DOSE TRANSFER AND SPRUCE BUDWORM BEHAVIOUR DURING OPERATIONAL APPLICATION OF FENITROTHION

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ABSTRACT — Spruce budworm larvae at the time of operational spraying with fenitrothion, confine themselves to and feed within the webbed area of their microhabitat. They are mostly in late third to early fifth instars and seldom crawl on the previous year's needles of balsam fir. The present best measure of effective spray deposit is 0.5 - 1 drop of fenitrothion >15 μm in size per previous year's needle. This amount correlates highly with effective foliage protection and insect mortality. However, it is an indirect measure of efficacy because most larvae do not live or feed on previous year's needles of balsam fir during spray operations. It is better than measuring droplets on Kromekote® cards or needle simulators for correlation of effectiveness. But, it cannot be related to the types and numbers of droplets going into the larval microhabitat, i.e., the webbed area where the budworm larva confines its activity during operational spraying. It is hypothesized that efficacy of sprays could be increased if droplets were targeted to the webbing and current foliage.

RÉSUMÉ — Au moment du traitement opérationnel au fénitrothion, les larves de tordeuse des bourgeons de l'épinette se réfugient et se nourrissent dans le réseau de fils de soie de leur microhabitat. Elles sont pour la plupart entre la fin du troisième stade et le début du cinquième et rampent rarement sur les aiguilles de sapin baumier de l'année précédente. Actuellement, la meilleure mesure d'un dépôt pulvérisé efficace est de 0,5 - 1 gouttelette de fénitrothion de plus de 15 μm par aiguille de l'année précédente. Il y a une corrélation étroite entre cette quantité et la protection efficace du feuillage et un taux de mortalité élevé chez les insectes. Toutefois, il s'agit d'une mesure indirecte de l'efficacité, parce que, pendant les opérations de pulvérisation, la plupart des larves ne vivent pas sur les aiguilles de sapin baumier de l'année précédente et ne s'en nourrissent pas. Elle est préférable à la mesure des gouttelettes sur des cartes Kromekote^{md} ou sur des simulateurs d'aiguilles pour ce qui est de la corrélation avec l'efficacité du traitement. Cependant, cette mesure ne peut pas être mise en relation avec le type et le nombre de gouttelettes qui pénètrent dans le microhabitat larvaire, c'est-à-dire dans le réseau de fils de soie dans lequel les larves de tordeuse se réfugient pendant la pulvérisation opérationnelle. On avance l'hypothèse selon laquelle l'efficacité des pulvérisations pourrait être augmentée si les gouttelettes visaient le réseau de fils de soie et les aiguilles de l'année.

INTRODUCTION

Aerial application of insecticides against forest insects is a well established pest management practice in Canada (Prebble 1975). Several insecticides have been registered and applied aerially against the spruce budworm, *Choristoneura fumiferana* (Clem.), based on empirical laboratory and field tests (Randall 1969, 1976; Nigam 1971, 1975; Dimond and Morris 1984; Shea and Nigam 1984).

In recent years, the number of insecticides available for operational use has decreased because of low industrial incentive to develop new insecticides, as a result of high development costs and stringent requirements of environmental safety by registering agencies (Metcalf 1980; Helson 1985; Nigam 1985). Only two insecticides, fenitrothion and *Bacillus thuringiensis* (*B.t.*) will be available for use against spruce budworm during the late 1980s because manufacture and testing of other suitable compounds, e.g., aminocarb and mexacarbate, are curtailed.

To make best use of available insecticides, studies to improve the effectiveness of fenitrothion were started under the auspicies of the New Brunswick Spray Efficacy Research Group (NB SERG) during the early 1980s (Varty and Godin 1983; Varty and Nigam 1985). The effectiveness of aerial application of an insecticide against spruce budworm is expressed in terms of percentage of foliage protected and larval mortality, which are functions of droplet density and size on the primary target surface on or near the larvae. The concentration of insecticide and the nature of the primary solvent, diluent, and adjuvant within the droplets play an important role in primary and secondary distribution.

Over the years, the effectiveness of various control operations after two applications of fenitrothion varied from 60 to 80% for larval mortality and 30 to 65% for foliage protection (Nigam 1980). Results were measured indirectly by counting the number of drops of insecticide on Kromekote® cards; 15-20 drops/cm^2 gave effective results (Randall 1969). More recently, the droplets on one-year-old needles were counted and 0.5 - 1 drop >15 μm in size per previous year's needle gave effective results (Kettela, E.G. personal communication).

The spray droplets that reach the coniferous foliage are in the range of 10 to 60 μm (Himel 1969; Spillman 1976; Barry et al. 1977; Joyce and Spillman 1978; Barry and Ekblad 1978) but the droplet spectrum has recently been further refined to 15-55 μm under New Brunswick conditions (Picot et al. 1987) for optimizing effectiveness and minimizing drift. However a basic understanding of the dose transfer processes of insecticides to the pest after deposition on the host from air or ground application is lacking (Ekblad et al. 1979; Graham-Bryce 1983; Hall 1986).

The objectives of this study were to determine (1) the dose transfer mechanism of fenitrothion from primary contact surfaces in the microhabitat to the spruce budworm larvae after operational or simulated aerial application, and (2) the significance of the dose transfer mechanism for improving efficiency of foliage protection.

HIGHLIGHTS OF ACCOMPLISHMENTS

Dose transfer was investigated under field and laboratory conditions after aerial and simulated applications of insecticide. Various studies using fenitrothion formulations were initiated to evaluate the role of dose transferred to the larvae by contact through the cuticle, orally as a stomach poison, or as vapours through the respiratory system. Contact toxicity may occur by direct impingement of droplets on the larvae or by larvae crawling on residues adsorbed on foliage or on silk of the microhabitat. Stomach toxicity may occur through (a) larvae feeding on foliage that has adsorbed or absorbed residues of fenitrothion; (b) feeding on systemically translocated fenitrothion in the developing buds; and (c) oral contamination from droplets on silk.

Studies of direct contact, gross residual toxicity, vapour activity, systemic activity, and behaviour of budworm larvae in their microhabitats and droplet interactions have been carried out since 1982. Sixteen experimental sprays were applied to balsam fir, *Abies balsamea* (L.) Mill., by Grumman Avenger (TBM), or Cessna-188 aircraft using various fenitrothion formulations consisting of 210 g AI/ha [emulsion (EC) and flowable (FL) as 11% AI in water @ 1.45 L/ha and ultra ultra low volume (UULV) as 38% AI in Dowanol @ 0.46 L/ha].

Direct Contact Toxicity

Drop trays were used in the field to study the direct impingement of droplets on the larvae. Larval activity and fallout were observed 15-30 minutes after spraying. Direct impingement of droplets on larvae took place in only one morning spray out of 16 experiments, under special circumstances in the field, i.e., when 60% of the larvae were in the 5th instar (L_5) and the previous overnight temperatures and budworm activity were high, as evidenced by quantity of frass.

Residual Toxicity

Residual toxicity was studied using drop trays in the field. Results showed a gross effect of interactions among various modes of dose transfer, larval behaviour, host development, and weather. L_5 were most vulnerable to residues as compared with earlier instars because of their movement on treated surfaces. Initial high drop counts of L_5 on drop trays decreased with time as a result of deterioration of fenitrothion residue. Initially, L_2 were little affected by residues as the larvae were concealed in the needles, but with time and warm weather they emerged and wandered on the treated needle surfaces. L_2 drop tray counts increased with time. Few L_3 and L_4 were found on drop trays because the larvae were protected inside the developing buds; there was no change in the daily rate of fallout up to 4 days.

The bioassay and chemical analysis of foliage carried out for toxicity and deterioration of residues after aerial application of the insecticide revealed that an initial good deposit had a great impact on residual toxicity of fenitrothion. The results, so far, indicate that the order of residual toxicity of various formulations is UULV < EC < FL. Foliage protection by these formulations also appears to be in the same order.

Vapour Activity

Effect of fenitrothion vapour on the feeding behaviour of spruce budworm larvae was measured in the field by comparing damage to buds of branches protected from direct sprays with buds on neighbouring exposed branches of the same tree. This was accomplished by covering branches with paper bags during spraying and uncovering them after 30 minutes, when the spray cloud had settled. Thus in the treated plots, covered branches were exposed only to fenitrothion vapour. In check plots, similar sets of covered and uncovered branches were used in the evaluation of results. The fenitrothion vapour in the air after aerial application was measured using National Research Council (NRC) air samplers and chemical analysis was done at NRC, Ottawa. Field observations were made from 1982 to 1984. Air samples were not analyzed in the first year. An apparatus to observe the impact of fenitrothion vapour on larvae under laboratory conditions was developed in cooperation with Dr. L. Elias during 1983-1984.

Results demonstrated that vapour concentrations of fenitrothion observed under field conditions do not contribute to insect mortality or to foliage protection. Vaporization reduces the persistence of residues on foliage. If vaporization could be reduced by modifications to formulations then efficacy of fenitrothion would increase accordingly.

Systemic Activity

Systemic activity of fenitrothion was measured by covering buds with Plasticine® during spraying so that individual buds were shielded from deposition of spray droplets. It was hypothesized that insecticide from neighbouring exposed foliage and buds would translocate through the xylem and phloem transport systems. Biological, chemical, and physical measurements of fenitrothion droplets were made to determine systemic activity in the field experiments. Some translocation of fenitrothion was detected, by chemical analysis, in buds collected 72 h after application. However, these results were confounded by resinous material in the buds during early spring. No insecticidal effect from translocated fenitrothion was detected.

Budworm Larval Behaviour and Droplet Interactions

It was originally hypothesized that in operational spraying, toxicity of 0.5 - 1 drop of fenitrothion per previous year's needle was the result of chance encounters by larvae, while engaged in various activities governed by weather. This led to the study of droplet and budworm behaviour in the microhabitat during spray operations and to the observation of micro- and macro-weather. In New Brunswick, budworm populations in balsam fir are mostly in late L_3 and early L_4 instars during the first application of fenitrothion spray. Second applications of fenitrothion are carried out when most of the larvae are in L_4 and early L_5. Video recordings were made using an operating microscope, time-lapse video cassette recorder, and video and surveillance cameras to observe budworm behaviour and microhabitats at various stages of larval development. The same equipment was used to study the impaction of droplets on the microhabitat and the droplet-larval interface. Weather parameters were recorded on a micrologger. Information on canopy level weather was collected using sensors mounted on a meteorological tower located in the middle of the experimental plot, while other sensors were located on host tree branches to collect weather data near larval microhabitats. Temperatures for each quadrant were measured on the trees using thermocouples tied to twigs close to the budworm microhabitat and needle surface. Leaf wetness sensors were mounted on the needles. The micrologger was synchronized with the 12 surveillance cameras so that behaviour and weather were recorded simultaneously. The surveillance cameras were mounted on trees at ghts of 5-6 m. Each camera recorded budworm behaviour for min and the micrologger averaged weather parameters for this period.

Budworm microhabitat in balsam fir consists of various ypes of silk strands and new needles of growing buds (class 2 to 4, Dorais and Kettela 1982) at the time of first and second spray-ing. Fenitrothion formulation has to contact larvae within their microhabitats for maximum efficacy. The thickness of the silk strands varies from 2 to 12 µm and each size has a different function. The budworm remains within the confines of the silk inside the developing buds. Within the microhabitat, it spins an inner tube of very fine silk among the new needles. This tube is its living chamber and its foraging activity is confined to the new needles within the webbed area. The larva eats the needles from the middle of the developing buds. The larva is at all times in touch with the silk through its body hairs or legs. This silk is the lifeline for the larva and it is used for various functions. The larva usually crawls over the webbed silk which functions as a "road system" within its microhabitat. Changes in tension of the silk strands make the budworm aware of the outside environment and intruders. Silk strands are good collectors of dew and rain droplets. Behaviour studies showed that instrinsic factors like moulting, circadian rhythm, and energy requirement (hunger) of larvae govern their activity more than extrinsic factors like temperature, humidity, and wind speed. Larvae were relatively more active late in the evening (dusk) and very early morning (dawn) than in the daytime.

In the summer of 1985, it was observed that droplets of dyed fenitrothion flowable formulation were intercepted by silk strands after aerial application. Most droplets were <15 µm and in some observations dead larvae were found within the microhabitat. Subsequent laboratory experiments carried out in the fall con-firmed that webbing is a good collector of droplets. Droplets <15 µm impinge more on the silk strands than on needles. When budworms in their microhabitats were sprayed with 8-12 µm droplets of 11% fenitrothion in isopropyl alcohol under laboratory conditions, 100% mortality of L_3-L_5 was observed.

In the summer of 1986, it was found that 210 g AI/ha of fenitrothion in UULV was more effective for foliage protection and larval mortality than the same amount of active ingredient per hectare of EC formulation. When the webbing from the treated microhabitats was chemically analyzed about 2 to 10 times more fenitrothion was found in UULV formulation samples than in EC samples.

During 1987 field trials with UULV formulation, an attempt was made to characterize the spectrum of droplets reaching the webbing. Because of evaporation and inadequate dye in the droplets, it was difficult to observe droplets <10 µm. Droplets from 6 to 85 µm were observed in the webbing with number mean diameter (NMD) 37 µm and volume mean diameter (VMD) 42 µm. The VMD/NMD ratio is equal to 1.1 which is close to unity denoting a narrow range in size of droplets.

CONCLUSIONS

Direct contact of spray droplets on spruce budworm larvae is rare. Vapour and systemic activity of fenitrothion has little impact on larvae. Residual toxicity plays an important role in efficacy of fenitrothion. The mechanism of dose transfer appears to be through contaminated webbing and new needles within the microhabitat either by direct impingement of droplets or by secondary distribution of fenitrothion from old needles via rain and dew. Spray efficiency can be improved if droplets are targeted to the webbing and new needles, and if UULV application is practiced. Evening sprays morning sprays because budworm actively feed and sp the evening and early morning, and also, fenitrothion deposits vaporise slower at night than during the daylight hours.

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