THE EFFICACY OF SINGLE AND DOUBLE APPLICATIONS OF A NEW INSECT GROWTH REGULATOR, TEBUFENOZIDE (RH5992®), ON JACK PINE BUDWORM IN ONTARIO

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ABSTRACT

The jack pine budworm (*Choristoneura pinus pinus* Free.) is the most destructive pest of the jack pine (*Pinus banksiana* Lamb.) resource in Ontario. In 1993, this forest pest caused moderate to severe defoliation over an area of 282,247 ha in the Central Region of the province.

In June 1994, a field trial was conducted in the Sudbury District to test the efficacy of a new insect growth regulator, Tebufenozide (RH5992®, Rohm & Haas Inc.), against the jack pine budworm. A Cessna 188 Ag-truck was used to treat two study blocks; one was treated with a single application of RH5992® at a rate of 70g/2.0L per ha, and the other was treated with two applications at the same rate, but 5 days apart.

The double application of RH5992® was very effective in reducing jack pine budworm populations and in protecting foliage. The single application was less effective, but did protect foliage in plots that had good spray deposit.

RÉSUMÉ

La tordeuse du pin gris (*Choristoneura pinus pinus* Free.) est le plus important ravageur du pin gris (*Pinus banksiana)* en Ontario. En 1993, elle a causé une défoliation modérée à grave sur une superficie de 282 247ha dans la région centrale de la province.

En juin 1994, un essai sur le terrain d'un nouveau régulateur de croissance des insectes, le tébufénozide (RH5992®, Rohm & Haas Inc.), a été effectué dans le district de Sudbury pour en contrôler l'efficacité contre la tordeuse du pin gris. Un appareil Cessna 188 Ag-truck a été utilisé pour traiter deux blocs d'étude : l'un a reçu une seule application de RH5992® à la dose de 70g (2,0L) par hectare; l'autre, deux applications à la même dose à cinq jours d'intervalle.

Le traitement par double application s'est montré très efficace pour la réduction des populations de la tordeuse et la protection du feuillage. L'application simple a été moins efficace, mais a quand même permis de protéger le feuillage dans les parcelles où il y a eu un bon dépôt du produit.

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Cover photo:
Jack pine budworm defoliation in Ontario forest plots treated in 1994
with single and double applications of RH 5992® at a rate of 70g/2.0L per ha.

INTRODUCTION

In the boreal forest region of northern Ontario, jack pine (*Pinus banksiana* Lamb) comprises 19 percent of the total wood volume. Commercially, however, it is the second most important species and represents more than 30 percent of the total volume harvested (Howse 1986). The jack pine budworm, *Choristoneura pinus pinus* Free., is the most destructive pest of this tree species in northern Ontario (Rose and Lindquist 1973, Howse 1986). Infestations typically last only a few years (Moody 1986), but high insect populations are capable of completely defoliating mature trees in a single year. Significant growth loss and tree mortality can occur in heavily defoliated stands and can continue for several years after defoliation has stopped (Gross and Meating 1994).

Currently, only two insecticides are registered in Canada for use against the jack pine budworm; fenitrothion and several formulations of *Bacillus thuringiensis* var. Kurstaki (B.t.). However, since 1985, B.t. has been the only material used in aerial spray programs in Ontario. While it has been very effective against this pest, the development of environmentally benign alternative control products should be encouraged.

During field tests conducted in 1993 a new insect growth regulator, Tebufenozide (RH5992® [MIMIC 2F]) (Rohm & Haas Inc., Springhouse, PA), was shown to be effective against the eastern spruce budworm *Choristoneura fumiferana* (Clem.). RH5992® is an ecdysteroid agonist that acts through the ecdysteroid receptor and induces an incomplete precocious molt. Upon ingestion, the larva goes into a molting phase. It stops feeding within 3 hours and a new cuticle is synthesized. Unlike the native hormone, RH5992® persists in the insect and prevents the completion of the molting cycle. The larva, with its head capsule slipped, lies in a moribund state and dies of starvation (Retnakaran et al. 1995). The spruce budworm and jack pine budworm are very similar taxonomically and laboratory tests indicated that RH5992® should also be effective in controlling the latter.

In 1992 and 1993, several areas in the Central Region of Ontario were infested with jack pine budworm (Fig. 1). In 1993, moderate to severe defoliation caused by the budworm was mapped over an area of 282 247 ha within

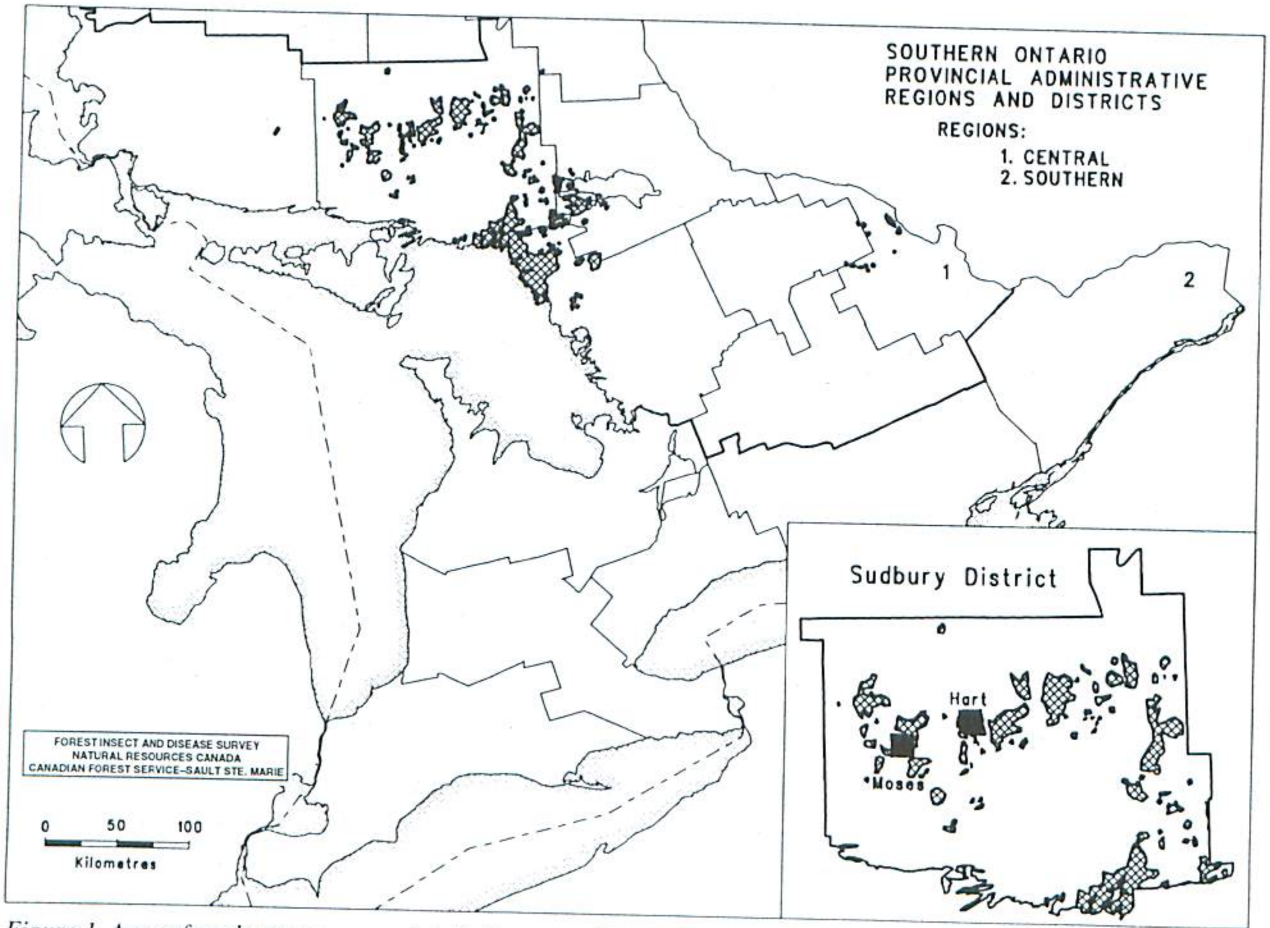

Figure 1. Area of moderate to severe defoliation caused by the jack pine budworm in Ontario in 1993. Insert shows study areas in the Sudbury District.

the region. An operational control program was planned to protect approximately 20 000 ha of high value jack pine stands in the Sudbury District in 1994. This was a cooperative project involving the Ontario Ministry of Natural Resources, E.B. Eddy Forest Products Ltd., and the Canadian Forest Service–Sault Ste. Marie. Two operational spray blocks were selected to field test the efficacy of RH5992® on another major forest pest.

METHODS

Study Area

Spray trials were conducted in jack pine stands located in Moses and Hart townships in the Sudbury District (Fig. 1). In 1992, jack pine budworm caused light levels of defoliation in both townships. The following year, moderate defoliation was recorded in Moses Township and light defoliation was observed in Hart Township. Foliage samples were collected from both areas during the winter of 1994 for assessment of overwintering second instar (L_2) larval populations. This survey indicated that budworm populations would be sufficient to cause moderate levels of defoliation (25–75 percent) in both locations in 1994.

In Hart Township (Block 1), a 50-ha study block was treated in jack pine stands ranging in age from 50–70 years. There was a small black spruce (*Picea mariana* [Mill.] B.S.P.) component (20–30 percent) in each of the three stands composing this block. A total of 55 ha was treated in the Moses Township (Block 2) spray block, which was located in a 240-ha stand of 65-year-old pure jack pine. At the request of the Ontario Ministry of the Environment, a 120-m unsprayed buffer zone was left along the Alces Creek, which formed the eastern boundary of this stand.

Insect and Host Development

The efficacy of an aerial spray program is significantly influenced by the timing of the operations in terms of insect and host phenology (Varty and Godin 1983). For jack pine budworm, good results in previous operations have been achieved when larvae were moving from staminate flowers to new foliage. This migratory behavior usually occurs about the time larvae are in the fourth or fifth instar (Lejeune 1950). At the same time new jack pine shoots are elongating and the needles have started to emerge from the fascicle and are separating to provide a good deposit surface for the insecticide (host index = 4). Of course, in any given year these processes may not be completely synchronous.

Insect and host development were checked regularly near both spray blocks before and during the treatments. On each sample date, 50 larvae were removed from the midcrown area of several host trees and their developmental stage was determined by microscopic examination. One hundred host shoots were also examined and rated. Assuming that insect and host development were synchronous, the spray program was targeted to begin when larvae were predominantly in the third and fourth instars (index = 3.5–4.0), and the host foliage index was 4.0.

Treatments

A single treatment of RH5992® (70g/2.0L per ha) was applied in Block 1 on the morning of 23 June 1994. Wind speed was less than 5 kph, temperature was 12–14°C, and the relative humidity (RH) was 90–99 percent (Appendix 1).

Block 2 received two applications of RH5992®; the first on 22 June and the second 5 days later on 27 June. Both were morning applications. On 22 June, the winds were light (<5 kph), the temperature was 10°C, and the RH was 99 percent. Conditions during the second application were very similar; winds were less than 5 kph, temperatures were 11–12°C, and the RH was 99 percent.

All treatments were applied using a Cessna 188 Ag-truck aircraft equipped with four AU4000 rotary atomizers (Micronair Ltd.). On-block navigation was supported by a Differential Global Positioning System and spray parameters (flow rate, air temperature, relative humidity, etc.) were monitored with an on-board data logging system (Appendix 1).

Assessment

In early June, ten assessment plots were established in each spray block. The plots were distributed throughout the block and transected it perpendicular to the anticipated flight path. Ten dominant or codominant jack pine trees were selected in each plot for prespray and postspray sampling.

The prespray samples were collected on 20 June and the postspray samples on 21 and 22 July. For both prespray and postspray samples, a single midcrown branch (60 cm) was removed from each of the sample trees. The branches were cut into smaller sections and placed in individual paper bags. Samples were kept at 4°C until they could be examined in the laboratory, then all jack pine budworm were removed and counted. Branches were examined twice to ensure that the larval counts were accurate. During the postspray survey, which occurred when larval feeding was essentially complete, the sample branches were rated for defoliation before they were clipped and bagged for transport to the laboratory. A total of 100 trees was sampled in each spray block. The data from these trees were compared to similar data gathered from unsprayed check plots (n = 47 plots) to assess spray efficacy.

In the laboratory, the number of shoots, male flowers, and jack pine budworm were determined for each branch. During the postspray survey, all larvae and pupae removed were reared at room temperature to determine the final number of emerging adult moths. Jack pine budworm survivorship data from spray and check plots were used to estimate the percent population reduction attributable to each treatment (Abbott 1925).

Spray Deposit

A tracer dye (Rhodamine WT,1 percent w/v) was added to every tank mix to help monitor spray deposit for each spray session. Prior to treatment, Kromecote® cards (three per plot) were affixed to the tops of 1-meter-long stakes placed in canopy openings in five plots transecting each spray block. The cards were retrieved approximately 1 hour after the completion of each spray session and returned to the laboratory for examination. Each card was viewed under a microscope and the number of spray droplets recorded for an area of 5 square centimeters per card.

Data Analysis

Prespray surveys revealed a high degree of variability in jack pine budworm larval populations within, and between, plots. Previous surveys had shown that the presence of staminate flowers on the host trees had a significant influence on jack pine budworm larval densities (Meating 1986). When larval populations on trees with staminate flowers were compared (Student's t-test) to those on trees without flowers, results showed that populations were significantly higher on the trees with flowers ($p < .01$). Therefore, spray efficacy was assessed with this factor in mind. Plot averages of prespray larval populations and defoliation are provided, but a more accurate assessment of the efficacy of RH5992® was presented when data from trees with, and without, staminate flowers were analyzed separately.

RESULTS

Insect and Host Development

Spring temperatures in the study area were generally much cooler than normal during April, May, and early June. Consequently, jack pine budworm emergence and larval development were delayed by approximately 1 week. Insect and host development curves for Moses and Hart townships show that insect development was ahead of host development at both locations, but there was little difference between the two locations (Fig. 2). A period of warm humid weather, which began on 15 June and lasted until 23 June, seemed to stimulate insect development.

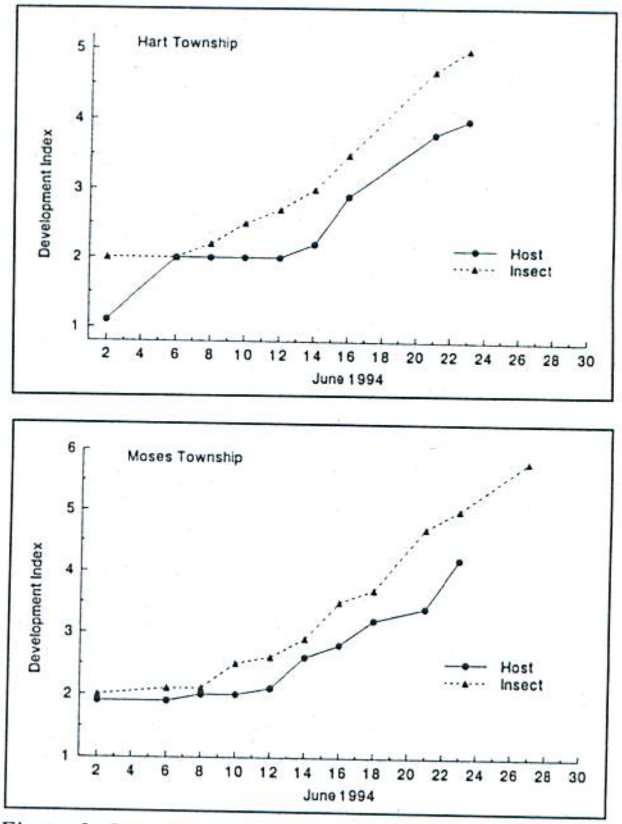

Figure 2. Jack pine budworm and jack pine development in Hart and Moses townships.

Daily maximum temperatures during this period ranged from 25–33°C; minimum temperatures were near 15 °C. On 22 June, during the first application in Block 2, the larval development index was 4.7 and the host index was 3.4. On 23 June in Block 1, the larval index was 4.8 and the host index was 4.0. For the second application in Block 2, the larval index was 5.8 and all host foliage was greater than 4.0.

Spray Deposit

There was considerable variability within and between plots in spray deposition on Kromecote® cards in both spray blocks (Table 1). In Block 2, the average number of droplets per cm^2 was 25.4 (SD = 17.8) on the first application and 22.3 (SD = 9.6) on the second application. No deposit was detected in Plot 1 for the first application. This plot was directly adjacent to the 120-m buffer zone along the eastern boundary of the block and apparently was not sprayed on 22 June. Deposit was high (avg. = 19.6 droplets/cm^2) in this plot on the second spray date. Deposit in Block 1 was considerably lower than in Block 2, with an average of 8.1 droplets /cm^2 (SD = 5.1). Overall, spray deposit on the Kromecote® cards was very high in most plots.

Table 1. Summary of spray deposit in two blocks treated with single and double applications of RH5992® (70g/2.0L per ha) in Ontario, 1994.

Block	Plot	1st application Droplets per cm²	SD*	2nd application Droplets per cm²	SD*
2	1	0	0	19.6	4.6
2	2	18.5	7.9	20.5	3.2
2	3	32.2	8.7	35.1	6.8
2	4	35.5	10.6	18.0	3.6
2	5	40.8	16.5	18.4	13.3
1	1	1.9	1.4		
1	2	7.1	3.0		
1	3	10.1	3.0		
1	5	8.9	3.3		
1	6	12.5	6.4		

*SD = Standard deviation.

Field Efficacy

Tables 2 and 3 show plot averages of prespray larval populations and 1994 defoliation levels in each of the ten assessment plots in the two spray blocks. Minimum and maximum values have also been included to demonstrate the considerable variability that was observed within and between plots. For example, in Block 1, prespray larval densities varied from 2–97 per branch in Plot 10. Defoliation levels varied from 10–90 percent in the same plot (Table 2).

In Block 1, the overall average prespray population was 13.7 larvae per branch, with a low of 5.4 in Plot 6 and a high of 26.9 in Plot 1 (Table 2). The average defoliation rate for the block was 26 percent. Defoliation was highest in Plot 1 (43.5 percent) and lowest in Plot 3 (10.5 percent).

Prespray larval populations averaged 14.3 per branch in Block 2. The highest population density occurred in Plot 9 (avg. = 27.9 larvae per branch) and the lowest in Plot 1 (avg. = 6.1 larvae per branch) (Table 3). Defoliation levels were significantly lower in Block 2 than in Block 1. The average defoliation rate for this block was 4 percent, but ranged from a high of 8 percent in Plot 5 to a low of 1 percent in Plots 6 and 10. Several plots had average defoliation levels of less than 5 percent.

As noted in Tables 4–7, host trees with and without staminate flowers were analyzed separately in each block. The data were also grouped into six classes of increasing prespray larval density (0–5, 6–10, 11–15, 16–20, 21–25, and >25 prespray larvae per branch) and compared to similar unsprayed check plots.

Prespray populations on trees with flowers averaged 28.5 and 18.7 larvae per branch in Block 1 and Block 2, respectively. On trees without flowers, populations were

Table 2. Plot summaries of prespray jack pine budworm larval densities and defoliation in jack pine stands aerially treated with a single application of RH5992® (70g/2.0L per ha) in Ontario, 1994.

Plot	Prespray larvae per branch Average	Min.	Max.	Defoliation (%) Average	Min.	Max.
1	26.9	6	77	43.5	5	85
2	11.5	0	63	19.0	5	70
3	6.2	2	17	10.5	5	25
4	21.0	0	63	40.5	5	90
5	8.7	0	26	11.5	5	30
6	5.4	0	12	19.0	5	70
7	10.2	0	43	12.0	5	25
8	13.1	2	52	29.0	5	90
9	10.6	2	30	39.0	15	55
10	23.6	2	97	32.0	10	90

Table 3. Plot summaries of prespray jack pine budworm larval densities and defoliation in stands aerially treated with two applications of RH5992® (70g/2.0L per ha) in Ontario, 1994.

Plot	Prespray larvae per branch Average	Min.	Max.	Defoliation (%) Average	Min.	Max.
1	6.1	1	27	1.5	0	5
2	11.7	0	29	1.7	0	5
3	7.2	2	14	3.3	0	5
4	17.8	2	95	2.4	0	5
5	11.8	2	25	8.4	2	20
6	11.0	0	42	1.4	0	2
7	11.0	0	29	7.7	2	25
8	20.2	3	65	4.7	2	10
9	27.9	3	88	3.6	0	5
10	18.7	0	71	1.3	0	5

significantly lower with an average of 7.1 larvae per branch in Block 1 and 12.1 larvae per branch in Block 2. Defoliation rates were also influenced by the presence or absence of flowers. In Block 1, the average defoliation rate on trees with flowers was 49 percent compared to 15 percent on trees without flowers. In Block 2, the difference between trees was less; the average defoliation rate was 4 percent on trees with flowers and 3 percent on trees without flowers.

Results of a single application of RH5992® in Block 1 are presented in Table 4 for trees with staminate flowers and in Table 5 for trees without flowers. In both instances, estimates of population reduction attributable to the treatment were quite high (63–100 percent). However, this did not always translate into high levels of foliage

Table 4. Efficacy of a single application of RH5992® (70g/2.0L per ha) on jack pine with staminate flowers present.

	Prespray larvae per 60-cm branch	Emerged adults per 60-cm branch	Population reduction due to treatment (%)	1994 defoliation (%)
Spray	3.6	0	100	37
Checks	2.2	2.2		31
Spray	7.7	1.0	64	45
Checks	8.1	3.0		30
Spray	11.5	1.0	71	40
Checks	13.2	4.0		54
Spray	18.2	0.2	95	38
Checks	18.5	4.2		56
Spray	21.0	1.0	79	30
Checks	23.4	5.2		57
Spray	51.4	1.0	87	62
Checks	42.2	6.6		68

Table 5. Efficacy of a single application of RH5992® (70g/2.0L per ha) on jack pine without staminate flowers present.

	Prespray larvae per 60-cm branch	Emerged adults per 60-cm branch	Population reduction due to treatment (%)	1994 defoliation (%)
Spray	2.5	0	100	10
Checks	2.2	0.9		17
Spray	7.5	0.1	95	17
Checks	8.1	2.2		30
Spray	11.7	1.3	63	21
Checks	13.0	3.9		32
Spray	18.0	0	100	31
Checks	18.1	5.6		40
Spray	24.0	0	100	12
Checks	22.4	6.9		66
Spray	26.0	0	100	15
Checks	38.0	4.4		51

protection. For trees with staminate flowers, defoliation levels on treated trees were often higher than, or almost the same as, defoliation rates observed on unsprayed check trees at all population densities. Foliage protection was substantially better on trees without staminate flowers.

Estimates of population reduction attributable to a double application of RH5992® in Block 2 were consistently 100 percent (Tables 6 and 7). This significant reduction in jack pine budworm populations resulted in very low defoliation levels in this block. On trees with, and without, staminate flowers, observed defoliation rates were generally less than 10 percent.

DISCUSSION

There is little doubt that a double application of RH5992® was effective in reducing jack pine budworm populations and protecting foliage. In total, 18 larvae and pupae were removed from the 100 postspray branch samples collected in Block 1. Only seven budworms were successful in completing development and producing adult moths.[1] Spray deposition in this block, based on an examination of Kromecote® cards, was exceptionally good and, although Plot 1 was missed on the first application, good deposit on the second application resulted in excellent foliage protection.

The results are not so unequivocal in Block 1, which received a single application of RH5992®. Prespray budworm populations were similar to those in Block 2 and the two blocks were treated only 1 day apart. Larval and host development curves for the two areas were almost identical, so it is unlikely that there were significant differences in defoliation levels at the time of treatment. The only major difference, other than the number of

[1] These adults do not appear in Tables 5 and 6 because of the effect of rounding averages.

Table 6. Efficacy of a double application of RH5992® (70g/2.0L per ha) on trees with staminate flowers present.

	Prespray larvae per 60-cm branch	Emerged adults per 60-cm branch	Population reduction due to treatment (%)	1994 defoliation (%)
Spray	3.0	0	100	2
Checks	2.2	2.2		31
Spray	8.7	0	100	2
Checks	8.1	3.0		46
Spray	12.3	0	100	5
Checks	13.2	4.0		54
Spray	17.0	0	100	7
Checks	18.5	4.2		56
Spray	25.0	0	100	20
Checks	23.4	5.2		57
Spray	60.8	0	100	6
Checks	42.2	6.6		68

Table 7. Efficacy of a double application of RH5992® (70g/2.0L per ha) on jack pine without staminate flowers present.

	Prespray larvae per 60-cm branch	Emerged adults per 60-cm branch	Population reduction due to treatment (%)	1994 defoliation (%)
Spray	2.6	0	100	2
Checks	2.2	0.9		17
Spray	7.5	0	100	5
Checks	8.1	2.2		30
Spray	13.7	0	100	6
Checks	13.0	3.9		32
Spray	16.7	0	100	3
Checks	18.1	5.6		40
Spray	23.5	0	100	3
Checks	22.4	6.9		66
Spray	47.2	0	100	2
Checks	38.0	4.4		51

treatments, seems to be in the levels of spray deposition measured in the two blocks. Records from the five plots assessed in each block show that spray deposition was greater in Block 2 (avg. = 25.4 drops/cm² first application, avg. = 22.3 drops/cm² second application) than in Block 1 (avg. = 8.1 drops/cm²). Despite the lower deposition rates observed in Block 1, however, densities of 7–12 drops per cm² would generally be considered quite acceptable. In fact, in Plots 2, 3, 5, and 6, where deposition was high, the level of foliage protection was generally very good, although individual trees had defoliation rates as high as 90 percent (Table 2). In Plot 1, where deposition was relatively low, foliage protection was poor. Unfortunately, spray deposit was not assessed in Plots 4, 7, 8, 9, and 10. However, when the locations of these plots within the spray block were considered, Plots 4, 8, 9, and 10 were close to the block boundaries and each had relatively poor results in terms of foliage protection. Plot 7 was located well within the block and foliage protection was very good. It would appear, therefore, that in Block 1, in Plots 2, 3, 5, and 6, where deposition was measured and was relatively high, and in Plot 7, located well inside the spray block, that a single application of RH5992® was effective in protecting foliage. In Plot 1, spray deposit was relatively low and results were poor. Deposition in the remaining plots is unknown but is suspected to have been poor because of their proximity to the spray block boundaries.

The deposition rates recorded on Kromecote® cards in both RH5992® study blocks were exceptionally high. Studies have shown that there is usually wide variation in spray deposition within and between blocks (Armstrong 1979). Armstrong (1979) noted that aircraft altitude, topography, wind direction and speed, and thermal stability are just a few of the factors that affect spray deposition. Also, spray deposition on Kromecote® cards at ground level does not always correlate well with deposition in the tree canopy. As this study did not monitor spray deposition within the tree canopy, caution must be exercised when relating spray efficacy to deposit. In a similar study against the spruce budworm, L. Cadogan[2] (personnal communication) found that RH5992® deposit rates within the host canopy averaged 1–2 drops/cm^2. If spray deposition was unusually high in the jack pine budworm study, how effective is RH5992® at lower rates?

A comparison of Tables 4 and 5 also shows that, at similar budworm densities, foliage protection was substantially greater on trees without staminate flowers than on trees with staminate flowers. There is no obvious reason from collected data as to why this should be so. One possible explanation is that when trees produce reproductive structures, such as staminate flowers, some of the resources that would normally be allocated to shoot development are redirected to flower production (Bazzaz et al. 1987). Consequently, vegetative shoots tend to be smaller in years when the tree is producing flowers. Therefore, any feeding on these smaller shoots would result in higher defoliation rates.

Another possible explanation is that larvae on trees with staminate flowers tend to spend as much time as possible feeding on pollen within the flowers. Exposure of larvae to insecticides may be somewhat reduced in this environment when compared to larvae feeding on vegetative shoots. It is possible that when the larvae finally did emerge from feeding in the staminate flowers, there was insufficient insecticide remaining on the foliage to effectively control populations and protect foliage. This is an unlikely explanation in Block 1 because the treatment occurred after the staminate flowers had shed their pollen and most larvae had left to continue feeding on the vegetative shoots.

CONCLUSIONS AND RECOMMENDATIONS

RH5992® (MIMIC 2F) was effective in reducing jack pine budworm populations and protecting foliage. The double application (2 x 70g/2.0L per ha) was the most effective treatment and defoliation rates averaged less than 10 percent. The single application (70g/2.0L per ha) was effective in reducing defoliation in plots where spray deposition was high, but results were inconsistent across the spray block.

A single application that effectively reduces defoliation by the jack pine budworm is certainly more economically appealing to the forest manager than is a double application strategy when large operational programs are being considered. Therefore, the authors recommend that additional field studies be conducted to more thoroughly evaluate the potential efficacy of a single application of RH5992® against the jack pine budworm.

The timing of previous operational spray programs to control jack pine budworm coincided with the movement of larvae from staminate flowers to vegetative shoots. This was approximately the time that Stage 4 vegetative shoots were appearing on the tree. Results of the 1994 operational spray program indicated that the best levels of foliage protection were achieved within the first 3 days of the program, which began shortly after the movement of larvae to the shoots (unpublished data). It is uncertain if treatments prior to this migration would be effective, but the 1994 data suggest that acceptable levels of foliage protection may be achieved with an earlier application. Therefore, the authors recommend that experimental field studies be conducted to evaluate the effectiveness of "early" treatments to reduce defoliation by the jack pine budworm.

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Appendix 1. Spray parameters monitored by the on-board data logger (REMSPEC ver. 3.2).

	Moses Township		Hart Township
	June 22	June 27	June 23
Altitude (m)	23.6	23.6	27.5
Air speed (kph)	182	198	188
Boom pressure (kPa)	162	182	160
RPM	5000	5300	5200
Air temperature (°C)	10	11	13
Relative humidity (%)	99	99	97
Total boom time (sec)	301	315	326
Total flow (L)	112.6	120.5	128.6
Flow rate (L/min)	22.4	23	23.7
Total area sprayed (ha)	60.5	67.1	68.3
Application rate (L/ha)	1.86	1.80	1.88