SOIL INCORPORATION OF CARBOFURAN FOR PROTECTING BLACK SPRUCE SEED TREES FROM INSECTS

W.H. FOGAL and S.M. LOPUSHANSKI

Petawawa National Forestry Institute, Agriculture Canada, Chalk River, Ontario, K0J 1J0

D.A. MACLEOD

Systems and Informatics Directorate, Environment Canada, Hull, Quebec, K1A 1C7

D.A. WINSTON

Canadian Forestry Service, Agriculture Canada, Pacific Forestry Centre, Victoria, B.C. V8Z 1M5

Abstract

Proc. ent. Soc. Ont. 119: 69-78

Carbofuran was applied to black spruce, *Picea mariana* (Mill.) B.S.P., seed trees by soil incorporation of granular and liquid formulations at rates of 5 or 10 g of active ingredient per cm diameter at breast height (AI/cm DBH). Numbers of spruce budworm, *Choristoneura fumiferana* (Clem), and spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munro, degree of defoliation, cone production, percentage of cones damaged by seed and cone insects, numbers of sound seeds per cone slice, numbers of female buds per branch from the cone-bearing portion of the tree, and phytotoxicity were assessed in the year of treatment and one year later. The liquid formulation effectively controlled budworm in the year of treatment and the year after; granular carbofuran was not effective in the year of treatment, but it was effective the following year. Treatments were effective at upper, middle, and lower crown positions. They had no detectable influence on cone yields or cone damage by insects but cone seed counts were increased by the liquid formulation at 5 g AI/cm DBH in the year after treatment. Treatments did not influence initiation of female cone buds. Phytotoxic stress was evident at the 10 g AI/cm DBH liquid formulation in the second year of assessment but not at the 5 g AI/cm DBH.

Introduction

Black spruce, *Picea mariana* (Mill) BSP (Coniferae: Pinaceae), is widely used in reforestation programs in Canada. Seed collection areas have been set aside in some provinces to ensure that source-identified seed is available for reforestation, and seed production areas are being established to maximize production of high-quality seed through intensive stand management (Lamontagne 1979). Seed orchards for production of genetically improved seed are also being developed (Morgenstern and Carlson 1979). In spite of these developments, current requirements for seed cannot always be met because of poor seed yields caused by natural periodicity of cone crops and destruction by insects (McPherson *et al.* 1982). A survey of black spruce seed stands in Ontario in 1980 revealed that insects responsible for losses of cones and seeds include spruce budworm *Choristoneura fumiferana* Clem. (Lepidoptera: Tortricidae), spruce coneworm *Dioryctria reniculelloides* Mutuura and Munroe (Lepidoptera: Pyralidae), cone maggot *Lasiomma anthracina* Czerny, (Diptera: Anthomyiidae), and a cone midge *Dasineura rachiphaga* Tripp. (Diptera: Cecidomyiidae) (Sterner and Davidson 1981).

In spite of the known destructiveness of cone and seed-feeding insects on spruces (Tripp and Hedlin 1956) only one insecticide, dimethoate (Cygon®), is registered for use as a foliar spray (Fogal and Lopushanski 1985); others are needed. Carbofuran (Furadan 10G®) is registered and used by means of soil incorporation for control of cone and seed insects in southern pine seed orchards (DeBarr 1978) and has recently been registered for use in northern pine seed orchards (Rush and Overton 1987) in the United States. A liquid formulation appeared to be more effective than a granular formulation for control of cone-damaging insects in a seed orchard of red pine *Pinus resinosa* Ait. (Coniferae: Pinaceae) (Rush and Overton 1987) and irrigation improved the efficacy of granular carbofuran in a seed orchard of loblolly pine *P. taeda* L. (Coniferae: Pinaceae) (Hertel and Barber 1978).

Carbofuran has been tested for control of a variety of insect pests of coniferous trees (Cerezke and Holmes 1986) but there is little information to support its use for control of cone- and seed-feeding insects in spruce orchards. There is evidence that it does reduce insect damage to foliage (Fogal *et* *al.* 1981) and to cones (Cerezke and Holmes 1986) of white spruce seed trees; however, phytotoxic effects were noted in both studies. In this report we describe results of an experiment on black spruce trees in a seed production area that had been heavily-defoliated by spruce budworm. The experiment was conducted to compare granular and liquid formulations of carbofuran for protecting trees from defoliating and cone- and seed-damaging insects, for possible effects on cone and seed yields, and for physiological responses including production of seed-cone buds and needle browning as measures of possible phytotoxic stress. We also wanted to know if the insecticide is equally effective at upper, middle, and lower crown positions for control of defoliation by budworm and if it persists in a toxic form in tree tissues one year after treatment.

Materials and Methods

1. Study Site

The experiment was conducted in a black spruce seed production plantation located at the Bonner Tree Improvement Centre of the Ontario Ministry of Natural Resources, Kapuskasing, Ontario (49° 21′N, 82°10′W). The plantation was on a flat 0.4-ha site of acidic (pH 5.9-6.2 in H_2O slurry and 4.9-5.3 in 0.1N KCl slurry) clay loam. It was surrounded by windbreaks of Scots pine *Pinus sylvestris* L. (Coniferae: Pinaceae) to the east and west, and natural mixed-wood stands to the north. Trees were planted at a spacing of 1.8 x 1.8 m in 1951 and thinned to 1.8 x 3.7 m in 1978 by removing every other row. In 1980, their mean diameter and standard error at breast height (DBH) was 9.7 ± 0.3 cm. Eighteen treatment plots were established in the plantation. Each plot contained five trees in a row (1.8 m spacing), with plot perimeters extending 2.4 m at the sides and ends of the rows. Plot edges were separated by at least 2.6 m to avoid the effect of one treatment on another. Rainfall records were obtained from Agriculture Canada, Research Branch, Experimental Farm, Kapuskasing, Ontario.

2. Treatments

Six treatments included the following combinations of formulation and rate of application: liquid or granular carbofuran at rates of 0 g (controls), 5 g, or 10 g AI/cm DBH. Three replicates of each treatment were assigned to plots in a completely randomized design on May 14, 1980, prior to budbreak.

The granular formulation of carbofuran (Furadan 10 G®: 10 per cent active ingredient) was applied by three passes with a hoe-drill (two furrows 60-cm apart) (Fogal and Lopushanski 1988) on each side of the row of trees. One pass covered the outer portion of the plot with the outermost furrow 10 to 20 cm from the plot edge; a second pass was made near the row of trees with the innermost furrow 40 to 50 cm from the row of trees. The third pass overlapped the first, so that 5 furrows from the outer edge of the plot were 30 cm apart and the 2 inner furrows were 60 cm apart. Granule delivery was adjusted to ensure that all of the active ingredient required for final rates of 5 g or 10 g AI/cm DBH per tree was applied in each plot. Chisels on the hoe-drill were allowed to penetrate 6 to 8 cm into the soil and any furrows that remained open following a pass were closed with a hand rake. Control plots receiving no insecticide were treated with an empty hoe-drill.

The liquid formulation of carbofuran (Furadan 4.8 F®: 49 per cent active ingredient was applied by means of a boom sprayer (1.2-m boom with 4 spray nozzles) (Fogal and Lopushanski 1988). The flowable product was made up to a volume of 50 L with water to provide final rates of 5 g or 10 g AI/cm DBH per tree in each plot. The 50 L volume of insecticide mixture was applied by making three passes on each side of the row of five trees within a plot. One pass covered the outside edge of the plot with the outer nozzle approximately 20 cm from the outside edge of the plot; a second pass was made with the inside nozzle as close as possible to the row of trees; the third pass equally overlapped the first and second. Controls included three undisturbed plots.

3. Response variables

The response of budworms and coneworms to treatments was assessed by taking a 46-cm branch sample from the lower, middle and upper crown of each of the five trees in each plot by means of a pruning pole equipped with a collecting basket. Samples were taken on 29 June, 1980, and 9 July, 1981. Budworm and coneworm larvae and pupae were counted. Defoliation of current-year needles was estimated subjectively by ranking each branch tip into one of the following defoliation classes: 0, 5, 15, 25 ... 85, 95, or 100% defoliation. In 1980, most of the new flush of foliage had been killed by a late spring frost, so budworm defoliation on each sample was determined by subtracting the per cent defoliation definitely attributed to freezing from the total caused by budworm and frost.

All cones from each tree were counted and collected on 20 August, 1980, and 18 August, 1981 to assess cone yields. Subsamples of 20 cones, or all cones collected if less than 20, were assessed for insect damage (Tripp and Hedlin 1956). Budworm-damaged cones were curled and distorted; cones damaged by coneworm had excavations and were filled with frass and silk. After slicing each cone in half longitudinally, damage by internal feeders was identified and assessed as follows: spruce seed moth *Cydia youngana* (Kearfott) (Lepidoptera: Olethreutidae) was identified by the presence of seeds filled with fine granular frass and the presence of one or more larvae in a cone-axis gallery; spruce cone maggot was characterized by the presence of reddish-brown resin-filled feeding tunnels around the cone axis; cone-axis midge was identified by the presence of a gallery in the cone axis where one or more larvae overwinter in silken cocoons. The number of sound seeds on the cut face of one slice was then counted to assess seed yield.

The physiological response of trees to treatments was assessed by counting the number of seed-cone buds on a branch from the third whorl below the leader and by rating each tree for possible phytotoxic stress. Stress was subjectively rated by degree of needle browning as follows: 1, no browning; 2, 1-25 per cent; 3, 26-50 per cent; 4, 51-75 per cent; 5, 76-99 per cent; 6, 100 per cent. Phytotoxicity ratings and branch collections were made on 5 November, 1980, and 3 November, 1981.

4. Statistical analyses

To equalize variances, the numbers of budworms, coneworms, cones, seeds, and female flower buds were transformed to $y = \log_e (x + 1)$; per cent defoliation and per cent cones damaged by insects were transformed to $y = \text{arc sine} \sqrt{x}$; phytotoxicity ratings were not transformed. Separate analyses of variance were run for the results form 1980 and 1981. Preliminary analysis revealed significant plot-to-plot variation for all variables and, as a result, all analyses were done on a plot basis using mean values per plot. A second preliminary analysis revealed no significant difference in plot-to-plot variation between cultivated and sprayed plots, so the two application methods were combined in the same analysis of variance. For each year's data, the six combinations of formulation and rate of application were compared as if they were six independent treatments. Where data were taken from branches sampled at three crown positions (budworm counts, coneworm counts, and per cent defoliation), a randomized split-plot analysis of variance was applied to test for effect of treatment, effect of branch position, and treatment – position interaction. A simple one-way analysis of variance was applied to all other data. When F-tests indicated significant differences ($P < 0.05$) among treatments, means were then compared using Duncan's multiple range test (Steel and Torrie 1960). Data are presented as plot means with standard errors.

Results

1. Numbers of budworm, coneworm and defoliation in relation to treatments and crown position.

Budworm densities were lower in 1981 than 1980, corresponding to a widespread decrease of budworm populations throughout northeastern Ontario and northwestern Quebec (Sterner and Davidson 1982) (Table I). Analyses of variance revealed significant effects of treatment on per cent defoliation and numbers of budworm per branch for both assessment years, but treatments had no effect on numbers of coneworms per branch. Differences were also detected for numbers of budworms per branch at different crown positions for both assessment years, and per cent defoliation in 1980 but not in 1981, whereas there were no differences in numbers of coneworms per branch in either year. No interaction between treatments and crown position were evident except for numbers of budworms per branch in 1981.

In 1980, budworm numbers and defoliation decreased progressively from upper crown to lower crown in most treatments (Table I). In 1981, budworm numbers appeared to be greatest at the mid-crown position in control treatments; however, the pattern was not so obvious in the insecticide treatments, perhaps because the numbers of budworm were so low. That may have contributed to the

TABLE I. Effects of treatments (carbofuran applied as a granular or liquid formulation at rates of 0, 5, or 10 g AI/cm DBH) and crown position of branch sample on number of budworms and coneworms and per cent defoliation per branch. Means are presented with standard errors.

Treatments (Carbofuran formulation and application rate, g AI/cm DBH)	Crown position of branch	Assessment years and branch variables					
		1980			1981		
		Budworms per branch	Coneworms per branch	Per cent defoliation	Budworms per branch	Coneworms per branch	Per cent defoliation
Granules, 0	Upper	11.2 ± 1.3	0.8 ± 0.3	12.8 ± 2.2	1.1 ± 0.4	0.1 ± 0.1	7.5 ± 1.7
	Middle	8.0 ± 0.7	0.2 ± 0.1	10.7 ± 1.4	2.6 ± 0.6	0.1 ± 0.1	7.5 ± 1.6
	Bottom	8.0 ± 1.9	0.1 ± 0.1	8.9 ± 1.6	0.7 ± 0.2	0	3.3 ± 1.4
	Average	9.1 ± 0.7^{a}	0.4 ± 0.1	10.8 ± 1.3^{a}	1.4 ± 0.3^{a}	0	6.1 ± 1.1^{a}
Granules, 5	Upper	14.2 ± 2.5	0.3 ± 0.2	12.1 ± 1.3	0.4 ± 0.1	0	1.4 ± 0.5
	Middle	9.6 ± 2.8	0.3 ± 0.1	10.5 ± 1.9	0.7 ± 0.4	0	3.4 ± 1.6
	Bottom	6.8 ± 1.7	0.2 ± 0.1	9.5 ± 1.6	0.6 ± 0.2	0	0.7 ± 0.4
	Average	10.2 ± 0.9^{a}	0.2 ± 0.1	10.7 ± 0.9^{a}	0.6 ± 0.2^{b}	0	1.8 ± 0.6^{b}
Granules, 10	Upper	8.8 ± 1.9	0.2 ± 0.1	13.3 ± 2.3	0.2 ± 0.1	0	0.9 ± 0.4
	Middle	7.1 ± 1.4	0.3 ± 0.2	9.1 ± 1.2	0.3 ± 0.1	0	1.3 ± 0.6
	Bottom	5.0 ± 0.9	0.1 ± 0.1	6.9 ± 1.2	0	0	0.1 ± 0.1
	Average	7.0 ± 0.8^{a}	0.2 ± 0.1	9.8 ± 1.3^{ab}	0.2 ± 0.1^{b}	0	0.8 ± 0.3^{b}
Liquid, 0	Upper	13.9 ± 1.7	0.5 ± 0.1	16.3 ± 1.7	0.8 ± 0.2	0.2 ± 0.1	3.6 ± 0.7
	Middle	10.3 ± 1.3	0.3 ± 0.1	13.7 ± 3.0	3.0 ± 0.6	0	8.1 ± 2.6
	Bottom	7.0 ± 1.1	0.1 ± 0.1	8.3 ± 1.2	1.7 ± 0.6	0.1 ± 0.1	8.7 ± 2.1
	Average	10.4 ± 0.8^{a}	0.3 ± 0.1	12.8 ± 1.4^{a}	1.8 ± 0.3^{a}	0.1 ± 0.0	6.8 ± 1.4^{a}
Liquid, 5	Upper	4.3 ± 1.5	0.2 ± 0.2	7.8 ± 2.1	0.4 ± 0.2	0.1 ± 0.1	1.8 ± 0.6
	Middle	1.5 ± 0.7	0.1 ± 0.1	5.3 ± 1.1	0.5 ± 0.3	0	2.1 ± 0.8
	Bottom	0.8 ± 0.4	0.1 ± 0.1	6.8 ± 1.5	0.5 ± 0.2	0	0.9 ± 0.4
	Average	2.2 ± 0.6^{b}	0.1 ± 0.1	6.7 ± 1.2^{b}	0.5 ± 0.2^{b}	0	1.6 ± 0.3^{b}
Liquid, 10	Upper	0.8 ± 0.3	0.1 ± 0.1	4.3 ± 1.2	0.1 ± 0.1	0	0.7 ± 0.4
	Middle	0.4 ± 0.2	0.1 ± 0.1	4.3 ± 1.3	0.2 ± 0.1	0	0.9 ± 0.4
	Bottom	0.1 ± 0.1	0	2.3 ± 0.7	0	0.1 ± 0.1	1.2 ± 1.0
	Average	0.4 ± 0.2^{c}	0	3.7 ± 0.9^{c}	0.1 ± 0.1^{b}	0	1.0 ± 0.4^{b}
ANOVA F Values							
Treatment		10.17**	2.52	9.03**	12.17**	1.36	4.84*
Crown position		32.00**	4.44	11.82**	10.12**	1.86	2.87
Treatment X Crown position		1.97	1.08	1.16	2.87*	1.34	2.04

Significance of ANOVA F-values: * ($P<0.05$); ** ($P<0.01$).
Averages that bear the same letter are not significantly different ($P<0.05$) as judged by Duncan's multiple range test.

significant interaction effect.

In 1980, there were 9.1 budworms per branch on control plots for the granular formulation and 10.4 on control plots for the liquid formulation; levels of defoliation were 10.8 per cent and 12.8 per cent respectively. The figures for defoliation do not include shoots that may have been partially destroyed by feeding and then completely destroyed by heavy frost damage, so they may appear relatively low. The analysis of variance revealed that budworm numbers were significantly reduced and in spite of frost damage, defoliation was also significantly reduced on trees in plots that were treated with the liquid formulation of carbofuran. No control or protection was provided by the granular formulation.

Lack of control with granular carbofuran in 1980 may have been caused by low rainfall up to the time of assessment for budworm control. There was no rain for 16 days after treatment and the total rainfall up to 29 June, 1980, when budworm larvae were counted, was only 74 mm. Thus, although granules had been incorporated into the soil, there may have been insufficient soil moisture to dissolve them for diffusion through soil and uptake by roots.

2. Cones per tree, cone damage by insects, and cone seed counts.

Cone yields on the trees were low in 1980, ranging from an average of 2.6 to 13.9 over all treatments (Table II). No differences among treatments were evident. About half of the cones had been damaged by budworm and almost half by cone maggot; few cones were damaged by the seed moth or coneworm and none by the cone axis midge. Treatments had no effects on proportion of cones damaged by those insects. The number of sound seeds per 10 cone slices ranged from 5.6 to 19.0 and treatments caused neither an increase nor reduction in counts.

In 1981, there were a few more cone-bearing trees and more cones per tree but, again, treatments had no discernible effect on numbers of cones. The change (from 1980) in the proportion of cones damaged by insects is likely related to change in the size of the cone crop, the insects' population levels, and competitive advantage among the insects (Tripp and Hedlin 1956): reduced damage by budworm is likely related to the drop in the budworm population; coneworm damage may have increased because of reduced competition from budworm; reduced damage by cone maggot and seedmoth may have been related to the increase in size of the cone crop; and, increased levels of damage by the cone-axis midge could have resulted from lower competition from the cone maggot and seed moth. None of the treatments provided protection of cones against insect feeding damage. The number of sound seeds per 10 cone slices tended to be lower than counts from 1980, and there was a significant increase in seed counts with the liquid formulation of insecticide at the 5 g AI/cm DBH level, but not at the higher level.

3. Seed-cone buds and phytotoxicity.

Treatments with insecticides did not induce an increase in numbers of seed cone buds in either year (Table III). In an experiment on white spruce we did note an increase in numbers of seed cone buds on trees treated with carbofuran at a rate of 21.6 g AI/cm DBH (Fogal *et al.* 1981). Although phytotoxicity ratings were not influenced by the treatments in 1980, in 1981 the rating was significantly higher for trees treated with 10 g AI/cm DBH of the liquid formulation than it was for the other treatments. Although statistically significant, this rating of 2.5 was only marginally greater than ratings for other treatments (1.7 to 2.0) and considerably less than the maximum possible rating of 6.0. Nonetheless, there appears to have been a slight, detectable level of stress associated with the highest rate of the liquid formulation but not with the lower rate or with either rate of the granular formulation.

TABLE II. Effects of treatments (carbofuran applied as a granular or liquid formulation at rates of 0, 5, or 10 g AI/cm DBH) on number of cones per tree, per cent cones damaged by insects, and number of filled seeds per 10 cone slices. Means are presented with standard errors.

Year of assessment and variable	**Treatments (formulation and application rates, g AI/cm DBH)**						**ANOVA F-values**
	Granules			**Liquid**			
	0	**5**	**10**	**0**	**5**	**10**	
1980							
Number of plots with cone-bearing trees	3	3	3	2	2	2	
Total number of cone-bearing trees	4	5	6	4	3	4	
Average number of cones per tree[1]	5.2 ± 3.2	2.6 ± 1.6	4.7 ± 2.1	7.7 ± 5.0	3.5 ± 1.9	13.9 ± 7.7	0.07
Per cent cones damaged by:							
Budworm	52.5 ± 18.9	72.2 ± 19.1	48.3 ± 16.9	74.3 ± 11.6	56.9 ± 6.4	28.8 ± 15.3	0.15
Coneworm	0.0	2.2 ± 2.2	0.0	0.0	0.0	0.0	0.72
Seedmoth	5.0 ± 5.0	33.2 ± 13.9	8.3 ± 8.3	0.0	0.0	0.0	1.43
Cone maggot	30.0 ± 16.7	63.2 ± 15.3	36.8 ± 14.1	48.0 ± 14.7	32.7 ± 27.4	42.5 ± 22.2	0.46
Cone-axis midge	0.0	0.0	0.0	0.0	0.0	0.0	—
Number of seeds per 10 cone slices	20.3 ± 6.2	7.5 ± 1.9	6.9 ± 3.9	10.2 ± 5.7	13.4 ± 1.2	15.6 ± 3.7	0.69
1981							
Number of plots with cone-bearing trees	3	3	3	3	2	3	
Total number of cone-bearing trees	8	8	8	5	6	8	
Number of cones per tree[1]	42.6 ± 29.6	2.7 ± 1.1	4.6 ± 2.2	4.9 ± 4.1	31.1 ± 11.5	23.9 ± 16.3	0.98
Per cent cones damaged by:							
Budworm	32.9 ± 8.2	10.4 ± 6.3	15.4 ± 6.8	13.0 ± 8.9	5.0 ± 1.8	6.8 ± 4.1	0.48
Coneworm	10.3 ± 6.3	3.6 ± 2.6	10.0 ± 7.6	10.6 ± 6.8	2.5 ± 1.7	12.5 ± 12.5	0.70
Seedmoth	0.0	0.0	0.0	0.0	5.0 ± 5.0	0.0	1.94
Cone maggot	25.0 ± 13.5	4.5 ± 17.3	0.6 ± 0.6	37.2 ± 19.8	6.7 ± 4.0	35.3 ± 12.0	0.94
Cone-axis midge	1.3 ± 1.3	0.0	2.5 ± 1.8	0.0	1.7 ± 1.1	0.6 ± 0.6	0.91
Number of seeds per 10 cone slices	6.9 ± 2.2^{b}	3.5 ± 1.7^{b}	8.6 ± 2.3^{b}	8.7 ± 3.5^{b}	22.0 ± 4.8^{a}	12.0 ± 2.3^{ab}	3.32*

[1] Average includes cone-bearing plus non-cone-bearing trees.

Significance of ANOVA F-values: *($P<0.05$).

Averages that bear the same letter are not significantly different ($P<0.05$) as judged by Duncan's multiple range test.

TABLE III. Effects of treatments (carbofuran applied as a granular or liquid formulation at rates of 0, 5, or 10 g AI/cm DBH) on number of female buds per sample branch and on phytotoxicity rating. Means are presented with standard errors.

Year of assessment and variable	Treatments (formulation and application rates, g AI/cm DBH)						ANOVA F-values
	Granules			Liquid			
	0	5	10	0	5	10	
1980							
Female buds per sample branch	0.5 ± 0.2	0.9 ± 0.9	0.2 ± 0.2	0.1 ± 0.1	0.4 ± 0.3	0.3 ± 0.3	0.38
Phytotoxicity rating	1.7 ± 0.3	1.5 ± 0.3	1.6 ± 0.2	1.5 ± 0.3	1.4 ± 0.2	2.1 ± 0.6	0.55
1981							
Female buds per sample branch	2.1 ± 0.5	7.6 ± 3.6	4.5 ± 1.8	3.9 ± 1.5	3.4 ± 2.6	6.6 ± 4.0	0.47
Phytotoxity rating	1.7 ± 0.2^{b}	2.0 ± 0.1^{b}	1.9 ± 0.1^{b}	1.9 ± 0.1^{b}	1.9 ± 0.1^{b}	2.5 ± 0.3^{a}	3.28*

Significance of ANOVA F-values: *(P<0.05).
Averages that bear the same letter are not significantly different (P<0.05) as judged by Duncan's multiple range test.

Discussion

Adults and larvae of the spruce budworm are photopositive. Thus, there is a tendency for larvae to be found at the top of the crowns in a dense stand where lower levels of the crown are shaded. High temperature, absence of food, and direct incidence of strong sunlight cause late stage larvae to reduce their phototropic behavior and move down the tree. Other factors, such as strong winds and heavy rainshowers, also cause them to move to lower levels (Wellington 1948). In the year of treatment in this experiment, conditions were apparently favorable at the top of the trees because larger numbers of budworms and greater defoliation were found at the top of the crown. The plantation was relatively dense so that lower levels of the crown were shaded, wind was likely moderated by windbreaks, and there was little rainfall (46 cm) from June 1 to 30 when late-instar larvae were actively feeding. In addition, population densities were probably too low to cause forced downward movement because of starvation. When budworm counts were made, 52.8% of foliage had been lost to frost and an additional 11.8% lost to feeding by budworm, leaving an untouched excess of 35.4%. In 1981, budworm counts and defoliation were highest at mid-crown. The downward shift in distribution of larvae by comparison with 1980 may have been influenced by heavier rainfall in 1981 (100 mm from June 1 to 30) and exposure to intense sunlight as a result of heavy loss of foliage to frost in 1980.

Interaction of branch position with treatment for budworm counts and defoliation estimates was not evident, except for budworm counts in 1981 when overall densities were low. Absence of interaction for budworm counts suggests that insecticide treatments do not alter the insects' response to factors that modify intra-tree distribution; for defoliation, no interactions imply that treatments are equally effective at all levels of the tree crown, and that the toxicant is evenly distributed to all crown positions. Hence, the potential for preventing damage to seed cones, which are usually concentrated in the upper crown, and to pollen cones usually borne on the crown, should be similar. Another practical consequence of an absence of interaction is that valid comparisons among treatments can likely be made by sampling consistently at just one vertical position on the crown.

The insecticide was applied before budbreak, so control of budworm defoliation with the liquid formulation in the year of treatment may have resulted from rapid uptake and accumulation of carbofuran in the needles in large enough quantities to kill second-instar larvae following emergence from hibernacula. Emerging larvae are known to feed by mining previous-year needles. Toxicant absorbed by roots will likely be translocated in the transpiration stream and appear first in transpiring leaf tissue rather than in buds and reproductive structures (Kozlowski and Winget 1963). Thus, budworm larvae that feed on previous-year needles early in spring would more likely encounter toxicant than would later larvae feeding on developing shoots and strobili. Such a situation has been demonstrated for the European pine shoot moth *Rhyacionia buoliana* (Schiffermuller) (Lepidoptera:

Olethreutidae) feeding on mugho pine *P. mugho* Turra (Coniferae: Pinaceae); carbofuran accumulates in leaves but not buds and control of the shoot moth is most effective on needle-feeding stages as opposed to the bud-mining stage (Pree and Saunders 1972, 1973). In 1981, budworm counts were much lower and foliage was protected on trees receiving both formulations. Thus, the toxicant persisted in foliage of trees for at least one year. However, there was a lag in the uptake and distribution of toxicant when applied as a granular formulation.

No cone protection or increase in seed counts was evident in 1980, whereas treatment with the low rate (5 g AI/cm DBH) of the liquid formulation did provide an increase in seed counts in 1981. This suggests that toxicant was not incorporated into reproductive structures early enough in the year of treatment to effect any increase in number of seed, whereas sufficient levels were accumulated by 1981 to effect an increase in seed counts but not enough to prevent invasion and signs of feeding by insects. Failure to obtain significant increases at the higher level may be explained by some physiological aberration; these trees displayed small but significantly elevated levels of needle browning as a result of treatments. That is consistent with reports of reduced seed yields in white spruce trees treated with 4.5 to 8.9 g AI/cm DBH of granular carbofuran (Cerezke and Holmes 1986).

The occurrence of toxicant in trees one year after treatment may result from persistence in the soil, the trees, or both. Carbofuran can persist in soil. Harris (1969) found that carbofuran residues were biologically active in sandy-loam soils for up to 16 weeks and Read (1969) detected activity in acid soils for up to 150 days. Felsot *et al.* (1982) have shown that carbofuran dissipates at a slower rate in acid soils not previously treated with insecticides, than it does in fields with a history of carbofuran use. Carbofuran appears to be a moderately persistent insecticide in soil, particularly in acidic clay-loam soils (Read 1986) like those associated with trees in this experiment. However, storage and retranslocation in the tree may also be responsible for persistent toxicity because carbofuran is metabolized very slowly over a period of years in coniferous trees (Pree and Saunders 1973, 1974). Persistence and control of insects for more than a single year in trees is common with systemic insecticides. For example, the introduced pine sawfly *Diprion similis* Hartig (Hymenoptera: Diprionidae) was controlled for two years with a single injection of systemic insecticide into white pine *Pinus strobus* L. (Coniferae: Pinaceae) and large quantities of toxicant were found in newly-formed needles in the spring of the second year (Norris and Coppel 1961). Implants of the same toxicant into American elm *Ulmus americana* L. (Urticales: Ulmaceae), controlled elm bark beetles *Scolytus multistriatus* (Marsh) (Coleoptera: Scolytidae) for two seasons (Al-Azawi and Norris 1959), and injections of either oxydemetonmethyl or dicrotophos provided two years' protection of white spruce cones from seed and cone insects (Fogal and Lopushanski 1984).

At a rate of 5 g AI/cm DBH, the liquid formulation effectively controlled budworm and provided increased cone seed counts in our experiment on black spruce seed trees. That rate is similar to those used for control of cone and seed insects on other pinaceae, including slash pine *P. elliottii* Engelm and loblolly pine *P. taeda* L. (DeBarr 1978, Barber 1979), white pine *P. strobus* L. (DeBarr *et al.* 1982), red pine *P. resinosa* Ait. (Rush and Overton 1987), tamarack *Larix laricina* (Du Roi) K. Koch (Amirault and Brown 1986), and white spruce *P. glauca* (Moench) Voss (Cerezke and Holmes 1986). While the use of a liquid formulation improved efficacy over a granular formulation for controlling budworm and enhancing cone-seed counts, the latter effect did not occur until the year after treatment. In addition, cone-seed counts were not increased by the higher level of 10 g AI/cm DBH, suggesting a possible phytotoxic effect on seed development. The lag in effectiveness and potential phytotoxicity of carbofuran may limit its usefulness for control of cone-feeding insects in black spruce. However, other insecticides can be applied as a soil drench for control of insects on conifers and hardwoods (Drouin and Kusch 1977, Dutcher and Harrison 1984). Some, including dimethoate and oxydemetonmethyl, are effective in white spruce as foliar sprays or stem injections (Fogal and Lopushanski 1984, 1985) and might also be effective in black spruce. In addition, alternative application times in late summer or autumn might overcome the apparent lag in effectiveness of carbofuran. Clearly, further studies are requried to find minimum effective rates, effective application times for carbofuran and alternative insecticides and to assess the benefits of insecticide application relative to potential increases in seed yields.

Acknowledgments

We gratefully acknowledge the cooperation and assistance of personnel at the Bonner Tree Improvement Centre, Moonbeam, Ontario and the Ontario Ministry of Natural Resources, Kapuskasing District. We also thank Miss M. Autayo and Mrs. E. Trottier for collating and entering data into the computer and Mr. J. Christie who programmed the data for easy access and calculation. Mrs. F. Christie-Boyle and Mr. D. McKenna assisted with data analysis and the manuscript was improved by suggestions from Drs. B.L. Cadogan, G.T. Harvey, and O. Hendrickson. Carbofuran was supplied through the courtesy of Chemagro Limited, 1355 Aerowood Drive, Mississauga, Ontario, L4W 1C2.

References

Al-Azawi, A.F., and D.M. Norris. 1959. Experimental prevention of bark beetle transmission of *Ceratosystis ulmi* (Buis) Moreau with the systemic insecticide Chipman R-6199. Journal of Economic Entomology, 52: 902-904.

Amirault, P.A. and N.R. Brown. 1986. Cone and seed insects of Tamarack, *Larix laricina* (Du Roi) K. Koch, and attempts to control damage using chemical insecticides. Canadian Entomologist, 118: 589-596.

Barber, L.R. 1979. Evaluation of two carbofuran soil incorporating systems. Southeastern Area, State and Private Forestry, United States Department of Agriculture, Forest Service. Forest Insect and Disease Management Report Number 79-1-17, 14 pp.

Cerezke, H.F. and R.E. Holmes. 1986. Control studies with carbofuran on seed and cone insects of white spruce. Canadian Forestry Service, Information Report, NOR-X-280, 10 pp.

DeBarr, G.L. 1978. Southwide tests of carbofuran for seedbug control in pine seed orchards. United States Department of Agriculture Forest Service Research Paper, SE-185, 24 pp.

DeBarr, G.L., L.R. Barber, and A.H. Maxwell. 1982. Use of carbofuran for control of eastern white pine cone and seed insects. Forest Ecology and Management, 4: 1-18.

Drouin, J.A. and D.S. Kusch. 1978. Pesticide field trials on shade and shelterbelt trees in Alberta, 1977. Canadian Forestry Service Information Report, NOR-X-205, 16 pp.

Dutcher, J.D. and K. Harrison. 1984. Application of reduced rates of systemic insecticides for control of foliar pecan arthropods. Journal of Economic Entomology, 77: 1037-1040.

Felsot, A., J.G. Wilson, D.E. Kuhlman, and K.L. Steffey. 1982. Rapid dissipation of carbofuran as a limiting factor in corn rootworm (Coleoptera: Chrysomelidae) control in fields with histories of continuous carbofuran use. Journal of Economic Entomology, 7: 1098-1103.

Fogal, W.H., D.A. Winston, S.M. Lopushanski, D.A. MacLeod, and A.J. Willcocks. 1981. Soil application of carbofuran to control spruce budworm *Choristoneura fumiferana* (Lepidoptera: Tortricidae) in a managed white spruce seed production area. Canadian Entomologist, 113: 949-951.

Fogal, W.H., and S.M. Lopushanski. 1984. Stem injection of insecticides for control of white spruce seed and cone insects *In*, Yates, H.O. III (ed.). Proceedings of the International Union of Forest Research Organizations Cone and Seed Insects Working Party Conference, Athens, Georgia. July 31 – August 3, 1983. pp. 157-167.

Fogal, W.H., and S.M. Lopushanski. 1985. A test of foliar-applied insecticides to prevent damage to white spruce cones by insects. Forestry Chronicle, 61: 499-502.

Fogal, W.H., and S.M. Lopushanski. 1988. Prototype equipment for soil-incorporating granular and liquid formulations of insecticides in seed stands. Proceedings of the Entomological Society of Ontario, 119: 79-81.

Harris, C.R. 1969. Laboratory studies on the persistence of biological activity of some insecticides in soils. Journal of Economic Entomology, 62: 1437-1441.

Hertel, G.D., and L.R. Barber. 1978. Bird mortality and insect control when using Furadan on Catawba Timber Company's irrigated pine seed orchard, Catawba, S.C. Southeastern Area, State and Private Forestry, USDA Forest Service. Forest Insect and Disease Management Report No. 78-2-10, 14 pp.

Kozlowski, T.T. and C.H. Winget. 1963. Patterns of water movement in forest trees. Botanical Gazette, 124: 301-311.

Lamontagne, Y. 1979. Seed collection and production areas. *In*, Morgenstern, E.K. and Carlson, L.W. (eds.) Tree seed production and tree improvement in Canada – research and development needs 1977-1987. Environment Canada, Canadian Forestry Service, Information Report PS-X-74, pp. 64-72.

McPherson, J.A., E.K. Morgenstern, and B.S.P. Wang. 1982. Seed production in grafted clonal orchards at Longlac, Ontario. Forestry Chronicle, 58: 31-34.

Morgenstern, E.K., and L.W. Carlson. 1979. Tree seed production and tree improvement in Canada. Research and development needs 1977-1987. Environment Canada, Canadian Forestry Service, Petawawa Forest Experiment Station Information Report, PS-X-74. 98 pp. plus appendices.

Norris, D.M. and H.C. Coppel. 1961. Translocation and stability of Chipman R-6199 in *Pinus strobus* as related to its control of the introduced pine sawfly, *Diprion similis*. Journal of Economic Entomology, 54: 159-161.

Pree, D.J. and J.L. Saunders. 1972. Chemical control of the European Pine Shoot Moth. Journal of Economic Entomology, 65:1081-1085.

Pree, D.J. and J.L. Saunders. 1973. Bioactivity and translocation of carbofuran residues in Mugho pine. Environmental Entomology, 2: 262-267.

Pree, D.J., and J.L. Saunders. 1974. Metabolism of carbofuran in mugho pine. Agriculture and Food Chemistry, 22: 620-625.

Read, D.C. 1969. Persistence of some newer insecticides in mineral soils measured by bioassay. Journal of Economic Entomology, 62: 338-342.

Read, D.C. 1986. Accelerated microbial breakdown of carbofuran in soil from previously treated fields. Agriculture, Ecosystems and Environment 15: 51-61.

Rush. P.A., and R.P. Overton. 1987. Carbofuran trials in a red pine seed orchard. Northern Journal of Applied Forestry 4: 177-180.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York. 481 pp.

Sterner, T.E., and A.G. Davidson. 1981. Forest Insect and Disease Survey Conditions in Canada 1980. Forest Insect and Disease Survey, Can. For. Serv., Ottawa. 43 pp.

Sterner, T.E., and A.G. Davidson. 1982. Forest Insect and Disease Survey Conditions in Canada 1981. Forest Insect and Disease Survey, Can. For. Serv., Ottawa. 46 pp.

Tripp, H.A. and A.F. Hedlin. 1956. An ecological study and damage appraisal of white spruce cone insects. Forestry Chronicle, 32: 400-410.

Wellington, W.G. 1948. The light reactions of the spruce budworm, *Choristoneura fumiferana* Clemens (Lepidoptera, Tortricidae). Canadian Entomologist, 80: 56-82A.

(Received 2 July 1987; accepted 1 February 1988)