AIRCRAFT OPERATIONS WITH FORAY PRODUCTS

section 4

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4.1 AIRCRAFT CALIBRATION

Proper calibration and spray atomization are paramount to achieving optimal Foray efficacy. Several methods exist for calibrating flow rates, each based on the type of equipment fitted to the aircraft. In all cases, some baseline calculations must be performed to establish the flow rate required by the spray system and the flow rate through each atomizer or nozzle.

> **Performance**
>
> Proper calibration and spray atomization are paramount to achieving optimal Foray efficacy.

STEP 1: Determine the spray system flow rate

Using example data, the formulas for determining system flow rates for US units and metric units can be found in **Figures 4.1(a) - 4.1(c)**.

Figures 4.1: Flow Rate Calibration/Calculation Formulas

Figure 4.1(a)

US Units

$$\text{Flow rate (gal/min)} = \frac{\text{Airspeed (mph) x Swath (ft) x Application Rate (gal/acre)}}{495}$$

Metric Units

$$\text{Flow rate (L/min)} = \frac{\text{Airspeed (km/h) x Swath (m) x Application Rate (L/Ha)}}{600}$$

Figure 4.1(b)

$$\text{Flow/Atomizer/Minute} = \frac{\text{System Flow Rate}}{\text{No. of atomizers}}$$

Figure 4.1(c)

US Units

$$\text{Gal/min} = \frac{\text{110 (mph) x (200) (ft) x Application Rate 0.5 (gal/acre)}}{495}$$

$$= \frac{\text{22.2 gal/min}}{\text{6 atomizers}}$$

$$= \text{3.7 gal/min/atomizer}$$

STEP 2: Choose the atomizer type and number (**Figure 4.2(b)**).

The droplet spectrum required for effective Foray application is determined by the type of atomizer or hydraulic nozzle being used. Using nozzle or atomizer flow charts supplied by the manufacturer, determine an appropriate combination of units + pressure and flow settings (or nozzle orifice size) to deliver the desired flow per minute through each atomizer/nozzle.

ⓘ **APPLICATION TIP**: Hydraulic nozzles (e.g. TeeJet®, etc.) have a narrow pressure (and flow rate) range for any particular droplet size. Rotary atomizers can be adjusted for different droplet sizes independent of their flow rates.

To obtain the flow rate per atomizer for either US or metric units, divide the flow rate by the number of atomizers that will be fitted to the aircraft.

Example 4.1(c): (US units) If airspeed is 110 mph, and the expected swath width is 200 feet, what is the calibrated flow rate through each rotary atomizer if 6 Micronair AU5000 units will be used and the applied volume is 64 fluid oz/acre? (Don't forget to convert ounces to gallons!)

The next step in the calibration process will depend upon the type of equipment fitted in the aircraft. If the spray system is powered by an engine driven pump (hydraulic or electric) and rotary atomizers are fitted, the aircraft can be statically calibrated on the ground by catching and measuring the output of the atomizers. If there are many nozzles, or if the system pump is wind-driven, then ground calibration becomes impractical and an airborne method is required.

> **Operations**
>
> Always monitor calibration during operational spraying by comparing the volume of product applied with the area being treated.

Most aircraft are now equipped with flow meters which are used to accurately calibrate the system and monitor the pesticide flow rate during operations. Most GPS-based aircraft navigation systems (e.g. AG-NAV®, DynaNav, SatLoc®, TracMap®) offer flow monitor and flow control devices as part of their onboard systems. These flow control/ flow monitoring devices link true ground speed to desired output and increase or decrease flow rates accordingly.

If applications are made over mountainous terrain, the systems automatically reduce output while the aircraft is flying uphill more slowly. Conversely, the output will be increased as the aircraft flies downhill to ensure that a consistent application rate is maintained.

At the start of a project, it may be a good idea to monitor the flow meter carefully to ensure that the "displayed" totals match the actual "spray total" volumes. Although it is not necessary to calibrate such-equipped aircraft on the ground, if there are any doubts as to meter accuracy, such a calibration can be performed as a simple cross-check.

Ground Calibration for Aircraft With Hydraulic or Electrical Pumps

STEP 1: Load sufficient product into the aircraft hopper (or saddle tanks installed on a helicopter) to prime the entire spray system, and allow enough product for the required number of tests.

STEP 2: Place collectors under each atomizer/nozzle and operate spray system for one or more minutes, so that a measurable volume is produced. Plastic jugs or plastic bags may be used to shroud the atomizers and to capture the spray being emitted.

STEP 3: Measure volume output per minute from each atomizer/nozzle and compare to calculated rate. Check total output.

STEP 4: Adjust the system pressure and/or atomizer setting, or change the nozzle orifice size, to increase or decrease output as needed. Retest system as per STEP 2.

Airborne Calibration for Aircraft With Wind-Driven Pumps

Note: It is often possible to obtain sufficient wind pump pressure by applying power while stationary. Consult the pilot for the standard operating procedure. In such cases, begin by following the calibration procedure in Section 4.1 and add these additional steps:

Photo Courtesy of ENVIROFOTO / SOPFIM

STEP 1: Load product into the hopper as described previously, with the exception that the system must be primed in flight.

STEP 2: After the system is primed and the aircraft has landed, position the aircraft on a level surface and mark the spot. Add a measured volume of product to the spray tank and note the level either through the sight window or by measuring the distance from the top or bottom of the tank to the fluid surface of the product with a measuring stick.

STEP 3: Instruct the pilot to fly the aircraft as in a normal application and to operate the spray system for a set amount of time, e.g., 1 minute, using a stopwatch.

STEP 4: Return the aircraft to the exact spot on the ground as marked in STEP 3, and measure the volume of product needed to refill to the original level. This volume can then be used to calculate output per minute.

STEP 5: Make adjustments to the spray system, if necessary, to change output.

APPLICATION TIP: If an aircraft has already had its spray system primed, a known quantity of spray mix can be pumped into the aircraft so that ground equipment, fitted with a previously calibrated and correct flowmeter, may be used for loading. The hopper site gauge may also be used if the aircraft is parked on level ground. The time taken to pump the measured volume is recorded with a stop watch, and the spray system settings adjusted accordingly and re-tested as necessary.

Operations

If your are confident the application rate will be within +/-10 percent of the target rate when calibrating, you may want to use your assessment run as the first load of the operation.

Aircraft with Electronic Flow Meters

Electronic flow monitors such as those manufactured by Onboard Systems® (Crophawk®) and Micronair or DGPS manufacturers (e.g. AG-NAV, DynaNav, Satloc, TracNav etc.) greatly facilitate aircraft calibration and enable in-flight adjustments when conditions demand. However, flow monitors and application computers should be calibrated with the product or spray mixture prior to operational use. Always refer to equipment manufacturers' directions for volumetrically calibrating flow meters with fluids other than water.

Also, flow monitors that have interchangeable cartridges of different flow range sensitivities should have the correct cartridge or flow turbine installed. Consult the appropriate manufacturers' directions.

DGPS manufacturers now offer flow monitoring systems interlinked with the DGPS system. Please consult with the technical representatives of the various DGPS manufacturers for more details. (See Appendix 1: Sources & Resources)

General Calibration Procedure

Foray formulations have been continually optimized to ensure that their viscosity is as low as possible.

When calibrating your system for Foray:

1) Assume that the Foray formulation will behave like water, and use the appropriate calibration factor in the flow meter.

Photo Courtesy of U.S. Forest Service

Performance

In general, the flow rate differential between water and the aqueous suspensions of Foray 48B and 76B is about 5-7%.

2) Add a known quantity of the spray material to the aircraft hopper. Ground equipment, fitted with a previously calibrated and correct flowmeter, may be used for loading. Alternatively, the hopper site gauge may be used if the aircraft is parked on level ground.

3) Make an adjustment to your flow meter calibration constant if the total volume sprayed (as indicated by your flow meter) is different from the amount that was pumped into the hopper. Typically this adjustment can be calculated as indicated below, but should also be cross-referenced with supplier operator's manual:

New Calibration Constant =

$$\text{Old Calibration Constant} \times \frac{\text{Volume Applied}}{\text{Volume Indicated}}$$

Both Foray 48B and 76B are aqueous suspensions with relatively consistent physical parameters. In general, the flow rate differential between water and Foray is about 5-7%. After the initial check with water, use this calibration factor (flow rate constant) to help calibrate the equipment more accurately and with fewer flow checks.

ⓘ **Pilot Tip**: Use the aircraft flow meter as your primary instrument for monitoring flow rate.

Performance

Strainer screens used with Foray should be no finer than 30 mesh. A 20 or 25 mesh slotted screen strainer is ideal. Aircraft manufacturers often install a 50 mesh screen as a standard on new planes. Although undiluted Foray will pass through a 50 mesh screen, product solids and foreign matter will likely build up on the screen and cause plugging.

With the new calibration constant, adjust the pressure of the spray system until the desired flow rate appears. This step may have to be repeated once or twice to determine the correct flow rate constant.

4.2 SPRAY SYSTEM FILTERS/SCREENS

Filters in aircraft spray systems are designed and installed to prohibit foreign particles from entering the system. Except for inline screens, the smallest orifices are found in the nozzles fitted to the aircraft.

Mesh size is defined by the number of openings there are per inch (e.g. a 30 mesh screen has 30 openings per linear inch of screen). But because of the thickness of the wire, the size of the orifice is not the inverse of the mesh size in inches.

The most common screen size found in aircraft inline screens is 50 mesh (holes in 50 mesh screens are 0.011" across).

Although undiluted Foray will pass through a 50 mesh screen, product solids will eventually build up the screen. When foreign matter is additionally collected on the screens, the buildup will occur more rapidly and will cause plugging of the screen.

Strainer screens should be no finer than 30 mesh when applying Foray formulations. A better alternative is the use of a 20 or 25 mesh slotted screen strainer as it is less prone to plugging.

Photo Courtesy of U.S. Forest Service

The same principle applies to 50 mesh nozzle screens. The pore sizes of various screen meshes, slotted strainer slots and nozzle openings are shown below in **Figures 4.2(a)** and **(b)**, in order of size increments.

It is clear from an evaluation of the sizes of various screen and nozzle openings shown in **Figures 4.2(a)** and **(b)** that the most commonly used nozzle openings (D-3, 8003 and VRU # 3 or 5) are significantly larger than a 30 mesh inline screen pore size.

Therefore the use of a 30 mesh inline screen or a 25 mesh slotted strainer installed in the nozzle body will enable the free flow of material to the atomizer orifices. No strainer or screen is necessary at the nozzle when using rotary atomizers.

Figure 4.2(a): Filter and screen mesh, sizes, ranked in order of size (inches)

INLINE SCREENS	NOZZLE SCREENS	NOZZLE* SLOTTED STRAINERS	HOLLOW CONE	NOZZLES FLAT FAN 80 SERIES	MICRONAIR VRU
50 mesh = 0.011	50 = 0.011	50 = 0.010			
30 mesh = 0.21		25 = 0.020			
	24 = 0.030	16 = 0.032		02 = 0.036	1 = 0.030
16 mesh = 0.045			D2 = 0.041	03 = 0.043	3 = 0.046
			D3 = 0.047		
				04 = 0.052	
				05 = 0.057	
			D4 = .0631	06 = 0.063	5 = 0.063
			D5 = .078		
					7 = 0.094

**Slotted strainers are recommended (required) for suspended solids where nozzle straining is required.*

Figure 4.2(b): Filter and screen mesh sizes, ranked in order of size (mm)

INLINE SCREENS	NOZZLE SCREENS	NOZZLE* SLOTTED STRAINERS	HOLLOW CONE	FLAT FAN 80 SERIES	NOZZLES MICRONAIR VRU
50 mesh = 0.28	50 = 0.28	50 = 0.25			
30 mesh = 0.53		25 = 0.51			
	24 = 0.76	16 = 0.81		8002 = 0.91	1 = 0.76
16 mesh = 1.14			D2 = 1.04	8003 = 1.09	3 = 1.17
			D3 = 1.19		
				8004 = 1.32	
				8005 = 1.45	
			D4 = 1.60	8006 = 1.60	5 = 1.60
			D5 = 1.98		
					7 = 2.39

**Slotted strainers are recommended (required) for suspended solids where nozzle straining is required.*

4.3 DROPLET SPECTRUM SIZE, ATOMIZER SELECTION & SPRAY ATOMIZATION

The manner in which Foray is atomized can markedly influence the effectiveness with which it controls the target insect. The impingement of droplets in a forest canopy, their distribution on foliage, and the likelihood of the target insect obtaining a lethal dose are all determined by the droplet size.

Performance

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Because of differing foliage shapes and densities, broad-leaf forests have slightly different droplet size parameters than coniferous forests. Habitat differentiation means that the target species can affect droplet size selection; thus a free-roaming insect like the Gypsy Moth may require a different droplet spectrum than sequestered insects like the spruce budworm.

The choice of atomizer will be largely determined by the required droplet spectrum. At air speeds below 120 mph (190 km/h), rotary atomizers such as the Micronair can deliver smaller droplets than conventional hydraulic nozzles. Their great advantage is the ability to alter droplet size independently of aircraft boom pressure or airspeed, and to do this as spray conditions change.

At higher airspeeds (greater than 125mph/200 kph), small drop diameter ranges are possible with large capacity Micronair rotary atomizers or with standard hydraulic nozzles with the assistance of high pressure and wind shear. Such airspeeds are typically obtained with single engine turbine agricultural airplanes and multi-engine converted passenger/transport airplanes.

Hydraulic nozzles such as Spraying Systems® and TeeJet Flat Fan or Hollow Cone (Disc-Core) also produce the preferred droplet sizes, but rotary atomizers are more versatile as more options within which a narrow range of droplet sizes may be produced.

Another factor that should be considered when selecting an atomizer is the range of meteorological conditions that may be encountered during the spray project. For example, as conditions become hotter and drier during the day, rotary atomizers can be adjusted to produce bigger droplets, which evaporate less quickly than smaller droplets, and are more likely to reach their desired target.

4.4 DROPLET SIZE CONSIDERATIONS

Any particular droplet will produce eight smaller droplets, each equivalent to half the diameter of the original. One 200 μm droplet will produce eight 100 μm droplets, which in turn produces eight 50 μm droplets. Thus the original 200 μm droplet will produce sixty-four 50 μm droplets. It can be seen that given the same volume of spray material, when effectively distributed throughout the forest canopy, numerous small droplets would increase the likelihood of encounter by a larva than a single large droplet.

There are physical and biological limits to the useful size of the droplets:

- Does the droplet contain a lethal dose?
- Will the droplet survive the evaporation stresses during descent?
- Will the droplet drift off-target?

The next two subsections deal in general with droplet sizes in coniferous and deciduous forests. As a baseline, recommendations will be presented for the two most researched insects in the respective forest types, Eastern Spruce Budworm (*Choristoneura fumiferana*) and Gypsy Moth (*Lymantria dispar*). However, many defoliators show similar susceptibility ranges, and foliage deposition considerations remain the same for both forest types. Consequently, many of the broad recommendations are directly applicable to other species of defoliators found in North America (e.g., Tent Caterpillars, *malacsoma* sp., Tussock Moths, *orgyia* sp.) as well as major forest defoliators such as the Pine Processionary Moth (*Thaumetopoea pityocumpa*) or the Nun Moth (*Lymantria monacha*) in Europe. Please refer to the product label in your region for an inclusive list of pests controlled by Foray.

Droplet size is important in ensuring optimum efficacy of aerially applied insecticides. Droplets that are too small may not contain enough active ingredient and will only provide a sub-lethal dose. Droplets that are too large are wasteful in that they may contain more active ingredient than is required. Additionally, there may not be enough droplets available to ensure adequate deposition and thorough coverage throughout the forest canopy.

Droplet numbers are important too; an adequate number of droplets must be produced to ensure that thorough coverage in the forest canopy is obtained.

In Foray applications, the goals are to ensure that there are a maximum number of droplets produced, they are widely distributed where the larvae feed, and that each droplet contains a lethal dose of the active ingredient.

When referring to the number of spray droplets, scientists and application specialists will refer to the NMD and VMD.

NMD (Number Median Diameter) refers to the median or midpoint of the total number of spray droplets produced, where 50% are above the NMD and 50% are below the NMD.

VMD (Volume Median Diameter) refers to a

Performance

Eastern Spruce Budworm programs are advised to maximize the number of small droplets generated, penetrating the canopy.

40 micron droplet of Foray electron microscopy photo.

Photo courtesy of Chuck Davis, Natural Resources Canada, Canadian Forestry Service.

baseline, midpoint droplet size, where 50% of the total volume of the spray is contained in droplets smaller than the VMD and 50% of the total volume of the spray is contained in droplets larger than the VMD.

In general, scientists, program managers and application pilots will refer to a VMD or an average droplet size that is targeted for optimal control of the forest defoliator.

Optimum Droplet Sizes in Coniferous Forests

Managers of aerial spray programs targeting coniferous defoliators (budworms, tussock moths, pine processionary moth, etc.) are advised to maximize the number of small droplets produced by the atomizers to ensure effective distribution throughout the targeted forest canopy. At one time, program managers preferred the application of larger droplets due to concerns about sub-lethal doses associated with smaller droplets. However, research conducted in eastern Canada by the Canadian Forest Service and others during the last 20-25 years has shown that higher potency Btk formulations can deliver a lethal dose in a smaller droplet, thereby negating concerns about sublethal effects and smaller droplet sizes.

We recommend that the extremely low size regime be avoided, and that the atomizers (Micronair AU 4000 and AU5000 rotary atomizers are preferred) be set to produce droplets with VMD (sometimes referred to as DV0.5) of around 80-120 µm.

Operations

Aircraft with AU 5000 units flying at the upper end of the range may benefit from the addition of small deflector rings to minimize any sheering effect that would prevent the formation of controlled droplet sizes as the spray leaves the rotating sleeves.

Optimum Droplet Sizes in Deciduous Forests

As in coniferous forests, there are advantages and disadvantages to finely atomizing an application of Btk. Although small droplets can provide thorough distribution in the forest canopy, this must be balanced by the possibility of larvae obtaining sublethal doses from droplets that are too small. Such doses may inadvertently protect the larvae by inhibiting feeding, preventing them from ingesting further Btk deposits until they recover. Studies show the size of the droplet required for effective mortality of Gypsy Moth larvae increases with larval instar, so that although droplets in the 100 µm range (VMD) are optimally effective against second instars, their size should be increased to 125-150 µm range if the population is in the third and fourth instar stage.

Droplets larger than 200 µm should not be applied because the resulting low droplet densities reduce the chance of effective dose acquisition by larvae. (See **Figure 4.4**)

Field studies on Gypsy Moth performed by the Northeast Forest Aerial Application Technology (NEFAAT) Group in the early 90s with undiluted Foray 48B sprayed with different atomizers showed that a range of droplet sizes will provide a similar level of control on second and third instar larval populations. Small orifice hydraulic nozzles (Flat Fan 8004 and 8004 Twin-Jets), as well as Micronair rotary atomizers, all produced droplets in size classes shown to be effective.

Figure 4.4: Strategies to Decrease Droplet Size

HYDRAULIC NOZZLES	WIND-DRIVEN ROTARY ATOMIZERS	ELECTRICALLY OR HYDRAULICALLY POWERED ROTARY ATOMIZERS
Smaller orifice size, increase boom pressure, orientation to 45° forward	Increase unit rpm, decrease blade angle; in slower speed helicopters, use a longer blade	Increase rpm or change sleeve size

We recommend that for the control of Gypsy Moth and other broad leaf defoliators, atomizers should be selected and adjusted to deliver droplets in the 100-150 µm VMD range. If using hydraulic nozzles, use the smallest orifice flat fan nozzles which can deliver a sufficient volume with medium-speed agricultural aircraft (100-120 mph).

Higher speed single engine airplanes (e.g. Thrush® 660, Air Tractor® 802, etc.) should be equipped with the AU4000 atomizers as their working range may exceed the safety limits with the AU 5000 units. Please consult with Micronair regarding your aircraft and its flight speed when choosing the correct rotary atomizers to install.

Rotary atomizers are recommended, especially in slower aircraft. The shear atomization – which aids the production of small droplets by hydraulic nozzles – is not adequate at low airspeeds. If operating at the flow capacity limits of your nozzles/atomizers, it would be wise to modify the numbers and/or types of atomizers fitted to your aircraft.

If you are having to increase the VRU setting of the Micronairs to their highest setting, consider adding more atomizers.

If you are working considerably below 40 psi (275 kPa) for hydraulic nozzles and cannot reduce their number, consider changing the orifice size, so that the adequate atomization, which is obtained at higher boom pressure, is assured.

If you are having to increase the VRU setting of the Micronairs to their highest setting, consider adding more atomizers.

If you are working considerably below 40 psi (275 kPa) for hydraulic nozzles and cannot reduce their number, consider changing the orifice size, so that the adequate atomization, which is obtained at higher boom pressure, is assured.

4.5 UNDILUTED AND DILUTED APPLICATIONS

Foray may be applied as undiluted or diluted sprays to control Gypsy Moth larvae. Traditionally, Btk formulations were diluted with water to provide a spray volume in the range of 96-128 oz/acre (7.5-10.0 L/Ha).

Significant advances in application technology and formulation science have shown that undiluted applications are generally superior to diluted applications given that proper atomization and adequate deposition are achieved.

Dilution of the Foray spray with water can be advantageous in certain circumstances. For example, when controlling Forest Tent Caterpillar, as this larvae is very sensitive to Foray Btk toxins, very low rates of insecticide are required to control the larvae. Smaller wood lots or individual forested residential areas may also benefit. For these applications, dilution of Foray with water (1:1 – 1:2 ratio) may provide a higher volume of spray material, making a good and thorough canopy deposition easier to achieve.

Performance

Undiluted Foray applications are generally superior to diluted applications given that atomization and adequate deposition are optimized.

Photo Courtesy of ENVIROFOTO / SOPFIM

The effectiveness of undiluted ULV applications of Foray on other lepidopteran pests such as elm spanworm, cankerworms, and other native species has also been successfully demonstrated. Undiluted applications have been shown to provide significant improvements in aircraft payload efficiency, improve spray timing and help reduce application costs.

Micronair Rotary Atomizers and Droplet Sizes

Figure 4.5 shows wind tunnel data for droplet sizes (DV 0.5) for undiluted Foray 48B formulations applied using a Micronair AU5000 atomizer. The charts and figures provided in the Micronair AU5000 operator's handbook are based upon the atomization of water, and they encompass all possible applications in agriculture, vector and forestry spraying.

4.6 LANE SEPARATIONS

Lane separation (or the effective swath width) is the offset distance between parallel tracks flown by a spray aircraft. It represents the span under the aircraft and parallel to the flight path which receives an effective deposit of the pesticide.

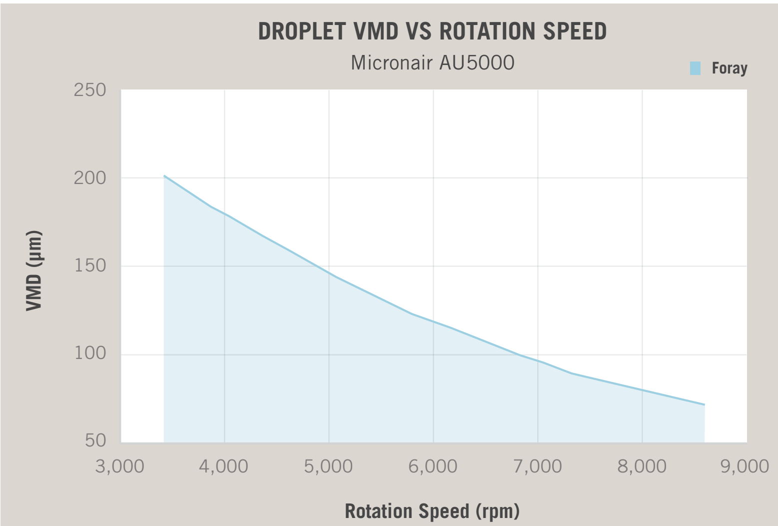
When accurately flown under most weather conditions, there will be no significant over- or under-application if this lane separation spacing is maintained. Note though that the effective swath is not the total swath, rather, it is that cross section portion of the spray deposited that is considered as adequate to provide a lethal dose to the larvae and to ensure uniform and homogenous coverage of the forest canopy.

The lane separation of aircraft varies depending upon the aircraft/spray system parameters (release height, atomizer setting, aircraft speed), the pesticide formulation, as well as factors such as meteorology and forest canopy architecture.

Pattern testing of aircraft over flat ground as well as in forests has shown that droplet size is one of the major factors which can affect the lane separation distance.

Smaller droplets are affected more by the aircraft wake and can travel greater distances. Wind direction has little effect on increasing the effective swath width. Although the finest droplets may drift long distances, they do not form part of the effective swath as there is very little biological activity in this portion of the droplet spectrum. For convenience, lane separation determinations are normally performed by flying the aircraft into wind so that the lateral drift of deposit is a function of the aircraft's wake rather than wind-borne distribution.

Figure 4.5



Please refer to the Micronair Operators Handbook and Parts Catalogue for more information.

The technique most used to measure the swath width is to assess deposit of dyed droplets on collectors, usually flat cards. White coated card stock (commercially known as Kromekote®) has been the most popular collector.

ⓘ **APPLICATION TIP**: A droplet density of between 5 - 20 droplets per square centimeter (range dependent on product potency) has been commonly held as a standard for an effective Btk deposit for field use. This numerical standard is now rarely used since the sole determinant of an adequate spray pattern. The number of fine droplets which are caught by flat cards is greatly influenced by the wind speed, and can give skewed readings under still conditions. With the increased use of image analysis pattern testing, it is more common to measure swath patterns in application rate units of gal/acre or L/Ha.

Although measuring spray deposit on the target foliage would provide a more meaningful representation of swath width, this requires more sophisticated measurement techniques and is generally not practical for most operational programs.

Consequently, despite their shortcomings in measuring fine droplets, the glossy-surfaced Kromekote-style cards are still a very cost-effective method of quickly assessing the spray pattern produced by an aircraft. Any reputable commercial printer can provide such cards. Request high-gloss coated card stock, coated on both sides and cut into convenient sizes of 5 inches x 3 inches (12cm x 8 cm), etc. Contact Valent BioSciences for additional information if required.

In general, for most forestry applications, the achievable swath width is approximately 3x the wing span/rotor diameter of the aircraft. For ultra-

low volume applications to large forested treatment areas, aircraft may fly at a higher altitude and achieve a wider swath width. This should be confirmed with calibration and characterization flight tests prior to the application.

Figure 4.7 presents various swath width ranges for a variety of aircraft and atomizers that have been used effectively in forestry programs with Btk formulations. Increasingly, many programs require the use of rotary atomizers for forestry work, but some allow hydraulic nozzles, although typically a shorter lane separation is then assigned. The US Forest Service and several states and provinces have performed extensive swath pattern testing using a variety of spray pattern analysis technologies. Multi-engine aircraft data were provided by the Forest Service and the US Air Force, based on similar studies.

The availability of high-capacity single-engine application aircraft has meant that older multi-engine aircraft are rarely used in modern forest protection programs. Where a range of lane separations is shown in **Figure 4.7**, the upper end of the range was obtained with aircraft equipped with Micronair rotary atomizers.

4.7 AIRCRAFT GUIDANCE

Over the last two decades, traditional aircraft navigation techniques (balloons, spotter aircraft etc.) have given way to the advent of satellite-based technology. Commonly referred to as GPS (Global Positioning System), the location of any feature, natural or man-made, can be confirmed through the use of intersecting signals from a network of geo-stationary satellites.

Not only can locations be identified on the earth's surface by latitude and longitude, aircraft may use these satellite transmissions to plan and follow a specific flight path above the earth's surface. Although accurate enough for waypoint navigation, the GPS system doesn't offer the level of accuracy required for proper spray aircraft guidance.

Performance

COVERAGE TIPS: Btk must be ingested by larvae to be effective. To ensure larval mortality, an accurate application is required to ensure an adequate dose of Foray is deposited across the canopy.

An extra signal, called differential correction, is necessary to achieve the precision required. When the satellite signals are differentially corrected (DGPS), an aerial application aircraft can follow a swath width (lane interval) to accuracies within two meters. DGPS systems calculate the aircraft's position (latitude, longitude and elevation) several times per second and use these calculations to provide the aerial applicator with highly accurate and sophisticated guidance. DGPS navigation has proven itself in the forest protection industry. Ground-based survey and assessment crews now use inexpensive and portable hand-held GPS systems to establish treatment boundaries or to locate assessment plots in the forest. No Spray Zones are also easily marked.

Aerial applicators, using the same basic technology as the portable hand-held GPS units, rely upon sophisticated instrumentation and cockpit displays to guide their aircraft across the spray block. Guidance

lights and small computer style screens provide continuous navigational assistance to the pilots by marking every swath and displaying the position of the aircraft in or near the treatment area. The most recent development in this technology is conjugation of the aircraft's spray system (flow control) with the DGPS, ensuring that an accurate application rate is maintained across the spray block regardless of the aircraft's groundspeed. Many DGPS units also provide a spray ON-OFF function that shuts flow off as the aircraft exits the spray block or while flying over No Spray or Exclusion Zones.

There are several manufacturers of high quality DGPS technologies available and approved for use in forest spraying programs. The most commonly used systems (AG-NAV, MapTrac and SatLoc) offer precise aircraft navigation along with flow control to compensate for air speed/ground speed fluctuations as well as auto ON-OFF features to enhance deposition accuracy.

The most advanced systems also offer real time remote flight tracking whereby the program managers may view progress and flight patterns of individual aircraft in the treatment area from a ground-based, Wi-Fi connected computer.

A list of DGPS manufacturers is included in Appendix 1: Sources & Resources

Sustainability

DGPS systems calculate the aircraft's position (latitude, longitude and elevation) several times per second and use these calculations to modify flow rate to not waste etc. Accuracy within less than 1 m.

Spray Pattern Modeling

In the 80s and 90s, the US Forest Service invested a considerable amount of resources to create a computer program that could accurately predict aircraft spray patterns and deposition within a forest canopy when given inputs on the aircraft, atomizers, spray mixture properties, weather details, and spray canopy structure.

The program that emerged from those efforts exists either as AGDISP™—which models the 'near wake' deposit (the spray pattern closest to the aircraft) but not drift or canopy deposition, or FSCBG—which adds a Gaussian plume model to AGDISP to simulate the latter effects. A third derivative of AGDISP is Ag-Drift®, which was created by the Spray Drift Task Force to model drift away from the site of application.

All three programs require some instruction before they can be used to model aerial spraying situations. Although they can be made to run with minimum effort, the maxim that a little knowledge is a dangerous thing should be taken to heart when running these powerful programs for the first time.

These models are all available at no charge. See www.continuum-dynamics.com/pr-agdisp.html cfs.nrcan.gc.ca/projects/133

The most recent model is the 'Spray Advisor', which is a comprehensive product developed by the US Forest Service incorporating many of the features in AgDisp and earlier models. However, the software that drives this model is becoming outdated; please consult the US Forest Service for further information on the availability of this software.

4.8 SWATH PATTERN ANALYSIS

In many forestry projects, it is common practice to examine the spray pattern of contracted spray aircraft before application to ensure that the aircraft has been optimally configured. Although established methods using microscopes to analyze cards exist, the last 20 years have seen the development of rapid and more powerful methods of measuring the deposition obtained on a line of cards laid out on the ground perpendicular to aircraft flight. Many of the earlier technologies have been superseded by advances in image analytics. Please contact Valent BioSciences if you need help searching for older or newer technologies.

Currently the REMSpC Stainalysis program is the most commonly used droplet size assessment technique. Valent BioSciences has made arrangements with the developers of this tool (REMSpec) to make it available online, free of charge. Visit http://www.remspc.com/Stainalysis/

Figure 4.7 Examples of Lane Separation for Btk Applications (Single Aircraft, Gypsy Moth Control*)

AIRCRAFT	LANE SEPARATION RANGE	
Single-Engine Fixed Wing Aircraft	**ft**	**m**
Piper Pawnee	65 - 100	20-30
Piper Brave	75	23
Cessna Ag Truck, Ag Wagon, Ag Husky	75 - 100	23-30
Ag Cat Model B	100 - 130	30-40
Antonov An-2	130 - 165	40-50
Thrush SR2 - Turbine	150	45
Thrush SR2 - Piston	150	45
PZL M-18 Dromader	150 - 175	45-53
Air Tractor 400 Piston	150	45
Air Tractor 402 Turbine	150	45
Air Tractor 502 Turbine	175	53
Air Tractor 602 Turbine	175	53
Air Tractor 802 Turbine	200	60

AIRCRAFT	LANE SEPARATION RANGE	
Multi-Engine Fixed Wing Aircraft	**ft**	**m**
Beech 18	150	45
DC-3	225	75
DC-4, DC-6, DC7	400	120
C-130	400	120
Rotary Wing Aircraft	**ft**	**m**
Bell 47G	75	23
Hiller 12E	75	23
Hughes/MD 500	75 - 90	23 - 27
Kamov Ka-26	80 - 90	24-27
Bell 47G Soloy	100	30
Hiller 12E Soloy	100	30
Bell 206 Jetranger, Long Ranger	100 - 120	30 - 36
Mil Mi-2	100 - 130	30 - 40
Bell 204/205/212/412/ UH-1	150	45

*Swath widths in programs for other pests may be larger. Please contact your Valent BioSciences Forest Health representative for more information.

With the advent of superior image analysis technology, there are numerous technologies that can be adapted for spray pattern analysis. You may also consult Valent BioSciences for any updates on these technologies and tools.

Droplet Spread Factors

Image analysis of spray deposits uses a spread factor to convert droplet stain sizes obtained on target cards to the diameters of the droplets that created the stains.

The spread factor is a ratio of droplet diameter to stain diameter. Thus a 100 μm droplet giving a stain diameter of 200 μm is said to have a spread factor of 0.5. Multiply the stain by the spread factor to determine the droplet size.

Some references use the inverse of 0.5 (2.0) to refer to the spread factor. If the spread factor is greater than 1.0, inverse notation is used. In making quick and simple assessments in the field, a spread factor of 0.5 (2.0) may be used for diluted and undiluted Btk sprays.

Tracer Dyes

To perform droplet deposit analysis using the glossy white spray cards, a dye must be added to make the formulation visible. A range of soluble food dyes can be used with aqueous Foray formulations and several manufacturers now produce special dyes to make applied sprays less visible on certain surfaces (i.e. green dye for turf grass spraying) and even dyes specifically for pattern analysis. Refer to Appendix 1: Sources and Resources for further information on the sources of dyes. Dye usually has to be incorporated at 1.5 to 2.0% (volume/volume) to allow for good visual acuity of smaller droplets.

Check with your nearest dyestuff supplier for a recommendation of a dye color and concentration that is suitable for spray pattern analysis; contact information is also included in Appendix 1: Sources and Resources. Please note that some of these tracer dyes are often available at a lawn and garden center, a big box store, or an agchem supply outlet.

Water-Sensitive Papers

One major alternative to using white target cards with added tracer dyes is the use of water-sensitive paper strips.

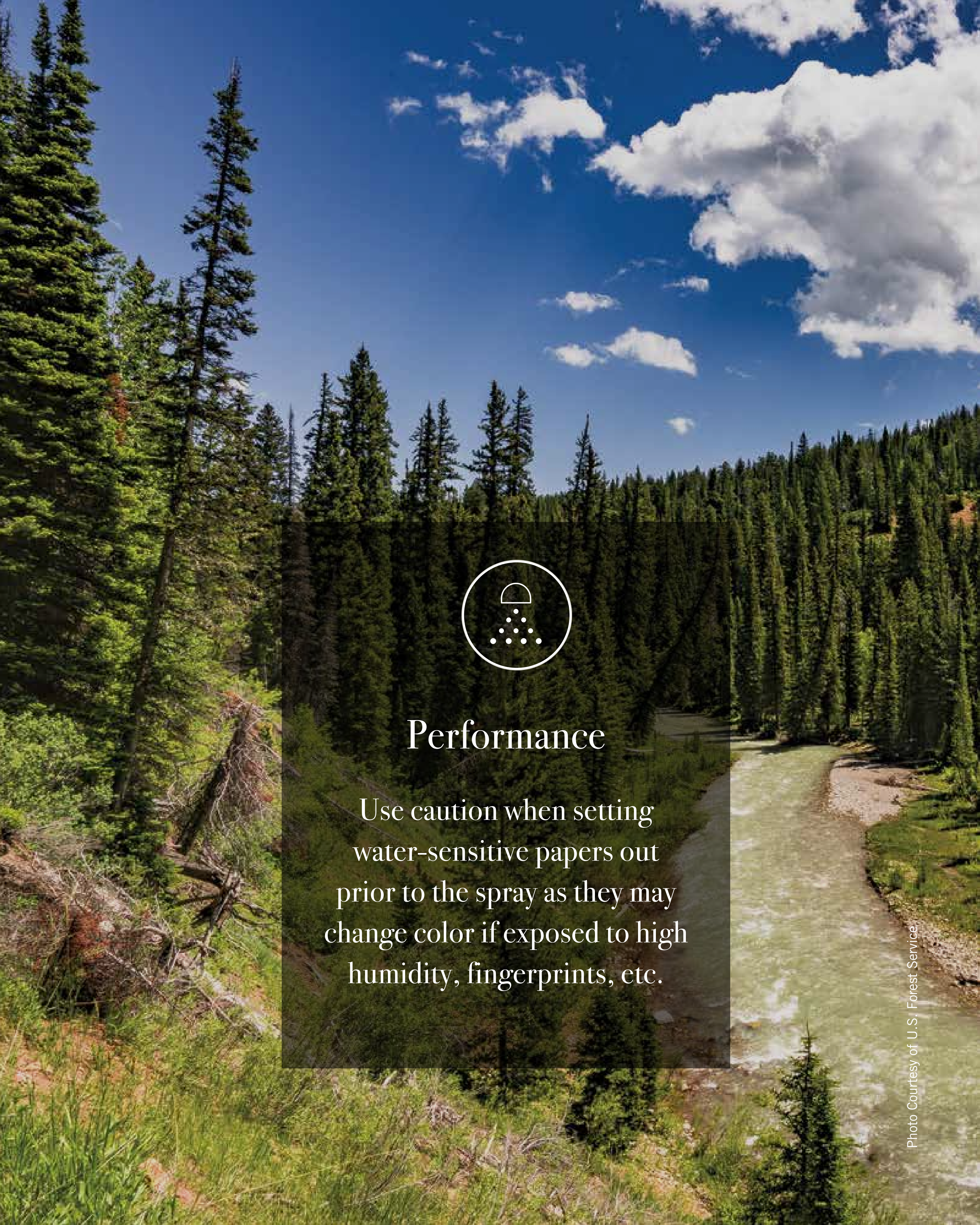
These cards have been developed specifically to react to aqueous formulations. Water sensitive cards work well with undiluted aqueous formulations, and with all diluted formulations. Following exposure to the spray droplets, the yellow papers will be stained blue.

What is a Spread Factor?

Droplets spread out upon impact so analysis requires a spread factor to correct for the difference between stain size and droplet size. The spread factor relates diameter of deposited drop to stain diameter (ratio).

Spread factor can vary with product used, tank mix, dye concentration, drop size, Time, Relative Humidity and type of collector surface (Glass, Petri dish, Kromekote card, sensitive cards).

Example: A 100 μm droplet giving a stain diameter of 200 μm has spread factor of 0.5 (2.0). Multiply the stain by the spread factor to come up with the droplet size (or vice versa).

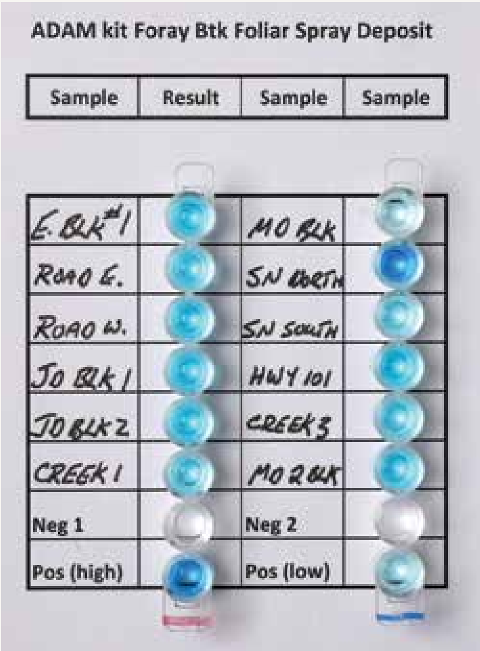


Performance

Use caution when setting water-sensitive papers out prior to the spray as they may change color if exposed to high humidity, fingerprints, etc.

Photo Courtesy of U.S. Forest Service

ADAM KIT TEST RESULTS



This shows the results of an ADAM kit application. The two bottom cells show a high level of Foray foliar deposit – labeled "Pos (high)" and a low level of deposit – labeled "Pos (low)". "Neg 1" and "Neg 2" cells should remain clear to ensure accuracy of sample processing. No color in any of the upper six cells would indicate that there was an inadequate deposit of Foray. The intensity of the blue reflects the amount of Foray deposited. The intensity of color in upper test cells should be greater than or equal to the Pos (low) cell.

Water-sensitive cards are produced in two sizes by Syngenta® in Switzerland and are available from a variety of sources including Spraying Systems Company. (see Appendix 1: Sources & Resources).

Accurate Deposit Assessment Methodology (ADAM)

Adequate spray deposition, penetration and coverage of the forest canopy are essential prerequisites for treatment success. Spray deposition has been traditionally assessed by visually analyzing spray deposit cards that have been placed in the treatment area. Colored dyes have also been routinely incorporated into the Foray formulation immediately prior to the application to assist in this visual assessment.

Spray cards, while a great tool for use in aircraft calibration and characterization, have shown to be an unreliable measure of spray deposit actually found on the foliage. More importantly, none of the traditional spray card technologies can accurately measure spray deposit remaining on the foliage after an unforeseen postspray rain event.

To this end, Valent BioSciences developed the ADAM (Accurate Deposit Assessment Methodology) kit to help program managers confirm the reliability of spray card analysis.

Dyes cannot be used on an operational basis due to several considerations including high cost, the significant effort required to place and retrieve spray deposit cards in the treatment area, and the potential for staining buildings or other objects located in forested, residential treatment areas.

The ADAM kit is based upon Enzyme Linked Immuno-Sorbent Assay (ELISA) technology to more accurately determine the presence of Foray spray deposit on conifer or deciduous foliage.

There is a kit for each type of foliage. This patented technology is produced by a reputable crop diagnostic firm using key components supplied by VBC to link the foliar spray deposit to the Btk forestry formulations produced by VBC. No laboratory equipment is needed. All essential components, including simple lab tools (forceps, etc.) are included in the kit. Twelve dozen foliage samples can be processed in 2 to 2.5 hours and the results are immediately visible and expressed in deepening shades of blue reflecting the relative level of Foray Btk deposited on the foliage.

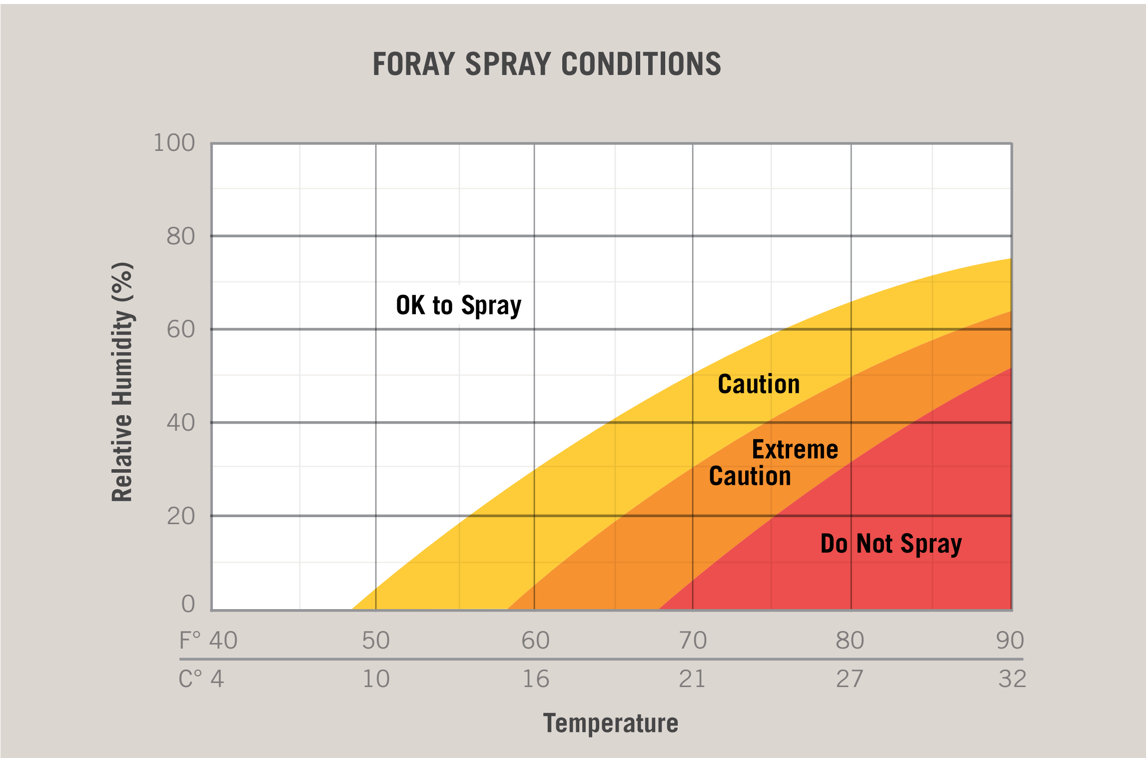
The ADAM kit has proven to be a valuable tool for forest protection program managers, especially in determining the need for a re-spray in the case of unexpected post-spray rainfall in the treatment area.

For further information on the ADAM kit, please contact your Valent Biosciences representative.

4.9 WEATHER CONDITIONS FOR SPRAYING

The weather has a tremendous impact on the aerial application process. Wind, temperature, and relative humidity (RH) affect how the spray is deposited on the forest canopy; temperature affects the feeding activity of the caterpillars, and sun and rain both serve to reduce the longevity of the Btk deposit.

Figure 4.9 Temperature/Relative Humidity relationship showing safe and unsafe meteorological conditions for spraying Foray.



Wind

Two considerations drive forest Btk application decisions: maximizing spray deposit in the forest canopy and minimizing spray drift outside the target area.

Wind is an factor affecting both variables.

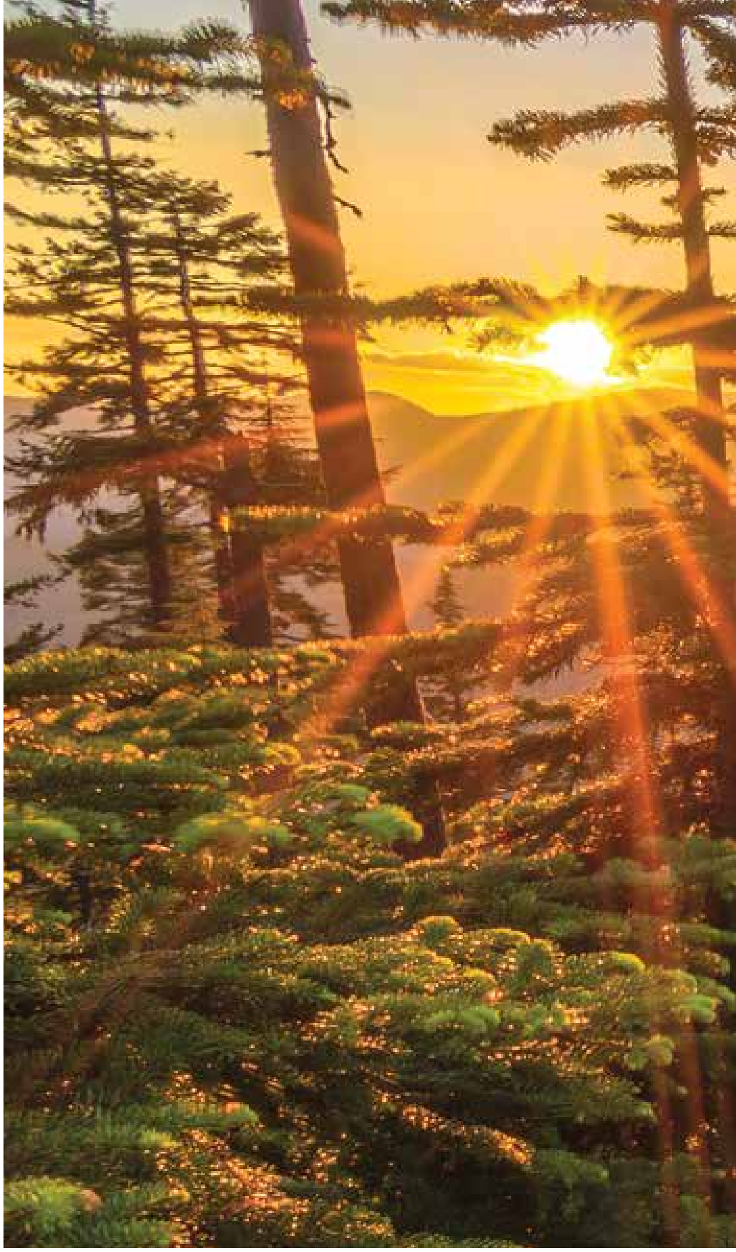
The best spraying conditions are under light to moderate wind with neutral stability, such as during cloudy or overcast days. Stable atmospheric conditions result in good foliage coverage in partly expanded broad leaf canopies, but carry the risk of drift of fine droplets, with little dispersal as the spray cloud drifts downwind.

The atmosphere shows a stable condition when air movements are dampened by the temperature gradient in the air. A temperature inversion, where a layer of cold air lies below a layer of warmer air after a cold clear night is a typical case of stable air. An unstable atmospheric condition occurs when any air movement is strengthened by the temperature gradient. A wind gust may start an upward movement which will then continue as a thermal. Neutral conditions imply that any air movement will not be dampened or magnified by the state of the atmosphere.

Temperature & Humidity

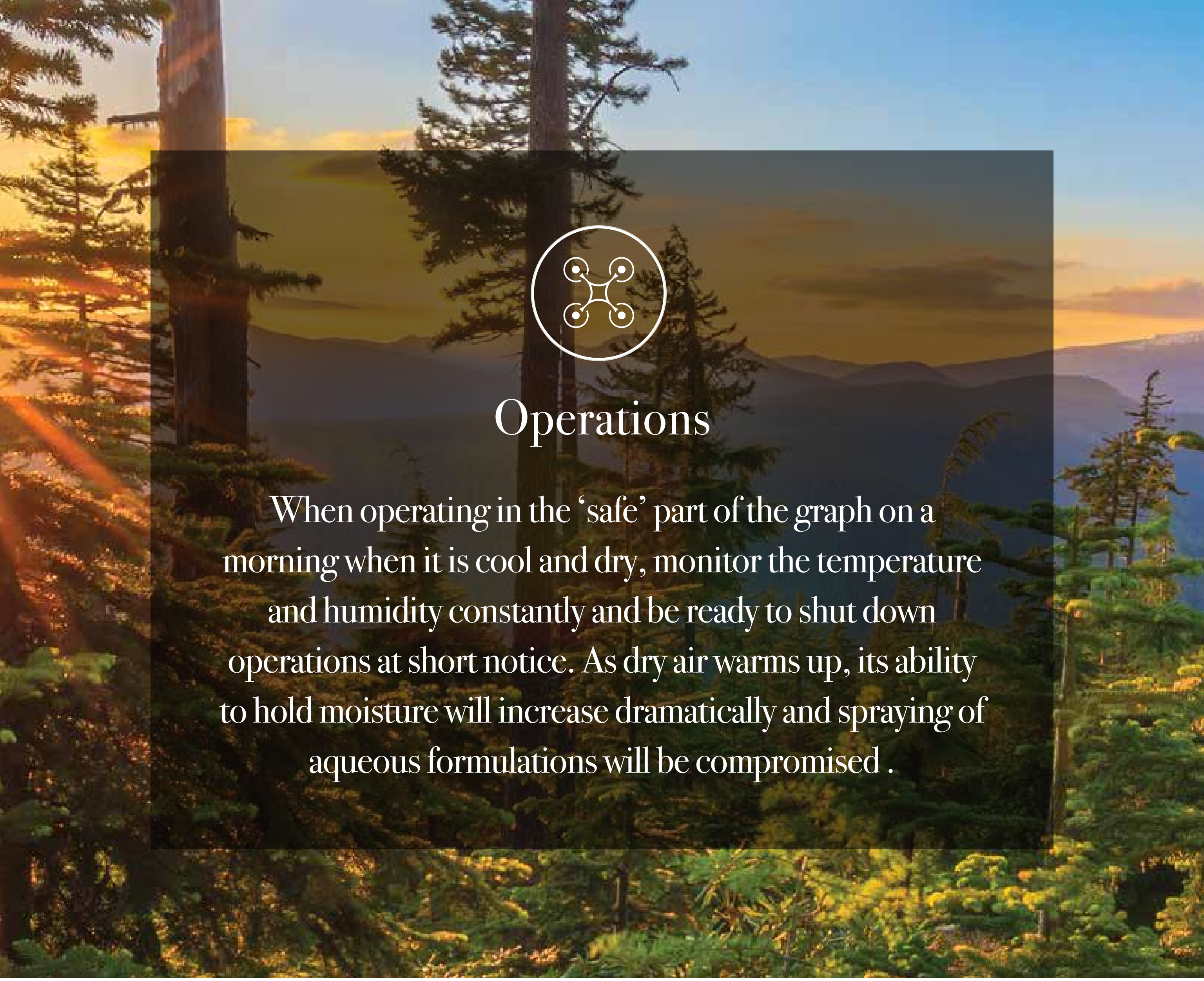
Foray aqueous formulations are designed to be highly resistant to evaporation under dry conditions but should never be sprayed under extreme conditions. Such extreme conditions are defined by a combination of temperature and humidity.

Relative humidity alone is not a valid parameter for determining whether or not you can spray. Cool air can be very dry, but because of its low temperature, it is not able to hold much moisture and does not substantially affect the evaporation of the water content of droplets.



In response to numerous subjective opinions on what is appropriate ‘spray weather’ and the use of seemingly arbitrary temperature and humidity conditions (e.g. 75° F, 50% RH), meteorological researchers at Penn State University were requested to develop a temperature/relative humidity reference chart that could be used in support of aerial spraying of Foray Btk formulations.

Figure 4.9 shows the risks of spraying Foray aqueous formulations under different temperature/



Operations

When operating in the 'safe' part of the graph on a morning when it is cool and dry, monitor the temperature and humidity constantly and be ready to shut down operations at short notice. As dry air warms up, its ability to hold moisture will increase dramatically and spraying of aqueous formulations will be compromised .

relative humidity conditions. The figure is advisory in nature and assumes that the correct droplet size is selected for the spray operation.

Because all Foray formulations are manufactured to be resistant to evaporation, the most common reason for shutting down spray operations during the day is vertical movement of air in thermal convection cells, which form after the air close to the ground has been heated by the sun. Applications made under such conditions can result in a highly variable coverage in the forest canopy and significant (but highly dispersed) spray drift.

This chart is also available in an electronic format that allows temperature and humidity readings to be plotted over time, allowing program managers the ability to detect a trend in weather during a spray operation and make appropriate decisions to continue or stop the operations due to current temperature and relative humidity conditions.

Rain & Dew

Formulation components of Foray provide good weatherability of spray deposits, particularly with undiluted applications. However, rainfall (1/10” [2.5 mm] or more) within several hours after spray application can reduce the biological activity of the spray deposit. It is recommended that a 6-hour period free of precipitation be allowed for the spray deposit to dry and adhere to the foliage.

Foray should not be applied when rain is forecast within six hours. However, once the Foray deposit is dry, it is difficult to dislodge the droplets from the foliage surface.

If early morning dew (or previous night’s rainfall) is sufficient to wet the foliage to the point of run-off, it is advisable to wait for a mild breeze or for warmer temperatures to dry the surface of the foliage before starting to spray. A small amount of foliage wetness (which does not produce run-off) will not affect the quality of the spray. However, if rainfall is forecast, ensure that the spray deposit has adequate time to dry before any precipitation. In general, six hours drying/feeding time is considered as adequate in these circumstances.

This cautionary 6-hour time interval can be reduced in certain circumstances. For example, if the spraying is completed in the morning and the spray deposit has had ample time to dry on the foliage, especially in sunny conditions, an afternoon rain shower should not have a negative impact upon the spray.

However, if the application was made during cool and cloudy weather which deteriorates into showers later that day, there will have been insufficient sunlight to dry the spray deposit adequately.

Performance

A 6-hour period free of precipitation should be allowed for Foray spray deposits to adhere to the foliage and dry.

There is a great deal of subjectivity in the interpretation of the degree of foliage wetness that may prevent an aerial application. This lack of standardization led to the development of the Domino Foliage Wetness Scale for use by ground-based observers during Gypsy Moth control operations in Wisconsin. Five levels of leaf moisture were identified and are now used by ground observers to assess foliage wetness in the treatment areas.

DOMINO FOLIAGE WETNESS SCALE

1. **Dry**: No moisture visible or felt when limb is shaken or foliage is rubbed with fingers.
2. **Damp**: Moisture can be felt when rubbing foliage.
3. **Moist**: There are only several droplets of water coming off a limb when it is shaken.
4. **Wet**: It has rained at some point during the night. When you shake a limb, a fair amount of water falls, comparable to a sprinkle.
5. **Drenched**: It has recently rained; when a limb is shaken it simulates a steady rain.

(John Domino, Wisconsin Department of Agriculture, Trade and Consumer Protection.)

Cold Weather Operations

Aerial applications over forests are usually conducted in a forest canopy in which the new foliage has at least partially expanded and ambient temperatures encourage larvae feeding. At higher latitudes, such conditions may still provide considerable diurnal temperature variations, with the possibility of near freezing temperatures occurring over night.

A few common sense procedures minimize possible flow problems when applying Btk in cool weather conditions:

- If possible, store product in bulk, as it is less likely to experience changes in temperature and viscosity.
- Before loading aircraft, recirculate any product that may be in loading hoses back into the bulk storage containers. This will ensure that all product is of a similar viscosity, and allows for a quick check of equipment before the aircraft is loaded with product.