RESPONSE OF THE SPRUCE BUDWORM, CHORISTONEURA FUMIFERANA (CLEM.) TO GRADED DOSAGE RATES AND SINGLE VERSUS DOUBLE APPLICATIONS OF BACILLUS THURINGIENSIS VAR. KURSTAKI

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ABSTRACT

Three insecticides, *permethrin* [3-phenoxybenzyl (±) trans-3-(2, 2-dichlorovinyl)-2,2-dimethyl-cyclorpropanecarboxylate], *carbaryl* (1-naphthyl methylcarbamate) and *chlorpyrifos-methyl* [0,0-dimethyl 0-(3,5,6-trichloro-2-pyridyl) phosphorothioate] were field tested for control of the eastern spruce budworm, *Choristoneura fumiferana* (Clem.) in New Brunswick in 1980. All formulations were applied using a Cessna Agtruck equipped with AU 3000 Micronair® rotary atomizers, flying at 160 km/hr with a swath interval of 60 metres and a height above the forest canopy of 10-20 m.

A double application of permethrin at 17 g (A.I.) in 1.46 L (20 fl. oz.) of Shell ID 585/ha resulted in 79% corrected mortality against 3rd and 4th instar spruce budworm larvae on balsam fir and 63% on red/black hybrid spruce sample trees. A single application of permethrin at the same dosage rate resulted in only 45.8% and 59.6% corrected mortalities on balsam fir and hybrid spruce, respectively.

A double application of carbaryl applied at 280 g (A.I.)/ha in a total volume of 1.46 L/ha resulted in average, corrected budworm mortality of 54.7% on balsam fir and 62.4% on red/black hybridized spruce.

Chlorpyrifos-methyl, when applied as two applications of 70 g (A.I.)/ha each, resulted in corrected mortalities of 61.0% on balsam fir and 27.7% on hybrid spruce.

Defoliation after each treatment was less than 10%, while untreated areas experienced 52-57% defoliation on balsam fir samples and 14-17% on the hybrid spruce.

RESUME

En 1980, au Nouveau-Brunswick, on a éprouvé en plein champ, contre la tordeause des bourgeons de l'épinette (Choristoneura fumiferana [Clem.]), troise insecticides: la perméthrine [(+) trans-dichloro-2, 2 vinyl-3 diméthyl-2, 2 cyclopropanecarboxylate de phénoxy-3 benzyle], le carbaryl [méthylcarbamate de naphtyle-1] et le chlorpyrifos-méthyle [phosphorothioate de 0, 0-diméthyle et de 0-(trichloro-3,5,6 pyridyle-2]. Toutes les préparations one été pulvérisées au moyen d'un Cessna Agtruck, muni d'atmoiseurs rotatifs Micronair ® AU 3000, volant à une vitesse de 160 km/h, à la hauteur de 10 à 20 m au-dessus du couvert forestier et selon des bandes de pulvérisation de 60 m de largeur.

Une double application de perméthrine, à raison de 17 g d'I.A. dans 1,46 L (20 onces liquides) de Shell I.D. 585/ha a causé une mortalité corrigée de 79% chez les larves du troisième et du quatrième stade, dans les sapins baumiers, et de 63% dans les hybrides d'épinette rouge et d'épinette noire. Une seule application, à la même dose, n'a provoqué respectivement que des mortalités corrigées de 45,8 et de 59,6%.

Une double application de carbaryl, à raison de 280 g d'I.A. à l'jectare, à raison d'une does totale de 1,46 litre à l'hectare, a provoqué en moyenne une mortalité corrigée de 54,7 et de 62,4% chez les larves, sur le sapin baumier et les épinette hybrides respectivement.

La double application de chlorpyrifos-méthyle, à raison de 70 g d'I.A. à l'hectare, a provoqué des mortalités corrigées de 61,0 et de 27,7% respectivement chez les larves infestant les sapins baumiers et les hybrides d'épinette respectivement.

Après chaque traitement, le taux de défoliation a été inférieur à 10%, tandis que dans les régions non traitées, les taux de défoliation des sapins baumiers et des hybrides d'épinette a été respectivement de 52 à 57 et de 14 à 17%.

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INTRODUCTION

Agricultural and forest insect pests can be expected to respond differently to toxic agents under laboratory and under field conditions. Thus, dosage response curves generated under artificial laboratory conditions cannot be directly extrapolated to field applications. Despite the considerable amount of field research carried out with *Bacillus thuringiensis* Berliner against the spruce budworm, *Choristoneura fumiferana* (Clem.), a dose-response relationship under field conditions has never been reported. This paper addresses this specific question with a view to providing pest control operators with information upon which cost-benefit strategies and decisions can be based.

METHODS AND MATERIALS

Plot Selection and Preparation

The field trials were conducted in northwestern Ontario along Highway 11 between Atikokan and Mine Centre in balsam fir, *Abies balsamea* (L.), stands which had been infested with budworm for the previous three years but had never been treated. A preliminary assessment of the general area for tree condition and density of overwintering larvae was conducted in the late fall of 1980. A number of trees along, and at some distance from the highway were sampled and the samples transported to the laboratory where visual estimates of current year defoliation were made and the branches examined for the density of 2nd instar (L_2) budworm using the KOH wash method (Miller *et al.* 1971). The experimental plot sites were chosen in areas where L_2 densities ranged from 1400 to 2500 insects per 9.3 m^2 of foliage, and buds were healthy.

In the spring of 1981, 20-ha spray plots were selected and an area was cleared beside each of the 30 balsam fir test trees per plot for deposit analysis at ground level. Two Millipore filter membranes were used at each tree site for deposit rate estimation, and the spray deposits were estimated as previously described (Morris *et al.* 1981). In order to assure that tree condition in all test plots was generally similar, bud densities were assessed on two branches per tree prior to spray application. Monitoring of larval development on balsam fir began on May 25, and continued at 2- to 3-day intervals until the last day of spray application.

Meteorological conditions were monitored within the spray plots at the time of each application using a truck-mounted Heathkit Digital Weather Computer Model #ID40001 and a wet and dry bulb hygrometer. In addition, a recording tipping bucket rain gauge, a hygrothermograph, and an Eppley Solar Ultraviolet radiometer, equipped with a digital recorder, were set up near the plots to record weather conditions during the biological assessment period.

A Cessna 185 aircraft equipped with 4 Micronair AU 3000 emission units was used for all applications and was calibrated for each tank mix beforehand to deliver the desired application rates. The droplet spectra generated by the calibration runs were determined by using 0.2% Rhodamine dye in the spray mixes and collecting the droplets on Kromekote cards laid out 3 meters apart on the airport runway across the flight path. The airplane flew about 10 m above the cards. The droplets were analyzed by a method previously described (Maksymiuk 1964, Barry *et al.* 1978).

Spray Formulation and Application

The formulations tested were Thuricide 32 BX (Sandoz, Inc., San Diego, Lot #7W04818) and Dipel 88® (Abbott Laboratories, North Chicago, Illinois, Lot #28-886BJ), diluted with tap water and containing 0.1% Chevron Sticker (Chevron Chem.) and 0.1% Uvitex ERN-P (Ciba Gergy, Montreal) as a fluorescent tracer dye. The fluorescent tracer was used to facilitate visualization of droplets on foliage, but this technique was abandoned because of the very rapid absorption of the tracer into the foliage tissue. The dosage rates applied were 10, 20, 40 and 80 Billion International Units (BIU) in 9.4 ℓ/ha for both products. The Micronairs were set uniformly at orifice #11, with pump pressure at 40 psi. The swath width was 15 m with the plane flying 3 m above the tree canopy. The first application started at 19:50 on May 31 and the final at 05:30 on June 7. Two plots were left untreated as checks to determine natural population decline.

Biological Assessment

The procedures for biological assessment of the results were similar to those reported earlier (Morris *et al.* 1981). The parameters studied were:

1. Effect of dosage on larval population reduction at 14 (post-spray I) and 31 days (post-spray II) post-application.

2. Budworm survival rates at adult emergence.

3. The rates of larval and pupal parasitism in Dipel-treated and untreated check plots. Larvae collected from the test plots at pre-spray, 14 and 21 days post-spray were reared in a laboratory on artificial diet (Grisdale 1970) (5 per cup) until parasites emerged. Pupae were collected at peak pupation and reared individually for parasite and adult emergence.

4. Changes in larval biomass following the spray application. Biomass from post-spray II was not measured due to lack of sufficient larvae.

5. Differences in biomass of female adults emerging from pupae collected in treated and untreated plots.

6. Effect of dosage on tree defoliation.

Double Applications

In addition to the above tests, double sprays of 10 BIU and 20 BIU respectively in 9.4 ℓ/ha were applied to compare their effectiveness with single applications of 20 BIU and 40 BIU/ha respectively. The criteria used for comparison were larval population reductions at 14 and 21 days post-application, and percentage defoliation.

Data Analysis

The percentage population reduction in treated and untreated plots was computed for each tree. Since the reduction ranged from 10-100%, transformation of the data was unnecesary (Steel and Torrie 1960). The raw data was then analyzed by ANOVA followed by Tukey's multiple range test at the 5% level. Significant differences between defoliation values were analyzed by the SNK test.

RESULTS AND DISCUSSION

Pre-Spray Plot Condition

The data on overwintering larval density (Table 1) indicated that, barring any unusual winter mortality of the existing L_2 population, the test populations would be moderately high and bud densities would be acceptable the following spring. The pre-spray counts (Table 2) showed that the current year's shoot densities were generally similar among the selected treated plots and untreated check plots, based on the mean number of shoots per 45 cm branch tip or m^2 of foliage. The data on larval development prior to and during spray application (Table 3) showed that the first spray was applied when larvae were between L_2 and L_3, and the final was applied when larvae were predominantly between L_4 and L_5.

Temperature and relative humidity at the times of application varied widely between sprays (Table 4), which is to be expected since the sprays were applied during both mornings and evenings. Wind speeds were generally low, varying between 0 and 7 km. Meteorological conditions during the total assessment period were normal for the time of year (Table 5).

Table 1

Density of overwintering larvae on balsam fir and estimation of current defoliation at prospective plot sites.

Location	Number of sites sampled	Av. number of overwintering larvae per 9.3 m^2 foliage (range)*	Estimated % defoliation in 1980 (visual)
Manion Lake Road	8	1686.8 (966-2439)	Moderate - Severe
Crilly Road	3	2443 (2207-1624)	Severe
Highway 11	3	1486 (1382-1624)	Light to Moderate

*Four branches per site examined. NaOH washing technique (Miller *et al.* 1971).

Table 2

Pre-spray densities of current year shoots on balsam fir sample trees.

Treatment Plots	Number of shoots per 45 cm branch tip	Number of shoots per m^2
Thuricide, 10 BIU/ha	106	1366
Thuricide, 20 BIU/ha	87	1054
Thuricide, 40 BIU/ha	60	893
Thuricide, 80 BIU/ha	100	1157
Thuricide, 2 x 20 BIU/ha	85	1156
Dipel, 10 BIU/ha	86	1193
Dipel, 20 BIU/ha	73	955
Dipel, 40 BIU/ha	77	897
Dipel, 80 BIU/ha	91	935
Dipel, 2 x 10 BIU/ha	76	1102
Check - I	69	714
Check - II	87	1096

Table 3

Spruce budworm larval development on balsam fir prior to and after spray applications.

Date 1981	Percentage larval population at					Development Index*
	L_2	L_3	L_4	L_5	L_6	
5/25	73	26	0	0	0	2.2
5/29	0	48	47	5	0	3.5
6/1	0	48	38	14	0	3.7
6/4	0	19	52	28	1	4.1
6/6	0	18	32	39	11	4.4

*Calculated by method of L. Dorais, Quebec Energy and Resources.

Table 4

Meteorological conditions and larval development at time of each spray application.

Treatment BIU/ha	Date	Time (hrs)	Approx. larval development Index*	Meteorological Conditions		
				Temp. °C L/H**	% R.H.	Wind km/h
Thuricide, 10	5/31	20:45	3.7	21/22	59	0 - 1
Thuricide, 20	6/4	07:56	4.1	16/19	70	4 - 5
Thuricide, 40	6/6	06:35	4.4	26/27	56	3 - 5
Thuricide, 80	6/6	18:49	4.4	22/22	64	0 - 2
Thuricide, 2 x 20	6/2	18:50	4.1	19/20	95	3 - 5
(second appln.)	6/6	18:50	4.4	22/22	64	0 - 2
Dipel 10	5/30	19:45	3.5	12/13	34	7.0
Dipel 20	6/3	19:08	4.1	22/23	65	5 - 6
Dipel 40	6/4	05:00	4.1	7/10	92	0
Dipel 80	6/4	06:25	4.1	13/17	88	4 - 5
Dipel 2 x 10	5/31	19:50	4.1	21/22	59	0 - 1
(second appln.)	6/7	05:19	4.4	12/13	84	3 - 5

*After L. Dorais, Quebec Dept. of Energy and Resources.

**L = low sensor; H = high sensor.

Table 5

Cummulative meteorological conditions in test area during the biological assessment period from May 30 to August 15, 1981.

Meteorological criteria	
Mean maximum temp. °C	22.2
Mean minimum temp. °C	9.4
Mean maximum relative humidity (%)	98.7
Mean minimum relative humitidy (%)	45.0
Total rainfall (cm)	8.74
Total solar radiation (295-385 μm) in Cal/cm^2	545

Deposit Analysis, Aircraft Calibration

Analyses of the droplet sizes on Kromekote® cards obtained during the aircraft calibration indicate that spread factor decreased and drop size increased as the concentrations of *B.t.* increased in the spray mixtures (Table 6). There was no apparent difference in spread factor between Dipel and Thuricide. The only apparent differences between the two products were in the droplet maximum diameter (Dmax), number median diameter (NMD) and volume median diameter (VMD) of the undiluted sprays. While the Dmin values were identical (17 µm), the Dmax of undiluted Dipel was nearly 50% greater than that of Thuricide. The diameters of half the droplets were less than 41 µm for Thuricide and less than 163 µm for Dipel. Half of the deposited volume of Thuricide resulted from droplets less than 66 µm in diameter, compared with 207 µm diameter for Dipel. It is thus evident that the atomization of undiluted Thuricide was far superior to that of undiluted Dipel. Since the smaller the numerical difference between NMD and VMD, the narrower the droplet spectrum, it is apparent that the best atomization was achieved with 50% Thuricide and 12.5-50% Dipel among the concentrations tested.

Table 6

Deposit analysis on Kromekote® cards obtained during aircraft calibration studies.

Formulations		Spread factor	D_{min} (µm)	D_{max} (µm)	NMD (µm)	VMD (µm)
Thuricide	12.5%	2.17 ± 0.09	9	161	23	66
	50%	1.93 ± 0.03	10	194	28	42
	100%	1.16 ± 0.01	17	302	41	66
Dipel	12.5%	2.15 ± 0.07	9	186	41	66
	50%	1.56 ± 0.05	13	186	38	71
	100%	1.20 ± 0.08	17	417	163	207

Deposit Analysis, Spray Trials

The deposit efficiencies of the Thuricide spray mix applied in the forest at 10 and 20 BIU/ha (12.5% and 25% mixes) were similar but, on the average, slightly less than half the efficiency of the 40 and 80 BIU/ha sprays (Table 7). Thus, in spite of the superior atomization of the more dilute mixes, the deposit efficiencies of the concentrated mixes were superior due, probably, to a lower rate of evaporation during descent. The relatively low deposit efficiency of Dipel applied at

40 and 80 BIU/ha, compared with that applied at 10 and 20 BIU/ha, corresponds with the coarse atomization of the concentrated mix observed during the calibration tests. On the whole, it appears that the deposit efficiency of Thuricide is better than that of Dipel at higher concentrations but lower than that of Dipel at lower concentrations.

Table 7

Relationship between meteorological conditions at time of application and ground level deposits.

Treatment BIU/ha	Plot met. conditions			
	Temp. °C	% R.H.	Wind (KM/H)	Droplets/cm²*
Thuricide - 10	21 - 22	59	0 - 1	31
Thuricide - 20	16 - 19	70	4 - 5	28
Thuricide - 40	26 - 27	56	3 - 5	77
Thuricide - 80	22	64	0 - 2	80
Dipel - 10	12 - 13	34	7	40
Dipel - 20	22 - 23	65	5 - 6	43
Dipel - 40	7 - 10	92	0	25
Dipel - 80	13 - 17	88	4 - 5	23

*Colonies on Millipore filter membranes.

An analysis of the relationship between meteorological conditions at the time of application and droplet density at the ground level was carried out primarily to establish whether wind speed and relative humidity had any direct effect on deposit efficiency. A recent study of the effect of wind on ground deposit efficiency of chemical pesticides indicated that better deposit is obtained under moderate wind conditions (7 m.p.h.) than under calm, temperature inversion conditions (2-3 m.p.h.) (Dumbauld *et al.* 1980). The data from the present tests (Table 7) suggested an opposite trend. In the Thuricide treatments, the lowest droplet density (28 cm^2) was recorded at the highest relative humidity and wind speed. With Dipel the lowest deposit (23 drops/cm^2) was recorded at high relative humidity (88%-92%) and the lowest wind speed (0-5 km/h). It would be speculative to assume that similar relationships occurred at the tree canopy level without deposit measurements at that level.

Effect of Treatments on Budworm Populations

There was a significant reduction in population density at the first post-spray assessment, as dosage rate increased between 10 BIU and 20 BIU/ha (Table 8). Mortality effects levelled off thereafter. At the second post-spray assessment, a similar trend was evident for larval mortality but, when the data were corrected for mortality among the pupae, the Dipel treatment apparently caused a significantly higher budworm kill than did Thuricide at the lowest dosage rate (Table 9). The differences between larval mortality and corrected budworm mortality were 33-48% at 10 BIU/ha and 14-24% at 20 BIU/ha, substantiating the need to incorporate pupal mortality effects in *B.t.* population reduction values.

Table 8

Effect of dosage on larval population reduction at 14 days post-application.

Dosage rate BIU/ha	Pre-spray larval density for 100 current shoots		Percent population density reduction*	
	Thuricide	Dipel	Thuricide	Dipel
10	15	22	0 cd	4 cd
20	14	24	63 ab	68 ab
40	27	32	89 b	56 ab
80	35	19	33 b	65 ab
Check I	17		0 d	
Check II	18		0 d	

*ANOVA followed by Tukey's multiple range test. Values followed by the same letter are not significantly different at 5% level.

In general, budworm survival rates decreased steadily with increasing dosage rates, whether the estimation was based on budworm per 100 shoots (Table 10) or on budworm per 45-cm branch tip (Table 11). Based on the number of budworm per 100 shoots, in the practical dosage range of 20-40 BIU/ha, the survival rate was 6-22 times lower than it was at 10 BIU/ha with Thuricide, and 12-22 times lower than it was at 10 BIU/ha with Dipel (Table 10). Equivalent values, based on number of budworm per 45-cm branch, were 4-8 and 11-22 times lower respectively (Table 11). The survival rates of pupae collected from untreated check plots were generally similar to the survival of pupae from plots treated at 10 BIU/ha, but generally higher than among pupae from the other treatment plots (Table 12).

Table 9

Effect of dosage on budworm population density reduction at 21 days post-application.

Dosage rate, BIU/ha	Percent population density reduction			
	Larval*		Budworm, corrected for pupal mortality	
	Thuricide	Dipel	Thuricide	Dipel
10	9 cd	47 bc	57	80
20	68 ab	84 ab	92	98
40	95 a	89 ab	97	99
80	95 a	85 ab	99	96
Check I	0 d		61	
Check II	0 d		73	

*ANOVA analysis followed by Tukey's multiple range test. Values followed by the same letters are not significantly different at 5% level.

Table 10

Budworm survival per 100 current shoots in blocks treated with increasing dosage rates of *B.t.*

Dosage Rates BIU/ha	Budworm percent survival (pre-spray density in brackets)*	
	Thuricide	Dipel
10	(15) 52.6	(22) 25.9
20	(14) 8.6	(24) 2.1
40	(27) 2.4	(32) 1.2
80	(35) 1.4	(19) 4.7
Check I	(17) 48.8	
Check II	(18) 37.7	

*Survival rate corrected for pupal mortality.

Table 11

Budworm survival per 45-cm branch in blocks treated with increasing dosage rates of *B.t.*

Dosage Rates BIU/ha	Surviving budworm per branch (pre-spray in brackets)*	
	Thuricide	Dipel
10	(16) 2.5	(19) 2.3
20	(12) 0.7	(18) 0.2
40	(16) 0.3	(25) 0.1
80	(35) 0.2	(18) 0.4
Check I	(12) 3.2	
Check II	(16) 3.2	

*Survival rate corrected for pupal mortality.

Table 12

Pupal survival in plots treated with increasing doses of *B.t.*

Dosage Rates BIU/ha	Percent pupal survival (No. reared in brackets)	
	Thuricide	Dipel
10	58 (430)	49 (297)
20	26 (47)	13 (284)
40	47 (92)	9 (77)
80	28 (36)	32 (47)
Check I	49 (495)	
Check II	38 (645)	

An analysis of the relationship between ground level density (droplets/cm^2) and population density reduction (Table 13) indicates that droplet concentration of active ingredient has some relationship to effectiveness, more so in the case of the Thuricide treatments. Here, the droplet densities at 10 and 20 BIU/ha were similar. The amount of active ingredient per droplet at 20 BIU/ha would be theoretically twice that of 10 BIU/ha and this is reflected in a 35%

increase in percentage population reduction. A levelling off of this effect is evident at the 40 and 80 BIU/ha dosage rates. In the Dipel treatments, the droplet densities decreased with increasing dosage rates from 20-80 BIU/ha. This would be expected with a non-Newtonian fluid like Dipel and is congruent with the large droplet sizes observed during the aircraft calibration of these tank mixes (Table 6). In this case, the efficacy levelling off took place at 20 BIU/ha and above. While the droplet densities at 10 and 20 BIU/ha were similar, the effectiveness of the latter rate was 18% greater due to the greater amount of active ingredient per droplet. These data indicate that efficacy increases not only as coverage (droplets/cm^2) increases but as the amount of active ingredient per droplet increases as well.

Table 13

Relationship between ground level droplet density and population reduction*.

Dosage BIU/ha	Colonies/cm^2			% Population reduction**	
	Thuricide	Dipel		Thuricide	Dipel
10	32	40		57	80
20	28	43		92	98
40	77	25		97	99
80	80	23		99	96
Check I			61		
Check II			73		

*Based on number budworm per 100 current year's buds.
**From droplets collected on Millipore filter membranes and incubated on trypticase soy agar.
***Adjusted for pupal mortality.

Effect of Dipel Treatments on Parasitism

Table 14 shows the number of larvae and pupae reared from each Dipel treatment plot, and the rates of parasitism. The relatively low numbers reared in some cases were due to a lack of live budworm in the plots at the collection time. The rate of parasitism was low at all collection times. The treatments had no apparent effect on parasitism on pupae. An analysis of the changes in the incidence of larval parasites between pre-spray and post-spray I, when any mortality effects attributable to the sprays would be most evident, showed no significant deleterious effect of the treatment on parasitism (Table 15). In a previous study, Morris (1977) reported no apparent effect of *B.t.* sprays on spruce budworm parasites.

Table 14

Percentage larval and pupal parasitism in plots treated with Dipel 88 (4L).

Dosage Rate BIU/ha	Percent larval parasitism (No. reared in brackets)			Percent Pupal parasitism***
	Pre-Spray*	Post-Spray*	Post-Spray II**	
10	11 (116)	4 (137)	6 (94)	4 (297)
20	26 (115)	9 (56)	4 (46)	7 (284)
40	14 (155)	16 (25)	8 (38)	6 (77)
80	27 (136)	20 (30)	3 (34)	6 (47)
Check I	21 (145)	11 (135)	13 (72)	3 (495)
Check II	29 (114)	8 (170)	20 (50)	5 (645)

*Hymenoptera
**Brachonids, Diptera and Ichneumonids
***Hymenoptera and Diptera

Table 15

Changes in incidence of larval parasitoids in plots treated with Dipel 88.

Dosage Rate BIU/ha	Percent change from	
	Pre-Spray to Post-Spray I	Post-Spray I to Post-Spray II
10	-7	+2
20	-16	-5
40	+2	-8
80	-7	-17
Check I	-10	-2
Check II	-21	+12

Effect of Treatments on Budworm Biomass

For the purpose of this report, budworm biomass is defined as the dry weight of the total spruce budworm population per current year's shoot. The data (Table 16) show pre-spray biomass ratios of untreated/treated varying widely between test plots. The post-spray ratios show an increasing trend as the dosage rate of both Thuricide and Dipel increased. The only exception was the Thuricide treatment at 80 BIU/ha, due to the late treatment of a high population density. In the operational dosage range of 20-40 BIU/ha, the biomass of Thuricide-treated survivors was 6-11 fold, lower than that among survivors from the untreated check, and the biomass of Dipel-treated survivors was 9-10 fold lower. When the Thuricide biomass ratios were plotted against defoliation, the result was a linear curve (r^2 = 0.90) indicating a direct relationship between biomass and feeding activity. A similar linear relationship was not observed with Dipel, but the defoliation levels in the 20-80 BIU/ha treatment plots with biomass ratios of 8-20 were significantly lower than defoliation at the 10 BIU/ha dosage with a ratio of 1.9, supporting the concept that feeding activity is related to dosage applied.

Table 16

Larval budworm biomass at 14 days post-application in balsam fir stands aerially treated with increasing dosage rates of *Bacillus thuringiensis* var. *kurstaki* in Ontario, 1981.

Dosage Rate, BIU/ha	Biomass in mg avg. dry wt/100 shoots*							
	Thuricide				Dipel			
	Pre-Spray		Post-Spray		Pre-Spray		Post-Spray	
10	3.7	(3.7)	37.9	(1.7)	4.7	(2.9)	32.4	(1.9)
20	6.8	(2.0)	10.3	(6.1)	6.5	(2.1)	7.2	(8.8)
40	27.3	(0.5)	6.0	(10.5)	13.5	(1.0)	6.2	(10.2)
80	36.4	(0.4)	16.7	(3.8)**	6.1	(2.2)	3.1	(20.3)
Check I and II Combined	13.7		63.0		13.7		63.0	

*Ratio of biomass in check/biomass in treated in brackets.
**Treated when larval development was 18% L_3, 32% L_4, 39% L_5 and 11% L_6.

A reduction in larval weight as *B.t.* dosage increased was reported by Morris (1973) following dosage-mortality laboratory studies among several forest insect pests. The present field results support those reported recently by Schesser and Bulla (1978) and Morris *et al.* (1981). A similar trend was not observed among pre-ovipositing female moths which emerged from field collected pupae (Table 17). The fecundity of these moths was not assessed, but *B.t.* has been reported in the past to affect fecundity (Soliman *et al.* 1970; Abdullah and Abdul-Nasr, 1970; Morris and Armstrong 1975) and cause teratogenesis in adults (Morris 1969).

Table 17

Mean dry wt. of newly-emerged female moths from pupal rearings*

<table>
<tr><th rowspan="2">Dosages BUI/ha</th><th colspan="2">Total ♀ pupae reared</th><th colspan="2">Mean Wt. of emerged moths in mg ± SD</th></tr>
<tr><th>Thuricide</th><th>Dipel</th><th>Thuricide</th><th>Dipel</th></tr>
<tr><td>10</td><td>207</td><td>105</td><td>23 ± 5</td><td>22 ± 4</td></tr>
<tr><td>20</td><td>23</td><td>148</td><td>12 ± 4</td><td>18 ± 6</td></tr>
<tr><td>40</td><td>51</td><td>35</td><td>20 ± 8</td><td>NA**</td></tr>
<tr><td>80</td><td>17</td><td>21</td><td>19 ± 8</td><td>14 ± 2</td></tr>
<tr><td>Check I</td><td colspan="2">145</td><td colspan="2">23 ± 5</td></tr>
<tr><td>Check II</td><td colspan="2">287</td><td colspan="2">22 ± 6</td></tr>
</table>

*Weighed before oviposition started.
**Only one moth emerged.

Effect of Treatments on Defoliation

The data on the effect of applied dosage rate on defoliation indicate that the 10 BIU/ha rate did not provide significant protection from defoliation (Table 18). When differences in population densities between treatment plots were ignored, the defoliation levels for all treatments above 10 BIU/ha were similar and well within the generally acceptable limit of 50% defoliation of current year's growth. The only exception was the treatment with Thuricide at 80 BIU/ha, and this was partly due to the lateness of the spray application (6/6), advanced larval developmental (40% L_5, 11% L_6) and relatively high larval density (35/100 buds or 36/45-cm branch tip). When percentage defoliation is adjusted for variations in pre-spray population densities, it is evident that, within the 20 to 40 BIU/ha dosage range, defoliation was lower in treated plots than in the combined untreated plots by 1.4-3.5 fold in case of Thuricide, and by 3.8-4.5 fold in the case of Dipel. At the lower dosage rate (20 BIU/ha), Dipel appeared to be slightly more effective than Thuricide, in spite of a higher pre-spray population density. The reason may be related to a substantially higher deposit efficiency of Dipel at this dosage rate. These differences may in turn reflect the population reduction differences cited earlier (Tables 8 and 9).

Effectiveness of Single Versus Double Applications

The data in Table 19 summarize the results of the tests of single versus double applications. The ground deposit values for double applications are the sums of the droplet counts on two separate Millipore filters per treatment. In the case of Dipel, the droplet density of the single spray was about half the density of the double

Table 18

Effects of dosage rate on defoliation of balsam fir trees

Dosage rate, BIU/ha	Pre-Spray larval density/100 current shoots (per 45 cm br.)		Deposit rates, colonies/cm^2		Percent defoliation ± SD*		Ratio of % defol./ pre-spray larval density	
	Thuricide	Dipel	Thuricide	Dipel	Thuricide	Dipel	Thuricide	Dipel
10	15 (16)	22 (19)	31	40	69 ± 24 b	71 ± 24 b	4.6	3.2
20	14 (12)	24 (16)	38	43	45 ± 25 a	24 ± 21 a	3.2	1.0
40	27 (16)	32 (25)	77	25	36 ± 20 a	39 ± 20 a	1.3	1.2
80	35 (36)	19 (17)	80	23	61 ± 26 b	37 ± 27 a	1.7	1.9
Check I	17 (12)				71 ± 21 b			
Check II	18 (16)				89 ± 10 b			

*Values followed by the same letter are not significantly different at 5% level.

Table 19

Effect of single application compared with double applications of the same dosage on population density reduction and defoliation.

Treatment BIU/ha	Budworm per 100 shoots at days post-application			Ground Deposit (drops/cm^2)**	Percent larval population reduction		defoliation***
	Pre-spray	PS 14*	PS 21*		PS 14*	PS 21*	
Dipel 2 x 10	23	5.6	1.5	82 (42 + 40)	58 a	91 a	35 ± 22 a
Dipel 1 x 20	24	5.9	3.2	42	68 a	84 a	24 ± 21 a
Thuricide 2 x 20	23	6.2	2.7	71 (28 + 43)	70 a	81 a	35 ± 22 a
Thuricide 1 x 40	27	2.5	1.4	77	89 a	95 a	36 ± 20 a
Check I –	17	20.6	13.4	–	0 b	0 b	71 ± 21 b
Check II –	18	20.7	12.9	–	0 b	0 b	89 ± 10 b

*PS 14, PS 21 = 14 and 21 days post-spray. PS 21 corrected for pupal mortality.
**Total number of colonies/cm^2 on Millipore filter membranes for each treatment.
***Values followed by the same letter are not significantly at 5% level.

spray, but theoretically similar in terms of total active ingredient. The population density reduction and defoliation levels were also similar. For the Thuricide treatments as well, there was obviously no advantage to the double application over the single. In fact, the single application of Thuricide may have been slightly superior to the double in terms of early larval kill.

CONCLUSIONS

The following conclusions were made from this study:

1. The efficacy of commercial *Bacillus thuringiensis* (*B.t.*) applied against the spruce budworm increases as dosage rates increase between 10 BIU and 40 BIU/ha in terms of population density reduction. The effectiveness levels off beyond 40 BIU/ha. The dosage rate of 20 BIU/ha, however, appears to be sub-optimal for consistently acceptable insect kill.

2. Application rates of up to 80 BIU/ha of Dipel 88 had no apparent deleterious effect on the incidence of spruce budworm parasites.

3. The effectiveness of *B.t.* in terms of foliage protection of balsam fir generally increased with dosage applied. The most effective, economical dosage rate was between 20 and 40 BIU/ha.

4. The weight of surviving larvae decreased significantly as dosage rate increased.

5. Under the conditions of these tests, there was no advantage to double applications over a single application of the same dosage.

6. Pending confirmation of these findings, an increase in operational dosage rate from 20 to 30 BIU/ha appears to be justified under conditions similar to those described above.

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