SYMPOSIUM ON
FORMULATION AND APPLICATION OF MICROBIALS FOR SPRUCE BUDWORM AND GYPSY MOTH CONTROL

J. A. Armstrong[1] and W. G. Yendol[2]

Introduction

This panel of experts from Canada and the United States has been brought together to discuss control techniques and strategies employed against these important defoliators - the spruce budworm and the gypsy moth. In selecting the panel we have chosen people with experience ranging from research to control. Our panel speakers are:

Bruce McGauley. - Supervisor, Pest Control Section, Ontario Ministry of Natural Resources. He will discuss the spruce budworm spray program in Ontario and the policies that government follows in organizing the spray program.

Michel Pelletier. - Quebec Ministry of Energy and Resources. He will speak about the spruce budworm program in Quebec, and the use of the large 4-engined spray aircraft.

Jack Barry. - USDA Forest Service. He has worked for many years on research programs aimed at furthering our knowledge of spray cloud movement and deposition.

David Smith. - Agricultural and Biological Engineering Department, Mississippi State. His specialty is in the area of droplet deposition on leaf surfaces and development of formulations and application technique to improve deposition.

Paul Fast. - Forest Pest Management Institute Canadian Forest Service. His research interests have been aimed at furthering our understanding of the mode of action of Bacillus thuringienses (Bt) and developing strategies and techniques to improve its efficacy.

Chester Himel. - University of Georgia, Athens. He has been involved in spray physics for a number of years, and today will discuss his research with Bacillus thuringiensis.

William Yendol. - Pennsylvania State University. He will bring to us his current experience in the field of aerial spray applications and will highlight some of the problems and some difficulties with aerial spray applications.

I would like to take the opportunity to welcome our speakers and the audience to this discussion session. There will be opportunities for questions from the floor and we hope that with your active participation we will have an interesting and beneficial discussion. Additionally, it is desired that these discussions on formulation and spray technology will create further research interaction and more clearly focus on those mutually important problems.

SPRUCE BUDWORM SPRAY PROGRAM IN ONTARIO

B. H. McGauley, Pest Control Section, Ontario Ministry of Natural Resources, Ontario, Canada.

Today I would like to explain why Ontario has a smaller budworm program than the provinces and states to the east.

To explain Ontario's approach, I will outline the current spruce budworm policy. For the benefit of the American audience, I would point out that the Canadian provinces have the responsibility of managing the natural resources while the federal government's mandate is to undertake forestry research. Therefore, the policy that I am about to outline has been established at the provincial level and applies specifically to Ontario. The policy allows for three control objectives: epicenter suppression, to eliminate small defined insect epidemics; outbreak control, to contain larger infestations; and protection spraying, to protect the current year's growth.

In 1983, the spruce budworm infestation in Ontario spread across some 9 million hectares and the gypsy moth covered some 40,000 hectares. Therefore, the objectives of epicenter suppression and outbreak control were judged impractical and all spraying planned for 1984 is for protection. There are two categories of protection spraying: high value forests including provincial parks, plantations, seed orchards, seed production areas, wildlife habitat; commercially operable forests, i.e., those scheduled for liquidation within a five year period. The high value forests are usually identified by the provincial forest managers while the commercially operable forests are identified by provincial forest managers in consultation with industry foresters.

There are several constraints imposed on commercial forest protection spraying. The company must commit to harvest the forest within a five-year period, to initiate accessing the area within the year that spraying begins and complete road construction within three years. Protection spraying will by undertaken only three times in the five-year period. There are

[1] J. A. Armstrong, A/Program Manager, Protection Canadian Forestry Service, Environment Canada.
[2] W. G. Yendol, Professor of Entomology, Pesti cide Research Laboratory, Entomology Dept., Pennsylvania State University.

other constraints, but those which I have identified here are the most important. These constraints help to ensure that short term protection spraying is combined with targeted and accelerated harvesting. The goal is to prevent the establishment of large areas of balsam fir, but at the same time ensure that the forest users have sufficient wood to maintain a viable industry.

SPRUCE BUDWORM SPRAY PROGRAM IN QUEBEC

Michel Pelletier, Quebec Ministry of Energy and Resources, 175 St. Jean, Quebec, Canada.

For this presentation I will give a general picture of our experiences with Bt in Quebec since 1974. We started in 1974, applying Bt using DC-6B and CL215 as spray aircraft. The tank mix was Thuricide 16B® plus sorbitol in a 50:50 preparation. There was no calibration of the aircraft as we would now use the word, rather we just checked the aircraft for flow rate and sent it off on its spray mission. Although the Bt sorbitol mix was a good non-volatile preparation, after pumping a few gallons the meter jammed. We had no idea exactly how much was added since we had to estimate visually. The spray nozzles were the standard spraying systems nozzle with the tip removed; this gave an open nozzle with a 3/8" orifice. Even this large orifice became plugged with the spray mix. In spite of these problems, we had sufficient success to encourage us to plan a large program for 1975.

Prior to the 1975 spray season, spray calibration trials were carried out at Barstow, California, with the assistance of A. P. Randall and staff of the Forest Pest Management Institute. The formulation finally selected was Bt:Sorbitol:water in the ratio 50:20:30. During the spray season we did more experiments; in fact 11 combinations to assess differing mixes, swath intervals, etc. We had no success at all. We realize now that we didn't have a consistant droplet spectrum to rely on or even knowledge of the required drop size to give good results. This experience so discouraged us that for 2 years no trials with Bt were carried out. In 1976 and 1977, Dr. Smirnoff of the Laurential Forest Research Centre was encouraged to participate and, although we don't know why, we had good results. Further tests were carried out in 1978. We realize that the major problem was aircraft calibration. At that time we really didn't know the best droplet spectrum, the desired deposit in terms of drops per unit area (degree of coverage), the volume per hectar required and the concentration of Bt required. We quickly determined that at an emission rate of 10 l/ha A treatment of 40 BIU/ha resulted in success. The mean deposit of Bt (measured in petri dishes) was 77 colonies/cm^2 (ranging from 31 to 122); budworm mortality was 97.6% compared to 63% in the untreated areas, and defoliation was only 30% compared to 73% in untreated check blocks.

This success encouraged us to continue, and in 1979 11,000 ha were treated using Dipel 88® (Dipel 4L®), Novabac® and Thuricide 32B®. The emission rate was reduced to 7.5 l/ha, but with the same dilution and the treatment was 30 BIU/ha. Dipel 88 was mixed with water to give a 40:60 mix ratio. When the open nozzles were used with 154 Tyre nozzles, a swath width of 150 m was obtained. Droplets were collected on Kromekote® cards, petri-dishes and Millipore filters. With Dipel 88-97% of the droplets collected on Kromekote paper were 0-75 microns and 5% over 150 microns. These assessments indicate that the sprays can be classified as being made up of small droplets. This nozzle arrangement has been maintained except with FUTURA®, where only 110 nozzles were used. With improvements we now have a 300 m swath. Calibrations were also done in 1983, and in 1984 we will be using from 1.6 to 2.5 l/ha. Thus, since our start in 1974 when we used 10 l/ha, we are now down to 2.5 l/ha. We still have the basic question - are we in the right range of emission? We don't know if the droplets we are producing are the correct size, if we are losing a lot of small droplets, or if some are too large. To be able to do a proper aircraft calibration, we must know the optimum drop size to kill a budworm and the optimum size of deposition. Without this knowledge our tests to compare different products are meaningless; we will not know why one product is doing a better job than another. As I see it, the most important thing we must do is to determine the best droplet size to kill the budworm and the best to ensure good foliar deposit.

AERIAL APPLICATION OF BACILLUS THURINGIENSIS IN THE WESTERN U.S.

John W. Barry, Forest Insect and Disease Manage ment, Forest Service, USDA, 2810 Chiles Rd., Davis, California.

The following summarizes my remarks relating to aerial application of Bacillus thuringiensis (Bt).

Quality of Application. No pesticide has ever been better than its application. Quality of application is dependent upon a correct prescription for treatment and proper execution of the prescription. Once the entomologist specifies what is needed on the target foliage for the biological effect, the spray strategist can write a prescription for delivering the proper number and size of drops to the target. But I emphasize, that the spray strategist must be told what is needed at the target. For the application to be successful, however, the applicator must be capable and willing to execute the prescription details, otherwise Bt, in all likelihood, will not be effective. The majority of aerial applicators are professional. Unfortuately, they may not be aware of new application technology, nor how to use it effectively.

Properly calibrated and clean application equipment are other important considerations. Calibration becomes more critical as the application rates decrease below one gallon per acre. Calibration includes checking to insure that the spray system has the correct number and size of nozzles for the desired flow rate, and that the system is clean. Calibration is basic and we shouldn't have to worry about these matters -- that's why we hire a professional. But we do worry and for good reason. We can do all the proper things and then the link breaks down with the applicator. I estimate that 75% of the pilots and even company operators don't know how to calibrate properly. Does this come as a surprise to you? It did to me. Fortunately, the epidemic of poor application is subsiding.

Technical Representative. Because technical representatives have a vested interest in their product, no one is more interested than the technical representative in seeing the product meet its expectations and the control project meet it goals. The technical representative has a responsibility of being well informed on product mixing, tank mix, stability, atomization, degradation, adjuvants, application, etc. The Project Officer should utilize this valuable source of information.

Tank Mixes. Tank mixes have been changing rapidly in the formulation, amounts applied per acre, and degree of dilution. We are now applying less than one gallon per acre and we are beginning to apply the formulation undiluted. Paul Fast, FPMI, has calculated the amount of toxin required for an LD_{50} for spruce budworm. Bt drops diluted more than 50% simply do not have enough potency to be effective. This insight has been a major breakthrough in understanding how to use Bt effectively. He further calculated that approximately two drops would be required per Douglas-fir needle. After aerial treatments of Bt tank mixes, applied at 96 to 128 oz/A, we observe approximately two Bt drops per spruce and fir needle. These two drops must contain sufficient toxin to provide a lethal dose to feeding budworm, and the lethal dose must be consumed before the effectiveness of the drops is lost through normal degradation.

The role and need for adjuvants in Bt tank mixes is not understood. We should be cautious in using an adjuvant until we understand its role regarding rainfastness, UV protection and impingement -- and until we know how to handle the adjuvant in the field.

Determining the Success of Bt Treatments. In the past Bt has been used and its effectiveness evaluated as if it were a chemical insecticide. Chemicals usually show results within a few days. This is not the case with Bt. Entomologists in the West and East have observed dramatic results with Bt in reducing egg masses, larval population, and defoliation the year following treatment. Unfortunately we seldom look at second year results. I submit that frequently those supposedly poor Bt treatments were indeed successful; we simply did not know how to measure our successes. There are other problems -- land managers do not know how to plan the use of an insecticide that gives benefits the year following treatment, and land managers in the West have little confidence in Bt.

Meteorology. Results of studies by Canadian and U.S. scientists in recent years have uncovered the mysteries of how atmospheric conditions influence spray deposit, spray drift, and drop impaction on target foliage. Spray meteorology is, however, a complicated process and cannot be treated adequately in this discussion. Prescribing the meteorlogical conditions for a particular treatment must consider the tank mix, application rate, spray release height, topography, forest characteristics (species, density, canopy and height), and drift. Reducing drift often is the overwhelming consideration, sometimes to the detriment of a successful project. As an example, if drift is acceptable we can use small drops to provide good coverage and wind energy to impact the drops on foliage. Results of field studies, wind tunnel tests, and modeling have provided information and an understanding of how meteorology relates to effective treatments. Significant advancements made in this area over the past 5 years allow us to prescribe meteorological conditions leading to successful applications.

Modeling Spray Behavior. The USDA Forest Service has two models that predict spray behavior. These models can be used effectively as a tool in planning spray operations. They can be used to select type and position of nozzle on spray booms, decide on release height, select meteorological conditions, and select the approximate tank mix and atomization. The models predict deposit on the canopy, on the forest floor, and off target. We need to adapt these models to predict the probability of achieving deposition under various atmospheric conditions and forest types. We need the capability to predict, for the land manager, the probability of project success so he can evaluate cost/benefits. The land manager makes the decision, we provide the information for the decision.

Spray Deposition. Studies have demonstrated that conifers are excellent scavengers of spray drops and that the majority of drops are collected by the upper crown. The smaller the drop the greater the chance that the drop will penetrate the canopy and deposit on the ground. The smaller particles (<20 μm) may enter, but eventually be ventilated out the canopy. Studies of spray deposition on the open ground vs on the forest floor show a higher percentage of large drops in the open (there was no vegetation for interception) and a higher percentage of small drops in the forest. On the other hand the majority of drops observed on foliage are less than 40 μm in diameter.

Examining foliage is an excellent way to evaluate the adequacy of spray coverage. Spray deposit papers should be used as a qualitative sampler to monitor quality of application and drift. Deposit papers are inexpensive and simple to handle. When a better method is developed (easier and less costly), this information will be made available.

Wind Tunnel Tests. Prior to the availability of lasers, wind tunnels were limited as a method to obtain information on nozzle atomization. Wind tunnels with particle measuring lasers can be highly effective in providing quantitative data on drop size. The wind tunnel provides a means of identifying the effects of nozzle type and orientation, boom pressure, airspeed, and tank mix on atomization. Information from wind tunnel tests is used for input to models that predict spray behavior and for developing spray prescriptions.

SOME IMPORTANT FACTORS TO BE CONSIDERED IN SPRAY TECHNOLOGY ASSESSMENT

David Smith, Agriculture and Biological Engineering Department, Mississippi State University, Mississippi State, MS.

Dosage mortality curves can be used in the field. By plotting the amount of mortality over deposit, an LD value can be obtained. If the degradation rate of the microbial product is also obtained, the established LD value can then be adjusted upward to compensate for this factor and, of course, this dosage level would be closer to the manufacturer's recommended dose.

There are dosage requirement differences between crop species. For example, to exemplify this, if we look at an adjuvant (this is a gustatory or feeding adjuvant on a soybean crop with *Bacillus thuringiensis* and *Trichoplusia ni*), we obtain about 78% mortality; on cotton 12.5% mortality; and cabbage 20.4% mortality. These relative mortality numbers change as you select different microbial-insect combinations on these same crops. For example, good dose-mortality response has been obtained with a cottonseed meal bait suspension applied on soybeans. On the other hand, PVA-carbon gave poor results. The point to be made is when the LD values are adjusted for degradation, formulation, crop, etc., we always fall short of the manufacturer's recommended dose. Thus, there appears to be a research gap that needs to be filled and this would be either in the application-formulation arena or the biological response of the pests.

There is need for some type of standard in many of our application trials. In the literature, one researcher will use one type of test at this location, while others will do different types of tests with entirely different equipment, different materials, etc. Thus, a poor basis of comparison results. Usually even the evaluation methodologies are different.

In the applications area, a number of different types of application studies have been conducted throughout the country. In considering the over-the-top type application, drift spraying has been done using droplets in the 30-50 micron range; with and without electrostatic charges; with oil, water, and also with oil/water mixtures. We have also tried to inject the material into the side of the soybean canopies because these materials are highly solar-sensitive.

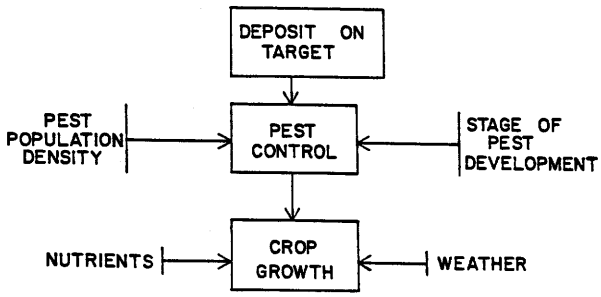
Vertical wedging in soybeans has also been tried. This technique forces leaves to the side so as to spray behind the wedge. We have also tried forcing the leaves vertically so as to spray in between the leaves as they are separating, again trying to penetrate the inner canopy.

The most promising technique is to simply bend the outer part of the canopy over and spray these areas as they are flipping back to an upright position. This increases canopy deposition about 20%. Probably the conventional over-the-top application for ground application is good as anything we have now.

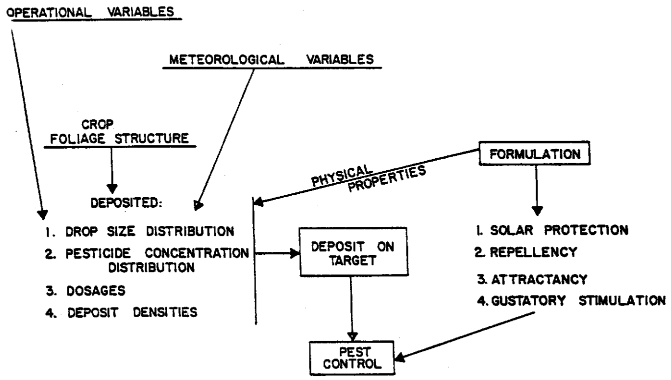
Deposit Variation. The literature indicates that both across-the-swath variations and down-the-row variations, with most of your ground applications, will have a coefficient of variation (CV) ranging from 20-25%, specifically with broadcast applications, on smooth surfaces, and not plant surfaces. When using the crop, the across-the-swath variations with ground applications results in CV's up to the 35% range. In aerial applications with forest canopies, many of these produce 35-50% CV values.

A coefficient of variation of 40% translates into a maximum deposit which is about 3.5 times greater than the minimum deposit within the same swath. There are also problems from an application perspective in getting the material into the inner canopy parts.

With reference to the following table:



We are primarily interested in crop growth with the inputs weather and nutrients being very important. Of course we are also interested in pest control and there are many variables which affect it. Let's first discuss the area of deposit on the target and, specifically, formulation.



First, consider formulation in terms of physical quantities; viscosity, density and surface tension. These properties can affect the droplet size distribution. Physical properties of the formulation can also affect its evaporation rate, and thus the amount of material deposited. Such properties as solar protection, repellency, attractancy, and gustatory stimulation may not affect the deposit on the target, but can affect the level of pest control.

The operational variables (such as pressure, nozzle size, nozzle type, flight height, flight speed, nozzle orientation) can affect the amount of on-target deposit. Meteorological variables (wind direction, wind speed, rainfall, temperature, humidity) also certainly have an effect. For a given crop, pesticide, pest and tank-mix formulation, there are four variables which can affect pest control (i.e., on-target droplet sizes, technical deposit, deposit density [no. drops/area] and tank-mix concentration).

Now let's consider aerial forest spraying at release heights of 50-200 feet above the crop. Drop size distribution, formulation and tank-mix concentration are generally reasonable well known.

Now, what do we know about these descending droplets that are volatile and evaporating, when they reach the canopy?

LOCATION	VARIABLES	KNOWLEDGE ABOUT VARIABLES
AT RELEASE HEIGHT:	1. DROP SIZE DISTRIBUTION	GOOD
	2. TANK MIX CONCENTRATION	VERY GOOD
	3. DOSE	VERY GOOD
AT TOP OF CROP:	1. DROP SIZE DISTRIBUTION	?
	2. PESTICIDE CONCENTRATION DISTRIBUTION	?
	3. POTENTIAL DOSAGE	?
	4. POTENTIAL DEPOSIT DENSITY	?
DEPOSIT ON CROP:	1. DROP SIZE DISTRIBUTION	REASONABLE
	2. PESTICIDE CONCENTRATION DISTRIBUTION	?
	3. ACTUAL DOSAGES	LIMITED
	4. ACTUAL DEPOSIT DENSITIES	REASONABLE
	PEST CONTROL	VARIABLE

Drop size distribution, very little; pesticide concentration inside the droplets, basically nothing (they have been evaporating) and we don't know the concentration or the potential dosage. For example, if we take an imaginary cube right above a tree, we do not know how to estimate the potential dosage. Potential deposit density (how many drops are in a cube above this tree) is also unknown. We know what left the aircraft, but the amount reaching a plane just above the target site is unknown.

There is some information available regarding deposited droplet size distributions and deposit densities. However, information about deposited pesticide concentrations and dosages is either severely limited or non-existent. Our research on row crops indicates that all 4, on-target variables are related to pest control. So when we have worked our way through these application problems, we eventually end up at our primary objective and that being pest control.