AERIAL SPRAY TECHNOLOGY: POSSIBILITIES AND LIMITATIONS FOR CONTROL OF PEAR THRIPS

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Abstract

The feasibility of using aerial application as a means of managing a pear thrips infestation in maple forest stands is examined, based on existing knowledge of forest aerial application acquired from theoretical and empirical studies. Specific strategies by which aerial application should be performed and potential problem areas are discussed. Two new tools, aircraft characterization equipment and an aerial spray program mission planning computer software package are briefly described as examples of technology transfer which have been used to improve aerial applications in forests.

Introduction

This paper examines the feasibility of using aerial application as a means of dealing with the infestation of pear thrips in maple forest stands. It approaches the problem from theoretical and empirical standpoints based on knowledge that has been acquired on aerial application and suggests specific ways in which aerial application should be performed. No presumption is made that this is necessarily the correct approach, nor that it should be done in isolation, without integrated pest management considerations. Aerial application spray trials of specific insecticides for pear thrips management have been performed by others, and will be reported during this conference (H. B. Teillon & B. L. Parker, this publication).

To use an insecticide effectively for controlling a pest, the following facts should be known: (1) the distribution and behavior of the susceptible stage of the pest in space and time, (2) the approximate lethal dose required, (3) an efficient way of ensuring that an adequate number of toxic doses are deposited on the biological target with minimum contamination of non-target biomass.

Little is known about the behavior of pear thrips, *Taeniothrips inconsequens* (Uzel). However it would appear that the most vulnerable stage of the insect is the adult female, which emerges from the ground at the time of bud break, and flies to the bud. The timing of an application of pesticide would need to be exact to assure that the presence of a lethal concentration of insecticide coincides with the entry of the adult into the bud. Control of later larval stages that feed on newly expanded leaves would give a longer time frame. Once the biological target has been defined, in terms of its location, growth stage and timing, it is necessary to examine ways by which the insecticide can be applied with minimum drift outside the area of treatment. It is the definition of the methods that are used to optimize this process which are the subject of this paper.

Objectives

- To examine and define possibilities and limitations of aerial application for controlling pear thrips.

- To approach the above question by extrapolating from existing knowledge of aerial application in broad-leafed and coniferous forests, and from theoretical considerations.

- To review available tools that provide aerial application projects with aircraft spray pattern assessment and computer planning and operation costs.

Insecticide Application Considerations

Target definition. When the adult pear thrips emerges from the ground, she is thought to fly to the tree buds directly, probably settling on several twig sites before reaching her final destination. The insect then squeezes her way into the bud, where feeding takes place. It is thought that the female exhibits considerable exploratory behavior, moving around the bud before she commences her entry. The most likely ideal target therefore would be the bud and adjacent twig. The bud would have to be sprayed before the adult female enters it; the adult would have effective protection from the insecticide after entering the bud, unless a systemic pesticide was used. To enable reasonable planning for a spray project and unexpected changes in weather, the areas would have to be sprayed up to a week before the known likely emergence date. Therefore an insecticide with some degree of residual action would have to be used.

Toxic dose. Carbaryl (Sevin) is one of the few insecticides approved for spraying in maple forests. The LC_{95} of carbaryl is not known for pear thrips, but for the purpose of this paper has been conservatively assumed to be between 10 and 100 ppm. This figure can be used to calculate the number of LD_{95} doses in a range of droplet sizes typically produced by commercial spray equipment. These estimated numbers of toxic doses can then be used in guidance of the selection of spray parameters, namely the application rate and droplet size to be used in the control.

Delivery of pesticide. The accurate delivery of pesticide to broad leaves or pine needles in forest stands is one of the most challenging problems facing the forest pest manager. The factors limiting such accurate application have been summarized (Ekblad & Barry 1983).

Although a few studies of foliage deposition have been made on broad-leafed forests (Yendol et al. 1990), and a larger number on pine forests, no comprehensive studies exist on aerial application projects made on broad-leafed trees before leaf expansion. Orchard spraying is commonly done on leafless trees, but the technique used involves very high application rates on short trees with ground sprayers, and bears little relevance to the situation being considered here.

It is therefore necessary to systematically examine the process of capture of droplets by targets the size of maple tree buds in order to get an indication of how to approach the aerial application problem.

Droplet size considerations. When sprays are aerially applied 15 m (50 ft) above a forest canopy, two kinds of off-target deposition may occur. Large droplets may fall through the canopy, at angles close to the vertical and impact on the forest floor or small droplets may drift away from the immediate target site, at angles close to horizontal without impacting on the buds and twigs. In the former situation unwanted contamination of the forest floor and understory foliage can take place, whereas with the latter situation, the contamination of an area outside the spray site may result.

Work on Douglas fir and other coniferous foliage in the control of spruce budworm, *Choristoneura occidentalis* (Freeman), established that pine needles most efficiently catch droplets below 50 μm, even at low wind speeds (Himel & Moore 1967, Barry et al. 1977). The mean diameter of such a pine needle is around 1.6 mm. Because maple buds and twigs are larger than pine needles (4-5 mm in diameter), the pine tree studies can only be used as broad indicators of application strategy.

Droplets are collected on plant surfaces by sedimentation and impaction. Smaller droplets (less than 100 μm), because of their near horizontal path in winds greater than 2.5 m/sec (5 mph), are always caught by impaction. Studies on impaction of droplets have shown a complex interaction between the size of the droplet, its relative velocity and the obstacle in its path (May & Clifford 1967). Briefly, the collection efficiency of a target (the percentage of drops caught by a target expressed as a proportion of droplets which could be caught) placed in an airstream increases with droplet size and velocity, and decreases as the target increases with size.

These factors can be brought together in one parameter, the impaction parameter (P). This parameter is a measure of the likelihood of a droplet striking a target assuming it is being transported towards the target with a windspeed V_o.

$$P = \frac{V_s V_o}{gD}$$

V_o = Windspeed
g = Acceleration due to gravity
D = Diameter of target
V_s = Sedimentation velocity of droplet of diameter D

Empirical work has been done to measure catch efficiency (*E*) for various values of the impaction parameter (P) for various shapes of targets by May & Clifford (1967). This work has been recently added to by Spillman & Tongpuy (1987) to take into account variations in turbulence around a target as target size increases. What this means is that if the target dimension and wind speed are known, it is possible to determine what size range of droplets would be able to be caught by the forest canopy.

Of course the airflow inside a canopy is never constant, and the above discussion can only be used as a guideline. Nevertheless, use of such aerodynamic calculations is a good starting point. Table 1 shows calculated droplet sizes which give a high catch efficiency (70%) for different cylinder (twig) diameters at three different wind speeds. It is apparent that even in light winds, small droplets can be caught by twigs. The theoretical data presented in the table would indicate that droplets of 80 - 100 μm would be suitable.

But what about drift? An 80 μm droplet sediments at 16 cm/sec. During the time it takes a droplet to fall from the spray height (typically 15 meters (50 ft) above the canopy) to the top of the forest canopy, one might think it would not have drifted very far. In fact, this is often not the case under commonly occurring weather conditions.

Table 1. Droplet sizes corresponding to capture efficiencies of 70% on different sized cylinders for three different wind speeds

Cylinder diameter (mm)	Windspeed (m/sec)	Minimum drop size (μm)
2.5	1.0	51
2.5	2.5	10
2.5	5.0	7
5.0	1.0	96
5.0	2.5	45
5.0	5.0	10
10.0	1.0	148
10.0	2.5	85
10.0	5.0	56

Droplets sprayed over forests are dispersed by two main mechanisms, sedimentation and turbulent dispersal. Large droplets (greater than 300 μm) have a high sedimentation velocity (V_s), and can be deflected by the turbulent air found within forest canopies. Although moving rapidly, such air behavior would not markedly affect the position of the droplet in relation to its point of release. Smaller droplets have much lower sedimentation velocities, and can be entrained in any turbulent air created by the roughness of the canopy. In other words, the droplet goes where the wind blows. As wind speed increases, the turbulent velocity increases also, and the size of the droplet that is dispersed by the turbulent mechanism (instead of sedimentation) increases. For example, at wind speeds of 1 m/sec, a 100 μm droplet may behave like a large droplet in a forest canopy, essentially reaching the ground through sedimentation. The same droplet dispersed in a 5 m/sec wind however will behave as a small droplet, through entrainment in the turbulent eddies. Such droplet behavior has direct implications on determining which kind of weather conditions should be used for application.

Toxicity of pesticide droplets. The total number of droplets required to provide a high probability that each bud has several toxic doses which would either be ingested or transferred to the insect through physical contact can be broadly estimated. From the previous studies on crops and forests, it is apparent that it is not possible to get an even distribution of droplets on all targets. Instead the pesticide is distributed across a range of targets in a log normal manner, whereby some targets receive no dose or a minute dose, a large proportion receive a small dose, and increasingly smaller groups of targets receive still higher doses (Yendol et al. 1990, Uk & Courshee 1982).

Assuming that the pattern of distribution of droplets on buds and/or twigs is the same as that obtained by Yendol et al. (1990) on foliage, to ensure that 90% of the buds get at least a certain threshold dose, the mean dose rate has to be about five times the threshold value, assuming that the overall catch efficiency of spray is 70%.

In our present example, taking the tree surface area index (the surface area of the trees growing on 1 ha as 1, and 1 liter of spray material evenly atomized into 90 μm droplets (2.62 X 10 drops), this would mean that 90% of the tree area, including buds would get 26.2/5 = 5.2 drops/cm. Admittedly, there are many assumptions and approximations made in this calculation, but accurate models which could be used do not yet exist in forest spray technology. In practice, atomization would be imperfect, resulting in the under production of ideal sized droplets. Application rates would therefore have to be higher than 1 liter/ha to ensure adequate coverage. A further advantage in increasing the application rate and at the same time decreasing the active ingredient concentration would be improved coverage because of the production of greater numbers of droplets. Such lower concentration material would have the added advantage of being less harmful to non-target organisms.

Droplet toxic dose considerations. Because of the very low weight of a pear thrips adult, 25 μg (Foster & Jones 1915), the amount of pesticide in a lethal dose would be very small. Assuming a LC in the range of 10 - 100 ppm, a 90 μm droplet would have between 600 and

60 toxic doses. During the process of bud entry, as well as movement on the bud surface, a thrips would almost certainly receive a toxic dose through ingestion or contact with the pesticide deposit. It has been noted that pear thrips perform considerable exploratory movement on the bud surface before selecting a location for entry into the bud. Therefore, although much of the bud surface might not be covered with pesticide, the acquisition of a lethal dose would still be highly probable if there were some deposits on the bud. An additional increase of pesticide coverage would take place as carbaryl in an oil formulation (Sevin 4-Oil), which would produce a pronounced spread of the insecticide after impaction on a waxy bud surface. These observations must be confirmed experimentally in the laboratory and in field trials before planning a spray program.

The practice in fruit orchards of spraying very high volumes (up to 5000 liters/ha) against thrips ensures that the whole tree is covered with a very low dose of pesticide, and minimizes undosed areas of the bud. Clearly such a strategy is not possible with aerial application.

Atomizer selection. Atomizers used in aerial application fall into two broad categories; rotary, and boom and nozzle. Rotary atomizers enable the droplet size to be controlled independently of the flow rate and spray boom pressure. They therefore have a considerable advantage over conventional nozzle equipment in that adjustments to the droplet spectrum can be made very quickly from the aircraft cockpit during flight with electrically driven units. With such a system the droplet size can be adjusted as required by circumstances. For example, a larger droplet size would be used in a small plot surrounded by sensitive areas to limit potential drift out of the area. A conventional boom and nozzle system would not have this flexibility.

One of the two main types of rotary atomizers used in aerial application is the air-driven Micronair series. Although excellent atomizers for fixed wing work, they would not be suitable on helicopters making short runs; these units require a finite period of time to get up to speed after a turn. Electrically driven Beecomist units, although not capable of handling large flow rates would be the atomizer of choice in helicopters.

Weather considerations. Wind can be used to increase the capture of droplets in the forest canopy. However spraying in a strong wind will result in an overall drift of the swath of spray in a down wind direction. Although, as stated before, under most conditions it will not result in a large long distance drift of off-target spray. Application under such conditions is difficult, however, and can be dangerous because of the turbulence experienced by the aircraft. It is therefore usual to place an upper limit on wind speed of around 5 m/sec (10 mph).

Clear nights during spring in the mountains of New England can produce a strong temperature inversion, where radiational cooling reduces the temperature of the ground and the air immediately in contact with it. Such conditions cause this layer of air to be very stable which tends to dampen down turbulence, whether caused by the wind or by the wake disturbance of an aircraft performing an application. This resistance to allowing mixing of air is potentially dangerous if small droplets (less than 70 μm) are sprayed. Because no turbulent dispersal and impaction occurs, and lateral dispersion is also dampened, such that slowly sedimenting droplets have the potential of drifting long distances out of the target area without much lateral dispersal before they reach the ground. This condition should be watched for, especially if the material to be applied has a potentially serious effect on non-target organisms.

Spatial and temporal dimensions. Given the likely behavior of the adult thrips entering the bud, the spray window open for an aerial application control program appears to be small, lasting over a period of several days. The implications of such a short window would be that the pesticide to be used for control must have a half life which would give it a residual effect 1 to 2 weeks after spraying. This would allow the spray campaign to be performed over a period of about 10 days.

The use of aqueous sprays applied at high volume rates, although still widely used in agricultural aviation, is becoming a rarity in forestry. The work output of spray aircraft is largely inversely proportional to the volume rate being applied. The application of low volume rates therefore enhances the productivity of the aircraft, resulting in the need for a small number of aircraft to perform the control operation. Selection of aircraft and measuring their potential productivity is covered below.

Sugar maple stands in the forests of Vermont are small, typically averaging 4 ha (10 ac) in size. As shown above, a small (80-100 μm) droplet will be the most effective at reaching the selected target (the tree buds). However it would be difficult to confine a spray with such a droplet spectrum within a narrow area. Larger droplets would limit the amount of off-target drift, but would also increase the contamination on the forest floor. Under such conditions a compromise between size and driftability must be made. It is difficult to say exactly how large the Volume Median Diameter (VMD) of the droplet spectrum would have to be; this is an area that should be investigated empirically with field trials. However, based on droplet sedimentation speeds and the excess number of toxic doses in large droplets, it seems unlikely that the droplet VMD should be larger than 150 μm.

Aircraft type. A square area of 4 ha would have dimensions of 200 X 200 meters. A typical single engine agricultural spray aircraft flying at 160 km/h (100 mph) would cover this distance in 4 seconds. A helicopter would be able to fly slower, and more accurately control its application. In addition, at speeds of 80 km/h (50 mph) the helicopter's rotor wash would contribute to the droplet cloud's penetration of the forest canopy. Helicopters also have the advantage of being able to operate closer to the forest areas needing to be sprayed, and not requiring airstrips that may be located some distance away.

Recent Technological Advances In Aerial Application

In recent years technological advances have become available to users involved in aerial application. Two are described here, aircraft characterization equipment and an aerial spray program mission planning computer software package.

The Swath Kit. One of the most difficult jobs in aerial pesticide application for agriculture or forestry is the characterization of aircraft. The Swath Kit was developed for the USDA Forest Service to make weather and deposit measurements on-site and to display results promptly. It allows the user to quickly pinpoint problem deposit patterns and enables quick adjustments to the spray system configuration to be made. The Forest Service recognized a need for such a tool, as existing equipment was not able to quantify spray deposit, nor provide data on droplet spectra.

Before being used operationally, an aircraft needs to be calibrated. However, the aircraft should not be flown until the shape of the deposit pattern beneath the aircraft has been inspected. This second characterization task is a much more difficult problem if more than a visual inspection of the deposit shape is to be made. It is at this stage that the Swath Kit is employed.

The Swath Kit consists of a portable DOS personal computer fitted with proprietary image analysis and weather sensor equipment which is used as a multipurpose data recorder and analyzer. Operationally it can be divided into three parts according to the three broad tasks which comprise the characterization of aircraft.

1) Weather and Information Recording: The weather is monitored during a spray application to ensure suitable conditions exist for the characterization test. The following parameters are measured: wind speed, wind direction, temperature and relative humidity. These are presented graphically on the computer screen to help the user make quick go/no-go judgments on the suitability of the weather.

2) Deposit measurement: After spraying a card-line, the Swath Kit is used in its image analysis mode to measure the deposit on the cards. Deposit is presented in terms of volume of spray per unit area, number of droplets per unit area and percentage of the surface area covered with spray. In addition, size parameters of the droplet spectrum received by each card are presented.

3) Pattern Assessment: Following card measurement, the Swath Kit is used to assess the pattern of the deposit obtained beneath the aircraft. This is done by modelling the swath and presenting visual and statistical data on overlapped swath patterns. Problems in the pattern, such as the presence of peaks or valleys, and assessment of the effective width of the pattern, can be studied at this stage.

CASPR (Computer Assisted Spray Productivity Routine). CASPR was developed and written by the USDA Forest Service Equipment Development Center to automate a method of comparing productivity and costs. This work has been published as a report entitled "A Method for Comparing Cost & Productivity of Aerial Spray Delivery" by Robert Banaugh, Report 84342807, November, 1984. The program is available from Robert Ekblad, at the USDA Forest Service Equipment Development Center, Missoula, Mont.

The computerized method enables "what-if" scenarios to be run for a series of known spray sites. Different aircraft operating from a variety of airports or airstrips can be modelled to maximize productivity and minimize cost. Large airplanes operating from distant airfields can be compared with smaller airplanes operating from nearby airstrips. The cost of using helicopters can be compared with the cost of using fixed wing aircraft. The program is easy to operate, and has context sensitive help available.

Examples of inputs and outputs are presented in Tables 1 and 2 and Figure 1 to demonstrate the rationale of the model. The modelling data are input into worksheets, dealing with application parameters and spray block dimensions, as well as additional ferrying information between spray blocks.

Table 1. Sample information provided by the Computer Assisted Spray Productivity Routine in the data worksheet

Factor	Data/unit	
Application Rate	0.77	liters/acre
Tank Capacity	662	liters
Swath Width	22.5	meters
Spray Speed	185	km/h
Ferry Speed	209	km/h
Turning Time	35	seconds
Auxiliary Ferry Distance	7.2	kilometers
Number Auxiliary Turns	2	
Touchup Constant	0.1	
Spraying Cost Rate	275	$/hour
Ferrying Cost Rate	275	$/hour
Turning Cost Rate	275	$/hour
Touchup Cost Rate	275	$/hour
Loading Cost Rate	0	$/hour
Loading Time/Cycle	7	minutes

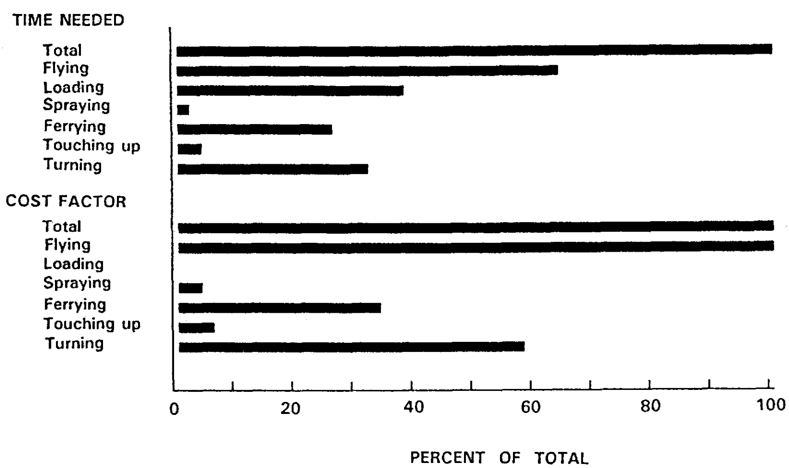

Figure 1. Sample graphic data output provided by the Computer Assisted Spray Productivity Routine from a 0.16 X 0.16 km (0.1^2 mile) block sprayed with a typical single engine fixed wing airplane.

Table 2. Tabular data provided by the Computer Assisted Spray Productivity Routine from a 0.1 X 0.1 mile block sprayed with a typical single engine fixed wing airplane

Factor	Data/unit
Total Spray Area	2.59 hectares
Material Flow Rate	68.81 liters/min
Spray Cycle Distance	17.70 kilometers
Number of Spray Cycles	1
Total Spray Distance	1.13 kilometers
Number of Spray Turns	8
Number of Ferry Turns	2
Number Auxiliary Turns	2
Total Number of Turns	12
Spraying Time	0.35 minutes
Ferrying Time	5.77 minutes
Turning Time	7.00 minutes
Touchup Time	0.74 minutes
Total Flying Time	13.86 minutes

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