Experimental aerial application of Insect Growth Regulators against the spruce budworm, *Choristoneura fumiferana* (Clem.) in Manitoulin Island in 1974 and 1975.

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Abstract

Three insect growth regulators: ZR-515, RO-103108, and Dimilin (PH 60-40) were field tested in 1974 and 1975 against the last larval instar of the spruce budworm, Choristoneura fumiferana on white spruce, Picea glauca and balsam fir, Abies balsamea in Manitoulin Island, Ontario. The candidate compounds were sprayed as water formulations from a Grumman Agcat equipped with a micronair system (except for one operation, 2 oz/acre Dimilin in 1975, where a boom and nozzle system was used) at the rate of 1 U.S. GPA (9.3 liters/hectare). Dimilin gave the best results with a population reduction of over 60% on both types of trees at 2 oz/acre. Impact studies indicated that Dimilin had little effect on the non-target species studied.

Résumé

Des essais expérimentaux ont été réalisés en 1975 et 1976 à l'aide des régulateurs de croissance ZR-515, RO-103108 et Dimilin (PH 60-40) sur le dernier âge larvaire de la Tordeuse des bourgeons de l'épinette, _Choristoneura fumiferana_ infestant le sapin baumier, _Abies balsamea_, et l'epinette blanche, _Picea glauca_, sur l'Île Manitoulin. Les produits ont été appliqués sous la forme d'un mélange liquide, à base d'eau, à l'aide d'un avion de type Grumman Agcat muni d'un système "micronair" et au taux de 1 gallon américain à l'acre (9.3 litres/hectare). Cependant, un essai au taux de 2 onces de Dimilin à l'acre a été effectué en 1975 à l'aide d'un système à rampe et buses. Le régulateur de croissance Dimilin, apliqué au taux de 2 onces à l'acre, a donné les meilleurs résultats entraînant une diminution de plus de 60% des populations larvaires sur les deux essences forestières. Des études d'impacts indiquent que le Dimilin a peu d'effet sur les autres espèces d'insectes étudiées.

Introduction

The use of conventional, broad-spectrum insecticides has been the only operational method for controlling spruce budworm outbreaks in Canada. Over the years long term detrimental effects of many of these chemicals have become increasingly apparent. Growing emphasis has been placed on a systematic search for alternative methods that will progressively decrease our dependency on broad-sprectrum insecticides. One suggested alternative is the use of Insect Growth Regulators.

Growth and development in insects has been shown to be under the control of at least three hormones. The brain hormone stimulates the prothoracic gland to produce the moulting hormone or ecdysone. This in turn induces the epidermal cells to begin the processes which lead to moulting. The outcome of the moult depends on the titer of juvenile hormone (JH) in the insect. A high titer ensures a larval-larval moult whereas a low titer results in a larval-pupal moult. J.H. is absent during the pupal-adult moult (Highnam and Hill, 1969). Application of the hormone during the last larval instar results in abnormal development. The pathological conditions induced is often lethal. Treated larvae that successfully pupate may show delayed effects such as adult deformities, mating difficulty, or in the subsequent generation embryonic mortality. The control potential of JH was recognized soon after its structure was elucidated (Roller et al 1967). Unlike brain hormone (peptide) and ecdysone (steroid), JH is a terpene that is lipid soluble and penetrates the cuticle with great ease. Also, it is a unique hormone found only in insects. Further interest in developing this method for control gained impetus when synthetic analogs that were more active than the natural hormone were described (Bowers 1969; Slama et al 1974; Staal 1975). These synthetic juvenile hormone analogs (JHA) or juvenoids, just like JH, had ovicidal effect on eggs; morphogenetic effect when applied to the last larval instar which resulted in abnormal pupation; and induced diapause development when overwintering adults were treated (Retnakaran 1970, 1973; 1974). Since these analogs interfere with the normal growth and development in insects, they were named Insect Growth Regulators (IGR). It becomes intuitively obvious, that when the adult is in the damaging stage, morphogenetic control by applying JHA to the last larval instar will be very effective. In cases like the spruce budworm, where the damage is caused by larval feeding, controlling the last larval instar will not provide foliage protection in the year of application but during the subsequent year the trees will be protected from defoliation provided immigration of moths is not significant.

JHA have several advantages over conventional broad spectrum insecticides. Toxicity to vertebrates and other invertebrates is extremely low. Among insects they affect only a specific developmental stage, the last larval instar. A majority of the parasites and predators associated with the target insect are protected because they are usually in a different developmental stage. JHA are easily broken down by micro-organisms and therefore do not accumulate in the environment (Retnakaran et al 1973; Wright 1976).

Recently a new group of IGRs that do not mimic the effect of JH but interfere with cuticle synthesis have been described. These compounds are benzoyl urea derivatives that have to be ingested in order to be effective (Wellinga et al 1973). They also are slow acting insecticides and manifest their effects at the moulting phase. Since they interfere with the normal moulting process which is an integral part of growth and development in insects they have been included with the JHA under the common term, IGRs. The compound that is currently being widely tested is PH 60-40 or Dimilin[R]. The mode of action of this IGR has been fairly well studied and it appears to inhibit the last stage of chitin biosynthesis (Post and Vincent, 1973). Although it interferes with every moult, in the spruce budworm its effect is most pronounced during the larval-pupal moult (Granett and Retnakaran, 1977; Retnakaran and Smith 1975). The abnormal pupae resulting from Dimilin treatment are very similar to those produced by JHA. This compound also has minimal environmental impact (Metcalf et al 1975).

In this report we present the results of two years of field testing of two JHA and Dimilin against the spruce budworm.

Laboratory and Greenhouse Studies

The three compounds tested in the field following laboratory and greenhouse investigations were (i) ZR-515 or Altosid^{R} or methoprene supplied by Zoecon Corp., Palo Alto, California as a 5% emulsifiable concentrate (5-E) (ii) RO-103108 supplied by Dr. Maag Ltd., Dielsdorf, Switzerland as 50% emulsifiable concentrate and (iii) Dimilin^{R} supplied by Philips-Duphar Ltd., Amsterdam as 25% wettable powder. The first two are JHA and the third is a disruptor of cuticle synthesis.

We tested various concentrations of these compounds in artificial diet (McMorran, 1965) on the growth and development of 4th, 5th, and 6th instar after the rearing method of Grisdale (1970). We confined ourselves to these stages since they were the ones that were open feeders and hence could be most easily reached with any test compound in the field. Stages earlier than the 4th instar feed inside the still enclosed bud. We found that all three compounds were most effective on the last larval instar.

Greenhouse testing was conducted on potted balsam fir and white spruce trees. Each tree was sprayed with 200 µl of a 1% solution (active ingredient) of the test material using a spray tower. It was found that all three materials were not easily degraded by short wave UV, all were reasonably resistant to leaching, and effective amounts persisted for at least 20 days (Retnakaran and Smith, 1975).

We also tested the combination of _Bacillus thuringiensis_ (B.t.) (Thuricide®) and ZR-515 on potted balsam fir and white spruce trees in the greenhouse. We found that _B.t._ alone had the best effect on 4th instars whereas ZR-515 alone had its best effect on 6th instars. When ZR-515 and _B.t._ were combined, the effect on 5th instars was better than either material alone. We felt that field testing the combination might provide some interesting results.

Plot layout for the 1974 spray program

A total of 13 plots were selected for the spray program on Manitoulin Island. Five of them served as controls and the remainder were test plots (Fig. 1). The list of compounds, quantity applied, and the area covered are summarized in Table 1.

B.t. was sprayed at concentrations of 6 BIU (Billion International Units)(plot I) and 3 BIU (plot L) on plots of 200 acres and 100 acres respectively and served as positive controls for the ZR-515/B.t. spray combination. The latter was sprayed at the rate of ZR-515-3 oz AI(Active Ingredients)/acre and B.t. -3 BIU/acre on a 100 acre plot (plot K).

The two JHA, ZR-515 (plots M & R) and RO-10-3108 (plots P & O) were sprayed at 5 and 3 oz per acre. All plots were 100 acres each except plot P (RO-10-3108, 3 oz/acre) which was 50 acres because of limited material.

Dimilin was sprayed at a rate of 5 oz/acre on a 100 acre plot (plot N).

A Grumman Agcat equipped with a micronair system was used for the spray operation. The system was calibrated to deliver approximately 1 U.S. gallon/acre. All the materials used were mixed with water. Rhodamine-B solution (20% solution, Dupont, Toronto) was added to give a final concentration of 0.1% in the spray mix. About 100 ml of the spray mix was saved as a spectrometric standard for assay of each material. Details of the assay procedure are described below.

The instar distribution of spruce budworm was monitored to find the right stage for spraying. When the majority of larvae were 5ths all materials excepting B.t. (6 BIU) were sprayed. The latter was sprayed earlier when most of the larvae were at the 4th instar stage.

Optimum spray conditions were determined by measuring RH, wind velocity, temperature and inversion. Inversion was calculated by measuring the temperatures at tree top level (T_2) and middle tree level (T_1). When the difference (T_2-T_1) was positive it indicated stable conditions for spraying whereas a negative reading indicated unstable or lapsed conditions. Details of the procedures have been described earlier (Retnakaran *et al* 1973).

All spraying was done early in the morning whenever conditions were acceptable; that is the wind velocity was below 4 mph, the relative humidity was above 90%, the temperature was above freezing but below 50°F, and an inversion (T_2-T_1) of at least 1 to 2°F.

Spray deposit analysis

The deposition of the spray in the plot was evaluated using the system developed at the Chemical Control Research Institute, Ottawa and has been described in detail earlier (Retnakaran et al 1973).

Spray plates were opened and placed at 50 foot intervals along one side of the plot and in line with the flight path of the aircraft. An hour after the spray, the spray plates were closed and returned to the laboratory for spectrophotometric analysis using the fluorescent property of Rhodamine-B (Absorption) max. of 550 nm and emission λ max. of 275 nm).

Standard curves were plotted using the sample taken from the spray mix used for each spray plot (Fig. 3). A 5 µl sample of the original spray mix was diluted to 5 ml in absolute ethanol. From this stock solution a series of 1:1 dilutions were made. Per cent emission was measured in a fluorescence spectrometer using the absorption and emission maxima for Rhodamine-B. The volume of spray mix to cover 37.5 cm^2 (the area of the slide in the spray plate) to give an equivalent of 1 GPA was calculated to be 3.51 µl. The following calculations were made for the % emission measured from the standard dilutions to directly read GPA from the curves:-

$$3.51\ \mu l = 1\ GPA$$

$$\text{Tube no. 1, } 5.00\ \mu l = \frac{1}{3.51} \times 5.00 = 1.4245\ GPA$$

Tube no. 2, 1:1 dilution of no. 1 = 1.4245÷2 = 0.7123 GPA

Tube no. 3, 1:1 dilution of no. 2 = 0.7123÷2 = 0.3562 GPA

Tube no. 4, 1:1 dilution of no. 3 = 0.3562÷2 = 0.1781 GPA

Tube no. 5, 1:1 dilution of no. 4 = 0.1781÷2 = 0.0891 GPA

Tube no. 6, 1:1 dilution of no. 5 = 0.0891÷2 = 0.0445 GPA

Each of the two slides from every spray plate was washed in 5 ml of absolute ethanol and the emission measured. The emission reading was converted to GPA from the standard curve (Fig. 3). The average values for all the slides from each plot gave the mean coverage in GPA for each plot (Table 2).

We have presented the data in the exact units used. For the benefit of those who would like to convert into other popular units, notably metric, some conversion factors are presented in Table 7.

Results and Discussion

Three sets of data were collected to determine the efficacy of the spray. First, pre-spray samples were collected from all the control and test plots. Second, a sample of larvae collected from each sprayed plot was reared in the lab to establish whether or not the characteristic syndrome for each test material appeared. Third, post-spray samples from all the plots were taken and the effect computed.

Laboratory rearing of larvae collected from the treated plots gave a good indication of what to expect (Table 3). Larvae were collected 5, 12, 17 and 22 days after spraying from each test plot and reared on uncontaminated foliage. Larvae from plots M (5 oz, ZR-515) and N (5 oz, Dimilin) showed significant occurrence of deformities.

Pre-spray sampling was done a day before actual spraying. Branch tips (18" long) from mid-crown level were collected and the number of larvae from each tip was counted. Two such tips were collected from each tree. Post-spray sampling was done when about 10% of the larvae reached the pupal stage. The data for the control plots labelled A, B, C, D and E are summarized in Table 4. The data for the test plots, I, K, L, M, N, O, P and R are shown in Table 5.

The results were analyzed as follows:

(1) The pre-spray density in the treatment plots for balsam fir (50 samples) and white spruce (50 samples) were noted.

The average number of budworm per 18" branch tip was calculated for both.

(2) The average pre-spray densities for the five control plots (25 balsam fir and 25 white spruce) were similarly calculated. The control plots were labelled A, B, C, D and E.

(3) For comparison, the average of control plots that gave the average denisty closest to the treatment plot was selected. For example, Plot I, the pre-spray density in balsam fir was 7.9. Average of control plots B, C and D gave a density of 7.5. These were the two sets of data used for this plot.

(4) Post-spray samples were similarly averaged. These were labelled as living budworm. They were then set in culture dishes and reared and those that survived to the adult stage were labelled emerged budworm.

(5) Dividing the emerged budworm by the pre-spray density gave the survival rate.

(6) The expected population in the treatment plot is computed by multiplying the pre-spray density by the survival rate in the control. For example in Plot I (balsam fir) it is 7.9 x 0.531 = 4.2. The observed population as emerged budworm is 1.9. The % population reduction is $\frac{4.2-1.9}{4.2} \times 100 = 55$.

(7) Defoliation was estimated from the branch tip collected for the post-spray sample. The % defoliation of the new foliage was considered an estimate of current year's defoliation.

The computation of the final results is presented in Table 6. The following conclusions were made based on the results obtained:

(i) Dimilin at 5 oz/acre on balsam fir was the most effective compound. A population reduction of 92% was obtained.

(ii) B.t. (6 BIU) was ineffective because of a torrential rain 12 hr after spray. Greenhouse tests have shown that a more efficient sticker is necessary.

(iii) The survival rates on white spruce controls were extremely poor for reasons that are not obvious so they are not discussed.

(iv) ZR-515 and RO 10-3108 did not work as well as expected. A higher dose is indicated.

Plot layout for the 1975 spray program

In 1975 Dimilin was tested in two plots. A 600 acre plot (plot 6) was chosen to confirm the results obtained in 1974 with 5 oz/U.S. gallon/acre. It was felt that a large plot might demonstrate foliage protection in the central region of the plot in the second year, provided influx of moths from the peripheral areas was minimal. Also, in cooperation with the Chemical Control Research Institute in Ottawa, impact of Dimilin on selected non-target species including aquatic fauna, was studied in this plot. A second plot of 100 acres (plot 7) was sprayed to determine whether or not 2 oz/U.S. gallon/acre would be adequate for control. Four control plots (check no. 7, 8, 9, and 10) were selected close to the treatment plots. The distribution of these plots is shown in Fig. 3. In addition, single tree experiments were conducted with R-103108 and an insecticide, MO-9087 (Mobil Chemical Co.) at 2, 7, and 15 oz/acre applied by means of a back-pack sprayer. All materials were mixed with water.

As in 1974, spraying was done at peak 5th instars. Plot 6 (5 oz, Dimilin) was sprayed with a micronair system in the morning whereas plot 7 (2 oz, Dimilin) was sprayed with a boom and nozzle system in the evening.

In single tree experiments with RO-103108 and MO-9087, the material was sprayed to run-off on the trees.

Spray plate analysis

Spray plates were placed at 50 foot intervals along one side in both plot 6 and 7. Additional spray plates were placed near the stream in plot 6.

A spectrophotometric assay using the 550 nm absorption peak of Rhodamine B was used instead of the fluorescence assay. It was felt that the superior sensitivity of the fluorescence method was unnecessary and the simpler spectrophotometric procedure was adequate. Except for this difference all other procedures were similar to the system used in 1974.

In addition to the GPA-spectrophotometric analysis, spray droplet size and distribution were analyzed. These results are summarized in Table 8. Micronair and boom and nozzle systems gave more or less similar coverage.

Results and discussion

The spray data were analyzed as in 1974. At 15 oz/acre both MO-9087 and RO-103108 proved very effective although at 7 oz/acre RO-103108 did not do well on the white spruce (Table 9). It is difficult to accurately interpret these results since the coverage was quite complete which is not the rule in aircraft sprays.

The effect of Dimilin (5 oz/acre, plot 6) was analyzed by collecting samples from three different areas in the plot. These are referred to as replicates in Table 10. The same table summarizes the results of 2 oz Dimilin in plot 7. Around 70% reduction in population was achieved in both plots. Use of boom and nozzle in plot 7 probably gave better coverage. Foliage protection was checked in 1976, but due to the heavy influz of moths from adjacent areas no significant difference was observed.

The impact studies indicated no apparent effects on (i) bee colonies (ii) small song birds (iii) bullheads and sunfish (iv) juvenile cray fish. Small mammal populations were too low to assess effects. The populations of aquatic beetle larvae and amphipods in a stream in the treatment area showed decline but because of a lack of similar populations in control areas, the effect could not be confirmed. Further work in this area is essential. Details of this impact study have been published by Buckner *et al* (1975).

Conclusions and Prognosis

Of the IGRs tested, Dimilin appears to be the most effective on the spruce budworm. A 70% reduction in population was achieved when the material was applied at the rate of 2 oz/acre in 1 U.S. gallon; however no foliage protection was achieved since the compound was sprayed on the last larval instar. The consistent results we have had in two years indicates that the effect is reproducible. The wettable powder formulation has a tendency to settle when mixed in water and allowed to sit overnight. The material is not easily resuspended.

Laboratory studies on the stadial sensitivity of the spruce budworm has indicated that the 6th instars are the most sensitive stage to Dimilin (Granett and Retnakaran 1977; Retnakaran and Smith 1975). Application to an earlier instar might provide some foliage protection but an increased dosage is indicated. If, however, a larger area is treated when the insect is in the last larval instar, foliage protection is possible in the subsequent year provided immigration of moths is not significant.

In conclusion, we would like to emphasize that Insect Growth Regulators as a class appear to have great promise. They have minimal environmental impact and perhaps in the near future will replace conventional insecticides to some extent. Of all the alternatives to conventional broad-spectrum insecticides, IGRs probably will be the first to become operational. Continued study is, therefore, warranted.

Acknowledgments

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2) We are grateful to Zoecon Ltd., Palo Alto, Calif. for supplying ZR-515; Dr. Maag Ltd., Dielsdorf, Switzerland for RO-103108; Philips-Duphar Ltd., Amsterdam, Netherlands for Dimilin; Mobil Chemical Co., Edison, New Jersey for MO-9087; and Sandoz-Wander, U.S.A. for Thuricide.

3) The cooperation of Dr. Buckner and his colleagues is gratefully acknowledged.

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Fig. 1. Plot layout on Manitoulin Island for the 1974 experimental spray program. The plots, materials sprayed, and the amount in 1 U.S. gallon/acre in water were: Plot K - ZR-515 and B.t. (3 oz. and 3 BIU); Plot L - B.t. (3 B.I.U.); Plot M - ZR-515 (5 oz.); Plot N - Dimilin (5 oz.); Plot O - RO-10-3108 (5 oz.); Plot P - RO-10-3108 (3 oz.); Plot I - B.t. (6 B.I.U.); Plot R - ZR-515 (3 oz.).

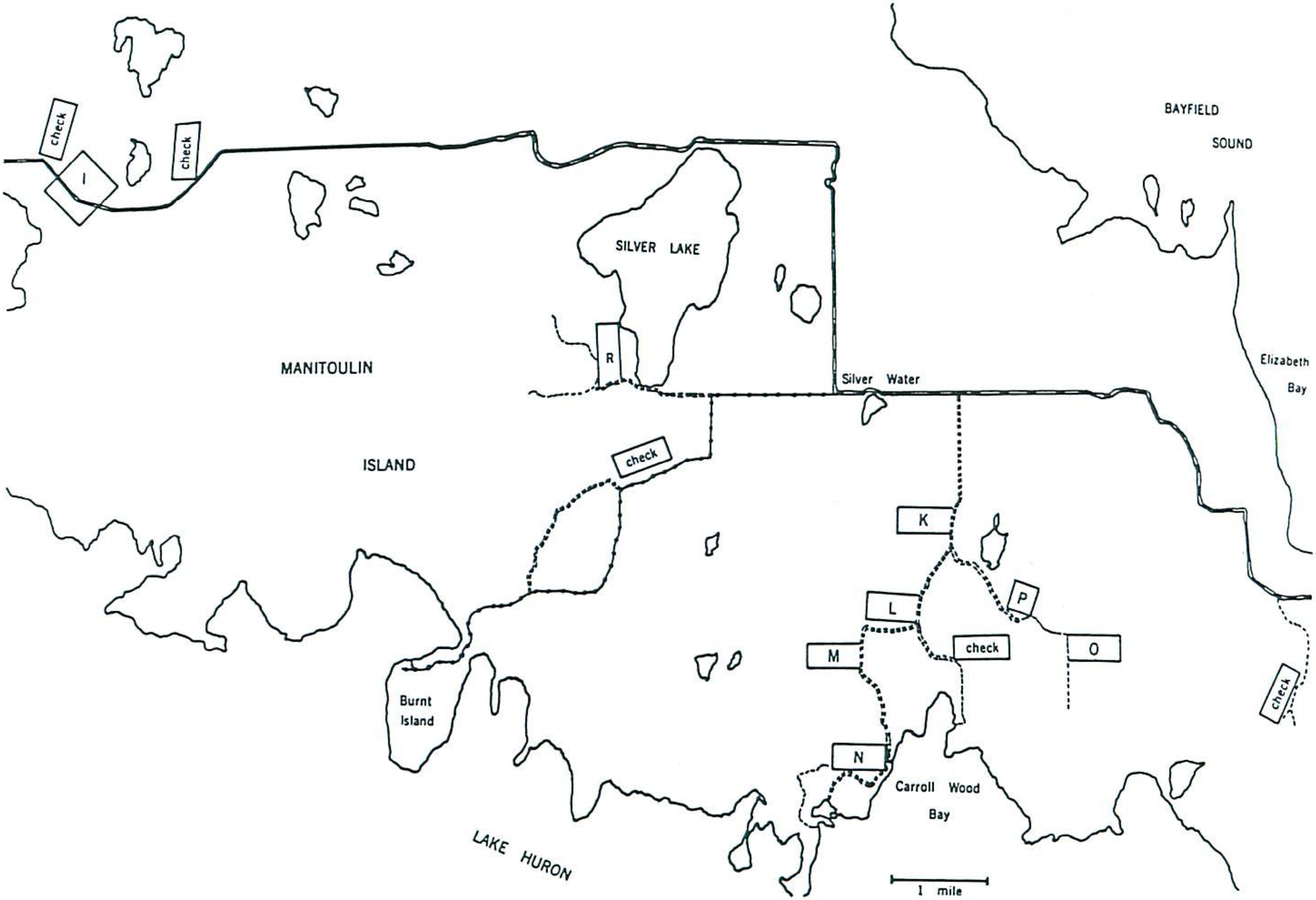

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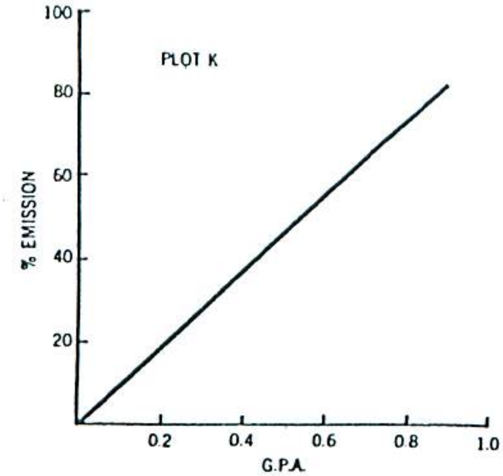
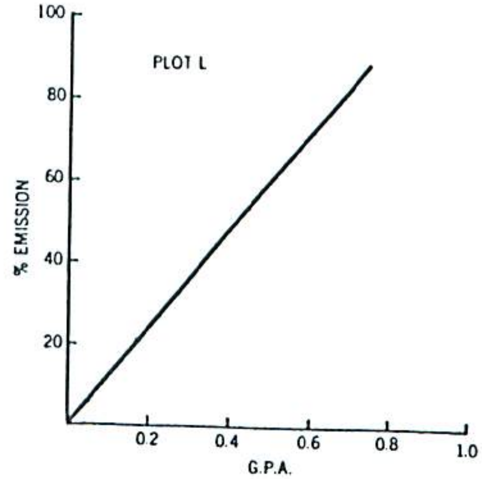
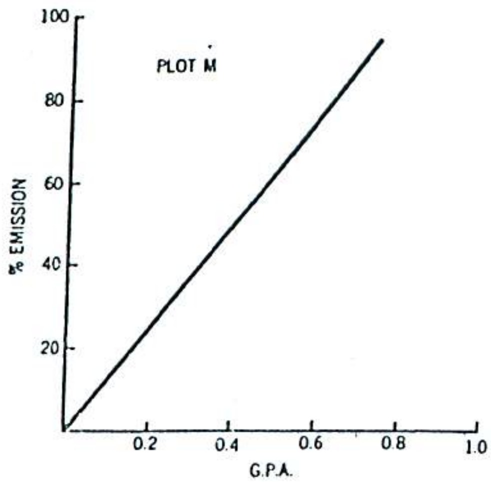
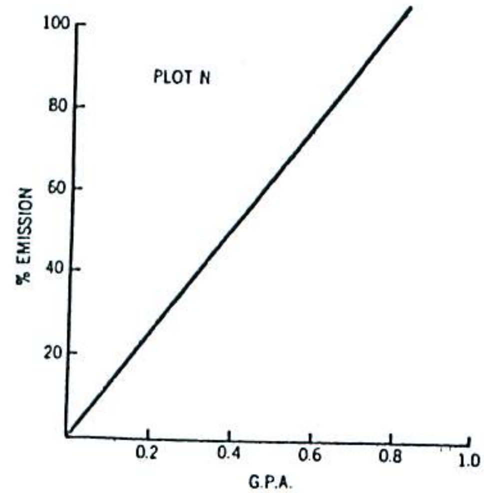
Fig. 2. Standard curves for fluorometric analyses of spray deposit in the eight test plots. Rhodamine-B was mixed with the material (0.1%). The standards were prepared from samples taken from the aircraft tank prior to actual spraying. Details of the procedure are described in text.

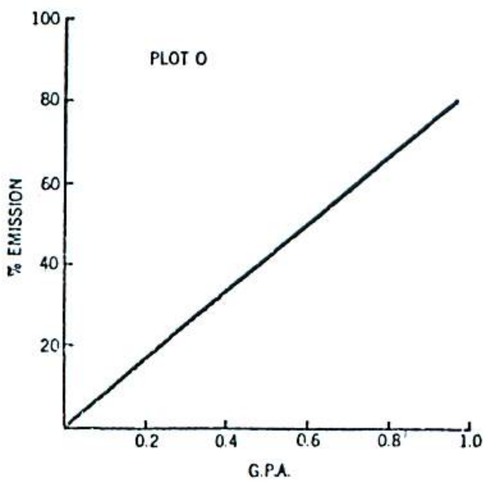
SPRAY PLATE ANALYSIS - STANDARD CURVES

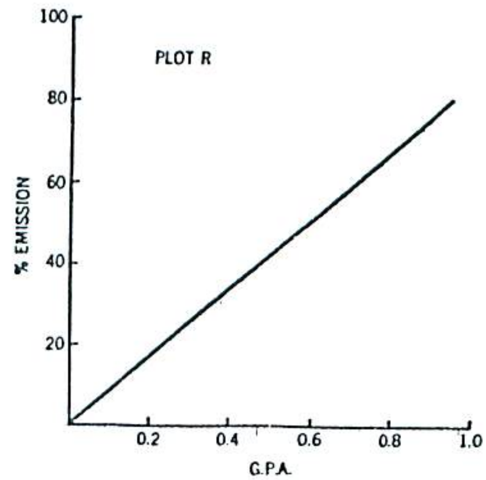


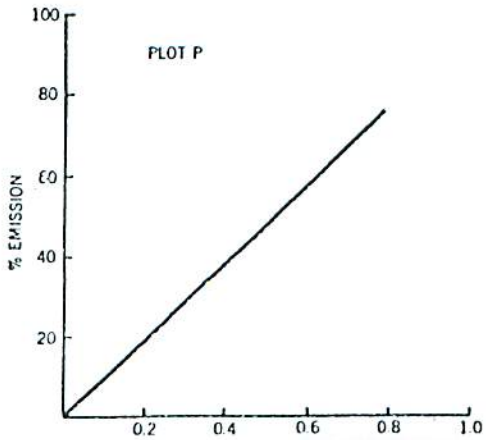












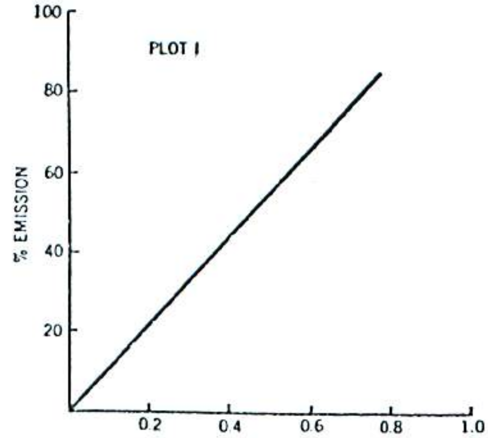
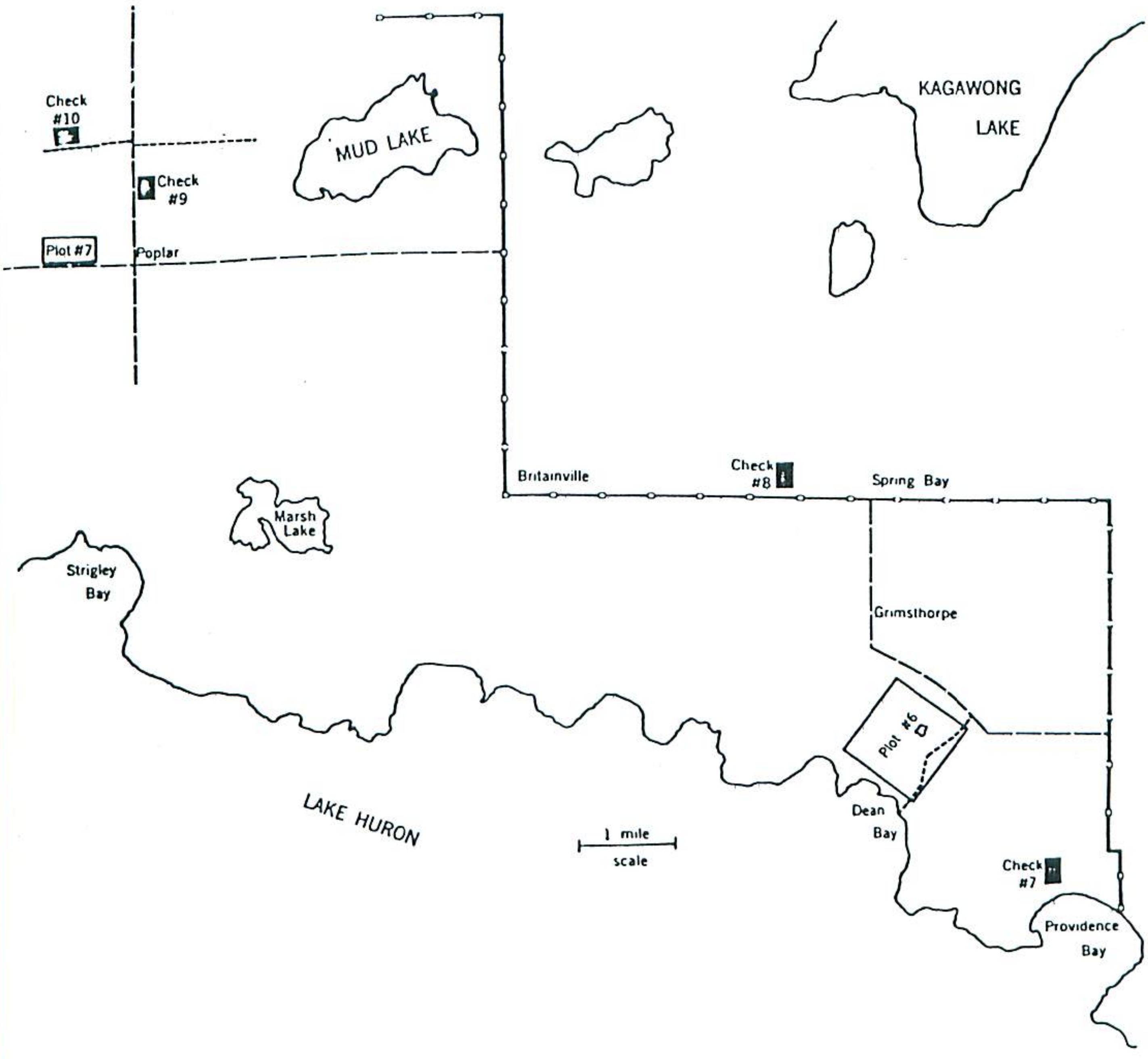


Fig. 3. Plot layout on Manitoulin Island for the 1975 experimental spray program. PH 60-40 was sprayed at the rate of 5 oz/U.S. gal/acre (Plot 6) and 2 oz/U.S. gallon/acre (Plot 7).

Table 1. List of materials which were sprayed on Manitoulin, 1974

Treatment and plot	Quantity of active ingredient/ U.S. gallon/acre	Area treated (acres)	Supplied by
1. Thuricide (I)	6 BIU	200	Sandoz-Wander, U.S.A.
2. Thuricide (L)	3 "	100	"
3. Thuricide and ZR-515-5E (K)	3 BIU and 3 oz	100	Sandoz-Wander Zoecon Corp.
4. ZR-515-5E (M)	5 oz	100	Zoecon Corp.
5. ZR-515-5E (R)	3 oz	100	" "
6. RO-10-3108 (P)	3 oz	50	Hoffman LaRoche
7. RO-10-3108 (O)	5 oz	100	" "
8. Dimilin (N)	5 oz	100	Philips-Duphar



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#10
Check
#9
Plot #7
Poplar
MUD LAKE
KAGAWONG
LAKE
Britainville
Check
#8
Spring Bay
Marsh
Lake
Strigley
Bay
Grimsthorpe
Plot #6
LAKE HURON
1 mile
scale
Dean
Bay
Check
#7
Providence
Bay

TABLE 2

Manitoulin Island Spray
Summary of Spray Deposit Analysis

Plot	Material Sprayed	Dosage Per U.S. Gal./Acre	Coverage U.S. Gal./Acre
K	ZR-515+B.t.	3 oz.+3 B.I.U.	0.115
L	B.t.	3 B.I.U.	0.132
M	ZR-515	5 oz.	0.060
N	Dimilin	5 oz.	0.099
O	RO-10-3108	5 oz.	0.214
P	RO-10-3108	3 oz.	0.101
I	B.t.	6 B.I.U	0.145
R	ZR-515	3 oz.	0.048

Table 3. Results of rearing spruce budworm from treated plots to detect deformities and adult emergence (Deformity = larval-pupal intermediates that failed to become adults). Controls did not show any deformity.

Plot and Treatment (Active ingredients per acre in 1 U.S. Gal.)	Day 5			Day 12			Day 17			Day 22		
	No. larvae	% Normal	% Deformed	No.	% Normal	% Deformed	No.	% Normal	% Deformed	No.	% Normal	% Deformed
K JH+Bt 3 oz 515 + 3B IU	57	47.4	7.0	68	64.7	0	54	44.4	9.3	40	40	7.2
L Bt 3B IU	83	19.3	1.2	48	54.2	0	59	45.8	10.2**	24	57.3	0
M 5 oz 515	35	48.6	2.9	54	53.7	24.7	38	57.9	26.3	-	-	-
N Dimilin 5 oz.	25	0	48.0	34	8.8	58.8	27	11.1	88.9	-	-	-
O RO 10-3108 5 oz	65	41.5	4.6	50	54	12.0	58	46.6	37.9	-	-	-
P RO 10-3108 3 oz.	57	59.7	8.8	51	62.8	13.7	56	64.3	16.1	-	-	-
R ZR-515 3 oz.	50	58	4	49	63.3	4.1	64	79.7	1.6	-	-	-

** = All from 1 tree at the edge of plot - possible drift.

TABLE 4. Sampling data from control plots (1974).

Plot	Host	PRESPRAY Date	PRESPRAY No. of samples	PRESPRAY Living Budworm per 18" Tip	POST SPRAY Date	POST SPRAY No. of Samples	POST SPRAY Living Budworm per 18" Tip	POST SPRAY Emerged Budworm per 18" Tip	POST SPRAY % 1974 Defoliation
A	BF	18/6/74	25	20.3	10/7/74	25	16.4	10.8	66
	WS	18/6/74	25	37.6	10/7/74	25	3.6	2.6	70
	BF				18/7/74	25	12.3	11.1	66
	WS				18/7/74	25	4.1	3.9	70
B	BF	18/6/74	23	6.1	10/7/74	25	6.2	3.9	22
	WS	18/6/74	26	16.9	10/7/74	25	3.8	2.8	50
	BF				16/7/74	25	3.5	2.7	22
	WS				16/7/74	25	4.0	3.7	50
C	BF	18/6/74	25	6.9	9/7/74	25	5.6	3.9	26
	WS	18/6/74	25	22.1	9/7/74	25	5.6	4.9	52
	BF				16/7/74	25	3.9	3.0	26
	WS				16/7/74	26	4.9	4.5	52
D	BF	18/6/74	25	9.6	10/7/74	25	8.6	4.2	32
	WS	18/6/74	25	31.1	10/7/74	25	4.9	3.2	67
	BF				18/7/74	24	5.5	4.0	32
	WS				18/7/74	25	4.0	3.2	67
E	BF	18/6/74	25	32.2	11/7/74	25	9.3	6.2	98
	WS	18/6/74	25	41.8	11/7/74	25	8.3	6.5	96
	BF				16/7/74	25	7.5	7.0	98
	WS				16/7/74	25	6.6	5.8	96

Table 5. Sampling data from treatment plots (1974).

		PRESPRAY			POST SPRAY				
Plot	Host	Date	No. of Samples	Living Budworm per 18" Tip	Date	No. of Samples	Living Budworm per 18" Tip	Emerged Budworm per 18" Tip	% 1974 Defoliation
I	BF	18/6/74	50	7.9	9/7/74	50	3.7	1.9	23
	WS	18/6/74	50	19.0	9/7/74	50	6.0	4.0	42
K	BF	17/6/74	50	15.7	18/7/74	50	8.4	5.3	52
	WS	17/6/74	50	24.1	18/7/74	50	5.8	5.4	61
L	BF	18/6/74	50	18.4	11/7/74	50	7.6	3.5	76
	WS	17/6/74	49	34.8	11/7/74	51	6.9	4.4	86
	BF	NA	-	-	16/7/74	51	5.3	3.0	76
	WS	NA	-	-	16/7/74	50	4.8	4.0	86
M	BF	19/6/74	50	13.8	18/7/74	50	8.4	7.1	83
	WS	19/6/74	50	25.8	18/7/74	50	9.5	8.3	46
N	BF	19/6/74	50	11.9	18.7.74	51	2.1	.4	59
	WS	19/6/74	48	29.3	18/7/74	50	3.9	2.3	55
O	BF	20/6/74	50	17.1	16/7/74	50	8.7	7.0	90
	WS	20/6/74	30	37.0	16/7/74	27	7.5	7.0	83
P	BF	20/6/74	48	14.2	18/7/74	51	10.6	9.3	75
	WS	20/6/74	44	25.9	18/7/74	44	9.5	9.2	80
R	BF	20/6/74	50	16.3	16/7/74	43	7.7	6.6	67
	WS	20/6/74	28	19.5	16/7/74	19	6.1	5.7	65

Table 6. Results of 1974 Spray Program in Manitoulin Island. Budworm numbers are per 18 inch branch tip.

Plot	Host	n	Prespray density	Living budworm	Emerged budworm	Survival Rate (Emerged/Pre)	% Population reduction	% 1974 defoliation	% Successful emergence
I	BF	50	7.9	3.7	1.9	.240	55	23	51
Check	BF	75 (B+C+C)	7.5	6.8	4.0	.531		27	59
I	WS	50	19.0	6.0	4.0	·210	0	42	67
Check	WS	50 (B+C)	19.5	4.7	3.8	.197		51	82
K	BF	50	15.7	8.4	5.3	.338	33	52	63
Check	BF	50 (A+D)	14.95	8.9	7.55	.505		49	85
K	WS	50	24.1	5.8	5.4	.224	0	61	93
Check	WS	75 (B+C+D)	23.4	4.3	3.8	.162		56	88
L	BF	50	18.4	7.6	3.5	.190	44	76	46
Check	BF	75 (A+D+E)	20.7	11.4	7.1	.343		66	62
L	WS	50	34.8	6.9	4.4	.126	0	86	64
Check	WS	50 (A+D)	34.4	4.25	2.9	.084		69	68
M	BF	50	13.8	8.4	7.1	.514	0	83	84
Check	BF	50 (A+D)	14.95	8.9	7.55	.505		49	85
M	WS	50	25.8	9.5	8.3	.322	0	46	87
Check	WS	50 (C+D)	26.6	4.45	3.85	.145		60	86
N	BF	50	11.9	2.1	.4	.0336	92	59	19
Check	BF	25 (D)	9.6	5.5	4.0	.417		32	73
N	WS	50	29.3	3.9	2.3	.0785	23	55	59
Check	WS	25 (D)	31.1	4.0	3.2	.103		67	80

Table 6. Continued

Plot	Host		Prespray density	Living budworm	Emerged budworm	Survival Rate (Emerged/Pre)	% Population reduction	% 1974 defoliation	% Successful emergence
O	BF	50	17.1	8.7	7.0	.409	19	90	80
Check	BF	50 (A+D)	14.95	8.9	7.55	.505		49	82
O	WS	30	37.0	7.5	7.0	.189	0	83	93
Check	WS	50 (A+E)	39.7	5.35	4.85	.122		83	91
P	BF	50	14.2	10.6	9.3	.655	0	75	88
Check	BF	50 (A+D)	14.95	8.9	7.55	.505		49	82
P	WS	44	25.9	9.5	9.2	.355	0	80	97
Check	WS	50 (C+D)	26.6	4.45	3.85	.145		60	86
R	BF	50	16.3	7.7	6.6	.405	20	67	86
Check	BF	50 (A+D)	14.95	8.9	7.55	.505		49	82
R	WS	28	19.5	6.1	5.7	.292	0	65	93
Check	WS	50 (B+C)	19.5	4.45	4.1	.210		51	92

Table 7. Conversion factors

	Unit	To convert to	Multiply by
Weight	Ounce (avoirdupois)	gram	28.349
	gram	ounce (avoirdupois)	0.0353
	Pound (avoirdupois)	gram	453.592
	gram	pound (avoirdupois)	0.0022
Tem- per- ature	°Fahrenheit	° centigrade	(...°F-32)0.56
	°Centigrade	° Fahrenheit	(...°Cx1.8)+32
Length	Chains (Gunter's)	feet	66
	Chains (Gunter's)	meters	20.117
	Meters	Chains (Gunter's)	0.04971
	Feet	Chains (Gunter's)	0.0152
	Miles	kilometers	1.609
	Kilometers	miles	0.621
	Inches	centimeters	2.54
	Centimeters	inches	0.394
Volume	U.S. gallon (liquid)	liters	3.785
	liter	U.S. gallon (liquid)	0.2642
	Imperial gallon	liters	4.546
	liter	Imperial gallon	0.2199
	U.S. gallon	Imperial gallon	0.8326
spray & area	U.S. gallon/acre	liters/hectare	9.3549
	liters/hectare	U.S. gallon/acre	0.1069
	oz(avoirdupois/U.S. gallon)	grams/liter	7.4898
	grams/liter	oz(avoirdupos)/U.S. gallon	0.1336
	acre	hectare	0.405
	hectare	acre	2.4711

Table 8. Spray deposit analysis in 1975. Approximately 1 U.S. GPA was sprayed from the aircraft.

A.) Spectrophotometric analysis of spray deposit on glass plates using Rhodamine-B as the indicator. Spray droplets were counted from the kromecote card.

Plot	Material & dosage	Deposit analysis (GPA)	$\bar{X}$ droplets/cm^2 $\pm$ SD
6	PH-60/40 5 oz./acre	0.31	11 ± 8
7	PH-60/40 2 oz./acre	1.24	8 ± 6
Stream	PH-60/40 5 oz./acre	0.51	NA

B.) Droplet size analysis

Plot	Method of application	Droplet range in microns (% of total droplets is presented)							
		0-40	41-80	81-120	121-160	161-200	201-400	401-600	601-800
6	Micronair	20.9	29.3	6.5	5.5	9.1	25.4	2.6	0.7
7	Boom & Nozzle	20.3	3.4	3.4	5.1	6.8	30.5	23.7	6.8

TABLE 9. Single tree experimental spray. A comparative study between RO-10-3108 and Mobil-9087.

Material	Dosage	Pre-spray larvae/18" branch tip		Surviving pupae/18" branch tip		% Population reduction due to IGR spray		% Successful[1] pupal emergence		% 1975 defoliation	
		BF	WS	BF	WS	BF	WS	BF	WS	BF	WS
Mobil 9087	2 oz./acre	10.6	12.8	0.40	1.80	87	34	40	90	88	59
Check	–	17.4	20.6	5.00	4.40	–	–	83	92	84	98
Mobil 9087	7 oz./acre	9.8	24.0	0.20	0.60	93	88	100	100	22	24
Check	–	17.4	20.6	5.00	4.40	–	–	83	92	84	98
Mobil 9087	15 oz./acre	15.8	7.8	0	0	100	100	–	–	43	14
Check	–	17.4	20.6	5.00	4.40	–	–	83	92	84	98
R10-3108	2 oz./acre	15.2	13.8	2.60	2.20	43	2	65	58	46	63
Check	–	16.8	27.0	5.00	4.40	–	–	83	92	84	98
R10-3108	7 oz./acre	11.2	17.0	0	1.50	100	37	0	70	74	65
Check	–	16.8	27.0	5.00	4.40	–	–	83	92	84	98
R10-3108	15 oz./acre	12.0	24.4	0.20	0.80	94	80	33	40	49	81
Check	–	16.8	27.0	5.00	4.40	–	–	83	92	84	98

1. % successful pupal emergence = $\frac{\text{emerged budworm}}{\text{budworm alive on sample date}} \times 100$

TABLE 10. Population reduction[1], pupal survival and current defoliation on trees sprayed with Dimilin in Manitoulin Island in 1975. (BF = Balsam fir, WS = White spruce)

Plot	Dosage	Pre-spray larvae/18" branch tip BF	Pre-spray larvae/18" branch tip WS	Surviving pupae/18" branch tip BF	Surviving pupae/18" branch tip WS	% Population reduction due IGR spray. BF	% Population reduction due IGR spray. WS	% Successful[2] pupal emergence BF	% Successful[2] pupal emergence WS	% 1975 defoliation BF	% 1975 defoliation WS
6 (1st replicate)	5 oz./gal./acre	30.4	41.6	1.70	2.70	70	65	59	89	99	98
Check		30.6	38.6	5.73	7.20	-	-	62	83	85	92
6 (2nd replicate)	5 oz./gal./acre	27.3	40.4	1.85	3.70	64	51	39	89	99	98
Check		30.6	38.6	5.73	7.20	-	-	62	83	85	92
6 (3rd replicate)	5 oz./gal./acre	22.7	53.6	1.70	3.55	73	67	40	63	87	91
Check		20.8	58.2	5.73	11.73	-	-	62	86	85	85
7	2 oz./gal./acre	23.4	39.0	1.88	.73	78	90	43	65	95	96
Check		22.0	38.6	8.00	7.20	-	-	68	83	92	92

1. Population reduction values have been adjusted for natural mortality.

2. % successful emergence = $\frac{\text{emerged budworm}}{\text{budworm alive on sample date}} \times 100$