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PRELIMINARY FIELD STUDIES ON THE USE OF ADDITIVES TO IMPROVE DEPOSITION RATE AND EFFICACY OF COMMERCIAL FORMULATIONS OF *BACILLUS THURINGIENSIS* APPLIED AGAINST THE SPRUCE BUDWORM, *CHORISTONEURA FUMIFERANA* (LEPIDOPTERA: TORTRICIDAE)

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ABSTRACT

Results of the 1976 tests were inconclusive, due partly to an apparent collapse in budworm population densities on all plots. Deposit rates of active ingredients were poor due to clogging of spray nozzle systems.

In 1977, two treatments each of 10 Billion International Units (BIU) of Thuricide 16B + 56g active ingredient (AI) acephate + 1% Uvitex ERN-P +1% + 0.02% Kelzan +1% Uvitex ERN-P +1% of Uvinul DS49 in 4.7 litre per ha applied when larvae were at peak L_3 and L_4, were deposited at ground level at the rate of 15.9 BIU/ha and 11.4 BIU/ha, respectively and were both highly effective in terms of population density reduction and foliage protection. Residual spruce budworm population densitities were significantly lower and budworm development was significantly retarded in these treatment plots when compared with those of their respective untreated check plots. An acephate treatment applied at 56g/ha (i.e., 6 to 10% of the operational rate) reduced larval population density but did not protect the trees from defoliation as effectively as did the combined B.t. - acephate treatments. The biocide treatments caused no apparent deleterious effect on budworm parasitism. Based on deposit efficiency and foliage protection criteria, double applications of the new tank mixes were considered highly effective for spruce budworm control.

RÉSUMÉ

Les résultats des essais de 1976 n'ont pas été concluants, en partie à cause d'une baisse apparente de la densité des populations de Tordeuse dans toutes les placettes d'échantillonnage. Les taux d'application de matières actives ont été mediocres à cause des systèmes d'arrosage défectueux.

En 1977, on a effectué au niveau du sol deux traitements composés chacun de 10 milliards d'Unités Internationales (BIU) de Thuricide 16B + 56 g de matière active (m.a.) d'acéphate + 1 % Uvitex ERN-P+0.02 % Kelzan + 1 % Uvitex ERN-P + 1 % d'Uvinul DS49 dans 4,7 litres/ha, appliqués au moment où les larves étaient au point culminant L_3 et L_4; les taux d'application ont été de 15,9 BIU/ha et 11,4 BIU/ha respectivement et tous deux furent très efficaces quant à la réduction des populations et à la protection du feuillage. Les densités de populations résiduelles de Tordeuse des bourgeons de l'Epinette ont été significativement plus faibles et le développement de la Tordeuse a été significativement retardé dans les placettes traitées, comparativement aux placettes témoins. Un traitement à l'acéphate, à raison de 56 g/ha (c.-à-d. 6 à 10 % du taux opérationnel) a réduit la densité des populations mais n'a pas protégé les arbres contre la défoliation aussi efficacement que les traitements de B.t. - acéphate. Les traitements d'insecticides n'ont causé aucun effet délétère au parasitisme de la Tordeuse. En se fondant sur les critères de protection du feuillage et d'efficacité des applications, de doubles applications de nouveaux mélanges ont été considérées comme très efficaces pour la répression de la Tordeuse.

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INTRODUCTION

Liquid formulations of microbial agents for spray application against insect pests should have good wetting, spreading, sticking and flow characteristics and should contain additives to minimize spray drift and reduce the rate of inactivation of the microorganism by sunlight. The formulation of Bacillus thuringiensis kurstaki (B.t.) which are presently available commercially do not fully meet these requirements.

Results of several aerial spray trials against Choristoneura fumiferana (Clem.) in Canada in recent years have indicated that 7.5 billion international units (BIU) or more of B.t. deposited/ha at sites of balsam fir (Abies balsamea) (L.) trees supporting moderate populations of spruce budworm would likely prevent unacceptable defoliation of the trees. The residual activity half-life of B.t. exposed to bright sunlight on coniferous trees ranges from about 1 to 5 days depending on droplet size and meteorological conditions (Morris and Moore 1975; Thompson et al. 1977; Greigo and Spence 1978). The efficacy of B.t. against spruce budworm can be improved by addition of sunlight screens to spray mixtures (Morris and McErlane 1975; Morris and Moore 1975). B. thuringiensis (Dipel WP) without sun screen applied to white spruce, Picea glauca (Moench) Voss, was totally inactivated after three days of weathering (98 cal/cm^2, 295-385 nm solar radiation at Petawawa, Ontario) but only 40% inactivated when mixed with 1.0% w/v Uvinul DS49 (Chemical Developments of Canada Ltd., Montreal) (Morris and Moore 1975). The toxicity of Dipel 36B to spruce budworm without sunscreen on white spruce was reduced 50% after an exposure to 39.2 cal/cm^2 but required 68.6 cal/cm^2 when mixed with 1.0% DS49 and 0.1% Erio Acid Red X B 100 (Ciba Geigy, Montreal) for 50% inactivation. A mixture of DS49 and 1.0% Uvitex-ERN-P (Chemical Developments

of Canada Ltd., Montreal) fully protected B.t. activity for three days (Morris, unpublished data). "Shade" (Sandoz, Inc., Homestead, Florida) at 0.6% w/v protected B.t. spores on Douglas fir, Pseudotsuga menziesii var glauca (Beissn.) Franco for three days and residual toxicity for five days (Thompson et al. 1977). Efficacy would likely be enhanced even further if sprays were applied several days apart so as to extend the period of time in which the foliage is supporting a lethal dose of the pathogen.

Another technique which appears highly promising in terms of enhancing the effectiveness of B.t. against the spruce budworm is the addition of low doses of Acephate (O, S-dimethylphosphoramidothioate, at about 6 to 10% of the operational dosage rate) to B.t. tank mixes. Twenty BIU of B.t./ha combined with 43 gm active ingredient of acephate/ha aerially applied against the spruce budworm, increased larval mortality by 17 to 34% compared with mortality from a B.t. treatment. The B.t.-acephate treatments resulted in no significant reduction in defoliation due largely to low deposit rates (4.4 to 6.2 BIU/ha) and rapid inactivation of microbial activity (Morris 1977b).

In an attempt to increase the efficacy of commercially prepared B.t. against the budworm, a series of field trials was designed and conducted in 1976 and 1977 to (a) improve deposit efficiency of B.t.-acephate combinations when applied by aircraft, (b) increase the time period in which budworm larvae would be exposed to active ingredient and (c) determine the effect of additives on effectiveness of commercial B. thuringiensis kurstaki formulations. This paper summarizes the results of these field trials.

MATERIALS AND METHODS

The formulations used in 1976 on two replicate plots contained 33% v/v Dipel 36B (Abbott Laboratories, North Chicago, Illinois) Lot No. 52-881-CD, 0.25% w/v sodium carboxymethycellulose (CMC-R 295 F, Chemical Developments of Canada Ltd., Montreal), 1.0% w/v polyvinylpyrrolidone (PVP-K30, Chemical Developments of Canada Ltd.), 1.0% w/v Uvinul DS49, 0.1% w/v Erio Acid Red XB 100 (Ciba, Montreal) 0.1% v/v Chevron Spray Sticker (Chevron Chemicals, Toronto) and 0.56% w/v 94% technical acephate (Chevron Chemicals, Toronto) in water. A third plot was treated with a similar formulation but without DS49 and acephate.

In 1977, a Thuricide formulation contained 47.5% v/v Thuricide 16B Lot No. 2W-12540 (Sandoz Inc., Homestead, Florida), concentrations of DS49 and Chevron spray sticker as above, 1.0% v/v Uvitex ERN-P and 0.69% w/v technical acephate in water. A dipel-Kelzan formulation contained 22% v/v Dipel 36B, Lot No. 75-127-CD, 0.025% w/v Kelzan (Kelco Co., Montreal), Uvinul DS49, Uvitex and Chevron spray sticker as above and 0.69% w/v acephate in water. Acephate-Kelzan contained Kelzan, Uvitex, and sticker as above and 0.69% w/v acephate in water.

Plot sizes were all 20 hectares except Dipel-CMC without DS49 and acephate (30 ha). Dipel-CMC sprays (1976) were single applications at 30 Billion International Units (BIU) in 9.4 l/ha. All 1977 trials were double applications of 10 BIU in 4.7 l/ha each. Dipel contained 9.5 BIU/l and Thuricide 4.2 BIU/l.

Sodium carboxymethylcellulose, is a water soluble cellulose ether used commercially in the food industry, particularly for its unique film forming, suspending, stabilizing, thickening and adhesive properties. Polyvinyl-

pyrrolidone is a water soluble polymer and protective colloid used in drugs, detergent formulations and cosmetic preparations. According to the manufacturer, PVP films become tacky at 70% relative humidity and at 50% R.H. they contain 18% moisture, a property which suggests utility for aerial applications under low relative humidity conditions. PVP, however, has the disadvantage of forming complexes with some toxins and microorganisms thereby reducing their toxicity (Wood 1970). Kelzan, a food grade xanthan gum, is a high molecular weight linear polysaccharide with extreme pseudoplasticity, i.e., low viscosity and excellent flow under high shear and high viscosity at rest. It has outstanding suspending properties and, because of its high viscosity at rest, spray droplets tend to be coarser, thereby reducing spray mist and providing a narrower, more uniform spray pattern and good drift control. CMC and Kelzan were moistened with absolute alcohol to facilitate dissolution in water. The thickeners were only added to the Dipel formulation since Thuricide 16B is already highly viscous due to the presence of a large concentration of sugars. Erio acid Red and Uvitex were used as tracer dyes and Uvinul was used as a sunlight protectant. All additives were laboratory tested at concentrations slated for field use and found compatible with B. thuringiensis var. kurstaki (Morris 1975b; Morris and McErlane 1975; Morris et al. 1977).

Field Trials

The procedures used in field tests were similar to those previously reported (Morris 1977b). Test plots consisted of mixed white spruce and balsam fir stands located at Ranking Township (1976) and Mattawa (1977), Ontario. Fifty sampling stations (25 white spruce and 25 balsam fir trees) were established in each spray plot and in two untreated check plots for assessment of the effectiveness of the sprays on the target organism. A spray deposit kit consisting of two glass

plates (7.5 cm x 5.0 cm) for estimating volume deposit and one Kromekote card for estimating drop size and density was place on the ground in a clearing adjacent to each sampling station. Tree conditions in the plots were assessed on the basis of the number of buds/m^2 of foliage. Treatments consisted of single or double applications of B. thuringiensis with and without acephate and acephate. Sprays were applied in late May at the rate of 20 to 30 BIU of B. thuringiensis plus 42 to 56 g acephate in 9.4 l/ha. Larval development at spray time was peak L_3 for single applications in 1976 and peak L_3 and peak L_4 for double applications in 1977. White spruce buds were 90% flushed at spray time. A Cessna 185, equipped with four AU 3000 Micronair emission units, was used and all applications took place in early morning or late evening under conditions of temperature inversion, low temperatures (12-15°C) and high relative humidity (75-95%) which were measured by meteorological instruments located in the plots. Aircraft pump pressure, speed and height above tree tops were 40 p.s.i., 160 km/hr and 3-5 m, respectively, in both years. Swath width was 15 m in 1976 and 50 m in 1977.

The glass plates were washed with water and the dyed suspensions were analyzed colorimetrically in 1976 and fluorometrically in 1977 to estimate volume deposit rates. Drop sizes and densities of the Dipel-CMC spray formulations (1976 tests) were estimated with a microcard reader using a laboratory determined spread factor of 2 (W. Halliburton data personal communication). For the Dipel-Kelzan and Thuricide treatments (1977 tests) containing Uvitex as a fluorescent tracer dye, a dissecting microscope at 30X manification was used with incident black light illumination at 350 nm wavelength and an eyepiece grid. Only drop cores (i.e., the circular areas containing active

ingredients of B.t.) were measured, thus eliminating the need for spread factor in calculating droplet sizes.

The biological effects of the treatments were measured as budworm population reduction, larval development rate, current year's foliage loss, and parasitism of survivors (Morris 1977b). The survival rate of B. thuringiensis spores on white spruce and balsam fir needles was studied (Morris 1977b).

RESULTS AND DISCUSSION

Bud Densities at Sampling Stations

Bud densities on white spruce and balsam fir trees were higher in the 1976 than in the 1977 test plots (Table 1). However, with the possible exception of the Dipel-CMC-3 treatment, the ratios of bud densities/population densities on treatment plots were similar to the ratios on their respective untreated check plots. This indicates that the tree conditions in relation to budworm density were similar in all the test plots.

Deposit Efficiency

The Dipel-Kelzan and Thuricide formulations deposited at ground level at significantly high rates (Table II). Mean deposit rate for Dipel-CMC plots was 3.9 ± 2.6 BIU per hectare compared with 11.4 for Dipel-Kelzan and 15.9 for Thuricide. Mean drop densities/cm^2 for Dipel-CMC ranged from 20 ± 15 to 91 ± 53 versus 69 ± 49 to 143 ± 37 for Dipel-Kelzan and Thuricide respectively. Mean drop diameters (µm) for Dipel-CMC ranged from 16 ± 6 to 22 ± 10 compared with 120 ± 74 to 150 ± 75 for Dipel-Kelzan and Thuricide. Only 0.2% of Dipel-CMC droplets exceeded 200 µm in diameter compared with 29.2% and 46.8% of Dipel-Kelzan and Thuricide droplets, respectively. The ratio

TABLE I. Effectiveness of experimental formulations of Bacillus thuringiensis kurstaki and/or acephate aerially applied against the spruce budworm at Rankin and Mattawa, Ontario

Assessment Criteria		Treatments							
		1976				1977			
		Untreated Check	Dipel-CMC + acephate-1	Dipel CMC + acephate-2	Dipel-CMC-3	Untreated Check	Acephate-Kelzan	Dipel Kelzan + acephate	Thuricide + acephate
No. buds/m^2 of foliage	wS	809	826	740	684	485	495	504	493
	bF	707	753	683	966	314	540	508	529
Pre-spray larval density	wS	12(17)	13(17)	12(14)	9(11)	19(15)	30(29)	25(23)	24(19)
No./100 buds (per 45cm branch)	bF	7(9)	7(8)	7(6)	6(6)	13(7)	16(16)	17(13)	19(15)
Ratio of bud density	wS	67	64	62	76	26	17	20	21
to larval density	bF	101	108	98	161	24	34	30	28
% Population reduction	wS	-	92	92	86	-	90	94	91
due to treatment[2]	bF	-	81	92	96	-	87	95	99
Residual population	wS	2.0	1.0	0.9	1.3	3.3	0.6	0.5	0.4
density (per 100 buds)	bF	1.9	1.3	0.5	0.2	3.5	0.7	0.3	0.1
Ratio of % defoliation/ pre-spray larval density (wS and bF combined)		1.9	0.9	0.8	0.6	4.4	2.9	1.8	1.0
% Pupation on final sample date		87	75	61	81	75	85	54	47
% Larval parasitism		9	9	0.6	5	ND	ND	ND	ND
% Pupal parasitism		6	11	7	11	10	18	6	14

Continued . . . .

TABLE I (Concluded)

Assessment Criteria	Treatments							
	1976				1977			
	Untreated Check	Dipel CMC + acephate-1	Dipel CMC + acephate-2	Dipel CMC-3	Untreated Check	Acephate-Kelzan	Dipel-Kelzan +acephate	Thuricide +acephate
% Egg mass parasitism	28	18	22	15	28	23	34	51

[1]Cumulative solar UV radiation (Cal/cm^2, 295-385 nm); mean max./mean min. temp. (°C) and rainfall (cm) during tests were 509, 26.1/12.1, and 4.5, respectively, in 1976 and 504, 20.6/7.2 and 4.75, respectively in 1977.

[2]Corrected by Abbott's formula.

ND-No data collected.

Table II. Spray deposits of experimental formulations of *Bacillus thuringiensis* (at ground level and on trees) aerially applied at the rate of 9.4 ℓ/ha.

Formulations	BIU deposited/ha	Percent of emitted volume deposited at ground level[1]	Mean drop density (no./cm^2) ± SD	Mean drop diameter (μm) ± SD	No. viable spores/g foliage x 10^5
Dipel + CMC + PVP + DS49 + EAR + acephate[2]	6.9	23.2	91 ± 53	20 ± 10	9.8
Dipel + CMC + PVP + DS49 + EAR + acephate[2]	3.1	10.5	20 ± 15	22 ± 10	12.8
Dipel + CMC + PVP + EAR[2]	1.9	6.5	34 ± 28	16 ± 6	14.8
Dipel + Kelzan + DS49 + Uvitex + acephate[3]	11.4	57.9	69 ± 49	120 ± 74	15.0*
Thuricide + DS49 + Uvitex + acephate[3]	15.9	80.5	143 ± 37	150 ± 75	19.4*

[1]Based on colorimetric (EAR) or fluormetric (Uvitex) analysis of glass plate deposits.

[2]Single application of 9.4 ℓ/ha.

[3]Two applications of 4.7 ℓ/ha each.

*Samples taken immediately after 1st application of 10 BIU/ha.

of BIU deposited to droplet diameter was 0.10 for both the Dipel-Kelzan and Thuricide applications. The ratio of BIU deposited to drop density, on the other hand was 0.08 and 0.16 respectively. Thus spray atomization was greater using Thuricide than using the Dipel formulation. The spray cloud from the acephate treatment did not reach ground surface. Due to a wind shift during application this plot was sprayed in a manner which allowed the spray cloud to drift into the tree canopy.

The deposit rate of Thuricide on foliage was the highest of all treatments. It should be noted that foliage deposits were recorded following Dipel-CMC application rates of 9.4 l/ha but, due to manpower limitations, only following the first application of Dipel-Kelzan and Thuricide at 4.7 l/ha. Thus the total foliage deposit rates for the latter two formulations may have been about double those indicated. Stelzer et al. (1977) demonstrated that deposit rate doubled when the volume of water suspensions of nuclear polyhedrosis virus was doubled.

In general, the deposit efficiency of Thuricide was similar to or slightly better than that achieved in 1974 with a similar formulation without sunscreen when 81.0% of the emitted volume reached ground surface (Morris 1976). In that test 8.1 BIU/ha were recorded at ground level when applied at 10 BIU in 4.7 l/ha compared with 15.9 BIU/ha in the present test applied at 20 BIU in 9.4 l/ha. Fluorescent tracer dyes were used in both tests. In the present test, 58 ± 21% of Dipel-Kelzan reached ground surface compared with 174 ± 22% for seven previous aerial applications of Dipel 36B all under roughly similar meterological conditions of temperature inversion, high humidity and low temperature.

The relatively poor deposit efficiency of Dipel-CMC was partly due to clogging of the Micronair emission system resulting in too fine a break-up and consequent loss of material by drift. This observation may be related to the fact that droplet formation with solutions of polymer, tend to be connected by thin threads on which secondary instabilities in the form of very fine droplets may develop (Goldin et al. 1969). Also, on leaving the spray nozzles, the PVP could have crystallized out because of the natural cooling effect. The result would be a build-up of solid matrix at the orifice of the spray head causing finer and finer atomization of the spray as time progressed. Such phenomena could lead to significant evaporation of droplets between 60 and 70 µm (Morris 1977b). The low viscosity of Kelzan under high shear could explain the high deposit of Dipel-Kelzan. Once free of the spray nozzle, Kelzan solutions return to their high at-rest viscosity, thereby coursening the droplet size spectrum, increasing sticking, reducing spray mist and providing a narrower and more uniform spray pattern (Kelco Technical Bulletin I #24).

Residual Activity

The numbers of viable spores of B. thuringiensis per gram of foliage from trees sprayed with Thuricide 16B was higher than those from other treatment plots over the 19-day check period (Table III). Five days following the first spray, the numbers of viable Dipel-CMC spores declined by 95% compared with 56% and 0% on Dipel-Kelzan and Thuricide plots, respectively. Nineteen days post-spray, the decline on all plots was 96% except on Thuricide-sprayed balsam fir which showed a decline of 0.9%. In general, the number of viable spores was higher on balsam fir than on white spruce trees. White spruce foliage has previously been shown to cause 78% inactivation of B. thuringiensis kurstaki after 14 days in the dark (Morris and Moore 1975).

TABLE III. Number of viable Bacillus thuringiensis kurstaki spores per g of white spruce and balsam fir needles at various time intervals after aerial application of experimental formulations at Rankin and Mattawa, Ontario during May-June, 1976 and 1977.[1]

Days after application	Cumulative solar ultraviolet radiation (295-385 nm) Cal/cm^2	Percent spore survival by treatment plots (No./gm x 10)							
		Dipel-CMC, 1,2 combined		Dipel-36B-CMC-3		Dipel-Kelzan		Thuricide-16B	
		wS	bF	wS	bF	wS	bF	wS	bF
0	0	100(883)	100(1293)	100(1930)	100(1020)	100(1080)	100(442)	100(680)	100(1160)
5*	127	1.9(17)	15.9(206)	0.2(4)	0.6(6)	33.7(364)	54.0(228)	100(690)	100(1250)
19	699	16.0(141)	4.1(53)	0.1(2)	0.4(4)	0.3(3)	0.9(4)	8.7(59)	99.1(1149)

[1]Averages for 2 replicate trees (1 branch/tree) per plot per sample period.

* 2 days after second application of Dipel-Kelzan and Thuricide plots.

Balsam fir foliage collected at various intervals after spray application showed no mortality on the Dipel-CMC plot and 69% and 90% on the Dipel-Kelzan and Thuricide plots, respectively, 5 days post-spray (Table IV). The small droplet size and the low deposit rates at least partly explain the rapid loss of activity on the Dipel-CMC treatment plots. Thomson et al. (1977) observed that the residual activity of course droplets of Thuricide 16B applied to Douglas fir lasted for 3 days post-spray while fine droplets started to degrade immediately after spray application. The two-spray regime in the present tests was probably also partly responsible for the difference between the 1976 and 1977 results. Larval mortality on balsam fir aerially sprayed with Thuricide 16B without the addition of a sunlight protectant was 52.0% after 5 days of weathering in Algonquin Park, Ontario (Morris and Hildebrand 1974). In spite o the high numbers of viable spores on balsam fir foliage even at 19 days post-spray (Table III) on those two plots, the infectivity apparently declined steeply between 5 and 12 days post-application (Table IV).

Efficacy of the Treatments

The population density reductions due to treatments were significant (81-99%) for all tests and no significant differences were observed among formulations (Table I). The ratio of residual population density in the untreated check plot to that in the Dipel-CMC treatment plots ranged from 1.5 to 2.9 on white spruce and 1.5 to 9.5 on balsam fir. Equivalent values for the Dipel-Kelzan treatment were 6.6 (wS) and 11.7 (bF) and for the Thuricide treatment 8.3 (wS) and 35.0 (b), indicating much greater efficacy of these treatments with respect to total population density reduction.

TABLE IV. Mortality of spruce budworm 3rd and 4th instar larvae fed balsam fir foliage collected at various intervals after aerial spray application at Rankin and Mattawa, Ontario.

Days after application	Cumulative solar ultraviolet radiation Cal/cm^2 295-385 nm		Corrected % mortality (number larvae tested in brackets)		
	1976	1977	Dipel-CMC-1 1976	Dipel-Kelzan 1977	Thuricide 1977
1	25	15	0 (174)	63 (20)*	90 (19)*
5	127	117	0 (95)	69 (36)**	90 (19)**
12	247	253	0 (97)	37 (45)	0 (40)
19	699	444	0 (93)	0 (50)	0 (43)

[1]Values are averages of 2 trees, same branches as in Table III. Drop densities (No./cm^2) at ground level at the sampling sites were 162 for the single application of Dipel-CMC and 165 and 170 for two applications of Dipel-Kelzan and Thuricide, respectively. Mortality corrected by Abbott's formula.

* One day after first application.

** Two days after 2nd application.

TABLE V. Defoliation of current year's growth of white spruce (wS) and balsam fir (bF) trees infested with spruce balsam and aerially sprayed with experimental formulations of B. thuringiensis at Rankin and Mattawa, Ontario.

Formulations	% Defoliation	
	wS	bF
1976		
Dipel CMC-1	9[a]	7[b]
Dipel CMC-2	9[a]	5[b]
Dipel CMC-3	10[a]	3[a]
Untreated check	18[b]	16[c]
1977		
Dipel-Kelzan	36[b]	33[b]
Thuricide	22[a]	22[a]
Acephate alone	56[c]	60[d]
Untreated check	55[c]	74[e]

[1]Estimation of defoliation according to Fettes (1951). Four cardinal branches/tree examined. Defoliation on cardinal sides were not significantly different. Same letters in column indicate no significant differences (alpha = 0.05; Kruskal-Wallis one way analysis of variance).

The residual budworm population densities reflected the levels of defoliation in the B. thuringiensis treatments but not in the acephate treatment (Table V). The defoliation levels in Dipel-CMC plots were lower than expected. The pre-spray larval density of that check plot should have caused about 35% defoliation on white spruce and 50% on balsam fir based on a regression curve of larval density per 45 cm branch tip versus defoliation on 17 unsprayed forest plots studied in the past (Morris, unpublished data). Thus a population collapse must have occurred in these plots. Defoliation levels in the Dipel-Kelzan and Thuricide plots were very low (33-36% and 22%, respectively) when compared with their corresponding check plot (55-75%) and are a reflection of the high deposit and coverage rates, larger drop sizes, and the relatively high microbial numbers persisting in these plots. Defoliation in the acephate plot was similar to that in its corresponding untreated check plot. It should be pointed out, however, that in spite of the apparent 1976 population crash, the ratios of defoliation to pre-spray densities indicated that the treatment efficacies in terms of foliage protection were 2.1 to 3.8 times greater than no treatment at all. The 1977 B. thuringiensis treatments were 2.4 to 4.4 times as effective as no treatment and Thuricide plus protectant was 1.8 times as effective as Dipel-Kelzan plus treatment.

Post-larval Effects

The Dipel-Kelzan and Thuricide treatments significantly retarded budworm development as evidenced by pupal development on the last sample day (Table I). Such delayed effects can be important in terms of overall treatment efficacy (Morris and Armstrong 1975; Morris 1976). Pupal development in the acephate

plot was similar to that in the corresponding untreated check plot. Mean female pupal weight (70± 3 mg) from all B.t. treatment plots was significantly lower than that (101± 3 mg) on the untreated check plot (alpha = 0.05).

Effect of Treatments on Budworm Parasitism

The treatments had no apparent deleterious effects on larval, pupal or egg parasitism (Table I). These, along with already reported data (Morris and Armstrong 1975; Morris 1977b), support the conclusion that B. thuringiensis with or without a low dosage of acephate is a safe spruce budworm microbiological control agent.

It is apparent from these data that two applications of Thuricide 16B or Dipel 36B plus a low concentration of acephate plus sunlight protectants when deposited at a high rate on the target sites will provide acceptable protection to white spruce and balsam fir trees moderately to heavily infested with spruce budworm. Prior to any recommendation for use, however, it would be desirable to conduct replicate field trials on larger plots and monitor the test population responses over an extended period of time.

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