THE EFFECTIVENESS OF *BACILLUS THURINGIENSIS*, DIFLUBENZURON AND FENITROTHION AGAINST THE HEMLOCK LOOPER, *LAMBDINA FISCELLARIA*, IN NEWFOUNDLAND IN 1987

by

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FOREWORD

The experimental sprays in 1987 in Newfoundland were a joint research effort by the Forest Protection Division of the Newfoundland Department of Forest Resources and Lands, and the Newfoundland and Labrador Region and the Forest Pest Management Institute of Forestry Canada. Funding was provided by the Province through the Federal Provincial Forestry Agreements, by Corner Brook Pulp and Paper Ltd., Abitibi-Price of Newfoundland Inc. and Forestry Canada, supplemented by contributions from Sumitomo Chemical America Inc., Abbott Laboratories Ltd. and Duphar BV of Holland.

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ABSTRACT

The effectiveness of aerially applied formulations of *Bacillus thuringiensis* var. *kurstaki* (*B.t.*)(Dipel[R]), fenitrothion (Sumithion[R], Folithion[R]), and diflubenzuron (Dimilin[R]), were tested against the hemlock looper, *Lambdina fiscellaria* Guen. (Lepidoptera: Geometridae), in Newfoundland in 1987. We evaluated the effectiveness of earlier applications; new formulations of *B.t.*, fenitrothion and diflubenzuron; and a new nozzle, the Micronair AU4000. The dosages and formulations of insecticides were as follows:

1) ***B.t.*:**

Dipel 132	2 x 30 BIU in 2.36 ℓ/ha (oil-base)(early)
Dipel 176	2 x 30 BIU in 1.78 ℓ/ha (oil-base)(early)
Dipel 176	1 x 40 BIU in 2.36 ℓ/ha (oil-base)(normal)
Dipel 264	1 x 40 BIU in 1.58 ℓ/ha (oil-base)(normal)
Dipel 264	2 x 30 BIU in 1.18 ℓ/ha (oil-base)(early)

2) **Diflubenzuron:**

Dimilin, flowable

1 x 70 g ai/ha in 5.0 ℓ/ha (water-base)(early)

Dimilin, 25% wettable powder (WP)

2 x 70 g ai/ha in 5.0 ℓ/ha (water-base)(early)
2 x 70 g ai/ha in 2.5 ℓ/ha (water-base)(early)
1 x 70 g ai/ha in 2.5 ℓ/ha (water-base)(early)
1 x 70 g ai/ha in 5.0 ℓ/ha (water-base)(early)

3) **Fenitrothion:**

Sumithion

2 x 210 g ai/ha in 0.4 ℓ/ha (oil-base)(early)
2 x 210 g ai/ha in 0.4 ℓ/ha (oil-base)(normal)

Folithion

2 x 210 g ai/ha in 1.5 ℓ/ha (oil-base)(early)

The Folithion formulation was used in the operational sprays in 1987 and served as the benchmark for all the treatments.

The first sprays of "early" treatments were applied between 22 and 26 June when all hemlock looper larvae were in the first instar and over 90% of the larvae had hatched. Second sprays of "early" treatments and first sprays of "late" treatments were applied between 4 and 5 July when 50% to 70% were in the second instar and about equal proportions in first and third instar larvae. The second spray of late treatments were applied on 9 July when 30% of the larvae had molted to the third instar. Weather conditions for all sprays were classed as good to excellent.

The new Micronair AU4000 nozzle provided droplet size-spectra with a high percentage of droplets in the desirable range of 30 to 60 microns for all formulations of B.t. and fenitrothion, and better spray deposits than did other nozzles in past years. However, diflubenzuron formulations had a greater number of large-diameter droplets of near 100 microns than did the other insecticides. The use of this nozzle provided better spray deposits than did other nozzles in past years.

Density of spray deposit measured at ground level averaged 54.5 droplets/cm^2 for B.t., 21.2 droplets/cm^2 for fenitrothion and 2.7 droplets/cm^2 for diflubenzuron. Density of droplets was fairly uniform along a transect bisecting the plots for B.t. and fenitrothion application, but erratic for diflubenzuron sprays. The percent of emitted spray reaching the ground averaged 48% for B.t., and 15% and 6% for fenitrothion and diflubenzuron, respectively.

The droplet number/needle (d/n) averaged greater than 1.00 for all applications of B.t. sprays. Deposit of fenitrothion was greater than 0.40 d/n for four out of six applications, but only one application resulted in deposit of more than 1.00 d/n. Deposit of diflubenzuron was greater than 0.40 d/n in only two out of seven applications, and only one was greater than 1.00 d/n.

Estimates of deposit sampled at ground level were correlated to those sampled at mid-crown, and estimates of droplets per needle were correlated to quantitative estimates, except at very low deposit levels. Any of these methods may be used to assess spray deposit. Foliage simulators placed in the canopy gave relative measures of spray deposit. However, results from simulators need to be calibrated.

Fenitrothion persists in or on the needles of fir for at least 15 days, but at very low levels after three to five days.

B.t. treatments sharply reduced population levels in all plots. The single applications reduced larval levels by 74% to 97% and pupal numbers by nearly 100%. Double applications reduced larval numbers by more than 95% and pupal numbers by 100%. Early applications of a single dose of B.t. were as effective as a single dose applied at a later date in July. Mid-spray samples in double-application plots indicated reductions of 74% to 82%; only slightly lower than the 85% and 97% achieved in later applications.

Single applications of Dipel 176 reduced larval populations by 85% and pupal populations by 97%. These reductions were only slightly lower than the corresponding figures of 97% and 100% for the more potent Dipel 264.

Early treatments of fenitrothion reduced populations by more than 98% for larvae and by 100% for pupae. Even a single early application provided over 90% larval reduction at mid-spray. There was no difference in population reduction between the new formulation sprayed at 0.4 ℓ/ha and the operationally-used formulation sprayed at 1.5 ℓ/ha. However, the late treatment did not reduce larval population to the same degree as the early treatments.

Reduction of larval numbers in the diflubenzuron-sprayed plots was decidedly below that in plots treated with the other two insecticides. Double applications of diflubenzuron were more effective than single applications. Reduction of pupal numbers ranged from 44% to 88% for the single applications and about 97% for the double applications.

Defoliation was zero or near zero for all _B.t._-treated plots. Defoliation in plots treated early with fenitrothion also was zero, but defoliation in the plot sprayed late with fenitrothion averaged near 20% for the new growth and 6% for the old growth. Defoliation in plots treated with diflubenzuron was low only for the two plots with double applications of the wettable powder formulation; the single applications of this formulation were ineffective. The new flowable formulation provided a low level of foliage protection.

Based on these results _B.t._ and fenitrothion, applied at the occurrence of peak first-instar hemlock looper larvae, are recommended for operational control.

RÉSUMÉ

L'efficacité d'applications aériennes de formulations de *Bacillus thuringiensis* var. *kurstaki* (*B.t.*)(Dipel[R]), de fenitrothion (Sumithion[R], Folithion[R]) et de diflubenzuron (Dimilin[R]) pour lutter contre l'arpenteuse de la pruche, *Lambdina fiscellaria* Guen. (Lépidoptères: géométridae) a été vérifiée à Terre-Neuve en 1987. Nous avons évlué l'efficacité d'applications antérieures, de nouvelles formulations de *B.t.*, de fenitrothion et de diflubenzuron et d'une nouvelle buse, la Micronair AU4000. Les doses et les formulations d'insecticides étaient les suivantes:

1) *B.t.*

Dipel 132	2 x 30 MUI dans 2,36 L/ha (à base d'huile) tôt en saison)
Dipel 176	2 x 30 MUI dans 1,78 L/ha (à base d'huile) tôt en saison)
Dipel 176	1 x 40 MUI dans 2,36 L/ha (à base d'huile) (période habituelle)
Dipel 264	1 x 40 MUI dans 1,58 L/ha (à base d'huile) (période habituelle)
Dipel 264	2 x 30 MUI dans 1,18 L/ha (à base d'huile)(tôt en saison)

2) Diflubenzuron

<u>Dimilin, fluidifiable</u>

1 x 70 g m.a./ha dans 5 L/ha (à base d'eau) (tôt en saison)

<u>Dimilin, 25 % poudre mouillable</u>

2 x 70 g m.a./ha dans 5 L/ha (à base d'eau) (tôt en saison)
2 x 70 g m.a./ha dans 2,5 L/ha (à base d'eau) (tôt en saison)
1 x 70 g m.a./ha dans 2,5 L/ha (à base d'eau) (tôt en saison)
1 x 70 g m.a./ha dans 5 L/ha (à base d'eau) (tôt en saison)

3) Fenitrothion

<u>Sumithion</u>

2 x 210 g m.a./ha dans 0,4 L/ha (à base d'huile) (tôt en saison)
2 x 210 g m.a./ha dans 0,4 L/ha (à base d'huile) (période habituelle)

<u>Folithion</u>

2 x 210 g m.a./ha dans 1,5 L/ha (à base d'huile) (tôt en saison)

Le traitement au Folithion a été utilisé lors des opérations de pulvérisations de 1987 et servait de témoin à tous les traitements.

Les premières pulvérisations des traitements "tôt en saison" se sont déroulées du 22 au 26 juin lorsque toutes les larves de l'arpenteuse de la pruche en étaient à leur premier stade et que plus de 90 % des larves avaient émergé. Les deuxièmes pulvérisations des traitements "tôt en saison" et les premières des traitements "tardifs" ont eu lieu entre le 4 et le 5 juillet, lorsque de 50 à 70 % des larves en étaient à leur premier stade et qu'un pourcentage à peu près équivalent en étaient à leur premier et troisième stades larvaires. La deuxième pulvérisation du traitement tardif s'est déroulée le 9 juillet lorsque 30 % des larves en étaient arrivées à leur troisième stade. Les conditions météorologiques prévalant pendant tous les traitements ont été classées bonnes à excellentes.

La nouvelle buse Micronair AU4000 a permis d'obtenir un spectre de grosseur des gouttelettes où un pourcentage élevé des gouttelettes avaient les 30 à 60 microns souhaités pour toutes les formulations de B.t. et de fenitrothion ainsi qu'un meilleur dépôt que toutes les autres buses utilisées au cours des années précédentes. Le formulations de diflubenzuron avaient toutefois un nombre plus élevé de plus grosses gouttelettes (près de 100 microns) que les autres insecticides. L'utilisation de cette buse a permis d'obtenir un meilleur dépôt que toutes les autres buses utilisées au cours des années précédentes.

La densité au sol des gouttelettes déposées était en moyenne de 54,5 gouttelettes/cm^2 pour le B.t., de 21,2/cm^2 pour le fenitrothion et de 2,7/cm^2 pour le diflubenzuron. La densité des gouttelettes étaient plutôt uniforme le long d'un transect coupant les parcelles de traitement au B.t. et au fenitrothion, mais variable dans les parcelles traitées au diflubenzuron. Le pourcentage de jet pulvérisé atteignant le sol était en moyenne de 48 % dans le cas du B.t. et de 15 % et 6 % respectivement dans le cas du fenitrothion et du diflubenzuron.

Le nombre de gouttelettes par aiguilles (g/a) était en moyenne de plus de 1,00 lors de tous les traitements au B.t. Le dépôt de fenitrothion était supérieur à 0,40 g/a lors de 4 des 6 traitements, mais une seule application a donné un dépôt de plus de 1,00 g/a. Le dépôt de diflubenzuron était supérieur à 0,40 g/a lors de 2 des 7 applications et un seul dépassait 1,00 g/a.

Les estimations des dépôts échantillonnés au sol ont été corrélées à celles effectuées à mi-hauteur de la cime et les estimations du nombre de gouttelettes par aiguille ont été corrélées à des estimations quantitatives, sauf lorsque le dépôt était très faible. L'une de ces méthodes peut servir à évaluer le dépôt. Les simulateurs de feuillage installés dans le houppier donnait une mesure relative du dépôt de gouttelette. Il faut toutefois étalonner ces résultats.

Le fenitrothion persiste dans les aiguilles de sapin ou sur celles-ci pendant au moins 15 jours, mais ses niveaux étaient très faibles après 3 à 5 jours.

Les traitements au *B.t.* ont fortement réduit les niveaux de populations dans toutes les parcelles. Les applications uniques ont réduit les populations larvaires de 74 % à 97 % et le nombre de chrysalides de près de 100 %. Les doubles applications ont réduit le nombre de larves de plus de 95 % et celui de chrysalides de 100 %. Les applications tôt en saison d'une dose unique de *B.t.* ont été aussi efficaces qu'une dose unique appliquée plus tard en juin. Des échantillons prélevés à mi-traitement dans les parcelles à double application ont révélé des réductions de 74 % à 82 %, pourcentages qui ne sont que légèrement inférieurs à ceux de 85 % et de 97 % obtenus lors d'applications ultérieures.

Les applications uniques de Dipel 176 ont réduit les populations larvaires de 85 % et celles de chrysalides de 97 %. Ces réductions n'étaient que légèrement inférieures aux pourcentages correspondant de 97 % et 100 % obtenus avec le puissant Dipel 264.

Les traitements de fenitrothion effectués tôt en saison ont réduit les populations larvaires de plus de 98 % et celles des chrysalides de 100 %. Même une application unique en début de saison a entraîné une réduction des populations larvaires de plus de 90 % à mi-traitement. Nous n'avons relevé aucune différence de réduction des populations attribuable à la nouvelle formulation pulvérisée à une dose de 0,4 L/ha par rapport à la formulation utilisée à grande échelle à une dose de 1,5 L/ha. Le traitement plus tardif n'a toutefois pas entraîné une réduction aussi importante des populations larvaires que celui effectué plus tôt en saison.

La réduction des populations larvaires dans les parcelles traitées au diflubenzuron était définitivement inférieure à celle des parcelles pulvérisées à l'aide des deux autres insecticides. Les doubles applications de diflubenzuron ont été plus efficaces que l'application unique. La réduction du nombre de chrysalides variait de 44 % à 88 % lors des traitements uniques et était d'environ 97 % lors des doubles applications.

La défoliation était nulle ou presque nulle dans toutes les parcelles traitées au *B.t.* La défoliation dans les parcelles traitées tôt en saison au fénitrothion était également nulle, contrairement à la parcelle traité en fin de saison où la défoliation moyenne des nouvelles pousses était de près de 20 % et celle des vieilles aiguilles de 6 %. La défoliation dans les parcelles traitées au diflubenzuron n'était faible que dans les 2 parcelles ayant reçu une double application de la formulation de poudre mouillable; les applications uniques de cette formulation n'ont donné aucun résultat. La nouvelle formulation fluidifiable n'a procuré qu'un très faible degré de protection du feuillage.

D'après ces résultats, il est recommandé d'appliquer le *B.t.* et le fenitrothion au plus fort du premier stade larvaire de l'arpenteuse de la pruche lors des opérations de lutte.

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by

A.G. Raske, R.J. West, K.M.S. Sundaram and A. Sundaram

INTRODUCTION

The hemlock looper, *Lambdina fiscellaria* (Guen.), is one of the most destructive forest pests in Newfoundland. Its primary host is balsam fir, *Abies balsamea* (L.) Mill., which can succumb after one year of severe defoliation. This insect has reached outbreak levels and caused tree mortality at least six times since 1912 (Otvos *et al*. 1979). Prior to the current outbreak, the largest outbreak lasted from 1967 to 1971 and killed an estimated 12 000 000 m^3 volume of balsam fir (Otvos *et al*. 1979). Details of the life history of the looper, its impact on Newfoundland and past attempts to control the insect in Canada were recently reviewed (Raske *et al*. 1986).

The current outbreak of the hemlock looper started in 1983 in two widely separated areas of Newfoundland and caused 10 000 ha of moderate and severe defoliation. Areas with this degree of defoliation increased to 53 000 ha in 1984 (Clarke and Carew 1985), 52 000 ha in 1985 (Clarke and Carew 1986), to 215 000 ha in 1986 (Clarke and Carew 1987), and decreased to 150 000 ha in 1987 (Clarke and Carew 1988). The outbreak in 1987 was limited to western Newfoundland except for patches of defoliation around Victoria Lake and Red Indian Lake (Fig. 1). Several small patches of forest on the Avalon Peninsula were also defoliated.

Experimental aerial applications in 1985 of water-base formulations of *Bacillus thuringiensis* (*B.t.*), (Thuricide 48LV[R], Thuricide 64B[R], Futura[R]), diflubenzuron (Dimilin 25WP[R]), and fenitrothion (Sumithion Technical[R], Sumithion 20F[R]), resulted in fair to good larval reduction but in little or no foliage protection (Raske *et al*. 1986, West *et al*. 1987). Applications of aminocarb (Matacil 180F[R]) was not effective against the looper even at twice the maximum dosage registered for spruce budworm, *Choristoneura fumiferana* (Clem.), control.

Experimental aerial applications against the looper in 1986 tested two concentrations of diflubenzuron (Dimilin 25WP) and a new flowable formulation of fenitrothion sprayed at a reduced dosage of 180 g ai/ha (Raske and Retnakaran 1987). The more concentrated dose of diflubenzuron, 70 g ai in 2.5 ℓ/ha, provided population control only slightly below that of the same dose in 4.7 ℓ/ha. Poor foliar protection was attributed to delays in spraying. The flowable formulation of fenitrothion sprayed at 180 g ai/ha and the oil-base formulation at 210 g ai/ha both provided good larval reduction and adequate foliar protection. However, earlier application may have increased the foliar protection.

Based on results achieved in 1985 and 1986 we decided to test new formulations of *B.t.*, diflubenzuron and fenitrothion, to apply treatments when larvae were in the first to third instars, and to test a new nozzle for improved droplet formation. Results of these experiments in 1987 are here reported.

MATERIALS AND METHODS

Location and Experimental Design

The experimental area was near the town of Hawkes Bay on the Northern Peninsula of Newfoundland (50°29'55"N) (Fig. 2). Results of egg surveys in fall of 1986 and spring of 1987 were used to locate 13 treatment and five control blocks (Fig. 2). The terrain was generally flat and the forest consisted mainly of balsam fir with scattered trees of white spruce, Picea glauca (Moench) Voss., black spruce, P. mariana (Mill.) B.S.P., and white birch, Betula papyrifera Marsh. The most abundant forest site types in the spray plots were the following vegetation subassociations in decreasing order: Dryopteris balsam fir (northern type), Rubus balsam fir, Rubus balsam fir (wet variant), and Clintonia balsam fir (Meades and Moores 1989).

Trees in experimental blocks regenerated following logging operations in the 1940's and were 8 m to 12 m in height and 15 cm to 30 cm in diameter. Some blocks had been thinned within the last 10 years.

All treated plots were 30 ha in area and measured 300 m by 1000 m (Fig. 2). The blocks were bisected by roads of 5 m to 20 m width or by a cut transect of 10 m width (Fig. 2). Overhanging branches along the transect were removed to create discrete canopy openings to the ground. These openings enabled the ground crew to guide the spray aircraft with a helium-filled balloon, and allowed unrestricted movement of spray droplets to Kromekote[R] cards placed on this transect.

Trees to be sampled for looper numbers and spray deposit within the plots were chosen at or near the road or transect that bisected the plots. All sample trees were at least 60 m from the plot edges to ensure spray deposit if the spray cloud drifted (Fig. 3).

Five untreated areas were designated as control plots (Fig. 2).

Spray Application

A total of 13 treatments were evaluated: various formulations of B.t. (Dipel^R), fenitrothion (Sumithion^R and Folithion^R) and diflubenzuron (Dimilin^R) applied once or twice (Table 1). These applications began about 12 days earlier than in 1985 and 1986 to evaluate the susceptibility of first and second instar looper larvae to control by aerial spraying.

Aircraft Parameters

All treatments were applied by a Piper Pawnee aircraft equipped with six Micronair AU4000^R atomizers (Micronair Aerial Ltd., Sandown, Isle of Wight, England) (Fig. 4). The aircraft flew 30 m swath widths, and the flow rate calibrated to deliver the desired volume while flying at 140 km/h and about 20 m above the tree canopy. The blade angle setting of the Micronair nozzles was set at 30° for all sprays.

Tanks in the airplane, booms and atomizers were thoroughly washed between sprays. The airstrip at Port-au-Choix, used for mixing and loading the aircraft, was about 20 km from the treated plots.

Communications

Our base of operations was the Management Unit Office, Department of Forest Resources in Port Saunders. Radio communications were maintained during spray operations between personnel at the airstrip, base of operations, spray blocks, weather station and in the spray aircraft.

Insecticide Formulations and Tank Mixes

Diflubenzuron (Dimilin 25 WP and Dimilin Flowable) formulations were water-base, but *B.t.* and fenitrothion were oil-based formulations (Table 1).

Dipel 132 (Lot No. 03-239-BJ), Dipel 176 (Lot No. 04-022-BR) and Dipel 264 (Lot No. 05-046 BR), all pre-mixed with 1% concentration of Day-Glo[R] fluorescent pigment, were applied undiluted at 30 billion international units (BIU) for the double applications and at 40 BIU for the single applications.

Fenitrothion formulations were mixed at the airstrip, and applied at a rate of 210 g ai/ha. The fenitrothion formulation applied at 0.4 ℓ/ha was composed of 39% technical fenitrothion (Sumithion Technical[R]) (98% + pure), 59% Dowanol TPM[R] and 2% of the tracer dye Automate Red B. The fenitrothion formulation applied at 1.5 ℓ/ha was composed of 11% technical fenitrothion (Folithion Technical[R]) (98% + pure), 40% Cyclosol 63[R], 48% ID585 oil (commercial stove oil) and 1% Automate Red B. The latter formulation was identical to the fenitrothion used for the 1987 operational spray program against the hemlock looper.

Diflubenzuron formulations were mixed at the airstrip to the desired concentration of 70 g ai/ha in either 2.5 ℓ or 5.0 ℓ. The dye Rhodamine B was added to the formulations to a concentration of 1% solution.

Meteorological Monitoring

Weather conditions during the spray were monitored at a station among the spray plots (Fig. 2) with a 21X data micrologger (Campbell Scientific Inc., Edmonton, AB). Wind speed and direction, relative humidity, mm of rain, and temperatures at 2 m and 13 m above the ground were recorded. The two temperatures were used to determine air stability beneath the temperature inversion layer. Stable weather conditions exist when the two temperatures are equal or the temperature at 2 m is less than the temperature at 13 m. Unstable weather conditions exist when the temperature at 2 m is higher than the temperature at 13 m indicating rising air currents. Weather records were supplemented by field observations.

Assessing Spray Deposit

Spray deposits at ground level were measured with units comprised of 10 cm x 10 cm Kromekote cards and two 5.0 cm x 7.5 cm glass plates. (Randall 1980). Ground units were placed in treatment plots less than 30 minutes before a spray and retrieved 30 to 60 minutes after. These units were placed at 15 m intervals along the transect, for a total of 21 cards per block per application.

The central 105 cm^2 of the Kromekote cards were analyzed for droplet density and droplet size-spectrum, and the Number Median Diameter (NMD) and Volume Median Diameter (VMD) were determined. Droplet NMD is the droplet diameter that halves the number of droplets: half are smaller and half are larger. Droplet VMD is the droplet diameter that halves the droplet volume: half the droplets have volumes larger than the VMD and half the droplets have volumes smaller.

The spray deposit on the glass plate was used to estimate the proportion of the spray volume that reached the ground. Deposit on the plate was washed off with methanol and colorimetrically measured for dye content in a Bausch and Lomb Spectronic 100 Spectrophotometer.

Spray deposit was also measured on foliage samples collected after both applications. Sampling to estimate the number of droplets/ needles (d/n) was uniform for all plots. However, sample sizes for other measures of foliar deposit varied between insecticide because of differences in analytical methods and in the costs involved.

To estimate the number of d/n, seven hundred 1986-year needles were examined on both sides as follows: seven needles/ shoot, five 1986 shoots/branch, two branches/tree and ten trees/plot. Samples were stored in paper bags and placed in a freezer within 120 minutes until examined. This minimized breakdown of the dye and absorption into the needles. Foliage samples from the *B.t.* plots were examined under black light because a fluorescent dye was used. Needles from the other blocks were sandwiched between two slides and examined under a stereo microscope within an hour after removal from the freezer.

Methods to estimate quantity of deposits differed with type of insecticide. Sample size for diflubenzuron sprays consisted of five 1986 plus 1987 shoots/mid-crown branch, one branch/tree, eight trees/cluster and three clusters/plot. The foliage was pooled by cluster and analyzed by the Department of Chemistry, Memorial University of Newfoundland. The extraction and cleanup of foliar deposit followed standard procedures

(Sundaram 1986a) and were quantified by chromatographic analysis (Duphar 1985).

Samples for fenitrothion sprays consisted of one 15 cm tip/branch, one mid-crown branch/tree, and ten trees/plot. The foliage for the ten trees was pooled for analysis. Extraction, cleanup and analysis followed standard procedures (Sundaram 1986b, Sundaram and Sundaram 1987). In addition samples were taken to determine the rate of break down of initial deposit of fenitrothion. The same ten trees were resampled after each application in the same way according to the following schedule of time after spray: 1h, 2h, 12h, 24h, 2d, 3d, 5d, 8d, 12d and 15d. This sampling frequency was followed for each first application only till the second application was applied and then restarted. The feasibility of using metal foliage simulators (Kristmanson et al. 1988) to measure foliage deposit was tested for two of the fenitrothion applications. Within 30 min. before the spray simulators were placed on eight of the ten trees and adjacent to the foliage sampled for deposit analyses. Six simulators were placed on each branch symmetrically with three on each side of the branch axis corresponding to 1986/87, to 1983/84 and to 1980/81 foliage (Fig. 5). The simulators were 68.3 mm long and their "needles" 15.5 mm long, 2.0 mm wide and 2.2 mm apart. Upper surface area per simulator, including center shaft, was 1,578 mm^2. Simulators were collected within 120 min. after the spray and stored at -20°C till processing. The three simulators on one side of the branch axis were shipped with dry ice to Sault Ste. Marie, ON (For. Pest Mgt. Inst.) to determine quantity of deposit. The number of droplets were counted on the three simulators on the other side of the branch axis.

Branches for all foliar deposit sampling and for placement of foliage simulators were always free of overhead branches for the portion sampled.

Assessing Insect Numbers

Larval sampling was done by dislodging larvae from sample trees onto a 2.3 x 3 m cloth placed beneath each tree. Larvae were dislodged by striking the branches on one side of the tree downward with a 3 m long pole and counting the larvae that had fallen onto the cloth. Trees were marked after sampling and were not resampled. The decision of when to spray was based on looper development monitored in the control plots.

Pre-spray samples were taken within 24 h prior to spraying except for diflubenzuron treatments where they were taken within four days following spray application. Pre second-spray larval samples were taken 6 to 10 days after the first spray and post spray larval samples 12 to 17 days after the second spray. Ten trees were sampled in control plots at each sampling date and 2 sets of 10 trees in each treatment plot to estimate treatment efficacy (Fleming and Retnakaran 1985).

At each sampling date 100 larvae from each plot were retained for rearing to determine percent parasitism and disease. These larvae were reared individually in 28 ml plastic containers at 25°C and under natural photo period (approximately 17:7, L:D) in a trailer near the plots. Larvae were fed balsam fir foliage from their respective plots to to approximate foliar toxicity to larval populations remaining in the treated and control plots. Foliage was changed every three to four days. Rearing continued until death or emergence of parasite or moth. Cadavars were examined for disease organisms.

A special collection was made toward the end of larval feeding in early August to determine the level of parasitism and disease in treated and control plots. A total of 100 larvae were collected in each plot, or if insufficient larvae occurred in the sprayed plots, they were collected adjacent to the plots. These larvae were reared individually on unsprayed foliage.

The number of looper larvae surviving to pupation was determined with the use of pupal traps (Otvos 1974). Pieces of burlap 90 cm long were folded and wrapped around the bole about 1.5 m from the ground and stapled to the tree (Fig. 6). Sample size was 20 traps for each treated and control plot. Traps were placed in late July prior to pupation and collected in late August when larvae no longer occurred in the crowns. The number of living pupae, dead larvae, dead pupae, and parasites in the traps were recorded. A sample of up to 100 pupae per treatment and control plot was reared to determine percent moth emergence and parasitism.

Assessing Population Reduction

The percent population reductions in the treatment blocks were corrected for natural mortality with Abbott's formula, as described by Fleming and Retnakaran (1985), as follows:

$$\% \text{ Population Reduction} = 1 - \frac{\text{post-spray pop. in treatment}}{\text{pre-spray pop. in treatment}} \times \frac{\text{pre-spray pop. in control}}{\text{post-spray pop. in control}} \times 100$$

Treatment plots were matched with control plots with similar pre-spray populations.

Assessing Defoliation

Estimates of defoliation were obtained from the ground on a per tree basis and from the air. Whole tree estimates were obtained on 10-11 August from the ground for 60 trees in each treated and control plot and for 40 trees outside the plot but within 200 m of the plot border. The degree of defoliation on current and old foliage was assessed as 0%, 100% or to the nearest 10% average for the entire tree.

Estimates of defoliation in each plot were recorded on aerial photographs on 13 August from a helicopter flying at 60 km/h and 150 m above the canopy. Areas within each plot and within 200 m of the plot boundry were mapped in four categories: nil (0%), light (15%), moderate (30%) and severe (50% and over). A weighted average was calculated for defoliation within mapped areas. The percent of foliage saved (F) for each treatment was calculated as follows:

$$F = \frac{D_c - D_t}{D_c} \times 100\text{, for comparison with control plots, or}$$

$$F = \frac{D_b - D_t}{D_b} \times 100, \text{ for comparison with plot boundary}$$

where: Dc = Average defoliation in the control plot

Db = Average defoliation in the area outside the plot boundary

Dt = Average defoliation in the treated plot

RESULTS AND DISCUSSION

Spray Operations

Sprays were applied as planned in relation to insect development (Table 2). First hatching occurred about 9 June and larval hatch was about 75% complete by 23 June when a small proportion of larvae had molted to the second instar. The first diflubenzuron sprays were then applied (Table 3A). Larval hatch was 93% complete when the first B.t. sprays were applied. The second application of all sprays and the late applications also were applied on schedule (Tables 2, 3A, B).

All B.t. and one fenitrothion applications were applied in the morning and all other applications in the evening. The foliage was dry for all sprays. Relative humidity was generally 80% to 90% for all sprays (Tables 3A, B). Temperatures at spray time were between 8° and -16°C.

Sprays were followed by a rain-free period of at least 48 h, except for the last fenitrothion spray on the morning of 9 July which had a 15 h rain-free period. All B.t. sprays were followed by rain-free periods of more than 75 h (Fig 7, Tables 3A, B). Therefore, the active ingredients were not washed off before the looper fed on the foliage. The one block with only a 15 h rain-free period received 2 mm of drizzle followed by 60 h without rain.

Average wind speed was always lower than 6 km/h at the blocks and wind gusts did not exceed 8 km/h (Tables 3A, B). All but two B.t. blocks were sprayed under stable air conditions and air stability had lapsed only slightly for these two B.t. sprays. Because wind speeds were low the vortex following the airplane wing brought the spray down into the canopy in all treatment blocks. While applying the first spray to plot F2, a few sudden gusts of wind (up to 12 km/h) towards the end of spraying may have caused uneven spray deposit.

Spray Deposit

Forest Floor - Quantity Deposited

Kromekote Cards - Average droplet densities for the whole block varied greatly between insecticides (Table 4). Densities were very low for the diflubenzuron blocks, ranging between 1 and 7 droplets/cm^2 ($\bar{x}$ = 2.7). The range in density was 7 to 51 ($\bar{x}$ = 21.2) for fenitrothion and 39 to 91 ($\bar{x}$ = 54.5) for B.t. The latter was extremely good deposit.

Fenitrothion deposits had the smallest average droplet size, 23 μm to 32 μm MND (Table 4), and therefore would have the greatest probability of being uniformly distributed on the target (Courshee et al. 1969, Randall 1969). The dowanol formulation, applied at 0.4 ℓ/ha, deposited fewer droplets ($\bar{x}$ = 11.7/cm^2) than did the standard formulation ($\bar{x}$ = 34.0/cm^2). B.t. and diflubenzuron both had MND's of about 40 μm to 50 μm, however average droplet size was much larger for diflubenzuron as evidenced by the larger MVD and larger D max. Therefore, diflubenzuron deposited in fewer droplets of relatively large size, whereas both B.t. and fenitrothion deposited many droplets of relatively uniform and small size.

The B.t. formulations had the best deposit and the highest percent of the droplets within the desired size-range, had the highest droplet density, and the highest proportion of spray emitted reaching the ground. Fenitrothion deposited on the foliage in even smaller droplets than did B.t. and also lacked the larger droplet sizes, however droplet density and percent of droplets reaching the ground was lower than for B.t. The water-base formulation of diflubenzuron deposited on the foliage in the largest percent of undesirable large droplets, deposited at low density and also a small proportion of the spray reached the ground. Diflubenzuron in an oil-base formulation may improve spray deposits.

Variations in droplet characteristics among formulations of any one insecticide were generally small. Measures of average droplet size (MND, MVD) generally increased with increasing spray volume emitted. This is partly attributed to the physics of passing a liquid through a rotary atomizer at a lower rate. Smaller spray volumes offer less resistance to the nozzle's propellers resulting in increased rpm and finer break-up of the spray. Within the B.t. sprays the high droplet density and percent deposit of the second application of the first plot was caused by ideal spray conditions. Ideal spray conditions also resulted in the highest droplet density and percent deposit among the fenitrothion sprays. The droplet sizes of fenitrothion applied at extremely low volumes of 0.4 ℓ/ha reached the ground in the same droplet sizes as did those of the higher application rate of 1.5 ℓ/ha.

Graphic presentations of the distributions of droplet number and droplet volume by droplet-diameter size-classes on the Kromekote cards are appended (Appendix I).

Droplet density on the 21 Kromekote cards placed across the plots varied considerably for the fenitrothion and diflubenzuron applications, but not for the *B.t.* applications (Table 4, Appendix II). For the latter, density distribution was nearly ideal except for the second application in block *B.t.*1 where densities were higher at the centre of the block. Density distribution for fenitrothion plots were "good" to "very good", except for the first applications of plots F1 and F2 where deposit was low within the first 100 m of the plots. Deposit patterns across the block were more erratic for the diflubenzuron treatments, but there was generally good coverage of the blocks.

Glass Plates - Deposit on glass plates was used to estimate the percent of emitted spray deposited on samplers at ground level (Table 5, last column). Of the three types of insecticides used, *B.t.* had the best deposit followed by fenitrothion. At least 35% of the *B.t.* sprays reached the ground in open areas. Deposit of seven of the eight applications ranged from 36% to 58%, with one very high deposit of 82%. Deposit of fenitrothion was decidedly lower; ranging from 3% to 32%, with five of the six applications depositing at 20% or less. Deposits of diflubenzuron ranged from 2% to 15% with six of the seven applications ranging from 2%

to 7%. The flowable formulation of this insecticide did not deposit better, at 4% recovery, than did the wettable powder formulations.

Foliage Droplets/Needle

The densities of d/n for the various insecticides varied similarly to the densities at ground level: highest for the B.t. sprays, lowest for the diflubenzuron sprays and intermediate for the fenitrothion sprays (Table 5). There were consistently more droplets on foliage sprayed twice suggesting that not all of the droplets had washed off or had been absorbed since the first spray.

B.t. Treatments - All of the B.t. applications provided excellent needle deposit of 1 d/n or more (Table 6). Droplet density generally increased with increasing dosages. The occurrence of 3.57 and 8.11 d/n was unusually high.

Fenitrothion Treatments - Only one of the six applications of fenitrothion gave excellent deposit of more than 1 d/n, and three others gave acceptable deposit of about 0.5 d/n (Table 6). There was no correlation of d/n with dose of formulation sprayed.

Diflubenzuron Treatments - Only one application of the eight gave excellent deposit on needles, and only one other application (plot D5) was near an acceptable deposit of 0.5 d/n. Formulations sprayed at 5 ℓ/ha had higher d/n than those sprayed at 2.5 ℓ/ha. The new flowable formulation (plot D1) deposited among the lowest at 0.16 d/n.

Foliage - Quantitative Estimates

Quantitative estimates of spray deposits of fenitrothion and diflubenzuron corresponded well to results measuring deposits in d/n

(Tables 6, 7)(Fig. 8, 9, 10). This is as expected because droplets that are too small to count contribute very little to total active ingredient on foliage.

Fenitrothion Treatments - The amount of fenitrothion recorded on the needles was not related to the quantity of the formulation sprayed (Table 7). The Dowanol formulation sprayed at 0.4 ℓ/ha, though depositing in fewer droplets, was more concentrated and yielded similar amounts of active ingredient on the needles, as did the standard formulation. The extremes in deposits, both low and high, were most likely caused by differences in weather conditions at the time of spray.

Diflubenzuron Treatments - The amount of active ingredient was lower than that of fenitrothion (Table 7). The flowable formulation (plot D1) did not deliver a larger number of droplets to the needles than did the sprays of the wettable powder formulation. Diflubenzuron was sprayed at 70 g ai/ha, one-third that of fenitrothion at 210 g ai/ha, but deposits of diflubenzuron averaged only about one-tenth those of fenitrothion.

Comparison of Measures of Deposits - Deposits of B.t. and of fenitrothion on the ground (density/cm^2 on Kromekote cards) were reasonably well correlated with density of droplets on mid-crown foliage (d/n)(Fig. 8), but not those for diflubenzuron. The poor correlation was caused by fewer droplets on the ground than was expected compared to that which occurred for the other two insecticides. Possibly diflubenzuron deposits were not well correlated because of the overall low deposit of this insecticide.

Deposits of fenitrothion on the ground were also reasonably well correlated with quantitative estimates of insecticide deposited on mid-crown foliage (Fig. 9A & B). However, those of diflubenzuron were also correlated, though the correlation was probably caused by one outlier set of data.

The tightest correlation expected was between droplets per needle on mid-crown foliage and quantity of active ingredient on other mid-crown foliage, though different trees were sampled for each type of measure. Again foliar deposits for fenitrothion were correlated and those for diflubenzuron were not (Fig. 10). However, the correlation was poorer than those comparing ground to foliage deposits. The reason for this is not known.

Percent of spray deposited of volume emitted was well correlated with droplet density/cm^2 for each insecticide (Fig. 11). The relation was the poorest for the Dimilin sprays, which were the most variable in all measures. Fenitrothion deposits were about equally well correlated as those of *B.t.* sprays. This good correlation was expected because both measures were taken side by side at ground level.

Foliage Simulators

Metal foliage simulators were adequate samplers of spray deposit of fenitrothion sprays. At low spray deposits (plot F1) the density of droplets/cm^2 was usually more than twice that of needles adjacent to the simulator, and for high sprays deposits (F3) simulators had about three to four times the density that of adjacent foliage (Table 8; see also Appendix III). Similar results were obtained when deposits were measured in active ingredient per unit area.

There was no correlation with density of deposits and position of the simulator within a branch. Simulators placed towards the apex of the branch had the lower deposits in one plot (F1), and the higher deposits in the other (F3). Within the small distance between simulators, branch position did not seem to influence density of deposits. The same conclusions were reached when deposits were measured in weight of active ingredient deposited (Table 8).

Droplet density on a flat and solid surface near ground level in open areas was decidedly higher than those recorded for the foliage and simulators at mid-crown. These higher deposits at ground level reflect results obtained when deposits on a solid surface are compared to those on a surface with gaps (needles or simulators) and when deposits on a two dimensional flat surface are related to the three dimensional configuration of tree canopies.

Performance of Atomizers

The Micronair AU4000 rotary atomizer provided good droplet spectra for all oil-base formulations used in experimental sprays in 1987 (Table 4). The droplet spectra of water-base formulations of Dimilin were inferior to that of the oil-base formulations, but for each type of formulation the droplet-size spectra was improved over that of other nozzles used in previous experimental sprays in Newfoundland (Raske *et al.* 1986, Raske and Retnakaran 1987). In 1987 a greater proportion of the droplets were in the 30 to 60 micron range, and fewer were greater than 100 microns, than in other years.

Persistence of Fenitrothion

Concentrations of fenitrothion on and in balsam fir foliage decreased to about half their original values in 24 hours for most applications (Table 9). Degradation slowed after the first day, and concentrations persisted for at least 15 days following the spray. By the fifth day all concentrations were below 1 µg/g of foliage, except for the highest deposit (F3, 2nd. appl.), and would have minimal influence on insect survival of insects feeding on this foliage. By this time the fenitrothion would be within the needles and not on the needle surface (Sundaram and Sundaram 1987).

Population Reduction

Field Samples

Reductions of larval and pupal numbers in the field varied consistently with insecticide; *B.t.* and fenitrothion suppressed populations more than did Dimilin (Table 10). Good reductions were obtained with early applications of the insecticides, indicating that operational spray operations can be initiated when looper larvae are still in the first instar.

B.t. Treatments - Two applications of *B.t.* applied when larvae are in the first or second instar provided larval reductions or 95% of greater in all three treatments. Single applications of *B.t.* provided larval reductions of 85% and 97%. Reductions in pupal numbers was near 100% for all *B.t.* applications.

Larval population reductions for B.t. were near 100% for the double application and the single application of Dipel 264. The reduction in larval populations for the single application of Dipel 176 at 85% was less. Perhaps this application was less effective than the single application of Dipel 264 (Plot B.t. 4) because of a lower d/n count and perhaps because Dipel 176 is less potent than Dipel 264.

Double application of the more potent sprays, Dipel 176 and Dipel 264, provided population reductions equal to those of the less potent Dipel 132. Single applications can also provide adequate larval reductions, and further studies are warranted to define the spray window and other factors to improve the consistency of obtaining good results with single applications.

Fenitrothion treatments - Larval population reductions were near 100% for the two early treatments (Plots F1 and F3) and about 85% for the late treatment (Plot F2). Pupal population reduction at 78% for the latter plot was also below the 100% obtained of the other two plots. High initial populations and more variable spray deposit may have been partly responsible for the reduced efficacy of the late treatment.

The formulation sprayed at 0.4 /ha can provide good population reduction and should be considered for operational spray for economic reasons.

Dimilin Treatments - Dimilin treatments provided larval population reductions of 45% to 84%. These reductions were decidedly lower than those provided by B.t. and fenitrothion. In addition larval numbers were not reduced immediately after the spray, but just prior to post spray sampling. Some feeding inhibition may have occurred, but this was not measured.

The flowable formulation (plot D1) provided the lowest reduction, probably caused by the low deposit of the active ingredient. There was no consistent relation between the number of applications per treatment and population reduction, neither was the volume of spray used to deliver the active ingredient related to population reduction. However, the high volume of spray (5.0 ℓ) sprayed twice (plot D2) provided the highest population reduction. The second spray applied to this plot deposited very well and probably was responsible for the highest reduction among the Dimilin sprays.

Pupal population reductions were decidedly higher than larval reductions, indicating that Dimilin was still active after the the post-spray larval sample had been taken or that the effects of Dimilin were delayed. Dimilin killed looper larvae during the later larval instars, after they have done considerable feeding.

Foliage and ground deposits of water-base formulations of Dimilin were lower than those of the oil-base formulations of the other insecticides. An oil-base formulation of Dimilin should be tested to see if better deposit and improved efficacy can be obtained.

Rearing Results

Survival of reared larvae to the pupal stage was above 70% (except one at 64%) for all larval samples collected from the control plots and fed on unsprayed foliage (Table 11), and generally near or above 90%. Survival of larvae collected from sprayed plots and fed on foliage from their respective spray plot was much lower than those of control plots except for a few post-spray collections in the Dimilin treated plots.

Percent moth emergence from surviving pupae in rearing from control plots was usually above 88% (Table 11).

B.t. treatments - All larvae collected from the B.t. plots before the spray was applied died within a few days after feeding on sprayed foliage (Table 11). Similarly, only one larvae survived to pupation of larvae collected at pre-second spray. However, up to one-half of the few larvae surviving to the post-spray sampling date also survived to the pupal stage.

Percent moth emergence of surviving pupae from the B.t. plots ranged between 48% and 93%, but averaged lower than that of pupae from the control plots.

Fenitrothion treatments - Survival of larvae collected at pre-spray and pre-second-spray from fenitrothion plots was generally very much reduced compared to that of control plots. As with larvae from the B.t. plots, a high proportion of larvae from the fenitrothion plots that survived to the post-spray sample, also survived to the pupal stage.

Percent moth emergence of surviving pupae, averaged higher than for the B.t. plots, and was only slightly lower than that of the control plots.

Dimilin treatments - Survival of larvae collected from the Dimilin plots at pre-, pre-second-, and post-spray times was somewhat reduced compared to that of the control plots, but generally was higher than survival of larvae collected from the B.t. and fenitrothion plots. Only on two occasions was survival below 30%.

Percent moth emergence from pupae collected in the Dimilin plots, however, was decidedly reduced compared to that in control plots and in plots sprayed with B.t. or fenitrothion. Dimilin-caused mortality continued past the feeding stage and affected moth emergence as well.

General - Results of mortality of reared larvae coincided well with results obtained from field sampling. Formulations that provided near complete population reductions, based on field sampling, also caused near 100% mortality of looper larvae in rearing. When some larvae survived in the field, a proportion of larvae also survived in the rearing. Survival probably was caused by uneven spray deposits (fenitrothion: F2), or by generally poor deposits (Dimilin: all plots).

Parasitism and Disease

Of the 4040 larvae reared in pre-, pre-second- and post-spray samples, 4 larvae were killed by parasites (2 by tachinids, and 2 by hymenoptera), 39 by the fungus *Paecillomyces farinosus* (Holm ex s.f. Gray) Brown and Smith, and one larvae was killed by the fungus *Erynia radicans* (Bref.) Humber, Ben-Ze'ev and Kenneth. Most of the larvae killed by fungi were collected in the Dimilin-treated plots. A total of 472 dead looper larvae contained yeast-like organisms, and 91 cadavers of these were filled to near bloating. The yeast-like organisms probably contributed to the death of these 91 larvae.

Only a small percent of the 2400 additional larvae collected near the end of larval feeding died of parasites or disease organisms.

A total of eight parasites emerged and six of these were tachinids. Larval mortality by all fungal diseases averaged 2.1%, and occurred rather uniformly in all sample sites. Pupal mortality averaged 14.6%, and was almost exclusively caused by diseases. Parasites and diseases caused little population reduction in the experimental spray are in 1987.

Defoliation Reduction

Defoliation Estimates

Severity of defoliation in sprayed plots was negatively correlated with population reduction (Table 12, Appendix V, VI). The amount of defoliation recorded in the *B.t.* plots 1, 2, 4 and 5 was zero and near zero in plot *B.t.* 3. In contrast the brown appearance of partly defoliated trees just outside the plot was very noticeable, and the boundary line between sprayed and unsprayed area was distinct, straight and accordance with the flight of the spray plane. Therefore significant drift of the spray had not occurred, and sufficient spray droplets had been delivered within the plot.

The distinctiveness between sprayed and unsprayed areas was also true for the fenitrothion plots. However, the difference between sprayed and unsprayed plots for fenitrothion sprays was not large because less and more patchy defoliation had occurred adjacent to the spray plot. Defoliation within the vicinity of plot F3 was especially low, with only a few patches of light defoliation adjacent to the plot. A few patches of light, moderate and two very small patches of severe defoliation occurred within F2 (Appendix VII), indicating the patchy nature of the spray deposited. These patches were in the last few swath widths, and were probably caused by a few gusts of wind towards the end.

Several patches of moderate and severe defoliation occurred in the Dimilin-treated plots (Appendix VII), and the appearance of the plot trees from the air was not very different from those adjacent to the plot. This was especially true of plots D4 and D5 (Table 11, Appendix V, VI). In general defoliation was least in plots with the greatest deposit, and was generally less in plots receiving two applications, rather than one application. The flowable formulation, though applied only once, had less defoliation than the other two plots receiving only one application.

Foliage Saved

B.t. and fenitrothion treatments provided adequate foliar protection, but foliar protection provided by the Dimilin formulation tested was insufficient (Table 13, Appendix VI). Foliage saved data compared to defoliation occurring outside the boundary of the spray plots was generally greater or equal to that saved when compared to defoliation of the control plots, probably because population densities in most plot border areas were higher than in the control plots.

Treatments in four B.t. plots saved all of the foliage, and almost all of the old-growth foliage in the fifth plot (B.t. 3) as well (Table 13). However a small amount of new foliage in plot B.t. 3 was lost to the looper possibly because of the late application, and because the application did not cause near 100% population reduction immediately. Dipel 176 and Dipel 264 were applied at lower volume rates, but saved as much foliage in double application as did the less potent Dipel 132. Therefore Dipel 176 and Dipel 264 can be recommended for operational sprays, however the exact spray window for single applications of these formulations needs to be defined.

Two of the three fenitrothion treatments saved all of the foliage (Table 13). More than half of the old-growth foliage was saved in the remaining plot (F2), but less than half of the new-growth foliage. The poorer performance of one of the fenitrothion sprays was caused by the late application of the formulation (some defoliation had occurred before the spray), and the spotty nature of one of the applications. The formulation sprayed at only 0.4 ℓ/ha (F1, F2) can provide population reduction and foliar protection equal to that of the formulation used for operational sprays. The lower volume application rate would be more cost-efficient. The two early applications (F1, F3), applied to the first larval instar, provided the best foliar protection.

Dimilin formulations tested, though also applied early in the feeding period, provided less than adequate foliar protection (Table 13). Double applications saved considerable old foliage, but much of the new foliage was lost to looper feeding. Single applications were inadequate, although the flowable formulation provided better protection than did the wettable powder formulation. Application of the same amount of active

10. The mortality of larvae collected in sprayed plots and reared on foliage from their respective sprayed plots simulated mortality estimated from field sampling. One method can be used to complement or supplement the other provided that natural larval mortality is low.

11. Fenitrothion persists in or on the needles of fir for at least 15 days, but its insecticidal properties are greatly reduced within 3 to 5 days.

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Table 1. Formulations, dosage rates of insecticides and larval development at time of application for experimental sprays against the hemlock looper near Hawkes Bay, Newfoundland in 1987.

Plot No.	Formulation	Dosage and No. Applications	Volume ℓ/ha	Larval development at time of application
B.t.				
*B.t.*1	Dipel 132	2 x 30 BIU	2.36	100% L_1 and 50% L_1, 50% L_2
*B.t.*2	Dipel 176	2 x 30 BIU	1.78	100% L_1 and 50% L_1, 50% L_2
*B.t.*3	Dipel 176	1 x 40 BIU	2.36	50% L_1, 50% L_2
*B.t.*4	Dipel 264	1 x 40 BIU	1.58	50% L_1, 50% L_2
*B.t.*5	Dipel 264	2 x 30 BIU	1.18	100% L_1 and 50% L_1, 50% L_2
Fenitrothion				
F1	Sumithion Tech.	2 x 210 g ai	0.4	100% L_1 and 50% L_1, 50% L_2
F2	Sumithion Tech.	2 x 210 g ai	0.4	50% L_1, 50% L_2 and 70% L_2, 30% L_3
F3	Folithion Tech.	2 x 210 g ai	1.5	100% L_1 and 50% L_1, 50% L_2
Diflubenzuron				
D1	Dimilin Flowable	1 x 70 g ai	5.0	100% L_1
D2	Dimilin 25WP	2 x 70 g ai	5.0	100% L_1 and 50% L_1, 50% L_2
D3	Dimilin 25WP	2 x 70 g ai	2.5	100% L_1 and 50% L_1, 50% L_2
D4	Dimilin 25WP	1 x 70 g ai	2.5	100% L_1
D5	Dimilin 25WP	1 x 70 g ai	5.0	100% L_1

Table 2. Formulations tested against hemlock looper larvae near Hawkes Bay, Newfoundland in 1987.

Formulation	Rate of application (ℓ/ha)	Area sprayed (ha)	Active ingredient/ha	Total vol. applied (ℓ)	Concentrate in mix	Vol. of dye (ℓ)	Emulsi-fier (ℓ)	Volume diluent (ℓ)	Type of diluent
<u>B</u>.<u>t</u>.-Dipel 132*	2.36	30	30 BIU	70.8	900 BIU	**	-	-	oil
<u>B</u>.<u>t</u>.-Dipel 176*	1.78	30	30 BIU	53.4	900 BIU	**	-	-	oil
<u>B</u>.<u>t</u>.-Dipel 176*	2.36	30	40 BIU	70.8	1200 BIU	**	-	-	oil
<u>B</u>.<u>t</u>.-Dipel 264*	1.18	30	30 BIU	35.4	900 BIU	**	-	-	oil
<u>B</u>.<u>t</u>.-Dipel 264*	1.58	30	40 BIU	47.4	1200 BIU	**	-	-	oil
Fenitrothion	0.4	30	210 g	12	4.7 ℓ	0.2[a]	-	7.1[c]	oil
Fenitrothion	1.5	30	210 g	45	4.9 ℓ	0.6[a]	17.8[b]	21.7[d]	oil
Dimilin Flowable	5	30	70 g	150	4.3 ℓ	0.8[e]	-	144.9	water
Dimilin 25 WP	5	30	70 g	150	8.38 kg	0.9[e]	-	149.1	water
Dimilin 25 WP	2.5	30	70 g	75	4.19 kg	0.9[e]	-	149.1	water

*Dipel arrived premixed, including dye and was applied without additions.

**Day glow orange, a fluorescent dye; supplied pre-mixed.

a = Automate Red B, b = Cyclosol, c = Dowanol TBM, d = ID 585 oil, e = Rhodamine B.

Table 3. Hemlock looper larva development near Hawkes Bay, Newfoundland in 1987.

Date	Percent Instar				Total No. in sample	No. trees sampled	Average No. per tree sample
	I	II	III	IV			
June							
9	100	0	0	0	24	10	2.4
17-18	100	0	0	0	5 521	67	82.4
22-24	98.7	1.3	0	0	8 624	80	107.8
25-27	98.1	1.9	0	0	25 057	170	147.4
30	71.1	28.9	0	0	7 891	50	157.8
July							
2	47.1	52.7	0.1	0	9 237	60	154.0
8	6.2	70.0	23.8	0	1 175	90	117.5
21-22	0	1.4	35.0	63.6	4 612	50	92.2

Table 4A. Application rates and weather parameters of experimental sprays for first applications of insecticides against the hemlock looper near Hawkes Bay, Newfoundland in 1987.

Plot No.	Treatment	Base	Rate ℓ/ha	Dose g or BIU/ha	Date sprayed	Time (h)	Ave. Temp. (°C)	Average R.H. (%)	No. hours to next rain	Ave. wind speed (km/h)	Max. wind speed (km/h)	Air stability
B.t. 1	Dipel 132	Oil	2.36	30	June 26	0540	8	91	76	4.0*	5.0	↔
B.t. 2	Dipel 176	Oil	1.78	30	June 26	0630	8	92	76	6.0*	6.0	↑
B.t. 3	Dipel 176	Oil	2.36	40	July 4	0600	10	84	144	5.0	6.0	↔
B.t. 4	Dipel 264	Oil	1.58	40	July 4	0610	10	82	144	5.0	7.0	↔
B.t. 5	Dipel 264	Oil	1.18	30	June 26	0715	8	90	76	7.0*	8.0	↑
F1	Fenitrothion	Oil	0.4	210	June 24	2050	11	84	48	3.0	4.0	↓
F2	Fenitrothion	Oil	0.4	210	July 4	2015	13	84	132	4.0	5.0	↔
F3	Fenitrothion	Oil	1.5	210	June 24	2130	10	82	48	2.0	3.0	↓
D1	Dimilin	Water	5.0	70	June 23	2105	13	80	96	2.0	3.0	↓
D2	Dimilin	Water	5.0	70	June 22	2105	10	84	120	5.0*	6.9	↔
D3	Dimilin	Water	2.5	70	June 22	2130	10	86	120	5.6*	7.0	↔
D4	Dimilin	Water	2.5	70	June 23	2050	13	84	96	4.0	1.0	↓
D5	Dimilin	Water	5.0	70	June 22	2205	9	87	120	1.0	1.0	↔

*Lower at plot.

↓, ↔ = stable conditions

↑ = unstable conditions

Table 4B. Application rates and weather parameters of experimental sprays for second applications of insecticides against the hemlock looper near Hawkes Bay, Newfoundland in 1987.

Plot No.	Treatment	Base	Rate ℓ/ha	Dose g or BIU/ha	Date sprayed	Time (h)	Ave. Temp. (°C)	Average R.H. (%)	No. hours to next rain	Ave. wind speed (km/h)	Max. wind speed (km/h)	Air stability
B.t. 1	Dipel 132	Oil	2.36	30	July 4	0640	10	82	144	6.0	7.0	↔
B.t. 2	Dipel 176	Oil	1.78	30	July 4	0535	10	84	144	5.0	7.0	↓
B.t. 5	Dipel 264	Oil	1.18	30	July 4	0640	10	82	144	6.0	7.0	↔
F1	Fenitrothion	Oil	0.4	210	July 4	2040	13	89	132	4.0	5.0	↔
F2	Fenitrothion	Oil	0.4	210	July 9	0510	14	84	15*	3.0	7.0	↓
F3	Fenitrothion	Oil	0.4	210	July 5	2050	16	76	108	3.0	3.0	↓
D2	Dimilin	Water	5.0	70	July 4	2030	13	88	132	3.0	4.0	↔
D3	Dimilin	Water	2.5	70	July 4	2110	12	87	132	4.0	5.0	↔

* 2 mm of drizzle fell in 2 hrs. followed by 60 hour rain free period.

Table 5. Spray deposit parameters following aerial application of insecticide formulations near Hawkes Bay, Newfoundland in 1987. Area analyzed per card = 105 cm^2, 21 cards per treatment.

Plot No.	Application No.	Application rate (ℓ/ha)	Droplet Density (μm^2)	MND[1] (μm)	MVD[2] (μm)	D min[3] (μm)	D max (μm)	Deposit[4] (mℓ/ha)	Deposit[5] (g ai/ha)	% Deposit
B.t. 1	1st	2.36	45	51	86	5	165	894	-	38
	2nd	2.36	91	52	91	5	160	1941	-	82
B.t. 2	1st	1.78	44	39	84	5	145	661	-	38
	2nd	1.78	67	40	85	5	138	1031	-	58
B.t. 3	-	2.36	57	50	93	5	165	1224	-	52
B.t. 4	-	1.58	50	39	77	5	130	651	-	41
B.t. 5	1st	1.18	43	39	78	5	110	492	-	42
	2nd	1.18	39	36	75	5	110	420	-	36
F1	1st	0.4	17	24	43	5	74	-	24	11
	2nd	0.4	11	29	42	5	65	-	17	8
F2	1st	0.4	7	23	39	5	67	-	7	3
	2nd	0.4	19	28	50	5	65	-	34	16
F3	1st	1.5	32	32	57	5	86	-	43	20
	2nd	1.5	51	26	54	5	84	-	68	32
D1	-	5.0	1.5	46	158	8	290	-	2.9	4
D2	1st	5.0	2.0	51	111	6	220	-	2.7	4
	2nd	5.0	7.0	53	112	6	220	-	10.6	15
D3	1st	2.5	2.2	44	80	6	140	-	4.1	6
	2nd	2.5	2.7	48	67	6	140	-	4.7	7
D4	-	5.0	1.1	45	183	8	290	-	1.5	2
D5	-	2.5	2.1	45	135	8	290	-	3.4	5

[1]Median number diameter - the droplet diameter that halves the number of droplets.
[2]Median volume diameter - the droplet diameter that halves the volume of droplets.
[3]For *B.t.* and fenitrothion this is the limit of detection.
[4]Calculated from Kromekote card data.
[5]Calculated from glass plate data. Measured by gas liquid chromotography for fenitrothion and high-performance liquid chromotography for diflubenzuron.

Table 6. Average number of droplets/needle on mid-crown branch tips following applications of insecticides near Hawkes Bay, Newfoundland in 1987. (See text for sampling methods.)

Plot No.	First application	Second application
B.t. 1	1.01	8.11
B.t. 2	1.24	3.57
B.t. 3	1.54	-
B.t. 4	1.90	-
B.t. 5	1.45	1.41
F1	.09	0.52
F2	0.23	0.48
F3	0.48	1.77
D1	0.17	-
D2	0.33	1.12
D3	0.20	0.35
D4	0.16	-
D5	0.42	-

Table 7. Average foliar deposit of active ingredient of insecticides on mid-crown branch tips following application of insecticides near Hawkes Bay, Newfoundland in 1987. (See text for methods of estimation and sample/size for each insecticide.)

Insecticide	Plot No.	First Application	Second Application
		μg/g fresh weight	μg/g fresh weight
Fenitrothion (pooled sample of 10 trees)	1	4.51	4.24
	2	2.22	5.13
	3	5.11	8.96
Dimilin (n = 3)	1	0.17	-
	2	0.68	0.85
	3	0.17	0.12
	4	0.24	-
	5	0.33	-

Table 8. Average number of droplets and active ingredient of fenitrothion on metal foliage simulators, on live foliage and on Kromekote cards near ground level following application of insecticides near Hawkes Bay, Newfoundland in 1987.

		Average Number of Droplets/cm² by Year of Growth[a]				AI by Year of Growth[b] (μg/cm²)			
Plot	Surface type	'86/87	'83/84	'80/81	Ave.	'86/87	'83/84	'80/81	Ave.
F1	Simulator	.39	.56	.58	.50	-	-	-	-
F1	Simulator	.30	.43	.45	.39	172	179	185	195
F1	Foliage	-	.23	-	.23	-	52	-	52
F1	Ground level	-	17	-	17	-	240	-	240
F3	Simulator	7.14	4.52	5.80	5.83	-	-	-	-
F3	Simulator	5.15	3.26	4.16	4.19	293	289	267	283
F3	Foliage	-	1.20	-	1.20	-	72	-	72
F3	Ground level	-	32	-	32	-	430	-	430

a = 3 simulators from one side of branch.
b = 3 simulators from other side of branch processed.

Table 9. Persistence of fenitrothion concentrations (µg/g fresh weight) on balsam fir foliage following application of insecticides near Hawkes Bay, Newfoundland in 1987.

Time after spray application	Concentration (µg/g fresh weight					
	F-1 (0.4 ℓ/ha)		F-2 (0.4 ℓ/ha)		F-3 (1.5 ℓ/ha)	
	1st Appln.	2nd Appln.	1st Appln.	2nd Appln.	1st Appln.	2nd Appln.
Prespray	N.D.*		N.D.		N.D.	
1 h	4.51	4.24		5.13	5.11	8.96
1.5 h			2.22			
2 h	3.20					
3 h				4.47		
6 h				3.23		
7 h	2.91	2.84	1.66		4.18	7.02
12 h	2.26	2.18	1.03	2.68	3.13	6.39
24 h		1.92	0.81	1.87		5.17
36 h	0.79				1.74	
2 d	0.68	1.60	0.42	1.41	0.88	3.49
3 d	0.55	1.11	0.20	1.04	0.64	2.63
5 d	0.47	0.77		0.68	0.52	1.42
8 d		0.60		0.49		0.93
12 d		0.41		0.33		0.62
15 d		0.32		0.27		0.46

*N.D. Not detected; detection limit 0.02 ppm.

Table 10. Hemlock looper population reductions following application of insecticides near Hawkes Bay, Newfoundland in 1987.

Treatment Plot and Matched Control Plot			Average Number Larvae Per Tree: Pre-spray	Pre-second spray	Post-spray	Avg.no. pupae per tree	% Population Reduction: Pre-second spray	Post-spray	Pupal
			B.t. (DIPEL)						
B.t. 1*	2 x 132	30 BIU	111.6	21.5	1.2	0.1	82.0	98.2	100
A	Control		90.7	97.0	54.4	196.7			
B.t. 2	2 x 176	30 BIU	228.3	47.1	1.0	0.4	79.0	99.5	100
C	Control		246.5	241.4	216.8	372.0			
B.t. 3	1 x 176	40 BIU	107.0	-	6.5	4.7	-	85.0	97.3
D	Control		104.3		42.3	167.8			
B.t. 4	1 x 264	40 BIU	151.5	-	1.9	0.0	-	97.0	100
B	Control		165.7	-	69.7	133.9			
B.t. 5	2 x 264	30 BIU	95.4	26.1	2.6	0.6	74.4	95.5	99.7
A	Control		90.7	97.0	54.4	196.7			
			FENITROTHION						
F 1	2 x 0.4 ℓ/ha - early		53.5	7.7	0.5	0.7	92.1	98.7	100
D	Control		57.0	104.3	42.3	167.8			
F 2	2 x 0.4 ℓ/ha - normal		195.7	40.6	15.7	30.3	84.3	86.4	78.7
E	Control		140.6	186.2	83.0	137.4			
F 3*	2 x 1.5 ℓ/ha - early		39.6	5.3	0.5	0.4	92.7	98.3	100
D	Control		57.0	104.3	42.3	167.8			
			DIMILIN						
D 1	1 x Flow. 5 ℓ/ha		190.2		45.5	53.5		46.7	61.9
E	Control		186.2		83.0	137.4			
D 2	2 x 5 ℓ/ha		84.5		7.7	2.1		83.7	98.8
A	Control		97.0		54.4	196.7			
D 3	2 x 2.5 ℓ/ha		232.2		56.7	7.9		58.6	96.5
E	Control		140.6		83.0	137.4			
D 4	1 x 2.5 ℓ/ha		640.5		207.5	118.9		63.2	87.7
C	Control		246.5		216.8	372.0			
D 5	1 x 5 ℓ/ha		256.1		104.9	139.1		58.1	44.4
E	Control		140.6		83.0	137.4			

* These treatments were also used in the operational program.

Table 13. Average foliage saved of foliage on current year and older shoots of balsam fir following application of insecticides near Hawkes Bay, Newfoundland, 1987.

	CURRENT GROWTH		OLD GROWTH	
Plot No.	% Foliage saved (control)	% Foliage saved (boundary)	% Foliage saved (control)	% Foliage saved (boundary)
B.t. 1	100	100	100	100
B.t. 2	100	100	100	100
B.t. 3	62.7	87.5	96.8	98.9
B.t. 4	100	100	100	100
B.t. 5	100	100	100	100
F1	100	100	100	100
F2	6.6	46.2	74.6	81.0
F3	100	100	100	100
D1	23.1	47.4	59.6	66.5
D2	66.2	68.6	92.0	91.6
D3	41.0	51.0	94.3	94.6
D4	0	14.5	1.0	31.3
D5	0	3.2	0	18.8

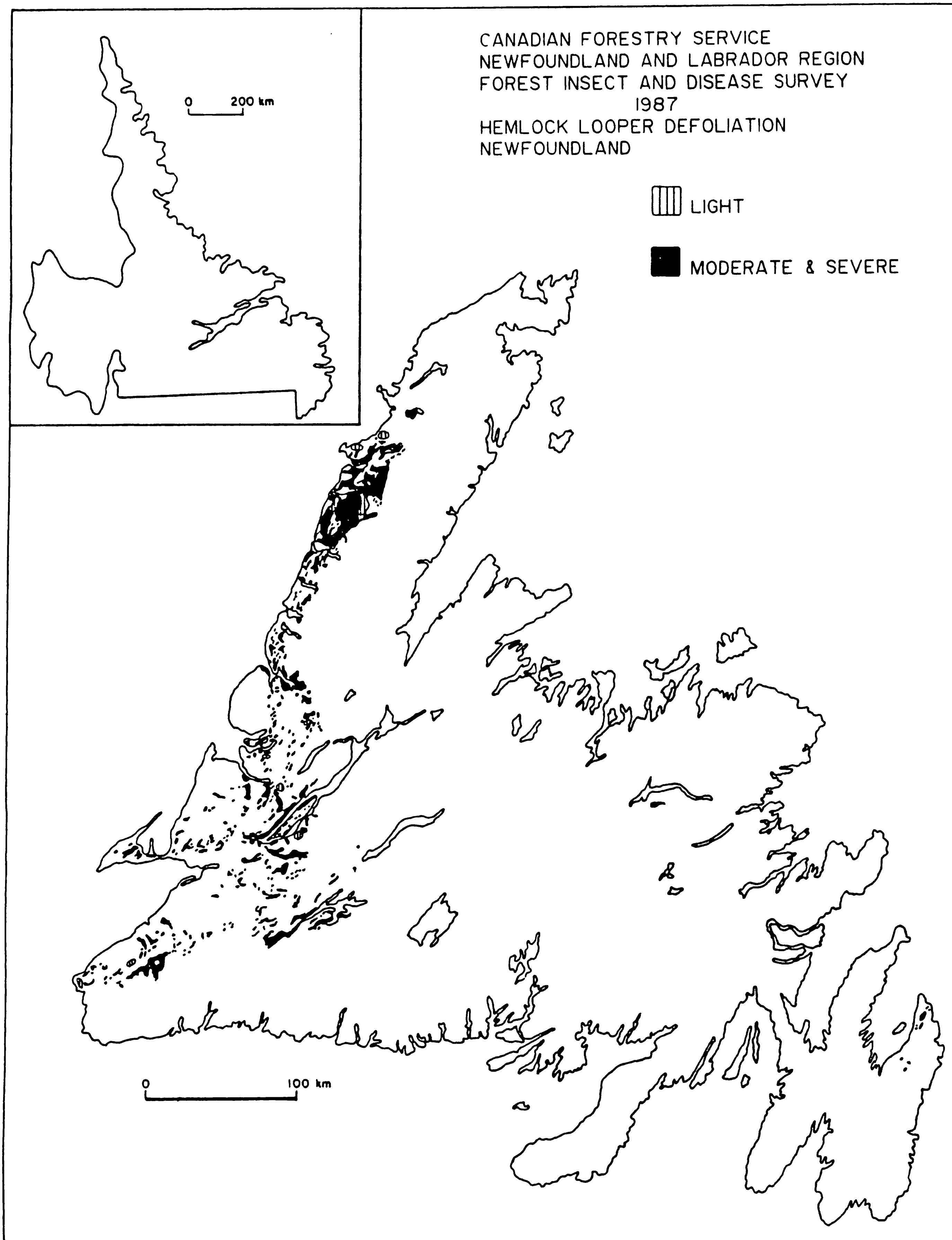


Figure 1. Areas of moderate and severe defoliation caused by the hemlock looper in Newfoundland in 1987.

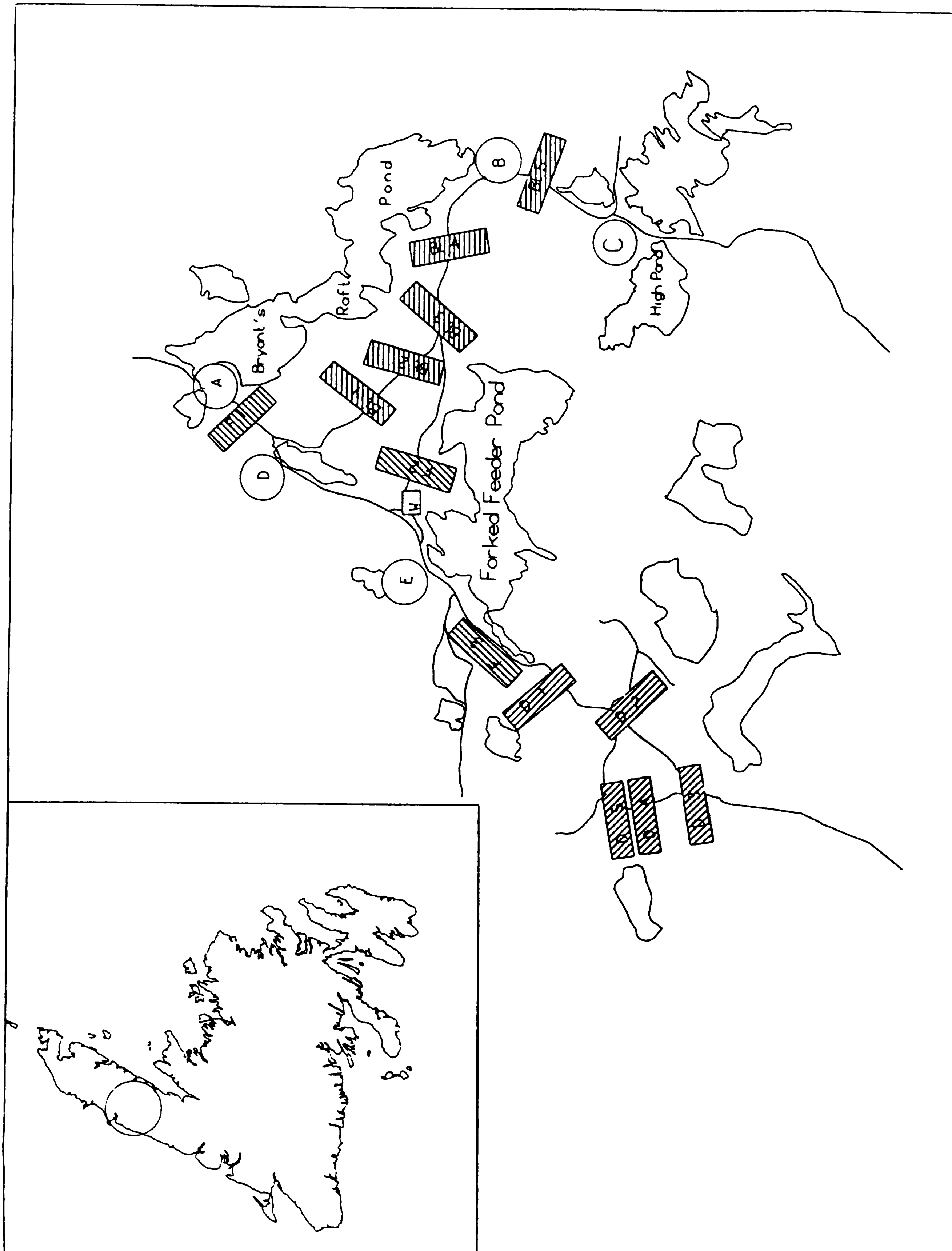


Figure 2. Experimental area for testing effectiveness of insecticides against the hemlock looper near Hawkes Bay, Newfoundland in 1987. (See Table 1 for details.) B.t. = treated with Bacillus thuringiensis, F = treated with fenitrothion, D = treated with diflubenzuron, A-E = control plots, W = location of weather station.

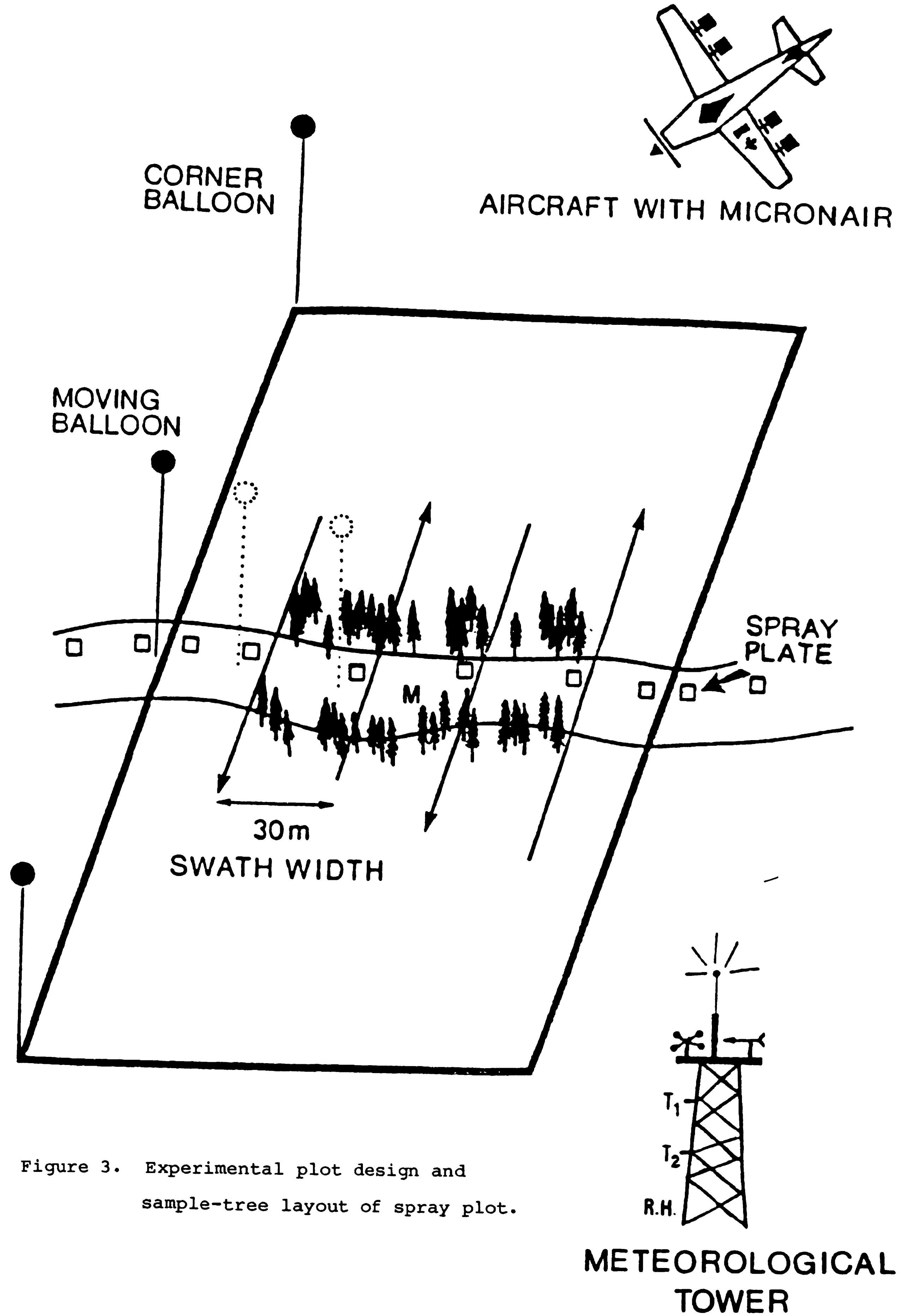


Figure 3. Experimental plot design and sample-tree layout of spray plot.

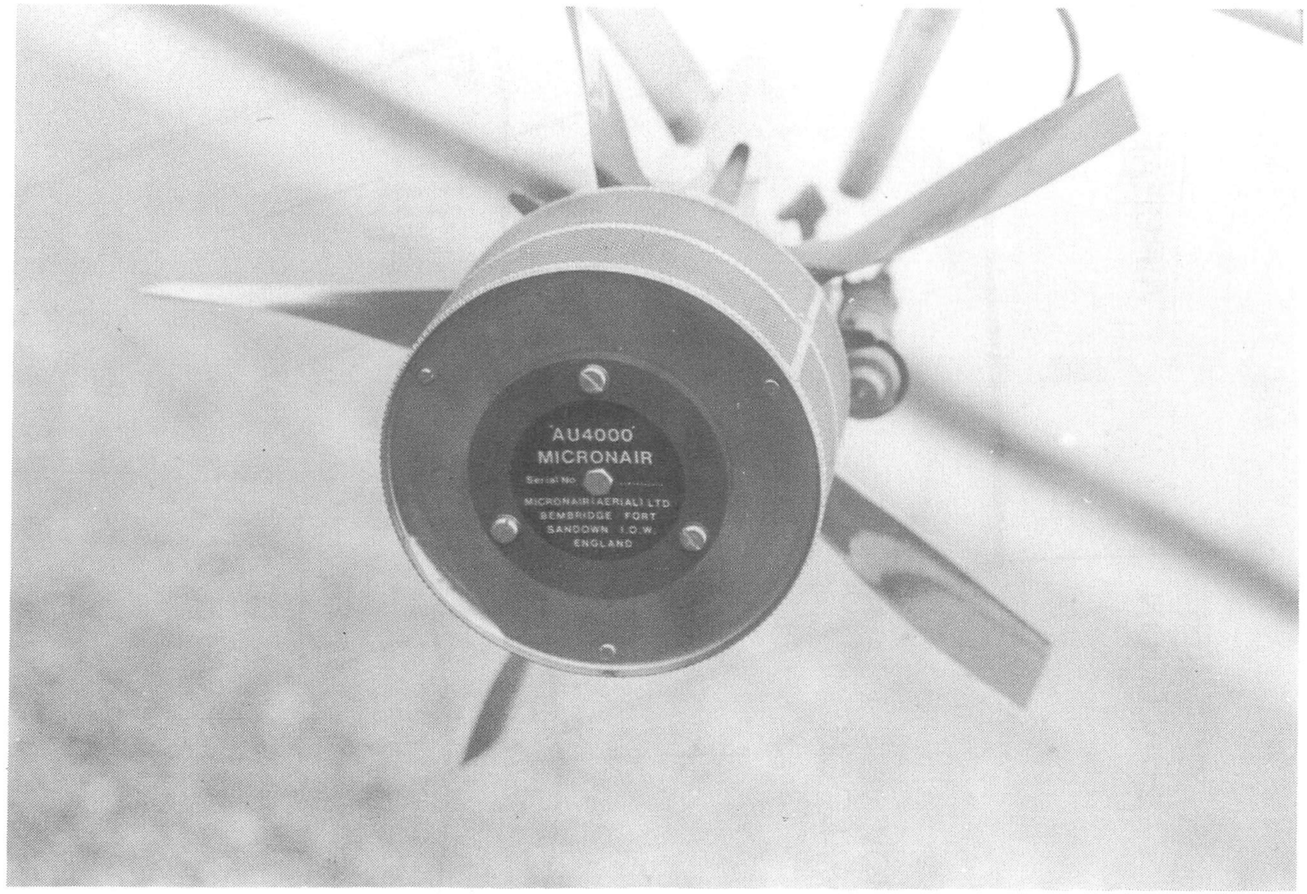


Figure 4. Micronair AU4000^{R} spray nozzle.

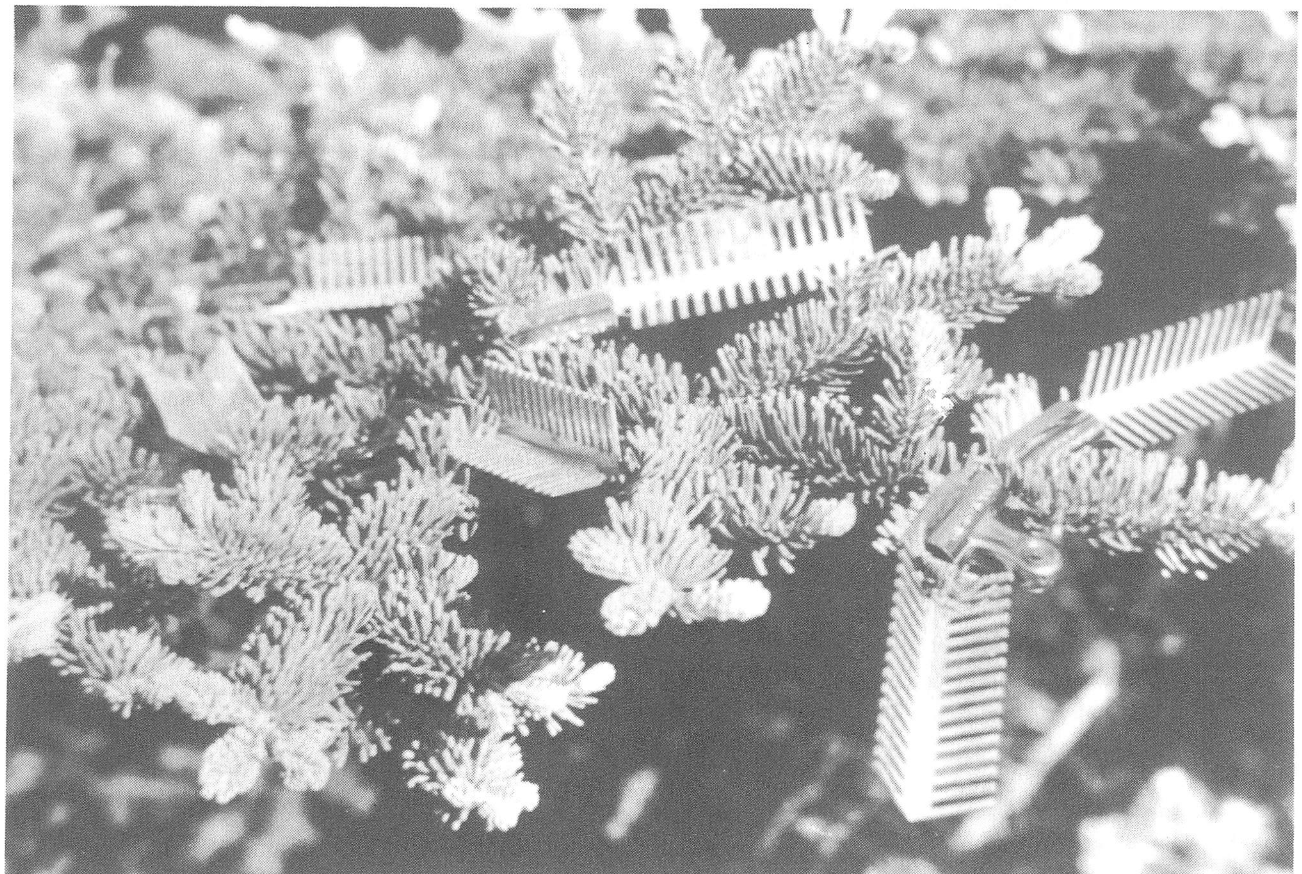


Figure 5. Metal foliage simulators used to measure fenitrothion deposits.

Figure 6. Burlap trap for hemlock looper larvae on bole of balsam fir.

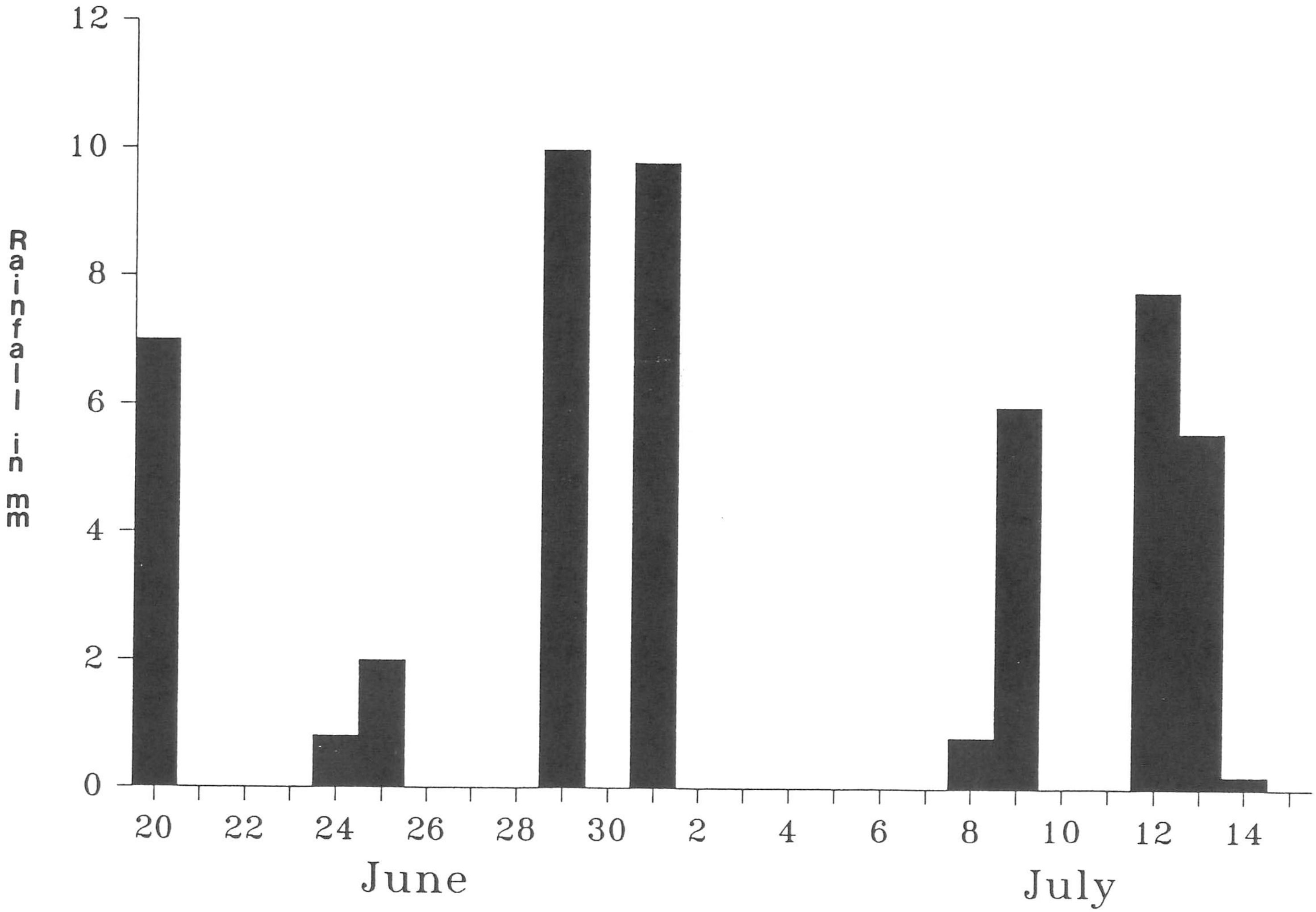


Figure 7. Daily rainfall from June 20 to July 15, 1987 in the experimental spray area near Hawkes Bay, Newfoundland.

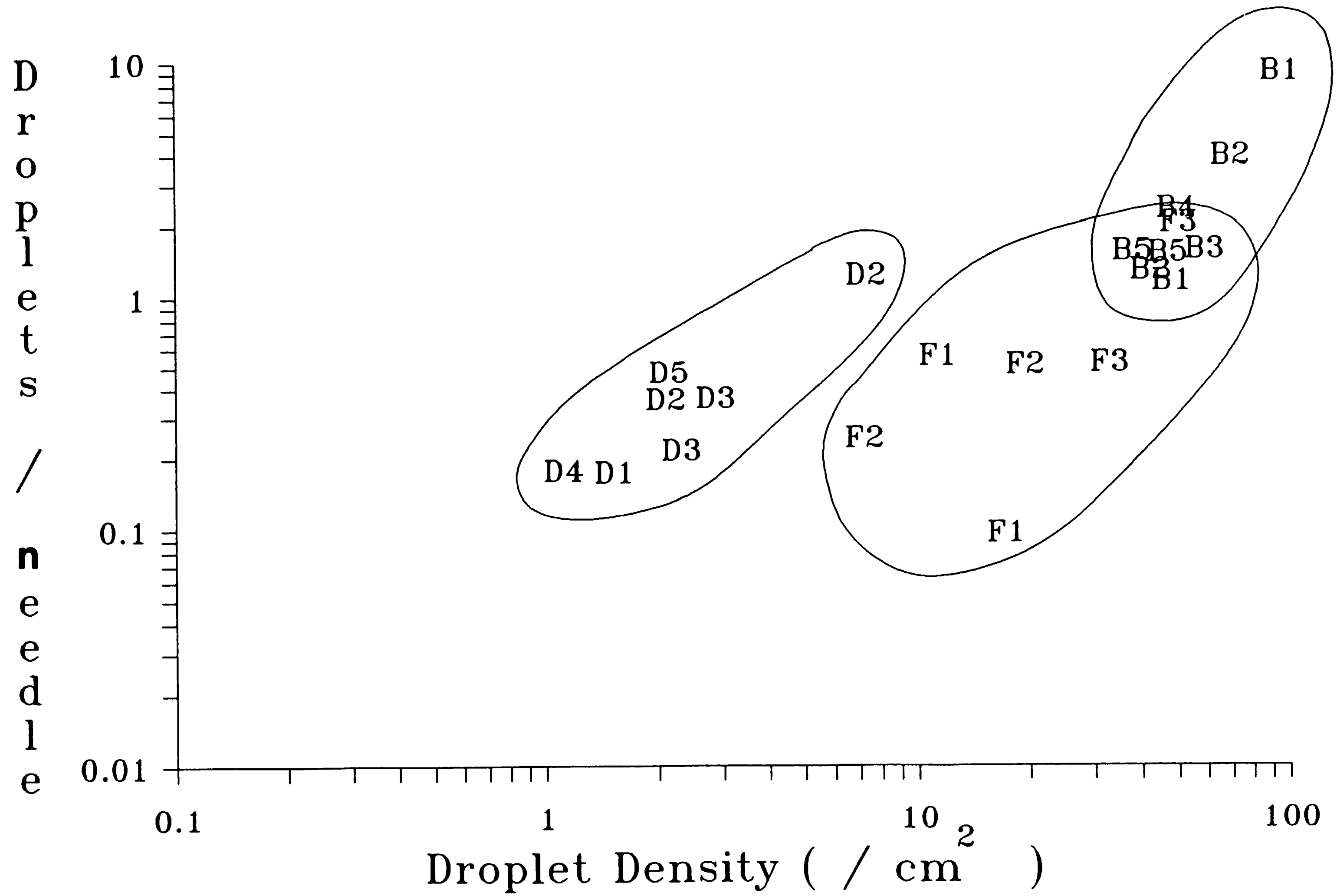


Figure 8. Relation of spray deposits measured as droplets/cm^2 on Kromekote[R] cards near the ground and droplets/needle at mid-crown following application of insecticides near Hawkes Bay, Newfoundland in 1987.

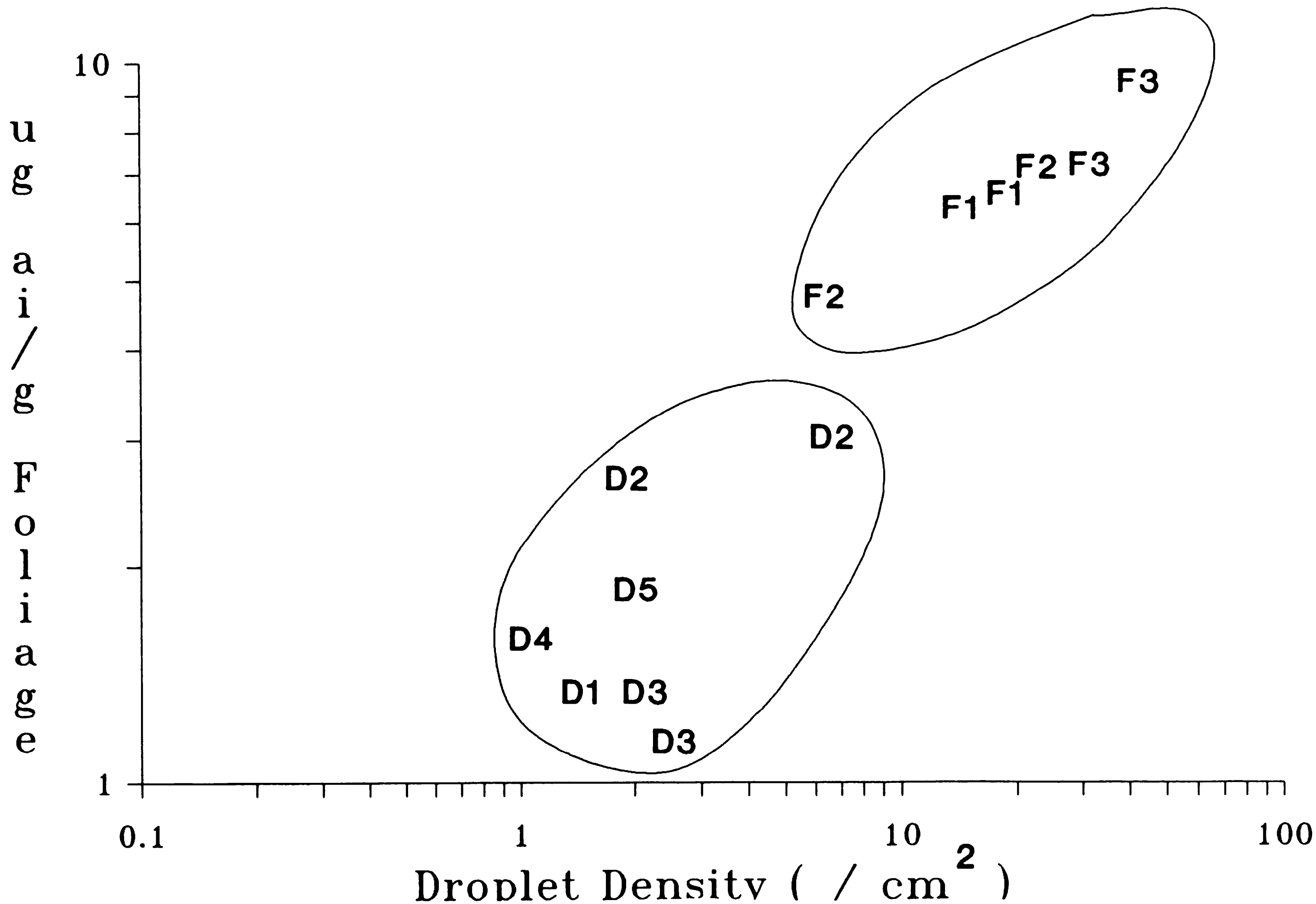


Figure 9. Relation of spray deposits measured as droplets/cm^2 on Kromecote[R] cards near the ground to quantity of active ingredients at mid-crown following application of insecticides near Hawkes Bay, Newfoundland in 1987.

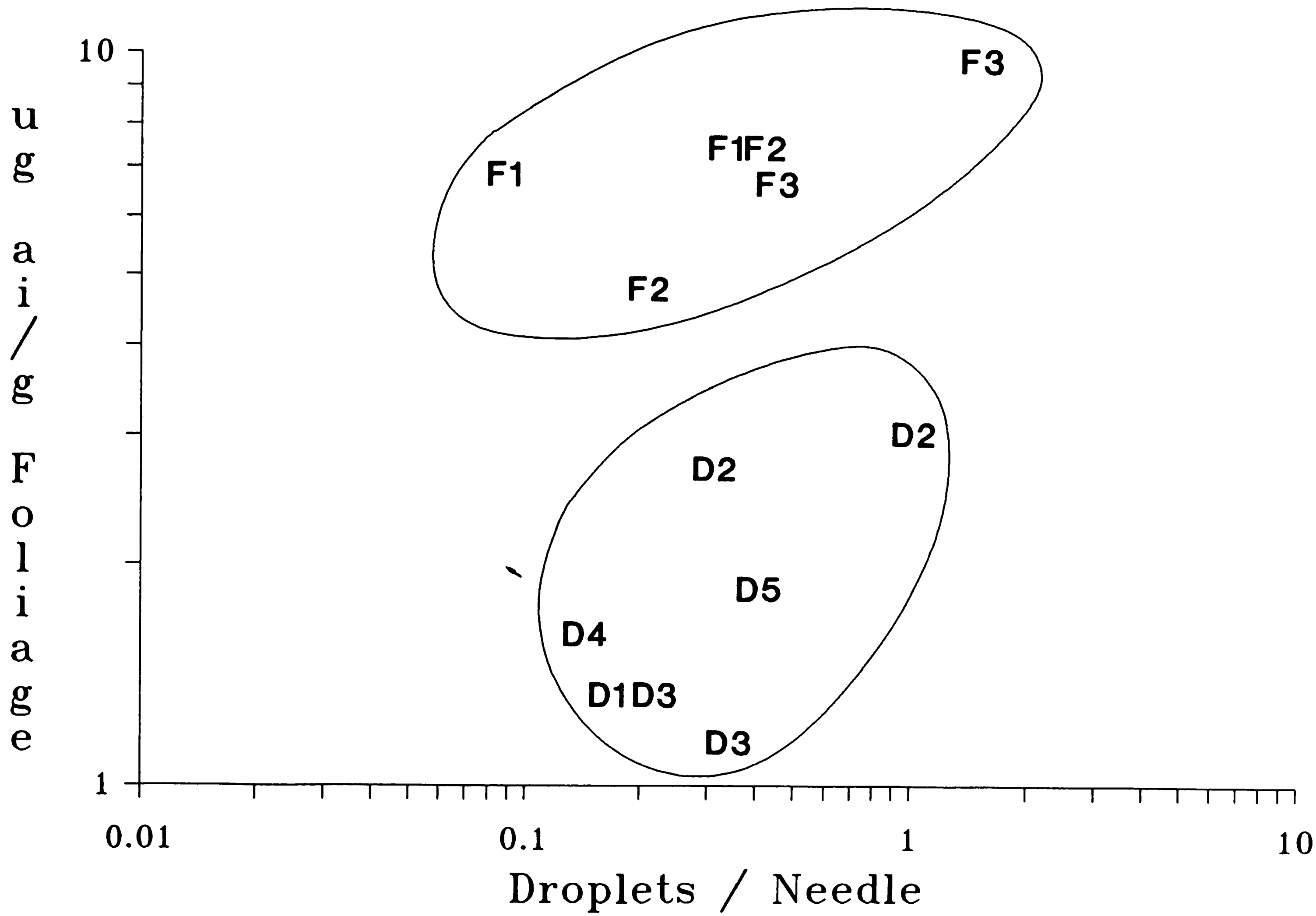


Figure 10. Relation of spray deposits measured as droplets/needle to quantity of active ingredients at mid-crown following application of insecticides near Hawkes Bay, Newfoundland in 1987.

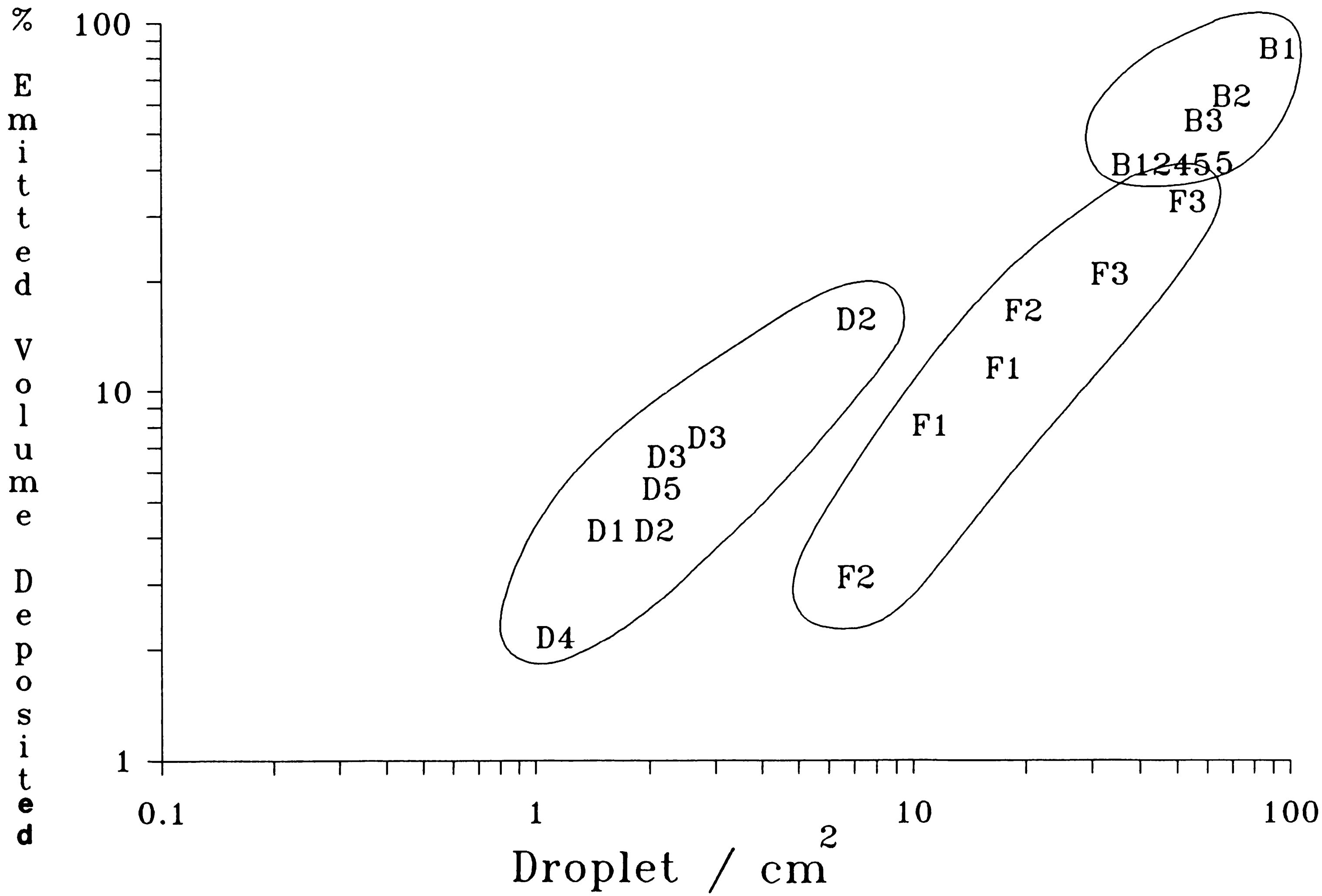
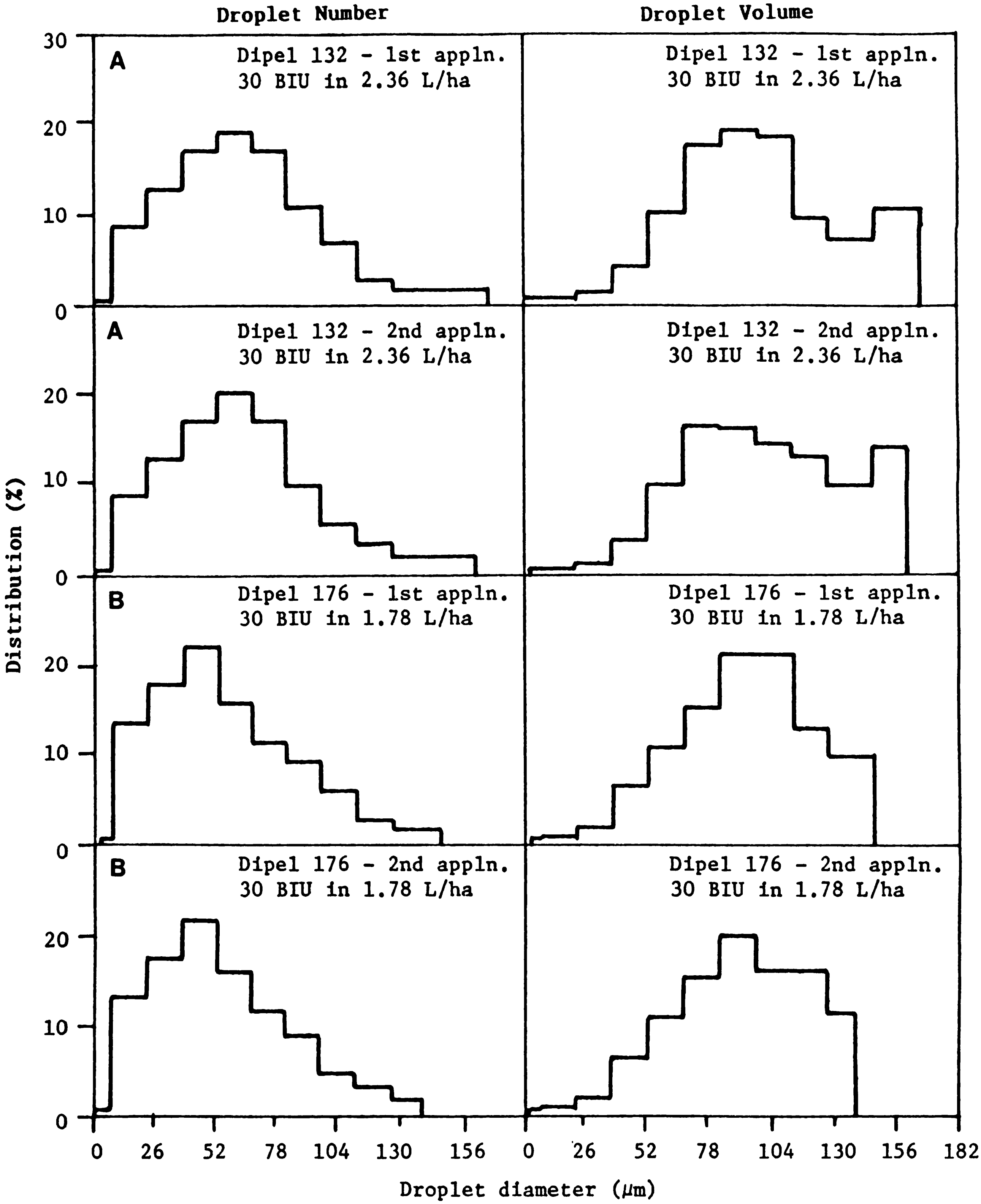
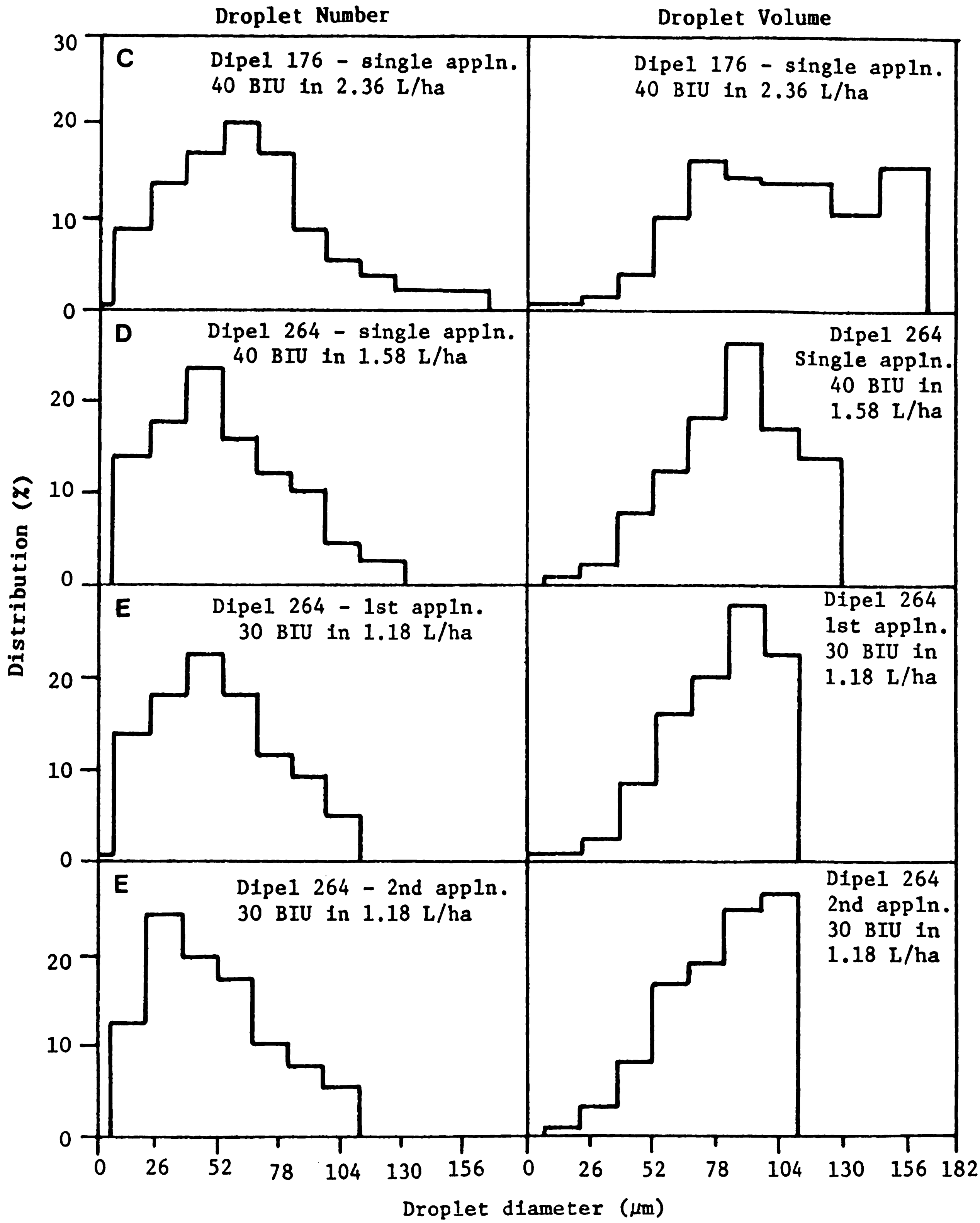


Figure 11. Relation of spray deposit measured as droplets/cm^2 on Kromecote[R] cards to percent of emitted spray volume deposited; both measured near the ground near Hawkes Bay, Newfoundland in 1987.

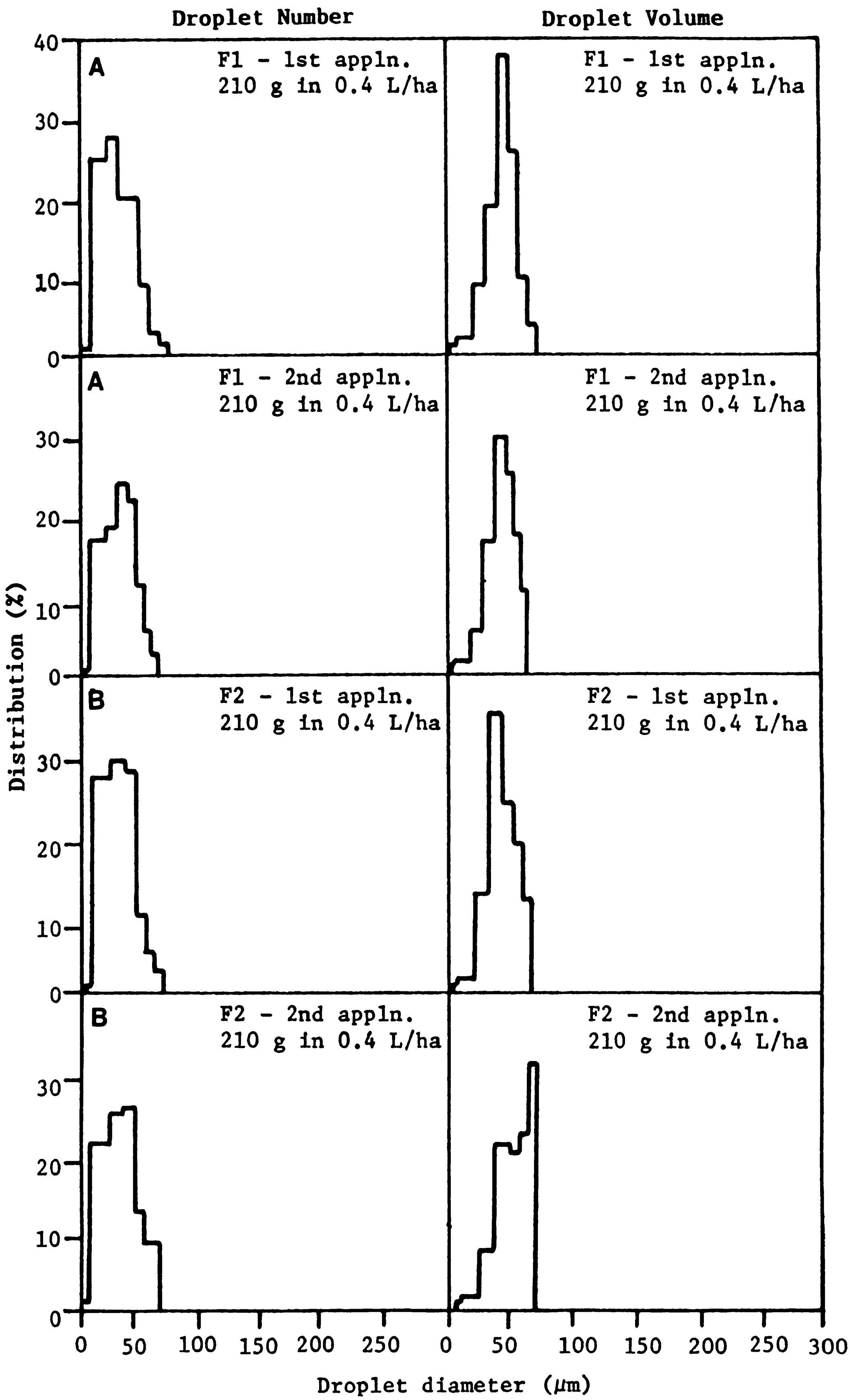
A P P E N D I C E S



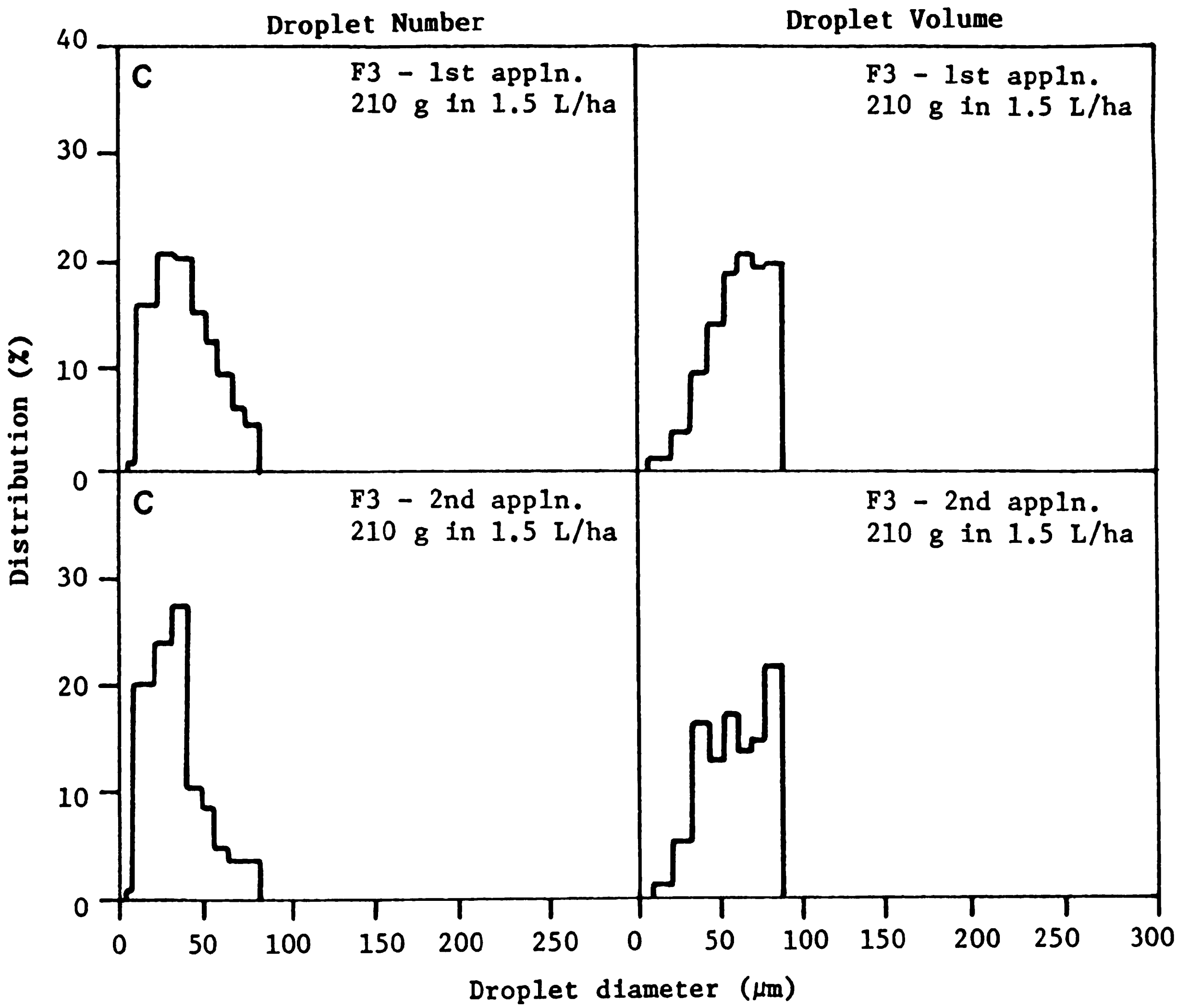
Appendix IA. Frequency distribution of droplet-diameter classes of aerially applied B.t. (Dipel[R]) on Kromekote[R] cards near the ground by droplet number and droplet volume. A = plot B.t. 1, B = plot B.t. 2.



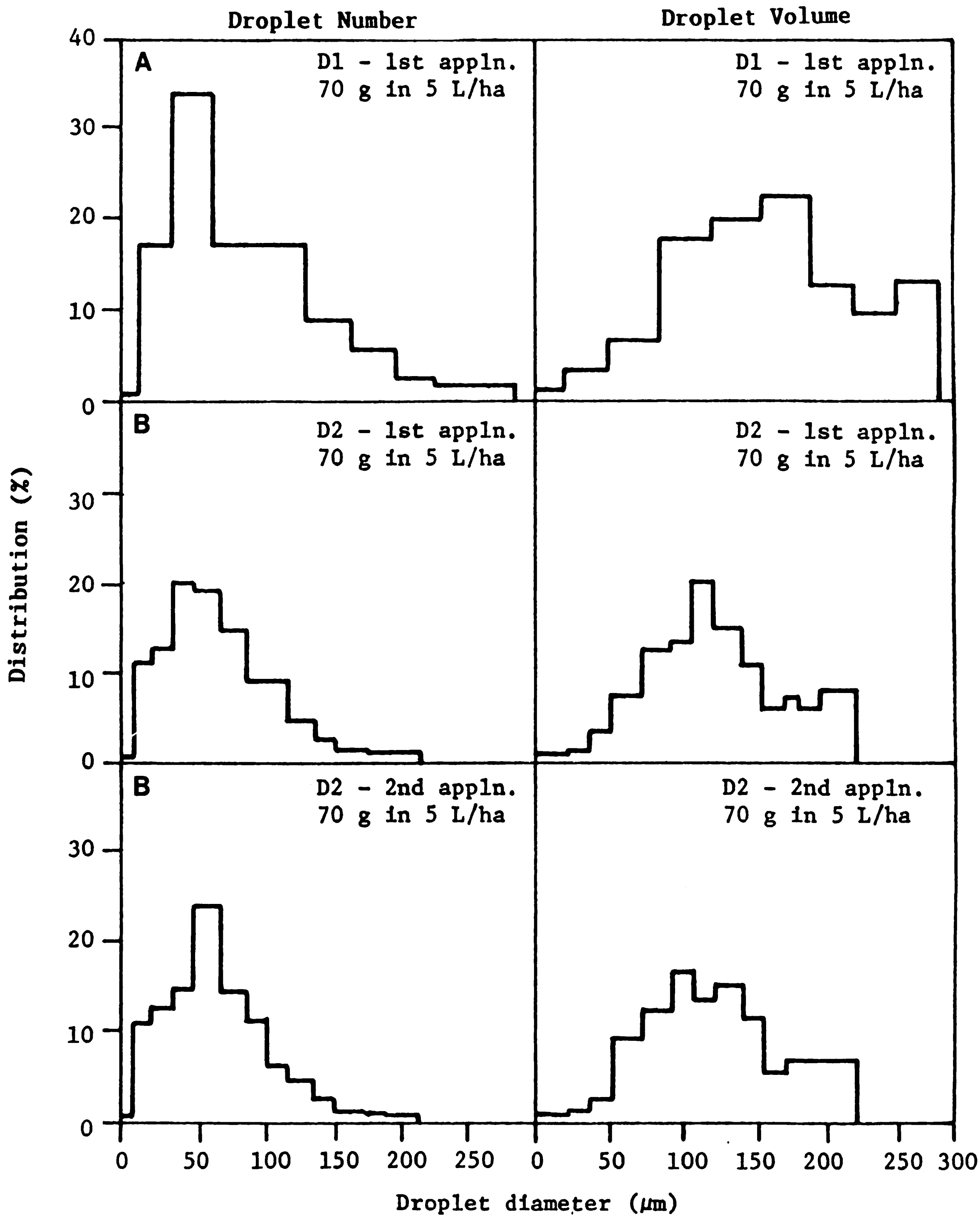
Appendix IB. Frequency distribution of droplet-diameter classes of aerially applied B.t. (Dipel[R]) on Kromekote[R] cards near the ground by droplet number and droplet volume. C = plot B.t. 3, D = plot B.t. 4, E = plot B.t. 5.



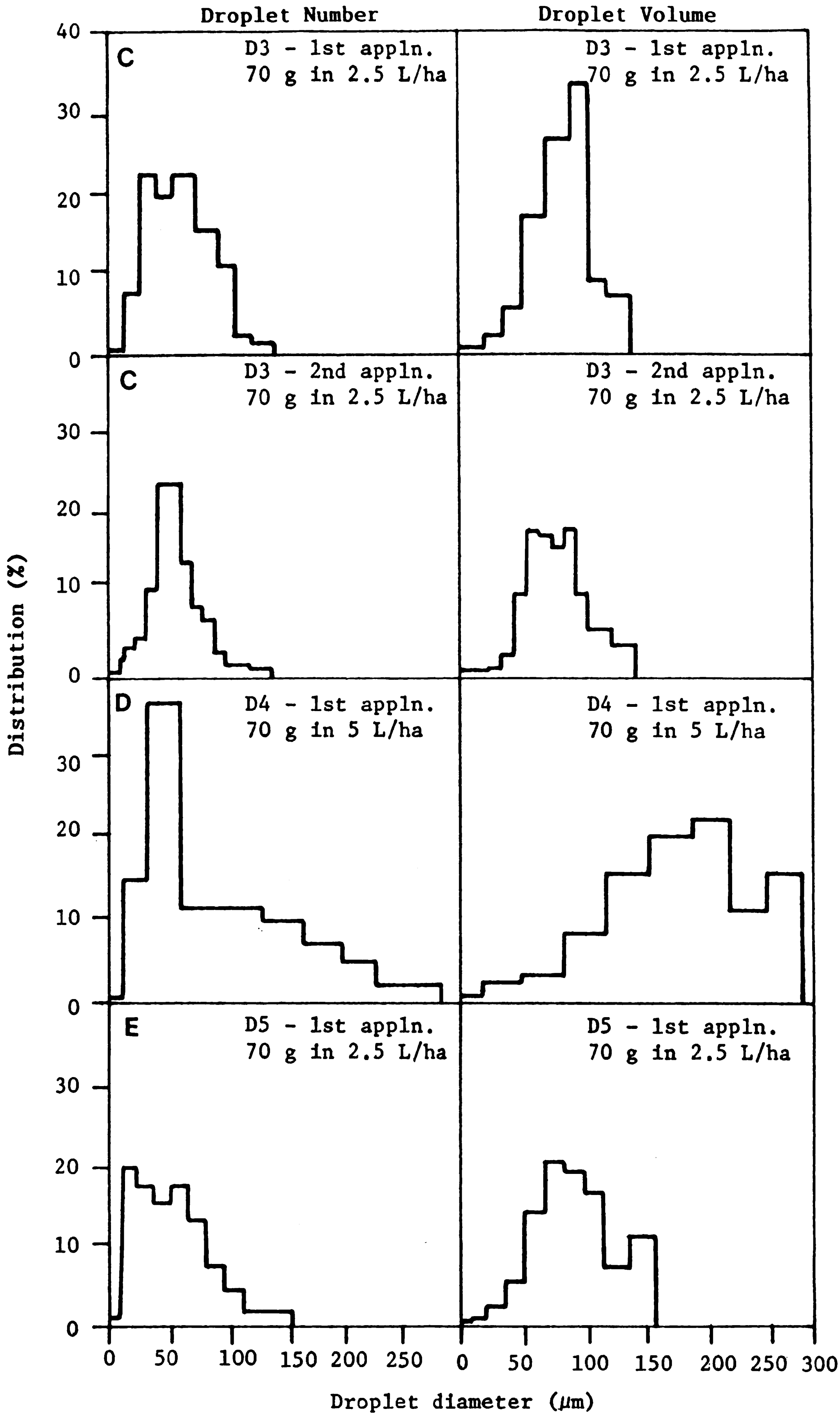
Appendix IC. Frequency distribution of droplet-diameter classes of aerially applied fenitrothion on Kromekote[R] cards near the ground by droplet number and droplet volume. A = plot F1, B = plot F2.



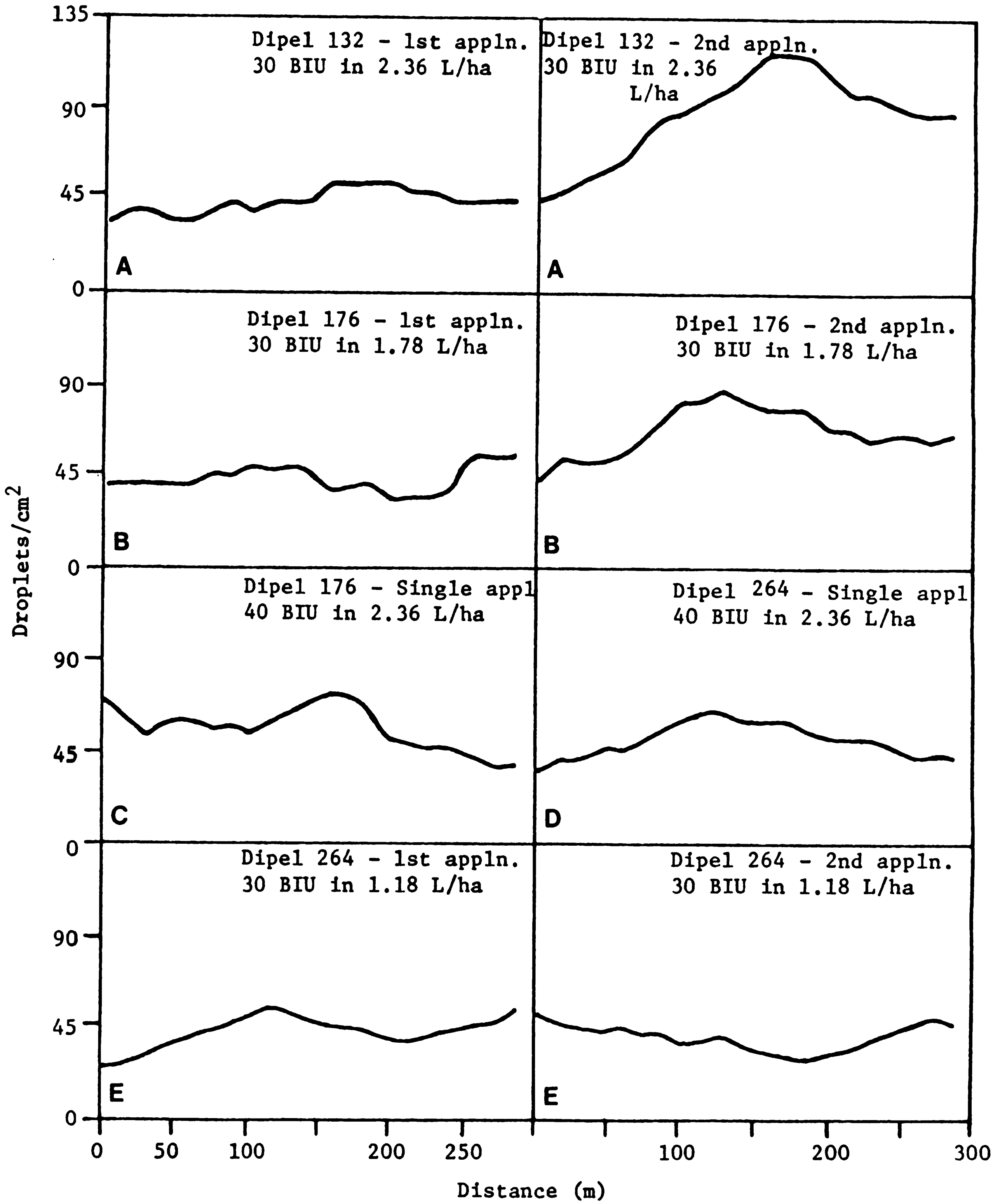
Appendix ID. Frequency distribution of droplet-diameter classes of aerially applied fenitrothion on Kromekote[R] cards near the ground by droplet number and droplet volume. C = plot F3.



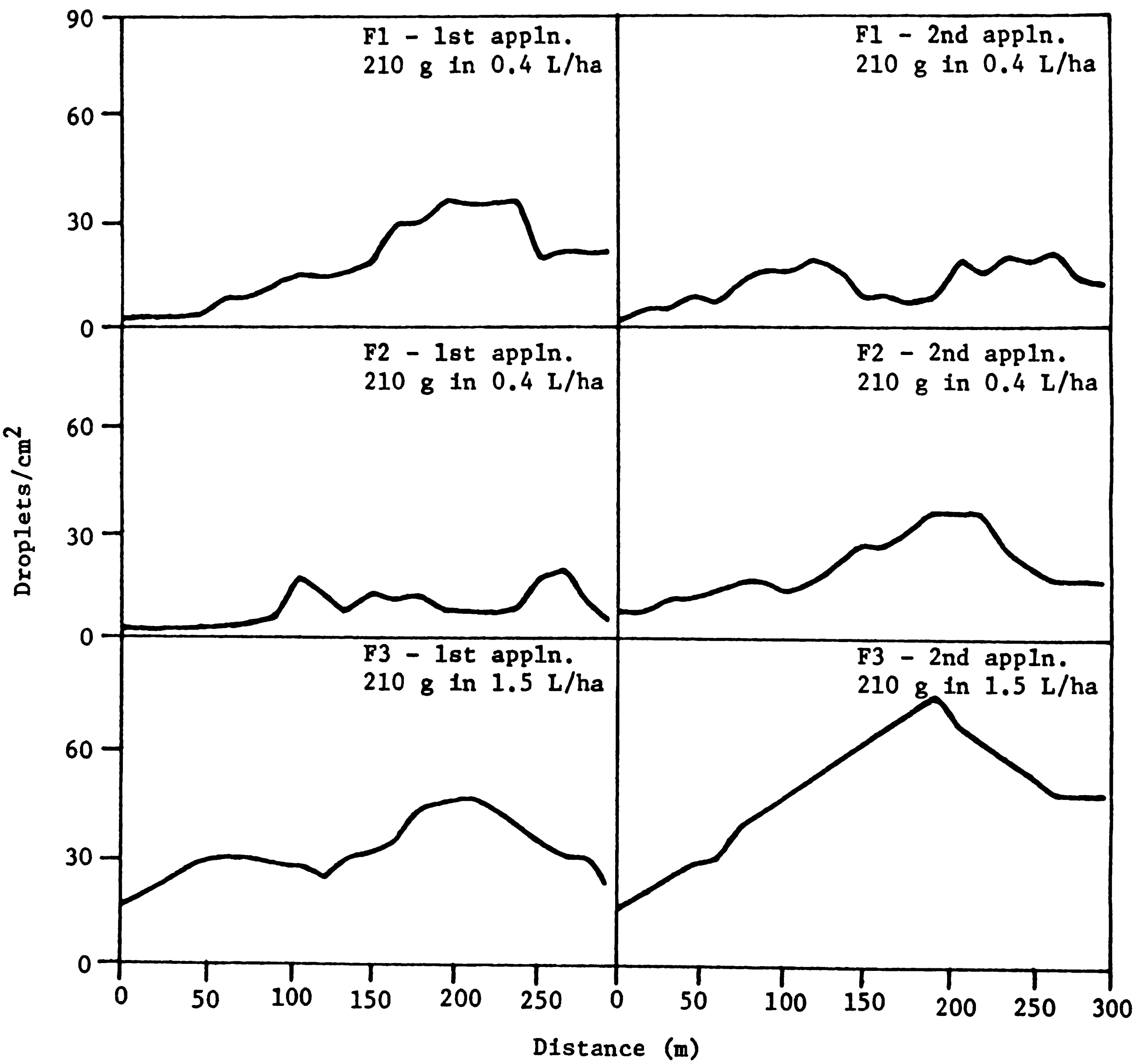
Appendix IE. Frequency distribution of droplet-diameter classes of aerially applied diflubenzuron on Kromekote[R] cards near the ground by droplet number and droplet volume. A = plot D1, B = plot D2.



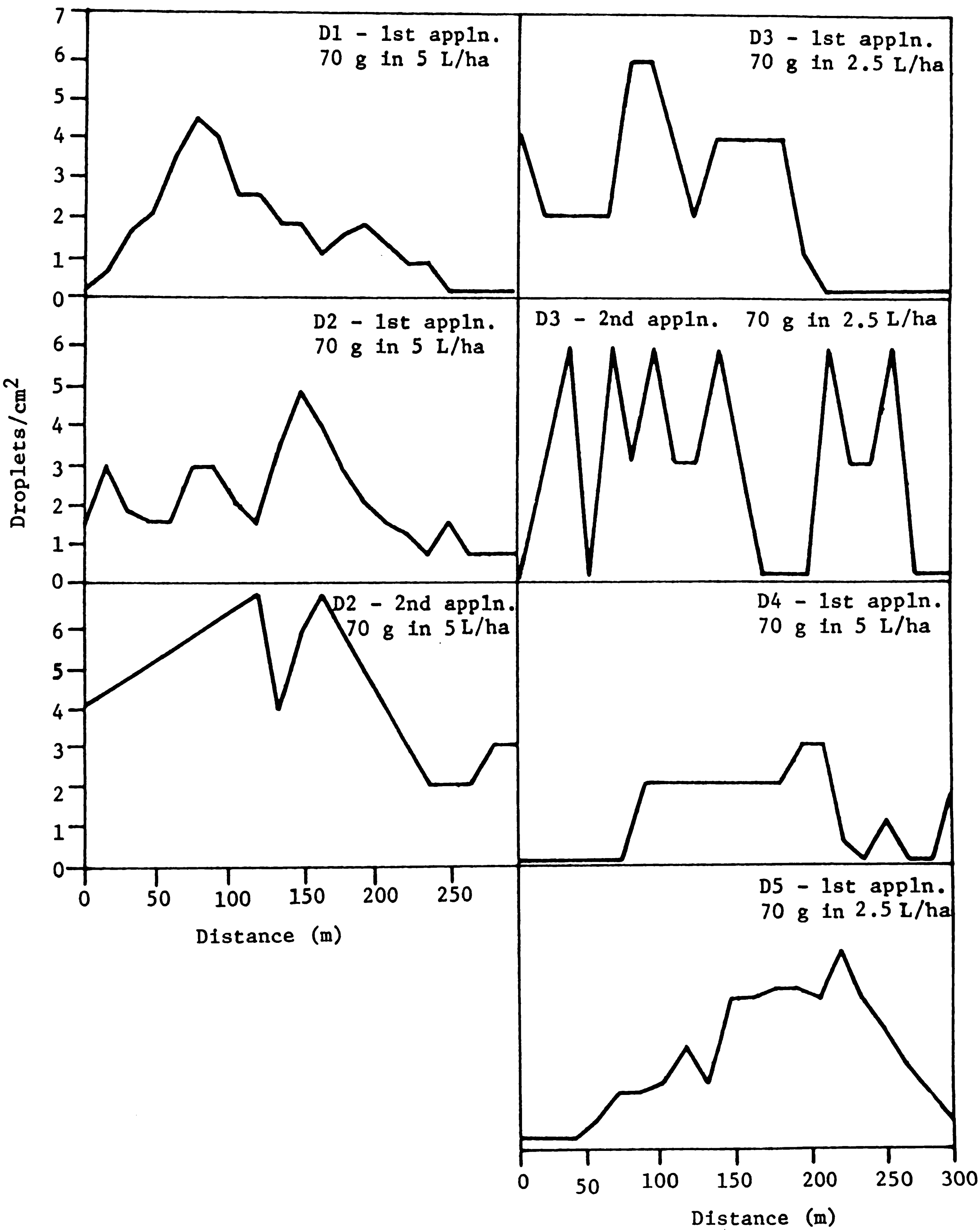
Appendix IF. Frequency distribution of droplet-diameter classes of aerially applied diflubenzuron on Kromekote[R] cards near the ground by droplet number and droplet volume. C = plot D3, D = plot D4, E = Plot D5.



Appendix IIA. Average droplet density (/cm^2) of aerially applied B.t. (Dipel[R]) on Kromekote[R] cards near the ground at 15 m intervals across spray plots. A = plot B.t. 1, B = plot B.t. 2, C = plot B.t. 3, D = plot B.t. 4, E = plot B.t. 5.



Appendix IIB. Average droplet density (/cm^2) of aerially applied fenitrothion on Kromekote^R cards near the ground at 15 m intervals across spray plots.



Appendix IIC. Average droplet density (/cm^2) of aerially applied diflubenzuron on Kromekote^R cards near the ground at 15 m intervals across spray plots.

Appendix III. Number of spray droplets of aerially applied fenitrothion on aluminum foliage simulators at mid-crown of balsam fir at three branch positions. (Upper and lower refer to side of sumulators)

Plot F1 - First Application

Tree No.	Br. No.	86/87 Growth Upper	86/87 Growth Lower	86/87 Growth Total	83/84 Growth Upper	83/84 Growth Lower	83/84 Growth Total	80/81 Growth Upper	80/81 Growth Lower	80/81 Growth Total	TOTAL Upper	TOTAL Lower	TOTAL Total	GRAND TOTAL
1	1	7	1	8	13	0	13	6	1	7	26	2	28	72
	2	16	0	16	10	0	10	14	4	18	40	4	44	
2	1	23	0	23	32	0	32	36	0	36	91	0	91	178
	2	29	1	30	32	1	33	23	1	24	84	3	87	
3	1	13	10	23	43	1	44	33	2	35	87	13	100	144
	2	1	1	2	22	0	22	18	2	20	41	3	44	
4	1	10	4	14	18	2	20	20	2	22	42	8	50	116
	2	18	6	24	16	2	18	22	2	24	56	10	66	
5	1	7	2	9	16	2	18	23	2	25	46	4	50	97
	2	18	0	18	3	6	9	20	0	20	41	6	47	
6	1	14	1	15	31	0	31	42	1	43	87	2	89	227
	2	40	0	40	54	1	55	41	2	43	35	3	138	
7	1	0	0	0	0	3	3	6	0	6	6	3	9	55
	2	1	0	0	27	1	28	17	0	17	45	1	46	
8	1	19	0	0	11	2	13	22	2	24	52	4	56	78
	2	4	2	6	5	3	8	8	0	8	17	5	22	
Total		220	28	248	333	24	357	351	21	372	896	71	967	967

Appendix III. (Concl'd.)

Plot F3 - First Application

Tree No.	Br. No.	86/87 Growth			83/84 Growth			80/81 Growth			TOTAL			GRAND TOTAL
		Upper	Lower	Total	Upper	Lower	Total	Upper	Lower	Total	Upper	Lower	Total	
1	1	50	62	112	134	7	141	68	11	79	252	80	332	332
	2	-	-	-	-	-	-	-	-	-	-	-	-	
2	1	8	628	636	69	132	201	80	251	331	157	1,011	1,168	2,151
	2	323	132	455	260	0	260	268	0	268	851	132	963	
3	1	828	19	847	127	64	191	787	23	810	1,742	106	1,848	4,330
	2	866	8	874	814	6	820	785	3	788	2,465	17	2,482	
4	1	37	2	39	28	0	28	38	0	38	103	2	105	316
	2	1	45	46	46	18	64	96	5	101	143	68	211	
5	1	591	16	607	587	0	587	634	1	635	1,812	17	1,829	2,863
	2	557	20	577	209	17	226	231	0	231	997	37	1,034	
6	1	10	6	16	3	4	7	10	3	13	23	13	36	80
	2	4	2	6	17	4	21	15	2	17	36	8	44	
7	1	39	1	40	48	6	54	56	3	59	143	10	153	230
	2	0	1	1	18	5	23	50	3	53	68	9	77	
8	1	2	8	10	26	56	82	19	5	24	47	69	116	189
	2	22	16	38	15	3	18	16	1	17	53	20	73	
Total		3,338	966	4,304	2,401	322	2,723	3,153	311	3,464	8,892	1,599	10,491	10,491

Appendix VI. Average ground estimates of hemlock looper defoliation within spray and control plots and outside boundary of spray plots of experimental sprays near Hawkes Bay, Newfoundland in 1987.

Plot No.	Plot Trees (n = 60) Cur.	Plot Trees (n = 60) Old.	Boundary I* (n = 20) Cur.	Boundary I* (n = 20) Old.	Boundary II* (n = 20) Cur.	Boundary II* (n = 20) Old.
B.t. 1	0	0	E17.5	15.5	W 9.0	9.0
B.t. 2	0	0	E 1.0	0.0	W34.0	27.5
B.t. 3	3.8	0.3	E37.5	33.0	W23.0	21.0
B.t. 4	0	0	E39.5	29.5	W43.0	42.5
B.t. 5	0	0	S31.0	23.5	N42.5	36.0
F1	0	0	S11.5	9.0	N20.0	12.5
F2	19.8	5.8	W51.0	40.5	E22.5	22.5
F3	0	0	E 9.5	4.5	W 7.0	2.5
D1	16.3	9.2	NE29.0	23.5	SW33.0	32.0
D2	7.7	1.2	N18.0	4.5	S31.0	24.0
D3	12.5	1.3	N35.0	32.5	S16.5	16.0
D4	46.0	38.5	N71.5	75.0	S36.0	27.5
D5	39.2	36.5	N 9.5	8.5	S71.5	74.5
A	22.8	15.0	-		-	
B	28.9	23.0	-		-	
C	45.2	38.8	-		-	
D	10.2	9.3	-		-	
E	21.2	22.8	-		-	

Percent Defoliation

* E, N, S, W = compass directions.

Appendix IV. Quantity of fenitrothion (ng ai/cm^2) on foliage simulators at mid-crown of balsam fir at three branch positions.

Plot F1 - First Application

Tree No.	86/87 Growth	83/84 Growth	80/81 Growth	Total
1	300	143	158	601
2	281	175	175	631
3	264	205	265	734
4	288	253	247	788
5	273	140	148	561
6	311	170	156	637
7	257	160	172	589
8	213	189	159	561
Total	2 187	1 435	1 480	5 102
Ave.	273	179	185	637 (213)

Plot F3 - First Application

Tree No.	86/87 Growth	83/84 Growth	80/81 Growth	Total
1	213	208	200	621
2	187	309	229	725
3	344	239	207	790
4	243	308	220	771
5	293	305	295	893
6	374	426	445	1 245
7	308	297	307	912
8	382	220	233	835
Total	2 344	2 312	2 136	6 792
Ave.	293	289	267	849 (283)

Appendix V. Average number of living and dead hemlock looper larvae and pupae in burlap traps (n = 20) placed on balsam fir boles in treatment and control plots.

Plot No.	Average total looper/trap	NO. LARVAE		NO. PRE-PUPAE		NO. PUPAE			Average total living	Average total dead
		Liv.	Dead	Liv.	Dead	Par.	Dis.	Dead/other		
A	196.7	0	1.4	0.1	0.3	0	0	2.0	193.0	3.7
B	133.1	0	0.5	0	0.5	0.1	0	1.5	130.6	2.5
C	372.0	0	19.0	0	3.4	0.2	0	10.7	338.8	33.2
D	167.8	0	1.2	0	0.4	0	0	1.4	164.9	3.0
E	137.4	0	7.8	0	6.9	0	0	5.7	117.1	20.3
B.t. 1	0.1	0	0	0	0	0	0	0	0.1	0
B.t. 2	0.4	0	0	0	0	0	0	0.1	0.3	0.1
B.t. 3	4.7	0	0.2	0	0.1	0.1	0	0.1	4.3	0.5
B.t. 4	0	0	0	0	0	0	0	0	0	0
B.t. 5	0.6	0	0	0	0	0	0	0	0.6	0
F1	0.7	0	0	0.1	0	0	0	0.1	0.7	0.1
F2	30.3	0	1.3	0.1	0.4	0	0	0.8	27.9	2.5
F3	0.4	0	0.1	0	0	0	0	0	0.3	0.1
D1	53.5	0	1.8	0	4.8	0.5	0	2.3	44.2	9.3
D2	2.1	0	0.2	0	1.1	0	0	0	0.9	1.3
D3	7.9	0	0.1	0	2.8	0	0	0	5.1	2.8
D4	118.9	0	3.3	0.2	1.2	0	0	5.2	109.3	9.7
D5	139.1	0.1	3.2	0.2	6.0	0.1	0	3.4	126.4	12.6

*Par = parasitized; Dis = diseased.

Appendix VI. Average ground estimates of hemlock looper defoliation within spray and control plots and outside boundary of spray plots of experimental sprays near Hawkes Bay, Newfoundland in 1987.

Plot No.	Percent Defoliation					
	Plot Trees (n = 60)		Boundary I* (n = 20)		Boundary II* (n = 20)	
	Cur.	Old.	Cur.	Old.	Cur.	Old.
B.t. 1	0	0	E17.5	15.5	W 9.0	9.0
B.t. 2	0	0	E 1.0	0.0	W34.0	27.5
B.t. 3	3.8	0.3	E37.5	33.0	W23.0	21.0
B.t. 4	0	0	E39.5	29.5	W43.0	42.5
B.t. 5	0	0	S31.0	23.5	N42.5	36.0
F1	0	0	S11.5	9.0	N20.0	12.5
F2	19.8	5.8	W51.0	40.5	E22.5	22.5
F3	0	0	E 9.5	4.5	W 7.0	2.5
D1	16.3	9.2	NE29.0	23.5	SW33.0	32.0
D2	7.7	1.2	N18.0	4.5	S31.0	24.0
D3	12.5	1.3	N35.0	32.5	S16.5	16.0
D4	46.0	38.5	N71.5	75.0	S36.0	27.5
D5	39.2	36.5	N 9.5	8.5	S71.5	74.5
A	22.8	15.0	-		-	
B	28.9	23.0	-		-	
C	45.2	38.8	-		-	
D	10.2	9.3	-		-	
E	21.2	22.8	-		-	

* E, N, S, W = compass directions.

Appendix VII. Average aerial estimates of hemlock looper defoliation within spray and control plots of experimental sprays near Hawkes Bay, Newfoundland in 1987.

Plot No.	Number ha				Defoliation	
	Nil (x 0)	Light (x 15)	Moderate (x 30)	Severe (x 50)	Total rating*	Average % per/ha
B.t. 1	30	0	0	0	0	0
B.t. 2	30	0	0	0	0	0
B.t. 3	30	0	0	0	0	0
B.t. 4	30	0	0	0	0	0
B.t. 5	30	0	0	0	0	0
F1	30	0	0	0	0	0
F2	26.3	1.2	1.8	.7	107	3.6
F3	30	0	0	0	0	0
D1	25.5	4.5	0	0	67	2.3
D2	26.5	3.5	0	0	53	1.7
D3	0	24.0	6.0	0	540	18.0
D4	2.0	12.0	9.0	7.0	800	26.7
D5	0	13.5	12.0	4.5	787	26.3
A	17	9.5	3.5	0	247.5	8.3
B	0	13.0	4.5	12.5	955	31.8
C	0	0	22.0	8.0	1060	35.3
D	7	23	0	0	345	11.5
E	0	15.0	15.0	0	675	22.5

*Rating: Nil = 0, Light = 15, Moderate = 30, Severe = 50. Plot averages weighted by the number of ha in each damage category.

Appendix VIII. Average defoliation and foliage saved of experimental plots sprayed with insecticides by treatment in relation to control plots and areas bordering treated plots.

	CURRENT GROWTH					OLD GROWTH				
Plot No.	In plot Def. (n = 60)	Contr. plot def. (n = 60)	Bound. plot def. (n = 40)	% Fol. saved (contr.)	% Fol. saved (bound.)	In plot def. (n = 60)	Contr. plot def. (n = 60)	Bound. plot def. (n = 40)	% Fol. saved (contr.)	% Fol. saved (bound.)
B.t. 1	0	22.8(A)	13.3	100	100	0	15.0(A)	12.3	100	100
B.t. 2	0	45.2(C)	17.5	100	100	0	38.8(C)	13.8	100	100
B.t. 3	3.8	10.2(D)	30.5	62.7	87.5	0.3	9.3(D)	27.0	96.8	98.9
B.t. 4	0	28.9(B)	41.3	100	100	0	23.0(B)	36.0	100	100
B.t. 5	0	22.8(A)	36.8	100	100	0	15.0(A)	29.5	100	100
F1	0	10.2(D)	15.8	100	100	0	9.3(D)	10.8	100	100
F2	19.8	21.2(E)	36.8	6.6	46.2	5.8	22.8(E)	31.3	74.6	81.0
F3	0	10.2(D)	8.2	100	100	0	9.3(D)	3.5	100	100
D1	16.3	21.2(E)	31.0	23.1	47.4	9.2	22.8(E)	27.5	59.6	66.5
D2	7.7	22.8(A)	24.5	66.2	68.6	1.2	15.0(A)	14.3	92.0	91.6
D3	12.5	21.2(E)	25.5	41.0	51.0	1.3	22.8(E)	24.3	94.3	94.6
D4	46.0	45.2(C)	53.8	0	14.5	38.5	38.8(C)	56.3	1.0	31.3
D5	39.2	21.2(E)	40.5	0	3.2	36.5	22.8(E)	42.5	0	18.8