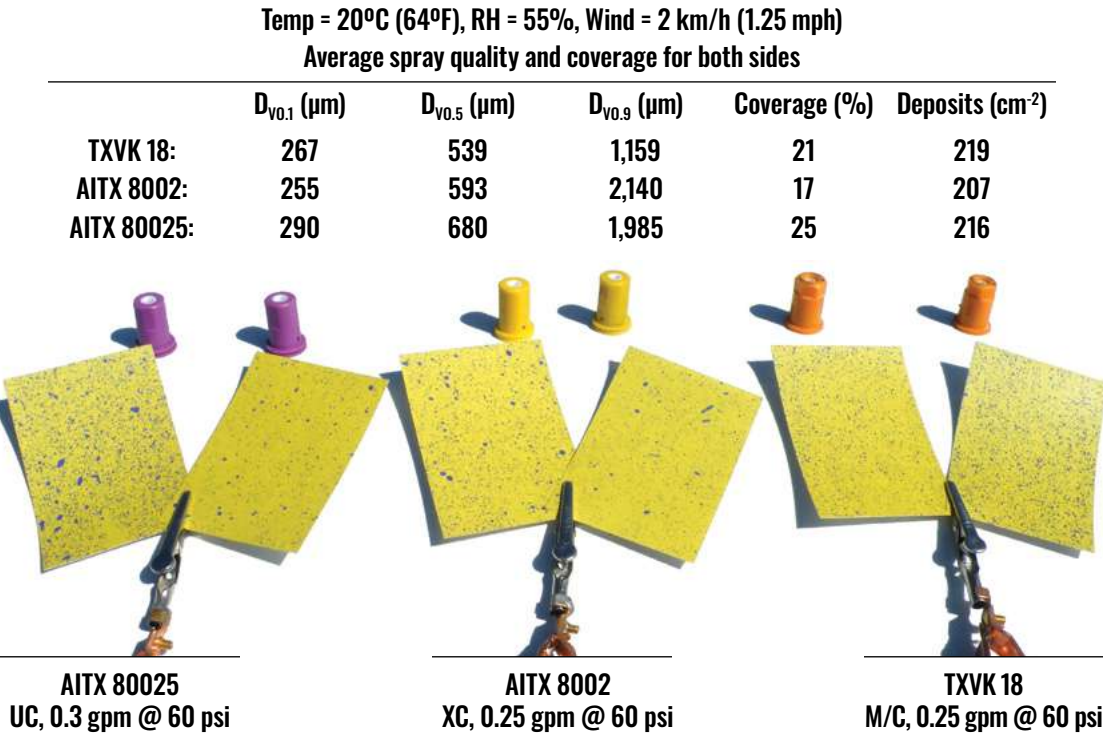
Drift cannot be entirely eliminated, but sprayer operators can greatly reduce the potential for pesticide drift. Much of what follows relates predominantly to particle drift, but it's never wrong to follow these best practices:

- Reduce the droplet travel time by minimizing the distance between spray outlet and the canopy.
- Use the coarsest effective droplet size (see figure on the following page).
- Observe labelled buffer zones (see Chapter 21.3.) and recommended sprayer settings.
- Avoid spraying during periods of high heat and low humidity to increase droplet survivability.
- Spray when wind speeds are light to moderate and moving away from any nearby sensitive crop, landscape or environmental areas.
- Adapt the sprayer configuration to changing environmental conditions, or halt the job until conditions improve.
- Adjust fan settings to produce the minimal effective air speed throughout the season.

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

21.1.1. CONTROLLING DRIFT DOES NOT HAVE TO COMPROMISE COVERAGE

Air induction nozzles positioned in the top nozzle positions of a sprayer will still give acceptable coverage. In the following image we see water sensitive papers that were positioned back-to-back at the top of a 3.4 m (11 ft.) tree. The coverage from conventional hollow cone nozzles (TX VK 18) is comparable to that of air induced hollow cones (AITX 8002 or 80025).



Water sensitive papers were located back-to-back at the top of a 3.4 m tree and sprayed with either air induction hollow cones (AITX 80025 and 8002) or a conventional hollow cone (TXVK). Spray quality was coarser for the air induction tips, and coverage was comparable to the conventional tip.

21.2. | Adjusting to environmental conditions

As we noted at the beginning of this chapter, some seasons are simply uncooperative. The frequency and duration of rain events, for example, can leave limited opportunity for spraying. Even then, the periods between rains are transitions between warm and moist conditions and cold fronts, which makes wind gusty and changeable. These same periods leave wet alleys prone to rutting and compaction, and conditions that favour spraying may also favour pollinator activity.

The decision to spray is not strictly a consideration of economics, productivity and risk tolerance. When environmental restrictions exist on a product label they are not suggestions but legal requirements. Statements might include:

- Do not spray when rain is forecast within 12 hours following application. This is, in part, to prevent water-soluble products from moving in surface or channel run off.
- Do not spray in calm conditions (generally <3 km/h (1.85 mph), as measured at the top or boundary of the planting). This is to prevent airborne spray from moving in unpredictable directions during a thermal inversion, or downhill with stratified air (see figure below).
- Do not spray in gusting or high wind conditions (generally >10 km/h (6.2 mph). Always refer to the most restrictive wind speed requirement, be it the label or regional guidelines. This is to prevent airborne spray from moving with the wind. This is of particular import when there are sensitive downwind areas that can bring buffer zones into play.



To determine wind speed, hold the weather meter above head-height at arm's length and turn to face into the wind. It's best to do this in an open area. Stand 6-8 times the distance of the tallest nearby object. Take the reading on the boundary of the planting but avoid standing in the shadow of windbreaks which can affect the readings.



When measuring temperature, shade the instrument with your body or spray equipment. This is especially critical if you are trying to assess temperature differentials to determine if an inversion is in place.

Technologies exist that extend the spray window, but they require long-term planning and may not be economical. They are generally a combination of planting architecture and sprayer design. Examples include:

- Tented plantings designed to exclude pests and insulate against frost, hail, wind and inversions.
- Shrouded sprayers, or any of the sprayer optimization strategies that fill this book.
- Solid-set emitters (recently commercialized in Europe and still experimental in North America) that reduce drift and can spray large areas quickly.
- Any sprayer design with lateral-downward oriented air angles that rely on the canopy itself to intercept the spray.

Assuming the pesticide label does not prohibit application, there are adjustments that can improve coverage and reduce drift in sub-optimal conditions, but only marginally. These are compromises that sacrifice efficiency and/or efficacy.

- Do not spray the last two or even three downwind rows.
- Convert top hydraulic nozzles to air induction.
- Be certain to turn off any nozzles spraying over the adjacent canopy.
- Adjust throw to only reach the middle of the upwind canopy.
- Turn off the downwind boom and adjust traffic pattern to upwind alternate-row spraying.

Of course the best advice is unpopular: Park the sprayer until conditions improve. Persistent inclement weather is inconvenient, highly frustrating and out of the operator's control, but do not be tempted to risk accusations of pesticide drift on a spray that may ultimately result in poor coverage anyway.

21.2.1. STABLE AIR CONDITIONS AND SPRAYING

The smallest spray droplets fall slowest, staying airborne for longer periods of time. If spraying occurs during calm conditions these particles can accumulate in the air rather than disperse. Our atmosphere behaves like a liquid and in calm conditions it tends to flow laterally. This means it can carry these particles into low-lying areas, or in unpredictable directions over great distances.

Conventional wisdom has historically favoured spraying in the mornings, evenings and at night due to the fact that many fruit-growing regions have strong day winds and dry conditions. Evaporative potential is a combination of temperature, relative humidity, and solar radiation. All are more favourable for spraying in the twilight and at night. For example, streptomycin applications for fire blight are photosensitive and operators are advised to apply in the evenings. That said, in many regions, surface inversions can set up through the evening and into the night that create spray drift conditions.

Let's consider how the weather works on a typical clear, relatively calm day:

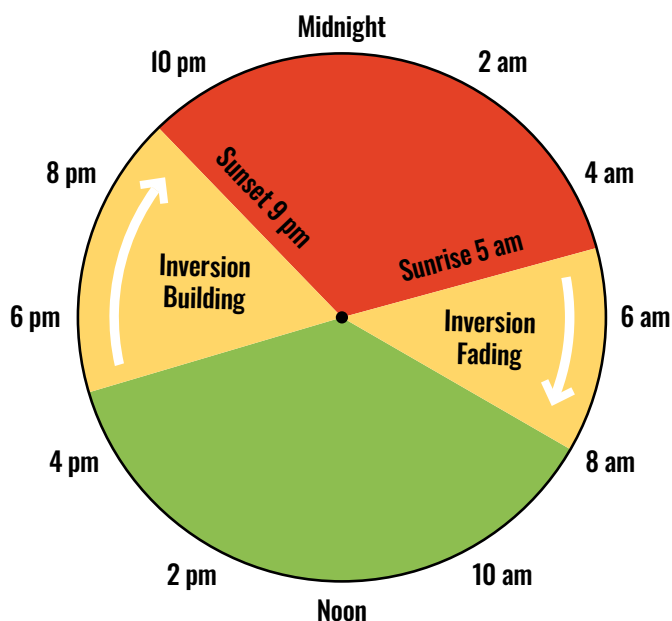
- **Early morning:** The morning sun emits shortwave radiation, which is absorbed by the Earth's surface. The surface conducts some of this energy deeper into the ground and also heats the air near the surface. This creates a temperature gradient wherein the surface is warmest and the air gets relatively cooler with elevation.
As the air near the surface warms, that energy causes air molecules to vibrate and push away from one another. Parcels of air become less dense and rise just like the gloop in a lava lamp. The cooler air around it falls to fill in the space left behind, and air begins to circulate in a Convection Cell. The rising parcel of air will eventually cool and shrink as it rises through the relatively cooler air above it. Even though we can't see them, these cells produce light and variable winds that shift wildly back and forth.
- **Mid to 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. Mechanical turbulence mixes warmer air near the ground with cooler air above. As long as it isn't too windy, this unstable air is the most desirable condition to spray in. Driftable fines that miss the canopy tend to rise and disperse.
- **Mid-afternoon to night:** As the energy from the sun lessens, the turbulence and instability begin to collapse. There are several ways inversions form, and they can be difficult to predict, but they all result in the same thing: a boundary layer that prevents upward movement of air. Below the inversion layer, turbulence is suppressed so we have a stable air mass. This air, if it moves, flows laterally and can "drain" into low-lying areas.

Inversions, once formed, persist until the sun rises and warms the Earth's surface (see figure below), or until winds increase and mix the stationary layers of air together, re-establishing a more neutral temperature profile.

Sunset is not a good indicator of the beginning of an inversion – it can start a few hours before. Therefore, evening spraying may be just as risky as night spraying. Very early mornings (e.g. around sunrise) are not much better. Remember, at sunrise, the inversion will be at its maximum height.

There are tools available for growers to monitor air conditions. Local weather networks, on-farm weather stations, and new portable inversion testers can offer insight. Your senses can also detect signs of an inversion: Ground fog, smoke or dust hanging over the field/gravel road, heavy dew, frost, sounds carrying long distances, and intense odors are all indications of inversion conditions.

During the growing season in many regions, inversions occur on the majority of days. 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 of pollinating insects, but when there's a strong inversion, consider morning spraying over evening/night.



21.3. | Buffer zones

Buffer zones are no-spray areas that extend from the downwind edge of the treated area to the closest edge of a sensitive aquatic or terrestrial habitat (see figure below). The product label, or regional requirements, will indicate the size of the spray buffer zone.

21.3.1. WINDBREAKS

A windbreak, or shelterbelt, is a barrier of one or more rows of trees or shrubs planted around the edges of farms. The nature of the windbreak should reflect the job for which it is intended. For example, a windbreak to stop snow drift is not the same as one that effectively filters pesticide drift. Windbreaks offer many advantages both economic and aesthetic but are only as effective as the planning that goes into them.

Advantages:

- Reduce odours by absorption and dilution.
- Reduce spray drift by intercepting spray and deflecting wind.
- Reduce noise by baffling sound.
- Control snow drift (on the down-wind side).
- Reduce dust, which also prevents sand-blasting crops.
- Create privacy.
- Increase crop yield for certain crops at a given distance from the break.
- Enhance biodiversity.
- Create the possibility of secondary production (e.g. timber, biomass, fruit).
- Enhance aesthetics.
- ...and, of course, manage damaging wind.

Possible disadvantages:

- Reduce the plantable area in an operation by encroachment or shading.
- Create a habitat for pests (e.g. birds, insects, deer, etc.).
- Increase the labelled buffer zone by creating a natural habitat.
- Create cooler temperatures, further reducing plantable area.
- Create conditions that might favour disease incubation.
- Create a lot of additional work through windbreak management.
- Create roots that compete with adjacent crops or destroy drainage tile.

Planning and preparing:

- Ground preparation is essential to creating a strong and healthy windbreak, just as it is in any perennial planting.
- 50% optical porosity is the goal. This isn't hard and fast, but thicker windbreaks tend to act like a wall and thinner windbreaks let too much spray through.
- Windbreak maintenance includes pruning, weed control, irrigation, fertilization and many other activities to ensure the windbreak forms as desired.
- Choice of plant is very important. Trees can grow quickly and require lots of maintenance (e.g. poplar) or slowly and mostly take care of themselves (e.g. cedar). Some plants are more tolerant of drought than others. Some fill in completely, while others are sparse. Some grow tall, some don't. Some have roots that grow laterally, some grow down.
- Plant spacing is very important. Wide spacing means the windbreak is less effective early on but requires less maintenance (e.g. removing every second tree) as it grows and fills.
- Plan for annual management – windbreaks can become infested with invasive plants (e.g. buckthorn shrubs and wild grapevines) which can damage the health of a windbreak if they are not controlled.

For more information on establishing windbreaks, contact your local university extension or conservation authority.

21.3.2. VEGETATIVE FILTER STRIPS

A vegetative filter strip is a permanently vegetated strip of land between an agricultural field and downslope surface waters. Typically >10 m wide from the edge of the planted area to the edge of the water body. It can be composed of grasses, but may also contain other vegetation (shrubs, trees, etc.).

Vegetative filter strips reduce the amount of pesticide entering surface waters from run off by slowing run off water and filtering out pesticides carried with the run off. Certain pesticide labels will require a vegetative filter strip; and, other labels will recommend a vegetative filter strip as a best management practice.

This apple orchard is less than 2 m from a cornfield. Depending on the wind direction, there's a lot of potential for drift issues here. A larger buffer would be prudent.



21.4. | Spray records

Detailed spray records aid in auditing and recordkeeping. They are an important part of a successful spraying strategy. This is your record of what you mixed, how you mixed it and where you applied it. It's important for traceability (e.g. Good Agricultural Practices) and for tracking successes and failures for next year. This is also where weather conditions are recorded. In-field readings from handheld weather meters or in-field weather stations will ensure you can defend your actions if you are accused of off-target drift.

There are several examples of spray record software that manage your pesticide inventory and support as-applied mapping, but at minimum, a spray record should include the following information:

1. Name and/or ID number of the applicator.
2. Location of the application, or name/number of the block. Include the area treated.
3. Any special information regarding sprayer/tractor configuration.
4. Product(s) applied including their product registration number, and the reason for the application. Include product rate and carrier volume used.
5. Weather conditions at the start and end of each spray job, and/or when you suspect conditions have changed. Note the location and time when recording wind speed, direction, temperature and relative humidity.
6. Note any potentially sensitive features along the downwind boundary of the treated area (e.g. natural habitats, area of human activity, residential or commercial buildings, other agricultural operations, etc.).

21.5. | Watchdog registries

Drift happens on both sides of the fence - agricultural operations can drift onto one another. This is why we strongly recommend that every grower explore registering their crops on a watchdog registry site. The example we will use here is DriftWatch in the United States. www.DriftWatch.org.

This not-for-profit map-based website allows users to freely register their crops as well as the presence of pollinators, organic registrations and other drift sensitive operations. This is a valuable resource that sprayer operators can consult when making decisions about when and how to spray. We hope to see more of these registries proliferate globally.

21.6. | Review and consider

- Does your spraying strategy include a risk-management section for when conditions are not optimal?
- Do you have long term plans for establishing windbreaks or vegetative buffer strips?
- Do you have enough capacity to spray your crops within weather periods that are compliant to your product?
- Have you considered installing in-planting weather stations?
Alternatively, have you considered subscribing to an agricultural weather network to access weather modeling or spray advisory information?



Epilogue



While writing a lifetime's experience in a book was something I always casually thought I would do some day, Jason convinced me that now was the time to join him in this rewrite. I agreed on the condition that we start from scratch with a global perspective.

We started in earnest on November 7, 2019 at Jason's kitchen table, thinking we would talk one weekend a month for a year or so. We had no idea the undertaking it would turn out to be. The pandemic made 2020 a challenging year, but it afforded us the time we needed to make this book all it needed to be. And oh, what it has become! It challenged us to put into words things we knew but had never verbalized. It became something that neither of us could have written on our own. We didn't hold anything back (well, maybe one or two things... come to our lectures). Every minute of the thousand hours writing, arguing and laughing over Skype from our kitchen tables have been a blessing and a privilege. If we never do anything better than this, we're ok with that.

Mark Ledebuhr



This book was written during a challenging time. Those of us in agricultural extension and consultation scrambled to find new ways to support the industry. This book represents our effort to create something positive and lasting from that situation. While physically isolated in three different countries, balancing our professional, social and domestic lives, we researched, debated and developed content for more than a year. We're pleased with the result, which would not have been possible without information freely shared by colleagues, growers and industry. On behalf of all of us, we hope you find value in what we've written.

Happy spraying,
Jason Deveau



Appendices

Appendix 1 | Sizing a pump

Pump capacity must satisfy the highest possible demand (e.g. a high-volume application), plus overcome back pressure and run any hydraulic agitation (see Chapter 5.3.) The following formulae will help you size a pump in Metric or US units. Performing these calculations ahead of time will help you have a constructive conversation with your pump retailer.

A.1.1. CALCULATING AGITATION REQUIREMENTS

All air-assist sprayers use dry products which require the greatest level of agitation. While we include the calculations for liquids we recommend using the calculations for wettable powders and flowables which have the highest demand.

Option 1 – Liquids:

$$\text{Tank volume (L)} \times 0.05 = \text{Agitation requirement (L/min.)}$$

$$\text{Tank volume (US gal.)} \times 0.05 = \text{Agitation requirement (gpm)}$$

Option 2 – Wettable powders and flowables:

$$\text{Tank volume (L)} \times 0.125 = \text{Agitation requirement (L/min.)}$$

$$\text{Tank volume (US gal.)} \times 0.125 = \text{Agitation requirement (gpm)}$$

Hydraulic agitation:

If the hydraulic agitation uses jets, it multiplies the agitation output without the need for additional flow. For example, a 5 L/min. flow input could be boosted to a 15 L/min. output. We account for this savings below.

$$\text{Agitation requirement (L/min.)} \times \frac{\text{Input}}{\text{Output}} = \text{Total agitation (L/min.)}$$

$$\text{Agitation requirement (gpm)} \times \frac{\text{Input}}{\text{Output}} = \text{Total agitation (gpm)}$$

A.1.2. CALCULATING NOZZLE REQUIREMENT

Once the agitation requirements are accounted for, we account for nozzles. The calculations are a little different for each sprayer, but they amount to the same thing: Total flow in Litres or US Gallons per minute.

$$\text{Total nozzle flow (L/min.)} = \frac{\text{Output (L/ha)} \times \text{Travel speed (km/h)} \times \text{swath width (m)}}{600}$$

$$\text{Total nozzle flow (gpm)} = \frac{\text{Output (gpa)} \times \text{Travel speed (mph)} \times \text{swath width (ft.)}}{495}$$

A.1.3. CALCULATING TOTAL FLOW REQUIREMENT

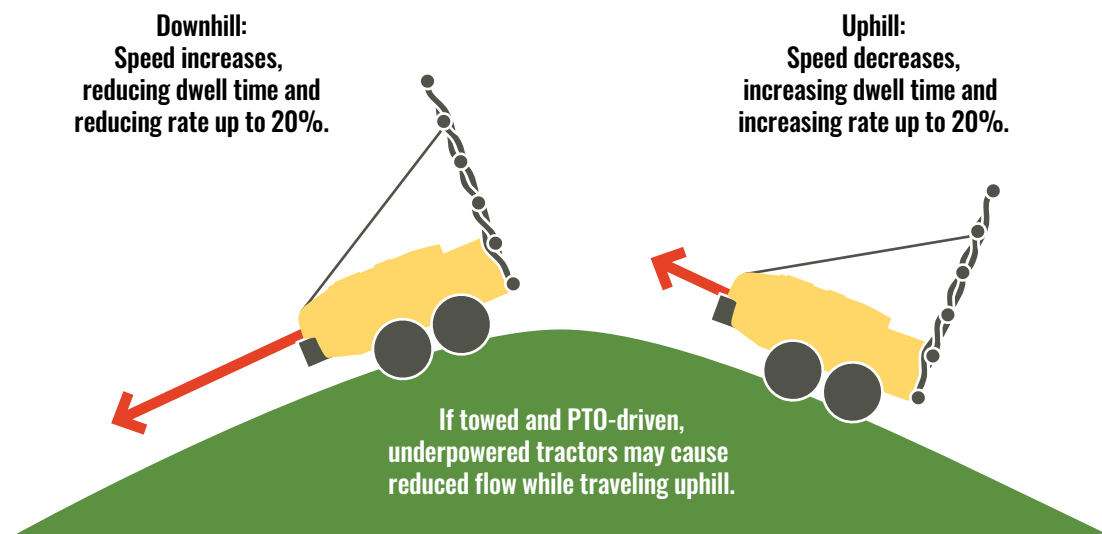
When both flow requirements have been calculated, they are added together. It is important not to under-size the pump. We factor in an extra 20% to account for changes in performance (such as pump wear and slower travel speeds) and pressure drop ([see Chapter 5.5.1.](#)).

$$(\text{Total agitation requirement} + \text{Total nozzle flow}) \times 1.2 = \text{Total flow requirement}$$

Finally, be sure to account for any other flow requirements, such as tank rinsing nozzles. It can also be helpful to note hose length/diameter (which causes pressure drops), and know where the pump will be located relative to the tractor and sprayer. Preparation will facilitate your discussion with the retailer as you select the pump that best suits your needs.

Appendix 2 | Rate controllers

There are many advantages to using rate controllers, but their primary role is to maintain a constant application rate. All sprayers change speed on hills, at row-ends, or in response to surface conditions. Since flow from an uncontrolled sprayer is constant, the application rate varies significantly (up to 40% in hilly conditions). Rate controllers compensate for changing speed by adjusting flow.

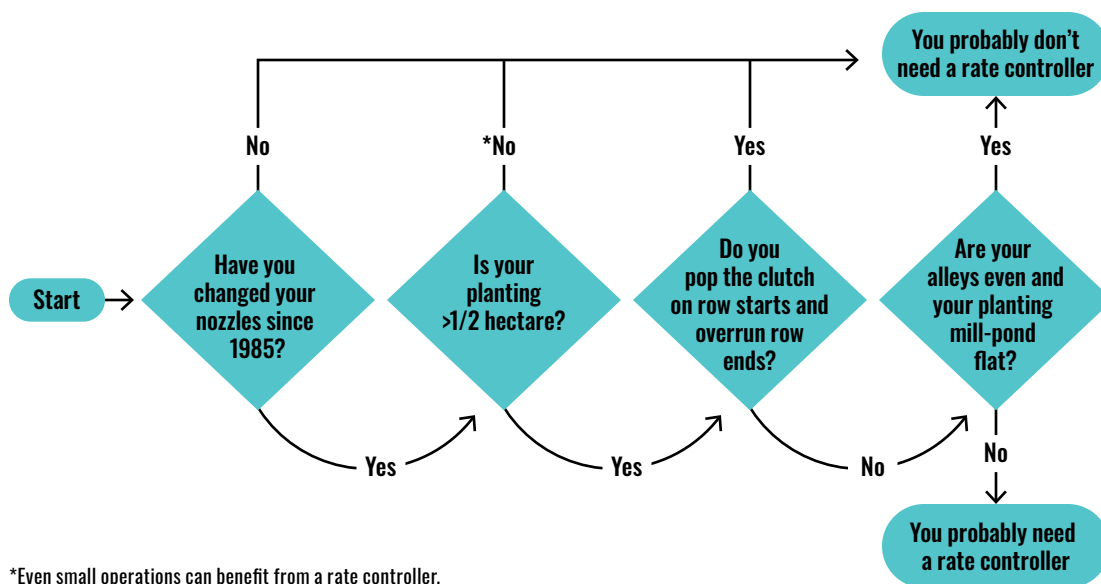


Hilly operations create highly variable application rates. Changes in travel speed can translate to 40% variability in rate applied. Rate controllers adjust flow to compensate.

Pesticide is not saved directly (since increased uphill rates already cancel out reduced downhill rates), but consider the pesticide label. Labels that list a range of rates are contingent on pest pressure and crop size, but also compensate for poor coverage from low-performing equipment. When coverage uniformity is improved, experience has shown that operators can safely spray at minimal rates.

Experience has also demonstrated that when coverage uniformity is improved, pack-out benefits follow. Even a modest improvement represents a quick return on investment. Equally important, a more consistent application reduces the risk of higher residue levels on the uphill and improves crop protection on the downhill.

Now, if you are wondering if a rate controller is right for your operation, or if you should just skip to the next chapter, consult this handy decision support matrix:



This decision support matrix will help you decide if a rate controller is right for your operation. Spoiler alert: It probably is.

A.2.1. RATE CONTROLLER CATEGORIES

The following table categorizes controllers based on how they control flow. The categories are successively more expensive and complicated, but there's commensurate value. For example, while not specified here, high-end rate controllers offer value-added features such as as-applied mapping (a powerful management tool). It may seem alien to those readers familiar with field sprayers, where pressure is critical to maintaining the correct flow and spray quality, but pressure is less of a concern in our universe. Maintaining proper flow rate is the crucial factor.

DESCRIPTION	PROS	CONS
GOOD Monitors and adjusts pressure. Uses math to assume flow.	<ul style="list-style-type: none"> • Fewest moving parts. • Simple interface. • Lowest cost. 	<ul style="list-style-type: none"> • System monitors pressure, but does not register flow. For example, if nozzle flow is restricted, back pressure increases. The controller will compensate to correct pressure, implicitly reducing flow, but the operator is not alerted to the actual problem.
BETTER Monitors and adjusts flow, not pressure.	<ul style="list-style-type: none"> • Alerts operator to changes in flow. Operator usually sets the percent error threshold a little high to ignore transient changes. 	<ul style="list-style-type: none"> • System will not register pressure deviations. At threshold speed, pressure may drop too low. This can cause inconsistent check valve operation and spray pattern collapse. With tall booms, the top nozzles may close completely.
BEST Monitors flow and pressure and adjusts flow.	<ul style="list-style-type: none"> • Best likelihood of a consistent application. • Alarms or automatic compensation of flow and pressure (user sets hard stops). • Provides a low tank level warning. • Stores preset calibrations to quickly switch between blocks. 	<ul style="list-style-type: none"> • Highest cost. • Steepest learning curve. More "wire-wiggling". • Operators often choose to over-apply at low speeds as a tradeoff for uniform output and consistent atomizer performance.

A.2.2. RATE CONTROLLER ADOPTION AND COMPONENTS

As we write this, less than 10% of air-assist sprayers have rate controllers. In the dark old days of the 1980s, air-assist operators were ill-advised to install high flow, low pressure field sprayer controllers. Those packages were well suited to field sprayers but not optimized for orchard needs. That history of mismatched components and subsequent bad experiences continues to hinder widespread adoption.

Today's components, however, are specific to air-assist sprayers and have made installations easier and more successful. Do your homework and speak with the manufacturer (not necessarily the local dealer) to ensure the controller, and all its components, meet your needs. Let's describe the components so you're prepared to have the conversation:

1.

Console

2.

Flow meter(s)

3.

Flow control valve (including electric boom shut-offs)

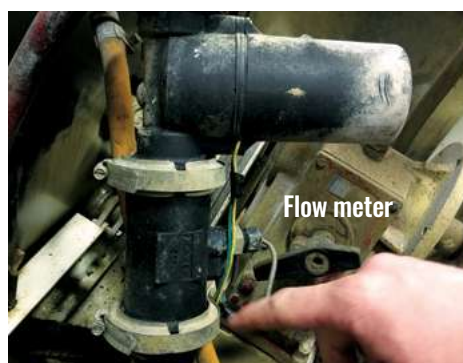
4.

Speed sensor

5.

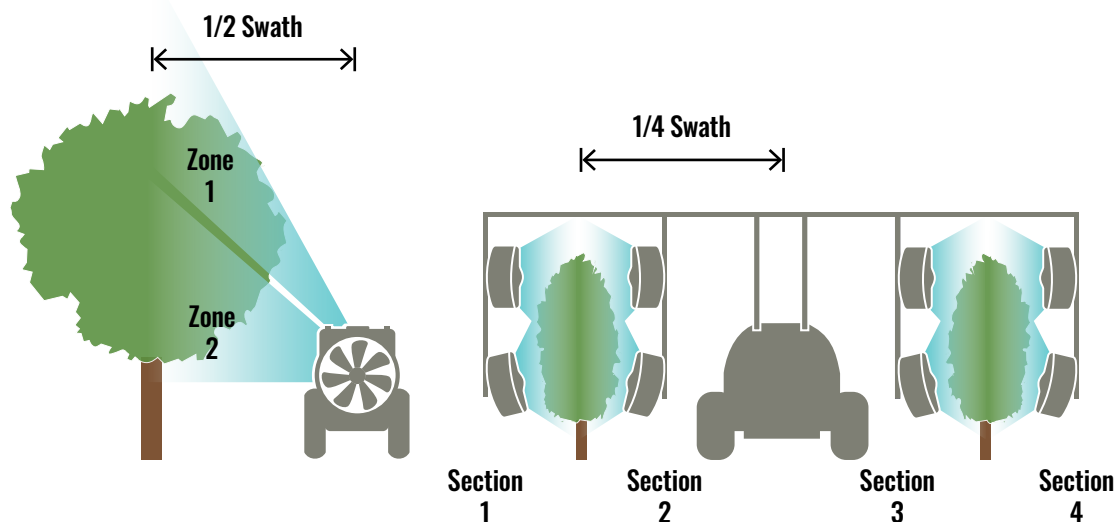
Wire harness

Examples of rate controller components.



A.2.2.1. CONSOLE

The console is the interface. The user enters criteria about the sprayer, the planting, and calibration data and receives information about sprayer performance. Select a console designed for air-assist sprayers and not field sprayers. Controllers intended for horizontal booms perceive swath in two dimensions, but air-assist controllers account for multiple vertical booms or boom sections in the swath (see the following figure).



Field sprayer rate controllers used in vertical crops must be “tricked” when programming swath.

LEFT: Leading air-assist rate controllers can assign flow to zones on a single vertical section and **RIGHT:** adjust swath (sometimes called width) for multiple booms.

A.2.2.2. FLOW METER

With rate controllers, flow is detected by one or more flow meters positioned pre-manifold. The relief valve (see Chapter 5.4.) becomes more of a safety device, defining the high pressure limit and bypassing flow if required. Most rate controllers use a flowmeter with no ability to monitor pressure. While still effective, adding a pressure sensor ensures nozzles are operating in the desired pressure range.

Turbine or paddle meters are inexpensive and acceptably accurate. They require periodic cleaning because some chemistry can accumulate and interfere with their moving parts. Filtration helps to minimize this issue. Magnetic or ultrasonic meters have no moving parts, higher resolution, wider metering ranges and aren't affected by the viscosity of the spraying solution or entrained foam. However, they are considerably more expensive than mechanical meters. Magnetic sensors may be affected by oily formulations.

A.2.2.3. FLOW CONTROL VALVE

Unlike boom control valves that are open or closed, flow control valves are capable of a range of adjustments. Valve actuation is controlled by 12 volt servomotors. The level of precision depends on the style of valve.

- **Butterfly valves:** Simple, inexpensive, and typically for pressures <10 bar (150 psi). Some have minor leak-by when closed. Control is less precise as the valve opens because the orifice gets geometrically larger. This gives a narrow metering range.
- **Ball valves:** Versions available for all pressures. May be simple flow through balls with similar metering limits to a butterfly. A better ball design is also available that offers a linear flow rate through the entire adjustment range, offering more stable rate control over the entire flow range. Several manufacturers offer these. All ball valves offer zero flow when closed.



LEFT: A butterfly valve. **RIGHT:** A ball valve. Notice how a small change in the opening angle translates into a large change in the orifice size; this is difficult to control manually. Actuators not pictured.

Compared to field sprayers, air-assist sprayers travel slower and use lower flow rates. It is a mistake to employ valves intended for high-flow, high-speed sprayers.



TURBULENT EDDY SAYS...

Using field sprayer valves on an air-assist rate controller is like making fine adjustments with a sledge hammer. Use the right sized tool for the job.

- **Speed:** Valves are rated by connection size (half inch, three-quarter inch, etc.) and opening time (e.g. 1-14 seconds are common). Many rate controllers can be programmed to optimize adjustments for the speed and size of the valve.
- **Precision:** As control valves open over their 90° range, the ability to control flow is less precise. Slower valves give less precision, but greater stability.
- **Size:** Valve size should accommodate maximum flow and no more. If the valve is too large, it can only meter flow over the first few degrees of opening. For example, let's say a valve capable of 200 L/min. (50 gpm) and rated 1 second is used. Your sprayer meters 0-20 L/min. (0-5 gpm). This means the whole metering range happens in the first tenth of a second. Even lightning-fast consoles will give unstable readings (aka hunting) as the computer overshoots the target in an effort to comply.

Control valves are “service parts”. Seals, moving parts and abrasive liquids mean they will require regular care and eventual replacement. It's a wise precaution to make them accessible and easily removable. We suggest installing them with quick-connects to make field-maintenance fast and easy.

A.2.2.4. SPEED SENSOR

Speed can be based on GPS, engine tachometer readings, radar, or wheel rotations. Newer rate controllers may even take the speed directly from the tractor's data feed. Price, reliability and crop conditions are all factors you should consider in the choice.

- **GPS:** Easiest to deploy, very accurate (especially RTK-GPS) and reasonably priced. However, overhead canopy can block satellite signals. Some controllers compensate for the GPS losses with sophisticated internal kinematic devices that measure the inertia of the sprayer and calculate speed when the GPS is not reliable.
- **Wheel rotation speed sensors:** An entry-level sensor, it's typically a reed switch or Hall effect sensor that detects either the lug nuts or magnets installed on the rotating wheel. More magnets improve accuracy. Its exposure makes it prone to physical damage, and readings change with tire radius (which changes as the solution tank empties, on soft ground and with temperature). This is why wheel sensors are calibrated in the alley, with the tank half full and both tires at the same pressure).
- **Radar speed sensors:** Employing the Doppler effect to measure speed, radar is the most accurate sensor. They are unaffected by terrain, slope or tank volume. They can be mounted anywhere in sight of the ground. They are, however, the most expensive and are typically not repairable if they fail.

- **Tachometer speed sensors:** Largely obsolete, they measure the tractor's tachometer speed and convert it to travel speed. Difficult to install and prone to the same inaccuracy as wheel sensors.
- **Interface sensors:** Relatively new, some rate controllers interface with tractor electronics to receive speed data. ISOBUS, the standard interface language that agricultural electronics are increasingly adopting, makes this data exchange more common.

A.2.2.5. WIRE HARNESS

It may seem we're drilling deep to mention wires, but standards are changing. Many controllers employ traditional analog wiring, but they are being made obsolete by the newer ISOBUS option.

- **Traditional Analog:** Simple wires with automotive or custom plugs designed to match components. Relatively inexpensive and sometimes field repairable, analog wiring carries signal voltage (and power) to and from the controller to drive valves and receive analog sensor data. Communication is one-way: Sensor to controller, controller to valves.
- **Modern ISOBUS:** Bus systems are more like a computer network, where digital signals travel back and forth between the controller and each component. Components that require power are wired directly to a battery. This results in a greatly simplified harness. The controller's single ISOBUS wire "daisy chains" all components to relay commands and receive status, which makes system monitoring and diagnosis easier and more effective.

Appendix 3 | Product rate calculations

This appendix describes how to calculate the amount of carrier and product required to complete a spray job. If you prefer your own calculations, carry on. If you choose to try our method, don't mix and match math from other methods. They are often incompatible and will yield false results.



Sprayer math in its natural habitat: Algebra and look-up tables on the tailgate of a truck with people watching and waiting. No pressure...

A.3.1. AREA-BASED RATE

Area-based product labels intend for a known quantity of product to be delivered to the treated area (e.g. g/ha or oz./ac). Sometimes a concentration is specified, or some minimum carrier volume must be observed (e.g. g/L/ha). While appropriate for row and broad-acre crops sprayed with a horizontal boom, rates presented per planted area are far less relevant for specialty crops (see Chapter 14.4.).

Question 1: What is the total area I need to spray?

Multiply the length of the area you plan to treat times the width. If using meters, then divide the product by 10,000, which is the number of m² in a hectare:

$$\text{Total area (ha)} = \frac{\text{length (m)} \times \text{width (m)}}{10,000 \text{ m}^2/\text{ha}}$$

If using feet and acres, divide by 43,560, which is the number of ft.² in an acre:

$$\text{Total area (ac.)} = \frac{\text{length (ft.)} \times \text{width (ft.)}}{43,560 \text{ ft}^2/\text{ac.}}$$

Question 2: How much product is needed to complete the job?

If you measure your area in hectares and the label is Metric, multiply the product rate by the number of hectares you intend to spray:

$$\text{Total product amount required} = \text{Labeled product amount (per ha)} \times \text{Total spray area (ha)}$$

If the label is in US units and you measure in acres, multiply the product rate by the number of acres you intend to spray:

$$\text{Total product amount required} = \text{Labeled product amount (per ac.)} \times \text{Total spray area (ac.)}$$

If the label is Metric and you think in acres (common in Canada), you will have to convert the area by multiplying by 0.4:

$$\text{Total product amount required} = \text{Labeled product amount (per ha)} \times \text{Total spray area (ac.)} \times 0.4 \text{ (a constant)}$$

Question 3: How much area can I cover on a full solution tank?

You must already know your intended spray volume per planted area (see Chapter 7.3.1.). This must be divided into the volume of your solution tank:

$$\text{Sprayed area per tank (ha or ac.)} = \frac{\text{Tank volume (L or US gal.)}}{\text{Sprayer output (L/ha or L/ac. or US gal./ac.)}}$$

Question 4: How much product do I add per solution tank?

Multiply the area that can be sprayed per solution tank by the labeled product rate:

$$\text{Product amount per tank} = \text{Sprayed area per tank (ha or ac.)} \times \text{Labeled product amount (per ha or ac.)}$$

Question 5: How much area is left after I empty a solution tank?

Just subtract the area you've already sprayed from the total area:

$$\text{Area left to spray (ha or ac.)} = \text{Total spray area (ha or ac.)} - \text{Area already sprayed (ha or ac.)}$$

Question 6: If I don't have enough area left to warrant a full tank, how much product do I use in the last, partially-full solution tank to finish spraying?

Multiply the area you have left by the product rate:

$$\text{Product amount in partial tank} = \text{Area left to spray (ha or ac.)} \times \text{Labeled product amount (per ha or ac.)}$$

Question 7: How much volume do I use in that last, partially-full solution tank?

In answering this, you should know how low your solution tank volume can go before the pump cavitates (i.e. begins to suck air). This minimum operating volume can vary with sprayer design and should be accounted for when filling a partial tank. The left-over liquid when a sprayer stops spraying is the residual volume. The volume required in a partial tank can be determined by comparing how much area you covered on a full tank to how much area remains to be sprayed:

$$\text{Volume in partial tank (L or US gal.)} = \frac{\text{Tank volume (L or US gal.)}}{\text{Sprayed area per tank (ha or ac.)}} \times \text{Area left to spray (ha or ac.)}$$

A.3.2. DISTANCE-BASED RATE

Distance-based calibration is common in Australasia. In New Zealand, for example, label rates for tree and vine crops are presented as quantity of product per 100 litres (e.g. mL/100 L). This concentration is intended for a dilute application. A per hectare rate is also provided, but only as a point of reference to prevent overdosing.

Sprayer operators must still determine how many liters of this solution are required to spray 100 m of row. Operators often turn to historical experience or regional guidelines that are based on research and experience (see Chapter 7.3.1.).

Question 1: What is the total row length I need to spray?

First calculate the total planted area. Then determine row length per hectare of planted area. Finally, calculate the total row length from the total planted area:

$$\text{Total area (ha)} = \frac{\text{length (m)} \times \text{width (m)}}{10,000 \text{ m}^2/\text{ha}}$$

$$\text{Row length per hectare (m/ha)} = \frac{10,000 \text{ m}^2/\text{ha}}{\text{Row spacing (m)}}$$

$$\text{Total row length (m)} = \text{Row length per hectare (m/ha)} \times \text{Total area (ha)}$$

Question 2: How much solution is needed to complete the job?

You must already know your intended sprayer output in liters per 100 m row length:

$$\text{Total volume required (L)} = \frac{\text{Total row length (m)}}{\text{Sprayer output (L/100 m)}}$$

Question 3: How much product is needed to complete the job?

Divide the volume required for the job by the labeled product amount per 100 L:

$$\text{Total product amount required} = \frac{\text{Total volume required (L)}}{\text{Labeled product amount (per 100 L)}}$$

Question 4: How much row length can I cover on a full solution tank? What is that in hectares?

Multiply your solution tank volume by 100 and then divide that by your intended sprayer output in L/100 m row length. Calculate area by relating the row length you can spray with a single solution tank to the total row length per hectare:

$$\text{Row length sprayed per tank (m)} = \frac{\text{Tank volume (L)} \times 100 \text{ (a constant)}}{\text{Sprayer output (L/100 m)}}$$

$$\text{Area sprayed per tank (ha)} = \frac{\text{Row length sprayed per tank (m)}}{\text{Row length per hectare (m/ha)}}$$

Question 5: How many solution tanks will I need?

Divide the total volume required by the volume of your solution tank:

$$\text{Number of tanks} = \frac{\text{Total volume required (L)}}{\text{Tank volume (L)}}$$

Question 6: How much product do I add per solution tank?

Divide the labeled product amount (per 100 L) by 100 and multiply that by the solution tank volume in litres:

$$\text{Product amount per tank} = \frac{\text{Tank volume (L)} \times \text{Labeled product amount (per 100 L)}}{100 \text{ (a constant)}}$$

Question 7: How much product will I need to complete the job?

Multiply the product amount per solution tank by the number of tanks required:

$$\text{Total product required} = \text{Product amount per tank} \times \text{Number of tanks}$$

Question 8: How much row length is left after I empty a solution tank?

Just subtract the length you've already sprayed from the total area:

$$\text{Row length left to spray (m)} = \text{Total row length (m)} - \text{Row length sprayed per tank (m)}$$

Question 9: If I don't have enough row length left to warrant a full tank, how much product do I use in the last, partially-full solution tank to finish spraying?

Calculate the product per m row length by multiplying the labelled product amount by the sprayer output and divide by 10,000. Then multiply that by the row length left to spray.

$$\text{Product /m row length} = \frac{\text{Sprayer output (L/100 m)} \times \text{Labeled product amount (per 100 L)}}{10,000 \text{ (a constant)}}$$

$$\text{Product amount in partial tank} = \text{Product /m row length} \times \text{Row length left to spray (m)}$$

Question 10: How much volume do I use in the last, partially-full tank to finish spraying? In answering this, you should know how low your solution tank volume can go before the pump cavitates (i.e. begins to suck air). This minimum operating volume can vary with sprayer design and should be accounted for when filling a partial tank. The left-over liquid when a sprayer stops spraying is the residual volume.

The volume required in a partial tank can be determined by comparing how much row length you covered on a full tank to how much length remains to be sprayed:

$$\text{Volume in partial tank (L)} = \frac{\text{Tank volume (L)}}{\text{Row length sprayed per tank (m)}} \times \text{Row length left to spray (m)}$$

A.3.3. RELATING LIQUID PRESSURE TO FLOW

Here are four useful calculations relating liquid pressure to flow:

Use the following formula to determine the change in spray volume (e.g. L/ha), sprayer output (e.g. gal./min.) or nozzle output (e.g. L/min.) resulting from a change in nozzle pressure.

Substitute sprayer output or nozzle output for spray volume where required.

$$\text{Spray volume}_{\text{new}} = \text{Spray volume}_{\text{original}} \times \left(\frac{\text{Pressure}_{\text{new}}}{\text{Pressure}_{\text{original}}} \right)^{-2}$$

Use the following formula to determine the pressure required to produce the desired spray volume, sprayer output or nozzle output. Substitute sprayer output or nozzle output for spray volume where required.

$$\text{Pressure}_{\text{new}} = \text{Pressure}_{\text{original}} \times \left(\frac{\text{Spray volume}_{\text{new}}}{\text{Spray volume}_{\text{original}}} \right)^2$$

Use the following formula to determine the spray volume that will result from a change in travel speed.

$$\text{Spray volume}_{\text{new}} = \frac{\text{Spray volume}_{\text{original}} \times \text{Speed}_{\text{original}}}{\text{Speed}_{\text{new}}}$$

Use the following formula to determine the travel speed required to change to a new spray volume.

$$\text{Speed}_{\text{new}} = \frac{\text{Spray volume}_{\text{original}} \times \text{Speed}_{\text{original}}}{\text{Spray volume}_{\text{new}}}$$

A.3.4. LIQUID UNIT CONVERSION FACTORS

For those located in countries with hybrid unit systems (e.g. Canada's Mock-tric system), we've assembled this helpful list of unit conversions to help with timed output tests.

If collecting in US ounces, converting to US gallons per minute:

$$\text{US gpm} = \frac{\text{Output (oz./min.)}}{128 \text{ (a constant)}}$$

If collecting in milliliters, converting to US gallons per minute:

$$\text{US gpm} = \frac{\text{Output (mL/min.)}}{3,785.4 \text{ (a constant)}}$$

If collecting in US ounces, converting to litres per minute:

$$\text{L/min} = \frac{\text{Output (oz./min.)}}{33.8 \text{ (a constant)}}$$

If collecting in milliliters, converting to litres per minute:

$$\text{L/min} = \frac{\text{Output (mL/min.)}}{1,000 \text{ (a constant)}}$$

If collecting in US ounces, converting to Imperial gallons per minute:

$$\text{Imp. gpm} = \frac{\text{Output (oz./min.)}}{153.7 \text{ (a constant)}}$$

If collecting in milliliters or grams converting to Imperial gallons per minute:

$$\text{Imp. gpm} = \frac{\text{Output (mL/min.)}}{4,546.1 \text{ (a constant)}}$$

Appendix 4 | Electrostatics

Agricultural sprayers first employed electrostatic charge in the late 1970s. They have become increasingly popular with air-assist sprayer operators in recent years.

A.4.1. INDUCING A CHARGE

“Electrostatic” means an electric charge is imparted on the spray. It can be added to any sprayer, but as we will discuss, it works best with finer droplets so it is usually paired with a twin-fluid atomizer. Electrostatic attraction is a weak force that can motivate very small droplets to travel very short distances. An uncharged droplet might ride along an aerodynamic boundary layer, missing the target. Or, perhaps gravity, wind or thermals draw it off course ([see Chapter 12](#)). An electrostatic charge can influence a droplet’s trajectory. This gives it the potential to overcome these influences and move upward against gravity towards the underside of a leaf, or deposit behind fruit or berries (see figure below).



A common trade show demonstration of electrostatic nozzles. Talc is sprayed at a grounded black sphere.

LEFT: Electrostatic charge is turned off.

RIGHT: Electrostatic charge is turned on.



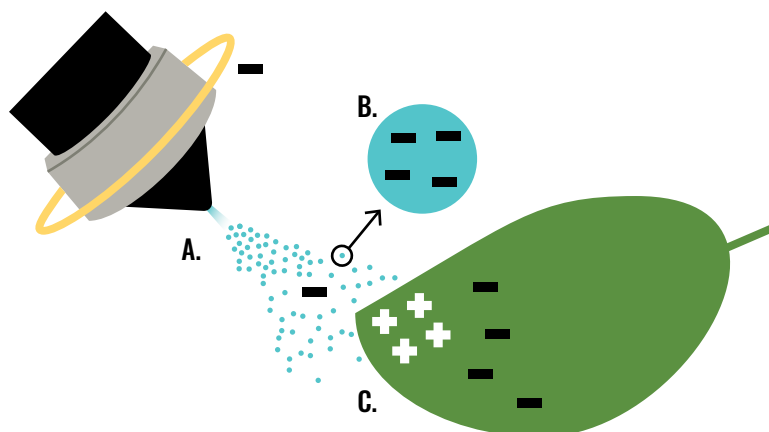
LAMINAR FLO SAYS...

Being connected to the Earth makes attraction stronger, but a target does not need to be “grounded”. Attraction will occur as long as the target is substantially larger than the droplet and able to absorb/disperse the charge.

Electrostatics are poorly understood in the marketplace and often oversold as a solution, but used correctly they offer useful benefits. You may be familiar with electrostatic painting systems. A 40,000 volt charge or higher is introduced to liquid. Yes, you read that right. The spray retains this charge as it is discharged. While incredibly effective, to our knowledge this method is not currently employed in any commercially available sprayers. Shocking.

In agriculture, electrostatic sprayers employ a phenomena called coronal discharge. A high-voltage (i.e. thousands of volts) charging plate or coil is located proximal to the atomizer exit orifice. As the spray passes through the electric field (or corona), droplets pick up extra electrons, inducing a negative charge (see figure below).

We will also mention an aftermarket ionic system that allegedly imparts an electrostatic effect on the spray. Consumable copper or silver anodes are installed in the liquid handling system. While the consumed metal likely changes the ionic chemistry of the water (a different non-electrostatic phenomena), the practical electrostatic impact on droplets is questionable. Caveat emptor.



The droplet becomes polarized when it passes through the A. electric field (yellow corona) and picks up electrons (negative charge). B. The negatively charged droplet now attracts any neutral charged object, C. which becomes positive in relation to the droplet, and the droplet is electrically motivated to “ground” on it.

A.4.2. CHARGE-TO-MASS-RATIO

Droplet size is a critical factor for electrostatic sprayers because electrostatic attraction is such a weak force. Droplets must be large enough to resist evaporation (see Chapter 12.1.) but small enough that the attractive force of the charge can change the droplet's trajectory when it comes close to a target.

Extensive experimentation has demonstrated that a Very Fine to Extremely Fine spray quality ($\sim 50 \mu\text{m}$ VMD) provides a reasonable balance. This is why twin-fluid nozzles are the most common atomizer for electrostatic technology. They can produce tiny droplets and direct them through a corona generated by a coil installed in the cap (see illustration of the previous page) or through corona-generating plates installed in the air outlet (see figure below).

Charged droplets must get very, very close to the target before any coverage advantage can be realized. Accounts vary, but the droplet must be within $\sim 2 \text{ cm}$ (1 in.) before attraction improves deposition. Our old friend the inverse square law tells us the closer the droplet and target, the greater the attraction.



This air-shear based sprayer employs the plate type electrostatic technology. Note the metal charge plate attached to the inside of the duct. The clearance between the droplets and the plates is quite large in relation to the very controlled distance inside a twin-fluid atomizer coil type charging system.

A.4.3. CONSIDERATIONS

So why doesn't everyone have an electrostatic sprayer? Likely because it's difficult to provide clear guidance on how to best use this technology. Several factors complicate the story:

- **Non-uniform canopy charge:** Dense canopies represent a concentrated electrical field. Droplets will preferentially deposit on the canopy exterior, which is the first object they encounter. High velocity air can push spray deeper into the canopy, but the finest droplets are aggressively filtered at first contact and prevented from moving deeper. The net effect is that electrostatics may reduce canopy penetration of the finest droplets, the most important for deep canopy coverage.
- **Non-uniform surface charge:** The strength of the grounding force is influenced by the shape of the target. Deposition is more uniform for rounded targets (e.g. fruit) than planar/pointed (e.g. leaves). Charged droplets are particularly attracted to the tips of pointed leaves, or the serrated edges of dentate leaves. This is because charge tends to concentrate on points. This is also why lightning strikes the highest point.

Electrostatic sprayers are marketed as drift reduction technologies. It is likely, in large canopies, that a great number of finer droplets remain in the canopy. But, recall from [Chapter 6](#) that the finer droplets represent only a fraction of the overall spray volume. Disproportionally high air velocities will push a lot of spray through the canopy, charged or not. Therefore, when using a sprayer that employs a droplet spectrum fine enough for electrostatic technology, it is critical to employ the optimization techniques described in this book.

To conclude, the physics of electrostatics are real and very appealing, but the current rules for practical application are inadequately defined. If anyone knows a few Ag engineers or PhD's looking for a project, this would be a great topic to suggest.

Sprayers 101

For more information on spraying in agriculture, be sure to check out www.sprayers101.com. Sprayers 101 is a free, nonprofit resource describing best practices in safe, efficient and effective agricultural spraying. The site is based in Canada with content contributed by international authors. Browse our ever-growing library of articles, videos, presentations, apps, downloadable calculators, tables and electronic publications (including this one).

Sprayers 101

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



