Research Report #94
MARCH 1983

NORTH DAKOTA
RESEARCH REPORT

Day and Night Application of *Bacillus thuringiensis* for Cankerworm Control

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ACKNOWLEDGEMENTS

We thank Lee Hinds, manager of the Lincoln-Oakes Nursery, Bismarck for providing laboratory and storage facilities, and Bill Brandvik, North Dakota State Entomologist, for his assistance in the early planning of the project and shelterbelt selection. The project was made possible through the cooperation of farm operators in the Bismarck area who agreed to use of their shelterbelts in the project. Thanks are extended to the Bacteriology Department, North Dakota State University for processing foliage samples to assess viability of *Bacillus thuringiensis* spores and spray coverage. Tony Jasumback and Bob Ekblad of the Missoula Equipment Development Center provided valuable assistance in calibrating the spray aircraft, mixing spray formulations, and monitoring weather conditions during spray periods. We thank Lynn Whyte, formerly of Method Applications Group at Davis, California for spray deposit Assessment.

SUMMARY

A project to demonstrate effectiveness of *Bacillus thuringiensis* kurstaki (hereafter referred to as Bt) to control cankerworms in shelterbelts was conducted in 1978 and 1979 by North Dakota State University, the USDA Forest Service, Forest Pest Management, Missoula, Montana and the Rocky Mountain Forest and Range Experiment Station, Bottineau, North Dakota; and the North Dakota Forest Service.

In 1978, Bt was applied by fixed-wing aircraft using two formulations and two application timings; ½ lb. Bt in 1 gallon of water/acre shortly after dawn and at night, and ½ lb. Bt in 3 gallons of water/acre shortly after dawn.

Most spray was deposited when 3 gallons of water/acre was used. The highest cankerworm mortality and least defoliation and the best dispersal of viable Bt spores in tree canopies was also obtained with the use of 3 gal. of water/acre. Although results were highly variable, analysis showed that results on sprayed plots and untreated plots were truly different.

Results were most consistent among plots treated with 3 gallons/acre. We attribute this to better spray coverage of those shelterbelts because ounces of Bt deposited did not differ significantly among spray treatments.

Night spray results were no better than day spray results and night spraying offered few advantages over day spraying. Night spraying by aircraft was more hazardous than day spraying because of reduced pilot vision and location of several high-voltage power lines near shelterbelts in the demonstration area. Because the occurrence of young cankerworm larvae, suitable weather conditions, and adequate moonlight for enhancement with night-vision goggles must coincide, effective treatment time was limited at night. Survival of spores applied at night was better than those applied during the day.

Bacillus thuringiensis applied at the ½ lb/acre rate in 1978 provided protection for shelterbelt foliage in 1978 and 1979.

Operational treatment cost per ½-mile shelterbelt with the 3 gallon/acre Bt preparation should average between $20 and $30, depending on the number of belts that can be treated in one day. Based on the landowner's average investment of about $2,800/belt, and on the average effective crop protection value of about $2,800/belt, a cost of $20 to $30 per belt to prevent serious defoliation by cankerworms appears to be justified.

INTRODUCTION

In many years, severe defoliation of Siberian elm, *Ulmus pumila* L., by spring and fall cankerworms, *Paleacrita vernata* (Peck) and *Alsophila pometaria* (Harris) occurs in late May and early June in North Dakota.

A cooperative investigation among the USDA Forest Service, Forest Pest Management, Missoula, Montana and the Rocky Mountain Forest and Range Experiment Station, Bottineau, North Dakota; North Dakota State University and the North Dakota Forest Service to determine operational effectiveness of the bacterium *Bacillus thuringiensis* (hereinafter referred to as Bt) applied aerially day and night against cankerworm larvae was conducted in the vicinity of Bismarck, ND in May and June 1978. A followup evaluation of extended belt protection afforded by Bt was made in 1979. Bt is an environmentally safe agent for management of cankerworm populations. The purpose of the study was to demonstrate the effectiveness of aerially applied Bt for cankerworm control, determine the feasibility of night spraying to reduce wind-caused spray drift and evaluate costs of aerial Bt applications.

MATERIALS AND METHODS

Experimental Design

Each of four treatments was replicated six times in a completely randomized test.

Treatments were as follows:

- Untreated Check
- ½ lb. Bt/1 gal. water/acre, day application
- ½ lb. Bt/3 gal. water/acre, day application
- ½ lb. Bt/1 gal. water/acre, night application

Spray Formulations

Dipel TM[5] wettable powder was utilized as a source of Bt. Sprays contained 0.2 percent Rhodamine B Extra S water soluble dye for spray

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[5] Abbott Laboratories, North Chicago, Illinois, 60064: mention of the product does not imply recommendation, guarantee, or warranty of the product by the persons or agencies involved; it does not infer approval to the exclusion of other similar products.

deposit assessment. Day sprays contained ½ lb. of the sunscreen, Shade TM, per gal. to protect Bt spores from ultraviolet radiation.

Spray Application

Plots were treated within a 48-hour period when sufficient moonlight for night flying coincided with the presence of early instar cankerworms in the trees. Treatments were applied from a height of 10 ft. above the trees. Spray preparations were applied in 50 ft. swaths from a Cessna Ag Truck at a speed of 115-120 mph. The aircraft was equipped with a conventional hydraulic spray system which had 14 flat fan nozzles (T8008)[6] for 1 gal./acre (gpa) applications and 42 (T8008) nozzles for 3 gpa applications. Crews used semifore flags to signal the pilot whether or not a plot was to be sprayed. During nighttime applications, the pilot wore night viewing goggles (FY 907)[7] to magnify ambient light (primarily moonlight).

Day sprays were applied shortly after dawn on 5/27/78 and 5/28/78. Cloud cover prevented night applications on those days. One-gallon night sprays were delayed until shortly before dawn on 5/29/78 because the moon rose late and was partially obscured by clouds.

Sampling

Temperature, relative humidity and wind speed and direction in the plots were monitored before and during spray applications. Kromekote® cards were used to sample spray deposits. A card was placed beneath the crown periphery on each side of 10 sample trees in a belt. Twenty additional Kromekote® cards were placed at 10 ft. intervals in a line perpendicular to the belt and near its midpoint (10 cards on each side of the belt).

Cankerworm larval populations were sampled five times; the first time within 48 hrs. before treatment and subsequent samples at two, five, seven and nine days posttreatment. Two ½ meter twigs were cut from each open side of the crown of the 10 sample trees; one sample at eye level (5 ft.) and one at midcrown (20 ft.). The sample trees were located at 100 ft. intervals near the middle of each shelterbelt. The number of living larvae on each twig was recorded.

Defoliation Estimates

Larval feeding was essentially completed in the third week of June, and the plots were visited to estimate defoliation in a 1,000 foot midsection of each shelterbelt. Most larvae had pupated but an occasional mature larvae was observed.

Defoliation in the crown was viewed from each open side of each sample tree. It was rated according to the following index:

1 = less than 25%
2 = more than 25% but less than 50%
3 = more than 50% but less than 75%
4 = more than 75% but less than 100%
5 = complete

An average of 40 defoliation indices (four per sample tree) was recorded for each plot in late June of 1978 and 1979.

The test shelterbelts were revisited in late June 1979 after larval feeding was essentially completed to rate defoliation within approximately the same 1,000 foot midsection of each test belt as was used in 1978.

Dispersal and Survival of Bt

To assess dispersal and survival of Bt, leaf samples were cut from the midcrown and the lower crown (eye level) of both open sides of three trees in each treatment every day for seven days postspray. The samples were immediately placed in coolers and flown to Fargo for processing. The number of viable Bt spores on five 0.25 in.^{2} leaf pieces cut from each leaf sample were counted. Serial dilutions were prepared from each daily sample and spread plated on plate count agar in five replicates of petri plates. The plates were incubated 24 hours at room temperature.

Analysis

Larval data were subjected to Bartlett's Test of Homogeniety (Sokal and Rohlf, 1969) and found to be nonhomogeneous. The raw data were transformed to Log_{10} $(x + 1)$ to stabilize variance. Power of the analyses to detect statistically significant differences among treatments (Pearson and Hartley, 1951) was computed for each sample day.

The spray deposit cards were processed with a Quantimet Image Analyzer with a 44 mm lens which recorded spray drop stain sizes and stain size frequency and distribution. Mean spray deposit in gallons per acre and drops per cm^2 were computed with a modified U. S. Army program (ASCAS).

Mean defoliation indices for the plots were converted to numerical rank and treatment rank sums were analyzed nonparametrically to detect significant differences with the Kruskal-Wallis statistic (Sokal and Rohlf, 1969).

Simple regressions of plot mean defoliation index over (a) mean number of cankerworm larvae in pretreatment samples, and (b) mean number of surviving larvae at nine days posttreatment were computed. Multiple regression of defoliation index over pretreatment larval numbers and spray deposit was conducted. In some cases, the data appear to more

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[6] Spray Systems, Wheaton, Illinois, 60187.

[7] International Electro Optics, St. Louis, Missouri, 63110

closely fit curvilinear models. However, because of difficulties encountered in illustrating curvilinear models, linear models are presented to show that significant relationships exist.

Data of dispersal of Bt spores in crowns of sample trees was analyzed with a "t" test from SAS[8]. A simple regression of the survival of Bt spores over time was also computed with SAS.

RESULTS AND DISCUSSION

Cankerworm Infestation

The cankerworm infestation in the plots (belts) prior to application of treatments is summarized in Table 1. Average larvae per ½ meter twig ranged from 1.2 to 57.8. There was considerable variation in between. Uniformity of the infestation was fairly good at the upper end of the range. The standard deviation was 0.4703 larvae and the variability 10.5%. Larval counts in the lower and upper halves of the tree crowns did not differ significantly.

Table 1. Pre-treatment cankerworm infestation in Siberian elm shelterbelts utilized as test plots, Bismarck, ND. 1978.

Plot No.	Mean larvae per ½ mile twig[1]	Crown[2]
17	57.8 a	Lower half 19.5a
5	37.5 b	Upper half 20.4 a
10	35.3 b	
4	34.4 b	
29	33.6 b	
6	31.3 b	
18	30.3 b c	
16	27.9 b c d	
12	27.9 b c d	
1	25.8 b c d	
20	25.6 b c d	
7	25.0 b c d	
26	18.2 c d e	
14	17.9 c d e	
13	17.6 c d e	
19	16.8 d e	
3	16.5 d e	
27	14.2 e f	
21	13.6 e f	
9	7.9 f g	
28	7.8 f g	
8	5.4 g h	
16	1.5 h	
24	1.2 h	

[1]Means followed by the same letter do not differ significantly at 0 = .05 (5% probability of error)
[2]Average of all plots.

[8] Statistical Analysis Systems

Although changes in the cankerworm population from just prior to treatment to nine days posttreatment were not significant, the treatments might have been more effective if application had been delayed two or three days until the population had peaked. Because the larvae were present and feeding over an unusually long period in 1978 determining application and sample time was difficult.

Application

Each treated shelterbelt was sprayed with a single 50-ft. swath; the treated area totalled 3 acres per ½-mile belt. Application time per ½-mile plot at 115 mph was 16 seconds. Three or 9 gallons of formulation containing 1½ lbs. of Dipel were applied per ½-mile plot depending on the assigned treatment.

A Cessna Ag Truck spraying 9 gallons of formulation per plot is capable of treating 15 ½-mile belts per load, and 15 belts in the same or adjacent sections could easily be treated in ½ hour.

Spray Deposit

Spray deposited on Kromekote® cards placed at the dripline of sample trees was quite variable and averaged less than 20 percent of the amount applied (Table 2). However, each plot was sprayed with only a single swath, and light winds carried much of the spray downwind from some treated belts and deposited drops on the drift Kromekote® cards. Best spray coverage occurred on plots treated at a rate of 3 gallons of spray per acre (Table 2), and greatest percent control of larval populations occurred in those same plots (Table 3a, Fig. 1). Higher percent population reduction in the 3 gallon per acre plots is attributed to better spray coverage on those plots because the amount of active ingredient (a.i.) measured in ounces of Bt deposited per acre was not significantly different among treatments (Table 2).

Table 2. Summary of deposit of *Bacillus thuringiensis* sprays in Siberian elm shelterbelts, Bismarck, ND. 1978.

Treatment (Volume/acre and time of application)	Spray deposit parameters (means ± standard errors)			
	vmd[1]	drops/cm[2]	gal/acre	Ounces Bt/acre[2]
3 gallon day	215.1 ± 6.0	20.95 ± 44.32	0.45 ± 0.05	1.19 ± 0.13
1 gallon day	216.6 ± 4.5	6.53 ± 2.31	0.14 ± 0.05	1.15 ± 0.42
1 gallon night	234.2 ± 11.7	6.77 ± 2.17	0.20 ± 0.04	1.64 ± 0.30

[1]Spray drop volume medium diameter in microns.
[2](Spray deposit in gal. per acre/formulations applied in gal. per acre) x 8 oz.

Population Suppression

Larval population reduction at nine days postspray, the approximate life of most field-sampled Bt spores on foliage, was disappointingly low (Table

Table 3a. Means and standard errors (S.E.) of cankerworm larval numbers per half meter twig sample in Siberian elm shelterbelts treated with *Bacillus thuringiensis* sprays, Bismarck, ND. 1978.

Treatment (Volume/Acre and time of application	Days after spray application									
		0		2		7[1]		9		5
	X	S.E.	X	S.E.	X	S.E.	X	S.E.	X	S.E.
check	34.2	4.3	45.3	5.7	39.5	4.7	38.8	4.4	38.7	4.9
3 gallon day	17.5	2.7	12.2	1.6	6.7	0.9	6.2	0.9	6.2	1.0
1 gallon day	16.8	3.2	18.2	2.9	12.5	1.9	---	---	13.4	2.4
1 gallon night	20.0	2.9	18.4	2.7	15.1	2.0	---	---	11.1	1.6

[1]Only check plots and 3 gallon day plots were sampled at 7 days postspray.

3a). Analysis of postspray larval numbers and percent larval mortalities, however, showed statistically significant differences were high only on the five-day, seven-day, and nine-day postspray sample dates (Table 3b).

Table 3b. Percent chance of the experiment (experimental power) to detect a statistically significant difference (P = .05) between cankerworm plots treated with *Bacillus thuringiensis* and untreated check plots, Bismarck, ND. 1978.

Number of days postspray				
0	2	5	7	9
		PERCENT		
42	65	84	99	88

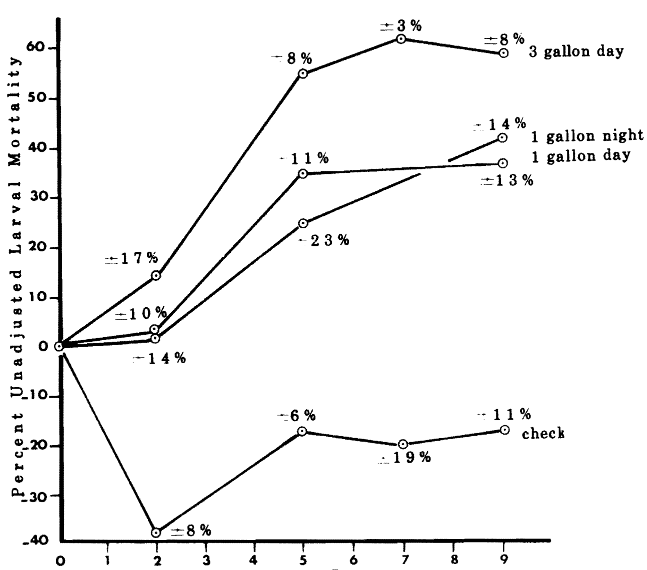

Figure 1. Postspray cankerworm mortality in Siberian elm shelterbelts, Bismarck, ND. 1978; mortality was highest when 3 gals. of *Bacillus thuringiensis* spray/acre was applied and leveled off at 7 days.

Although larval mortality appeared to level off at seven days postspray (Fig. 1), many surviving larvae appeared small and unhealthy in treated plots and feeding was substantially reduced. Larvae in untreated plots were large and healthy and continued feeding. Surviving larvae continued to feed after larval sampling was discontinued, and most defoliation occurred then.

Foliage Protection

Despite the unexpectedly low larval mortality at 9 days postspray, defoliation was significantly lower in treated plots than in check plots at the end of larval feeding (Table 4). This was not due entirely to spray treatment as the following discussion indicates.

Table 4. Nonparametric analysis of mean defoliation indices converted to numerical rank, Siberian elm shelterbelts treated with *Bacillus thuringiensis*, Bismarck, ND. 1978.

Treatment (Volume/acre and time of application)	Plot number	Defoliation index (avg. of 40 samples)	Rank Comparison: Checks and spray treatments	Rank Comparison: Spray treatments only
Check	5	3.70	21	---
	6	4.60	24	--
	12	3.95	22	--
	17	4.25	23	--
	18	3.50	20	--
	26	2.22	17	--
			Sum = 127	
3 gallon day	8	1.05	4	4
	9	1.12	6	6
	13	1.42	11	11
	19	1.55	13	13
	20	1.28	9	9
	29	1.40	10	10
			Sum = 53**	Sum = 53
1 gallon day	7	2.15	16	16
	10	2.50	19	18
	14	1.17	7	7
	21	1.17	8	8
	24	1.00	1	1
	28	1.02	2.5	2.5
			Sum = 53.5**	Sum = 52.5
1 gallon night	1	1.10	5	5
	3	1.67	15	14
	4	2.45	18	13
	15	1.02	2.5	2.5
	16	1.62	14	14
	27	1.50	15	15
			Sum = 66.5**	Sum = 65.5
Kruskal-Wallis Statistic			12.414**	0.65 n.s.

**Sums of treated plots significantly different than sums of the untreated check at P = .01 (1% probability of error)

The defoliation index was low in plots where most Bt was deposited (Fig. 2a) but also in plots where prespray larval numbers were low (Fig. 2b). The independent variables, prespray larval numbers and spray deposit, both influenced postspray larval numbers (Fig. 3) which, in turn, influenced the defoliation index (Fig. 4) more than the other variables.

Treated foliage showed defoliation characteristic of feeding by young larvae on early leaves, but many late developing leaves were untouched. Untreated leaves were often completely consumed except for midribs. Ground views of treated and untreated belts show noticeable differences in defoliation intensity (Fig. 5). Treatment in most cases provided adequate foliage protection, but substantial larval mortality in treated plots was delayed until after the last postspray samples were collected.

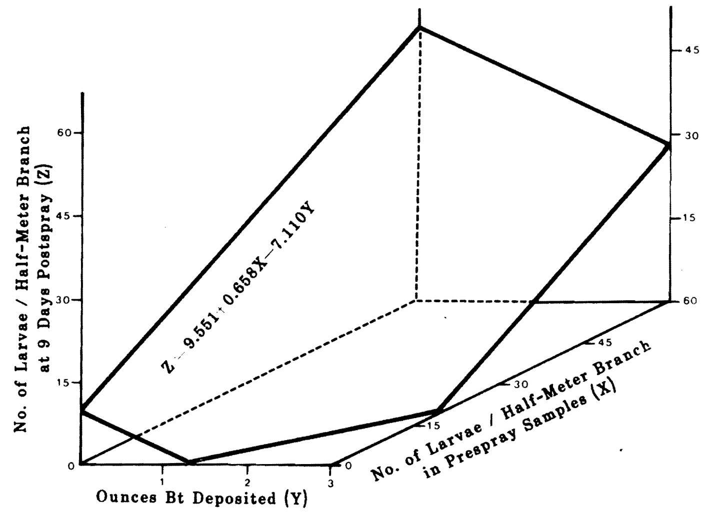

Figure 3. Relationship of postspray cankerworm larval numbers to prespray larval numbers and deposition of Bt spray in Siberian elm shelterbelts, Bismarck, ND. 1978; postspray larval numbers were low where prespray larval numbers were low and ounces of spray deposited were high.

Defoliation in 1979 was significantly less in shelterbelts treated in 1978 than in untreated belts, but there were no truly significant differences among the three spray treatments. However, the mean defoliation index was lowest and least variable among shelterbelts receiving the 3-gallon/acre treatment (Table 5).

Defoliation was generally lower in 1979 than in 1978 (Fig. 6). Why this is so is unknown, but the extremely cold winter of 1978-79 could have caused some mortality of overwintering fall cankerworm eggs. Spring cankerworms spend the winter in the soil and lay eggs on host trees in the spring and should be less susceptible to extremely cold winter temperatures. Cankerworm populations were not

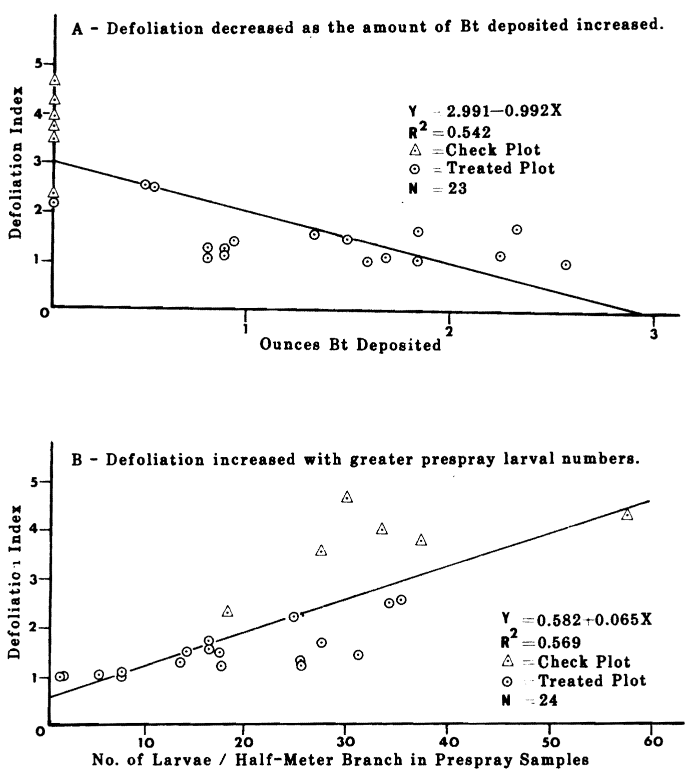

Figure 2. Cankerworm defoliation in Siberian elm shelterbelts treated with *Bacillus thuringiensis*, in Bismarck, N.D. 1978.

A—Defoliation decreased as the amount of Bt deposited increased.

B—Defoliation increased with greater prespray larval numbers.

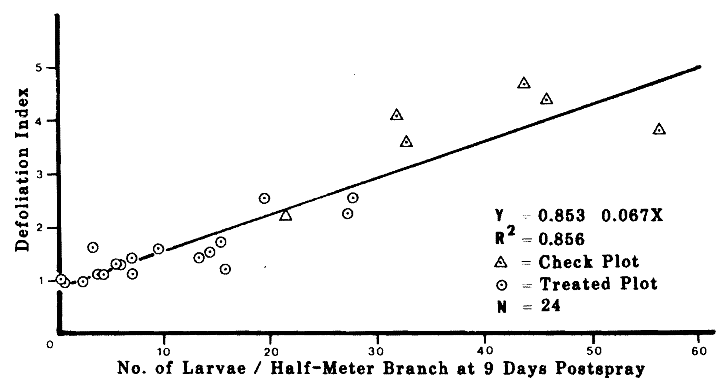

Figure 4. Relationship of cankerworm defoliation to postspray larval numbers in Siberian elm shelterbelts treated with *Bacillus thuringiensis*, Bismarck, ND. 1978; defoliation is very closely related to postspray larval numbers.

Figure 5. Defoliation by cankerworms in Siberian elm shelterbelts, Bismarck, ND. 1978; above — belt treated with the bacterium *Bacillus thuringiensis;* below — untreated belt.

monitored in 1979, so we do not know whether one or both cankerworm species were reduced in 1979 compared to 1978 populations.

Night Spray Results

The analysis did not detect significant mortality differences among spray treatments (Table 6). Lower mortality occurred in plots sprayed at a rate of 1 gallon per acre, but results in plots sprayed at night were no better than those sprayed during the day. The primary advantage of night spraying is reduced wind, but opportunities to spray successfully at night are limited because adequate moonlight, suitable spray weather, and cankerworm larval maturity appropriate for treatment must coincide. In addition, night spraying is more dangerous because pilot vision is reduced, and the pilot requires substantially more time to find spray plots because of reduced visibilty. Late evening applications when sunlight is reduced would probably provide the same advantages as night applications.

Table 5. Nonparametric analysis of mean defoliation indices converted to numerical rank, Siberian elm shelterbelts treated with *Bacillus thuringiensis*, Bismarck, ND. 1979.

Treatment (Volume/acre and time of application)	Plot number	Defoliation index (avg. of 40 samples)	Rank Comparison: Checks and spray treatments	Rank Comparison: Spray treatments only
Check	5	3.30	22	--
	6	3.55	24	--
	12	3.18	21	--
	17	3.10	20	--
	18	2.83	19	--
	26	3.40	23	--
			Sum = 129	
3 gallon day	8	1.70	14	14
	9	1.03	3.5	3.5
	13	1.08	5	15
	19	1.03	3.5	3.5
	20	1.23	9	9
	29	1.15	8	8
			Sum = 43**	Sum = 43
1 gallon day	7	1.75	15	15
	10	2.03	16	16
	14	2.18	17	17
	21	1.28	10	10
	24	1.00	1.5	1.5
	28	1.00	1.5	1.5
			Sum = 61**	Sum = 61
1 gallon night	1	1.10	6	6
	3	1.68	13	13
	4	1.65	12	12
	15	1.15	7	7
	16	1.30	11	11
	27	2.58	18	18
			Sum = 67**	Sum = 67

Kruskal-Wallis Statistic
14.00**
1.82 n.s.

**Sums of treated plots significantly different than sums of the untreated check at P = .01; the 3 gallon day treatment is significantly different from the 1 gallon treatments.

Table 6. F-values among cankerworm larval numbers in Siberian elm shelterbelts after treatment with *Bacillus thuringiensis*, Bismarck, ND. 1978.

Comparison	Number of days postspray: 0	2	5	7	9
Spray tmts. and checks	2.11 n.s.	4.46*	6.01	56.05**	6.77**
(degrees of freedom)	(3,20)	(3,20)	(3,20)	(1,10)	(3,20)
Spray tmts. only	0.27 n.s.	0.06 n.s.	0.48 n.s.	---	0.33 n.s.
(degrees of freedom)	(2,15)	(2,15)	(2,15)	---	(2,15)

n.s. = nonsignificantly different
* = significantly different at the 5 percent level.
** = significantly different at 1 percent level.

Economic Value of Shelterbelts

Bratkovich (1977) discusses two approaches to the economic valuation of shelterbelts but disregards recreation, wildlife and esthetic values. The first approach considers seedling, planting, past maintenance, tax and interest. It values a 15-year-old, 2-acre shelterbelt at $2,770. The income approach considers the cumulative crop protection value of a shelterbelt and discounts to the present at 6 percent the future protection value of a 40-year useful shelterbelt life. A ½-mile shelterbelt 26-35 feet high is valued at $2,825.

Either valuation is appropriate for the size and age shelterbelts that were treated near Bismarck, but are not additive. Each indicates that cankerworm sup-

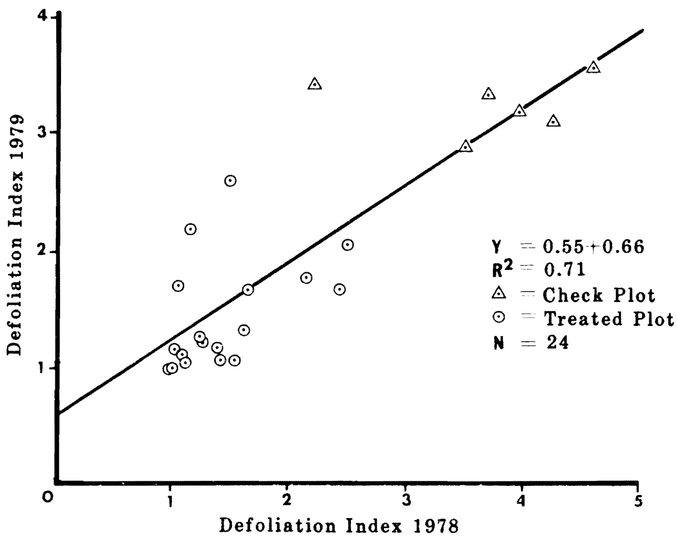

Figure 6. Defoliation in 1979 was closely related to but generally less than defoliation by cankerworms in 1978.

pression to prolong shelterbelt life and to maintain crop protection efficiency is justified economically.

Dispersal and Survival of Bt

Although only one tree from each treatment was used to assess dispersal and survival of Bt spores, the results are reported here because they concur with, and strengthen, results of similar assessments in recent years. Because approximately 1200 petri plates of agar were processed daily for seven days, more intensive sampling was impossible logistically.

Dispersal of Bt in trees is described in Table 7.

Table 7. Dispersal of *Bacillus thuringiensis* spores in the crown of Siberian elm trees, Bismarck, ND. 1978.

Treatment No. Application Method	Ave. spores[1] tree (× 10)[3]	Treatment comparisons Pair	Prob>t
Whole Crown Dispersal			
1. ½ lb. Dipel in 3 gals. water/ acre applied in daylight	724.4	1-2	.1587 n.s.
		1-3	.0539*
2. ½ lb. Dipel in 1 gal. water/ acre applied in daylight	143.2	2-3	.2058 n.s.
3. ½ lb. Dipel in 1 gal. water/ acre applied at night	37.7		
Partial Crown Dispersal			
1. 3 gals. day lower half of crown	133.7	1-2	.0458*
2. 3 gals. day upper half of crown	1,315.0	3-4	.6062 n.s.
3. 1 gal. day lower half of crown	214.7	5-6	.9429 n.s.
4. 1 gal. day upper half of crown	71.6		
5. 1 gal. night lower half of crown	48.8		
6. 1 gal. night upper half of crown	26.7		

[1]Average counts of viable *B. thuringiensis* spores from five 0.3167 cm^2 (0.25 in^2) foliage samples taken from the crown of Siberian elm trees immediately after treatment.
*Significantly different at P = .05
n.s. Nonsignificant

Better coverage in the entire tree crown was obtained when 3 gals. of water/acre was used to apply Bt during the day than when 1 gal. of water/acre was used for a night application. No significant difference in coverage between applications of Bt in 1 and 3 gallons during the day was detected. When coverage in the lower and upper halves of the crown was compared, it was much better in the upper crown when 3 gallons of water was applied. When 1 gallon of water was used during the day and at night, no significant difference in numbers of viable spores received by the lower and upper crown portions was detected.

Survival of Bt spores on Siberian elm foliage is summarized in Fig. 7. Again, dispersal was similar when 1 and 3 gals. water/acre were used to apply the bacterium during the day. Survival was also similar over seven days, and numbers of viable spores recovered from foliage declined at a similar rate over time. Coverage of foliage with spores was less when they were applied in 1 gal. of water/acre at night, but survival was greater between the third and seventh days. As in the past, counts of viable spores stabilized after one week. Variation in reduction of spore numbers on foliage due to variation in time was 92.4, 95.5, and 90.2 percent for 3 gals. day and 1 gal. day, and 1 gal. night, respectively.

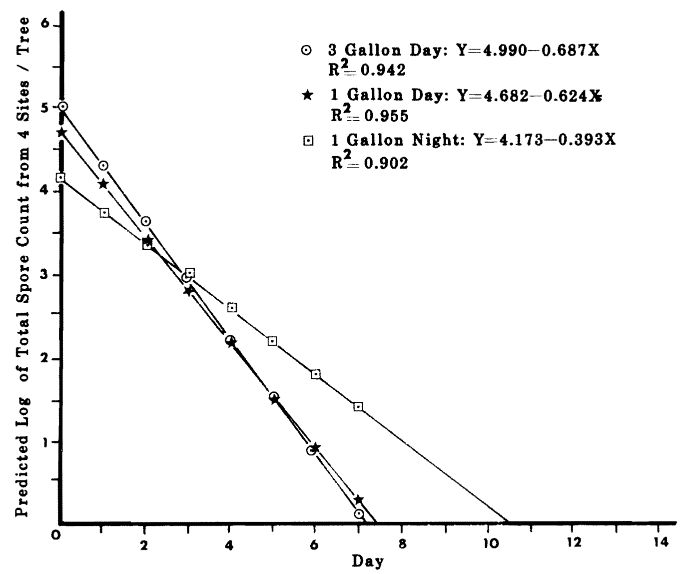

Figure 7. Relationships of viable *Bacillus thuringiensis* spores to time following aerial application of the bacterium to single row Siberian elm shelterbelts, Bismarck, ND. 1978.

CONCLUSIONS

Bt applied aerially at a rate of ½ lb. in 3 gallons of water per acre provided suitable and consistent protection of Siberian elm shelterbelts against defoliation by cankerworm larvae. One gallon of formulation per acre provided less consistent results. Night spraying is more hazardous and requires more time than day spraying, and spray opportunities are limited at night. Therefore, we conclude that night spraying offers few advantages over day or late evening spraying. In order to better assess treatment effects on larval populations, postspray larval sampling should have been continued beyond nine days postspray until substantial numbers of larvae pupated.

Dispersal of Bt on the crowns of the trees was better when the spores were applied during the day than at night. Dispersal during the day was similar when the spores were applied in 1 and 3 gals. of water per acre. Survival of Bt spores from three to seven days postspray was best when they were applied to the trees at night. Similar results could occur with application during late evening when solar radiation is reduced.

Defoliation by cankerworms in 1979 was significantly less in shelterbelts treated in 1978 than in belts not treated in 1978. Most shelterbelts treated in 1978 had produced enough foliage by late June 1979 so that adjacent crops were protected from wind. Aerially applied Bt at a rate of ½ lb./acre provided shelterbelt foliage protection for 2 seasons.

The current price of Dipel is about $8.45 per pound, and Shade costs approximately $1.20 per pound. One and one-half pounds of Dipel and 1½ pounds of Shade per belt would cost $14.50. Therefore, the cost of treated a ½-mile shelterbelt with fixed-wing aircraft should cost approximately $20 to $30 depending on the number of belts sprayed per day. The cost and income approaches to valuating shelterbelts each show that shelterbelts of the age, length, and height that we treated have an approximate present-day value of about $2,800 per belt. The landowner must decide whether shelterbelt foliage protection, and subsequent crop protection from the wind on adjacent acreage justifies his expense for shelterbelt treatment.

Key Words

Bacillus thuringiensis, cankerworms, pesticide application, microbial control, biological control.

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