RECENT FIELD RESEARCH EXPERIENCE WITH B.T. AGAINST SPRUCE BUDWORM IN THE EASTERN U.S.

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Recent testing in the eastern U. S. has led quickly to the adoption of 12 BIU/acre as the best operational dosage rate, with operational spray emission rates reduced to a quart or less per acre. Some recent work suggests that older larval instars of the budworm are highly susceptible to B.t. sprays, and the effective "spray window" can be broadened when budworm populations are moderate. New studies on second-year benefits of B.t. treatments are producing negative results.

Introduction

Development of B.t. for spruce budworm control has occurred rapidly and dynamically. In only 4 or 5 years B.t. has changed from a little used, expensive material, of questionable reliability, to one which is now perceived to compete favorably with chemical insecticides in quantities used (in some jurisdictions at least), in cost, and in reliability. The improvements in technology, made by the manufacturers of B.t. and tested by cooperating research groups, have rapidly become operational. These operational changes will have been discussed by other speakers, and we need not dwell on them at length.

The principal tests involved:

1. Comparisons of the major, competing formulations of B.t. (Walton and Lewis 1982, Dimond et al. 1981, Reardon et al. 1982, Grimble and Morris 1983, Morris 1981). These found no significant differences in efficacy.

2. Comparisons of three dosage rates and two dilution rates of B.t. sprays (Lewis et al., in press), as well as results of operational testing (Morris 1982), suggested that 12 billion International Units (BIU) per acre of B.t. produced more reliable results than the prevailing 8 BIU dosage, and should become the standard operational dosage. It was also concluded that spray emission rates of one gallon/acre provided no advantage over 0.5 gallon/acre.

3. Tests of applications of undiluted or "neat" B.t. (Dimond 1982) with spray emission rates as low as 1 quart/acre, were highly successful. This was followed by operational usage, with success, in 1983. Undiluted, or similar low-volume applications, are scheduled for wide use in 1984.

4. A combination of laboratory and field tests (Fast and Dimond 1984) suggested that the later larval stages of the budworm, through early sixth instar, are readily killed with B.t. It is no longer necessary to believe that a narrower "spray window" must be used with B.t. than with chemicals. Later applications, aimed at fourth and fifth instars, are likely to provide best results when budworm populations numbers are not unusually high.

5. In cooperation with Normand Dubois of the USDA, Forest Service, we field-tested one of his new strains of B.t., found in the laboratory to be more efficacious against the spruce budworm. Dubois will present these data in his contribution to this Symposium.

Prolonged Benefits of B.T. Treatments

For the balance of this presentation, I will summarize some unpublished information dealing with the question of second-year benefits of B.t. applications, sometimes called "carry-over effects". The latter term is a poor choice since it implies a possible persistence of B.t. organisms in substantial amounts within the budworm population or on the host trees for a year or more.

While some spores apparently can carry over to a second year (Reardon and Haissig 1983, 1984) there is no evidence that these are in sufficient quantities to affect budworm populations. Second year benefits could be explained, however, by the frequent observation that survivors of B.t. treatments often produce undersized, and presumeably unhealthy, pupae and moths (Morris and Moore 1983, Smirnoff 1983, Dimond and Spies 1980). It has been suggested that the generation of insects descending from these stunted survivors may have a low survival potential (Morris and Moore 1983, Smirnoff et al. 1974).

Evidence supporting second year benefits of B.t. applications has been circumstantial until recently. Dimond and Spies (1981) noted significantly less defoliation in small, 100 acre plots treated the previous year, than occurred in nearby control plots. They speculated that population reductions due to B.t. treatments were unlikely to have persisted to a second year because of the small sizes of plots and the high dispersive tendencies of both larvae and moths of the budworm (Greenbank et al. 1980); but, they had no counts of budworm numbers in the plots. Morris (1977) noted that over 2 to 3 years after treatment, both defoliation by and oviposition rates of spruce budworm were lower in treated plots than in untreated plots. In neither of the two cases above was it possible to identify any specific cause for these observations.

In further studies in 1981 (Dimond et al., unpublished[1]), we sampled budworm populations and damage in operational spray blocks (3,000 - 15,000 acres) treated by the Maine Bureau of Forestry the preceeding year. Seven blocks were selected, which had received satisfactory protection from B.t. applications in 1980, (Millers 1980), along with seven, nearby untreated areas. Samples of early-instar larvae, late-instar larvae, early pupae, and late pupae (= early adult) were collected in all plots. Insects were counted and instars determined. The latter step was to compare developmental rates between treatments. Subsamples of 200 insects from each collection in each block were reared in the laboratory to measure survival rates. Insects dying were examined for presence of entomopathogens. Defoliation rates were also checked on all blocks, using the standard Fettes system (Sanders 1980).

The results of these observations were inconclusive. Sprayed blocks began the season with somewhat higher mean numbers of insects than control stands (Table 1). However, the control stands had slightly higher numbers in the late collections. This suggests lower survival in the treated blocks, however, the differences were small and not statistically significant.

Percent of insects that were dead in collections were always slightly higher in the four treated blocks in the Molunkus area than in controls (Table 2). But, this was not true in the Caribou area. None of the differences were significant.

Percent of insects that died during rearing, for reasons other than emergence of parasitoids (Table 2), showed no significant differences. Causes of death (Table 3) showed a preponderance of microsporidian infections and unidentified deaths. Bacterial, viral, and fungal infections were rare, and B.t. was not recovered. There were no differences between treatments.

Developmental indices[2] (Table 4) showed treated and untreated populations in the Molunkus area to be equally advanced in the first collection, but sprayed populations were significantly delayed in the three later collections. In the Caribou blocks, development was significantly advanced in the treated blocks in the first collection, but with no difference in subsequent collections. Both cases suggest a statistically significant retardation of development of the treated populations, however, the differences were very minor, and perhaps of questionable ecological impact.

Pupal weights (Table 5) were different between areas, probably due to different insect densities in the two areas. But, there were no differences between treatments.

Defoliation (Table 6) in 1981 was greater or equal to levels in 1980, and there were no differences between treatment.

These findings were perplexing. Differences between treated and untreated plots were few and very minor in magnitude. If the differences were real, they were too small to explain the differences in defoliation rates seen the year earlier (Dimond and Spies 1981). But, on the other hand, we did not detect differences in defoliation (Table 7) in this series of blocks. We had no data to explain the earlier observations because prolonged benefits of B.t. treatments were not evident in the plots studied.

To further compound perplexity, we had one additional set of data, also taken in 1981. Defoliation observations were made in a series of 100 acre plots, 25 treated and 5 untreated that were sprayed experimentally with B.t. in 1980 (Dimond et al. 1981). These showed the same results (Table 7) that we had seen the year before; protection from defoliation appeared to persist for a second year. It is unfortunate that we had no population data from these small plots. We had chosen to study the large State blocks, believing that events there would be less influenced by redistribution of sprayed and unsprayed populations after treatment.

Similar studies continued in 1981[3]. Overwintering larvae were collected in April, 1982 in four State operational blocks that had been treated in 1981, and in four nearby untreated sites of similar character. Collections were made by pruning 25 balsam branches, 1 per tree, in each plot and forcing the larvae from hibernation. Larvae were counted as they emerged, and these were reared through to the pupal stage on artificial diet (Grisdale 1970). Plots had been treated with B.t. at 12 BIU/acre, and this was the first time that this dosage had been used operationally in Maine. No further collections were made on these plots because all were retreated with B.t. in 1982. Observations on the reared insects included development rates, survival rates, and pupal weights. Significantly more insects emerged from the untreated branch collections than from the treated branches (Table 8). There were no significant differences in rates of development or survival or in pupal weights.

[1]Dimond, J.B., D.G. Boucias, and C.J. Spies, 1981. Prolonged effects of *Bacillus thuringiensis* treatments on spruce budworm: field observations in Maine 1981. Office report. Entomology Department, University of Maine, Orono, 04469, 23 p. Report available from the author.

[2]A developmental index for a population containing 10% instar 2, 60% instar 3, and 30% instar 4 is calculated as (10 x 2) + (60 x 3) + 30 x 4)/100 = 3.2. A lower value of the d.i. indicates a younger age structure in the population.

[3]Dimond, J.B. 1983. Final report on a contract to continue studies of prolonged effects of B.t. applications on spruce budworm. Office report, Entomology Department, University of Maine, Orono, 04469, 12 p. Report available from author.

Table 1.--Numbers of spruce budworms collected in 1981 in operational spray blocks treated with B.t. the preceeding year and in unsprayed stands, mean and range (parentheses).

Block	Collection period - insects per 18 inch branch			
	Early larval	Late larval	Early pupal	Late pupal
Molunkus area sprayed	39(27-50)[a]	28(23-34)	15(11-18)	6(2-8)
Molunkus area unsprayed	30(24-37)[a]	30(25-40)	18(14-24)	6(4-10)
Caribou area sprayed	20(11-32)[b]	-- --	12 (9-15)	8(5-10)
Caribou area unsprayed	17(16-18)[b]	-- --	10 (9-11)	8(7-9)

[a]Mean and range of 4 replicates.
[b]Mean and range of 3 replicates.

Table 2.--Percentage of spruce budworms that were dead in collections or died during rearing (in parentheses).

Block	Collection period - % of insects			
	Early larval	Late larval	Early pupal	Late pupal
Molunkus area sprayed	10.0(16.8)	6.8(17.0)	3.2(11.8)	12.4(26.2)
Molunkus area unsprayed	9.9(15.1)	3.5(13.1)	3.1(11.3)	7.2(28.0)
Caribou area sprayed	18.3(15.7	-- --	8.2(22.1)	10.9(2.8)
Caribou area unsprayed	18.8(15.2)	-- --	10.6(22.5)	11.4(1.6)

Table 3.--Results of tissue analyses of dead larvae in collections and those dying during rearing.

Block	Numbers examined	Diagnosis of larvae, %				
		Bacteria	Virus	Microsporidia	Fungus	Unknown
Molunkus area sprayed	235	5	2	43	7	43
Molunkus area unsprayed	180	1	7	43	6	44
Caribou area sprayed	238	2	1	42	3	54
Caribou area unsprayed	168	3	1	49	8	39

Table 4.--Developmental indices of spruce budworm populations in blocks sprayed with B.t. the previous year and in unsprayed stands, mean and range (parentheses).

Block	Collection period			
	Early larval	Late larval	Early pupal	Late pupal
Molunkus area sprayed	3.4(2.9-3.9)	5.1(4.9-5.2)[a]	5.9(5.8-5.9)[b]	7.3(7.1-7.5)[b]
Molunkus area unsprayed	3.3(2.9-3.8)	5.3(5.1-5.4)	6.0(5.9-6.0)	7.6(7.5-7.7)
Caribou area sprayed	4.4(4.3-4.6)[b]	-- --	6.4(6.2-6.4)	7.0(6.9-7.0)
Caribou area unsprayed	3.9(3.8-3.9)	-- --	6.4(6.2-6.6)	7.0(6.9-7.0)

[a]Significant difference, $p < 0.10 > 0.05$
[b]Significant difference, $p < 0.05$

Table 5.--Weights of pupae collected in blocks sprayed the previous year with B.t. and in unsprayed stands, mean and range (parentheses).

Block	Females	Males
Molunkus area sprayed	28.1(27.0-30.3)[a]	14.2(13.8-14.7)
Molunkus area unsprayed	25.5(22.3-27.7)	14.4(13.9-14.8)
Caribou area sprayed	32.3(31.2-32.9)	16.4(16.1-16.8)
Caribou area unsprayed	31.5(30.1-33.6)	16.4(15.8-17.1)

[a]Each mean is derived from approximately 200 insects.

Table 6.--Percent defoliation of balsam fir on blocks treated in 1980 with B.t. and in unsprayed stands 1980 and 1981, mean and range (parentheses).

Block	1980	1981
Molunkus area sprayed	43(35-52)	69(55-81)
Molunkus area unsprayed	52(29-73)	71(63-81)
Caribou area sprayed	51(26-89)	79(62-89)
Caribou area unsprayed	86(79-94)	84(82-88)

Table 7.--Percent defoliation on small plots treated in 1980 with B.t. and in unsprayed plots, 1980 and 1981; means of five replicates.

Treatment	1980	1981
Dipel 1 gpa[d]	56 a[e]	27 a
Dipel 1/2 gpa	60 a	27 a
Thuricide 1/2 gpa	64 a, b	38 a, b
Dipel 1/4 gpa	65 a, b	25 a
Thuricide 1 gpa	77 b, c	46 b, c
Untreated	86 c	70 b, c

[d]All treatments at 8 BIU/acre but with different dilution rates.
[e]Means sharing the same letter are not significantly different, $p > 0.05$.

Table 8.--Observations made in 1982 in four operational spray blocks treated the previous year and in four comparable untreated stands, mean and range (parentheses).

Observation	Treated blocks	Untreated blocks
Numbers of larvae emerging from collected branches	175(95-282)[a]	378(274-494)
Days from emergence until pupation - males	21.3(16.8-23.0)	21.3(17.5-24.5)
- females	23.7(19.1-27.2)	23.9(20.6-26.3)
Percent survival of reared larvae	45 (28-56)	36 (31-41)
Weights of surviving pupae - males	42 (37-49)	44 (32-55)
- females	71 (55-87)	69 (49-93)

[a]Significant difference between treatments, $p > 0.05$.

Before drawing any conclusions from these results, one additional study should be reviewed. Reardon and Haissig (1983) studied 1-year post treatment densities of budworms and defoliation levels in a series of small plots in Wisconsin (Reardon et al. 1982). One year after treatment, populations and damage of the budworm were significantly lower in the treated plots than in controls. Populations declined on all plots in 1981, but the amount of decline was uniform among treatments. Development rates, as indicated by the distribution of larval instars in the collections, and pupal weights were not different. They attributed the reduced defoliation in 1981 as reflecting a persisting reduction in insect population, rather than any "carry over" influence of the B.t. treatments.

We have evidence in three cases (Morris 1977, Reardon and Haissig 1983, Table 8 of this report) that population reductions due to B.t. treatments persisted into a second year. This becomes the most credible explanation of reduced defoliation in B.t.-sprayed plots a year after treatment. We also have one case where population reductions did not persist into the next generation (Table 6). Data available on reduction in population survival of spruce budworms in the generation after treatment are largely negative (Tables 2-5, Table 8, Reardon and Haissig 1983) or show only very small differences. On the basis of results to date, there seems little evidence that the offspring of survivors of B.t. treatments are of less than normal vigor or have reduced potential for survival.

If the conclusions above are true, it follows that population reductions due to any agent, biological or chemical, may persist beyond the generation of treatment, and that prolonged benefits of B.t. treatments may not be a unique attribute of B.t. It may be significant that the three cases where population reductions persisted following B.t. treatments (Morris 1977, Reardon and Haissig 1983, Table 8), and two cases where only defoliation benefits have been reported (Dimond and Spies 1980, Table 7), have occurred in areas of declining population trend. Where there was no evidence of prolonged benefits of B.t. (Table 6), population were high or increasing (Table 1). There may be less redistribution of budworm populations, due to dispersal, and less re-invasion of sprayed plots, in declining populations.

There are delayed benefits of B.t. treatments in that survivors may be stunted, leading to lower survival of pupae and lower egg-production of moths. But, it now appears unlikely that any effect continues into the next generation.

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