Reproductive development and insect damage on white and black spruce seed trees treated with ammonium nitrate and carbofuran[1]

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Granular ammonium nitrate and carbofuran were applied to soil beneath white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) B.S.P.) seed trees to stimulate reproductive development and protect them from defoliating and cone-feeding insects. Rates of carbofuran application were 0, 10.8, or 21.6 g/cm DBH for white spruce, and 0, 5, or 10 g/cm DBH for black spruce. Both species received 0, 224, or 448 kg N/ha of ammonium nitrate. Trees were assessed for defoliation by the eastern spruce budworm (*Choristoneura fumiferana* Clem.), cone insect damage, seed-cone bud production, cone production, seed yields, and needle senescence for 3 years in white spruce, and 2 years in black spruce. On white spruce, carbofuran reduced defoliation and number of spruce budworm at both application rates in the year of treatment and at the high rate in the second year; no protection was observed in the third year. Seed-cone bud production was stimulated by carbofuran for 3 years following treatment. Needle senescence was increased by carbofuran. Ammonium nitrate decreased needle senescence but had no effects on other assessment variables. On black spruce, carbofuran did not reduce spruce budworm numbers or protect cones in the year of application but, in the year after treatment, both foliage and cones were protected. Defoliation was reduced by the low rate of applied ammonium nitrate. Treatments did not influence the number of seed-cone buds or cones or amount of needle senescence in black spruce.

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Du nitrate d'ammonium et du carbofuran, sous forme de granulés, ont été appliqués sur le sol sous des épinettes blanches (*Picea glauca* (Moench) Voss) et des épinettes noires (*Picea mariana* (Mill.) B.S.P.) semenciers afin de stimuler le développement des organes reproducteurs et de les protéger contre les insectes défoliateurs et les ravageurs des cônes. Les doses de carbofuran appliquées étaient de 0, 10,8 ou 21,6 g/cm de dhp dans le cas de l'épinette blanche, et de 0,5 ou 10 g/cm de dhp dans le cas de l'épinette noire. Les deux espèces ont reçu 0, 224 ou 448 kg N/ha de nitrate d'ammonium. Pendant 3 ans, on a effectué des évaluations en ce qui concerne la défoliation causée par la tordeuse de l'épinette (*Choristoneura fumiferana* Clem.), les dégâts causés par les ravageurs des cônes, la production de bourgeons de cônes, la production de cônes, le rendement en graines et le vieillissement des aiguilles chez l'épinette blanche et 2 ans chez l'épinette noire. Chez l'épinette blanche, le carbofuran a réduit la défoliation et le nombre de tordeuses des bourgeons, à tous les deux taux d'application, pendant l'année du traitement, et à la dose la plus élevée, pendant la deuxième année, mais n'a procuré aucune protection pendant la troisième année. La production de bourgeons de cônes a été stimulée par le carbofuran pendant les 3 années suivant le traitement. Le carbofuran a accéléré le vieillissement des aiguilles. Le nitrate d'ammonium a diminué le vieillissement des aiguilles, mais n'avait aucun effet sur les autres variables évaluées. Chez l'épinette noire, le carbofuran n'a pas réduit le nombre de tordeuses des bourgeons de l'épinette ni protégé les cônes pendant l'année du traitement, en revanche, il a entraîné, l'année suivante, une meilleure protection du feuillage de même que des cônes. La plus faible dose de nitrate d'ammonium appliquée a réduit la défoliation. Les traitements n'ont pas influencé le nombre de bourgeons de cônes ni le degré de vieillisssement des aiguilles chez l'épinette noire.

Introduction

Seed orchards that produce genetically improved forest tree seed are the result of long-range programs of tree selection and progeny testing. They require large capital investments for establishment and subsequent management over their lifetime (Matyas and Rauter 1987; Ontario Ministry of Natural Resources 1987). To maximize their productivity, control of cone and seed insects and stimulation of cone and seed production is required (Konishi 1981; Morgenstern and Carlson 1979).

Owens and Blake (1985) and Werner (1975) reviewed the various cultural treatments used to stimulate sexual reproductive development in forest seed trees. Prominent among them is the application of inorganic fertilizers, particularly the nitrate form of nitrogen (Ebell 1972; Puritch 1977). Under the appropriate conditions, nitrate nitrogen can increase cone and seed production in conifer trees, but effects are not observed until at least 1 year after treatment (Owens and Blake 1985). Increased sexual reproductive development following ammonium nitrate applications has been reported for white spruce (*Picea glauca* (Moench) Voss) (Holst 1961) and black spruce (*Picea mariana* (Mill.) B.S.P.) (Smith 1986).

[1]The use of trade, firm, or corporation names in this report is for the information and convenience of the reader. It does not constitute endorsement or approval by Natural Resources Canada, the Petawawa National Forestry Institute, or the authors.

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Positive effects of ammonium nitrate on seed yields per cone were noted on black spruce, but no effects on cone production were detected because of damage by the spruce budworm (*Choristoneura fumiferana* Clem.) (Sheedy 1988). Long-term stimulation of cone production with urea applications was observed on black spruce (Leech and Kim 1974). Application of inorganic fertilizers can also influence insect population dynamics and increase or decrease damage sustained by trees (Popp et al. 1986; Shaw et al. 1978; Stark 1965).

Control of cone- and seed-feeding insects has a high priority in seed orchard management because of the potential for very large losses (Tripp and Hedlin 1956). Many destructive insects are recognized (Hedlin et al. 1980) and soil-applied carbofuran is one of several insecticides investigated for potential use as a control agent on black and white spruce seed trees (Fogal and Plowman 1989). On black spruce, budworm defoliation was reduced by soil-applied carbofuran in the year of treatment and in the year after treatment, indicating a persistent action of the insecticide; persistent insecticidal activity was also noted with a reduction of damage to cones in the year after application (Fogal et al. 1988). Soil-applied carbofuran effectively reduced budworm defoliation on white spruce seed trees in the treatment year and there was some indication of physiological changes to the trees as judged by precocious needle senescence and increases in seed-cone bud production (Fogal et al. 1981). Carbofuran affects the physiology and can stimulate sexual reproductive development of plants (Daynard et al. 1975; Pless et al. 1971). Promotion of sexual reproductive development plus residual insect control on spruce seed trees would enhance the usefulness of carbofuran as a tool for protecting current and subsequent crops.

It is likely that insecticide and fertilizer applications will be used increasingly for improving seed yields of trees in seed orchards. Because both treatments may have to be used simultaneously, the possible interactions between them should be investigated. In this report we evaluate the effects of applying granular formulations of carbofuran and ammonium nitrate and their interactions on defoliation by the spruce budworm, cone insect damage, seed-cone bud production, cone production, seed yields, and needle senescence. Effects were evaluated for 3 years on white spruce and for 2 years on black spruce seed trees.

Materials and methods

Study sites

Experiments were conducted at the Bonner Tree Improvement Centre operated by the Ontario Ministry of Natural Resources near Kapuskasing, Ont. (49°21′N, 82°10′W) in 1.5-ha white spruce and 0.5-ha black spruce seed-production areas. The trees were planted on abandoned farm land in 1962 at a 0.9-m spacing and subsequently thinned to 1.8 m within rows and 3.7 m between rows. The white spruce site is gently sloping with soil ranging from imperfectly drained loam to a clay loam and pH ranging from 5.8 to 6.2. A thin layer of hardpan occurs at approximately 17 cm below the surface throughout the plantation. The black spruce is on rolling terrain with soil ranging from well-drained sandy loam to clay; pH values ranged from 4.8 to 6.1. The sandy loam is porous through the B and C horizons, while the clay areas have a thick hardpan below the plow layer. The surface of both areas was sparsely covered with mosses, grasses, and other minor vegetation, and there was a thin layer of litter.

Treatments and experimental design

The experiments were initiated in 1979 on white spruce and in 1980 on black spruce when the mean DBH of trees was 8.8 ± 0.1 and 7.7 ± 1.0 cm, respectively. Combinations of granular carbofuran and ammonium nitrate were applied to the soil in 4.8 × 12.0 m treatment plots. Plots, located within rows, contained seven uniformly spaced trees. Treatments were applied to plots as a unit with each tree being treated as part of the plot; all measurements and assessments were made on the five central trees. Plots were separated by several trees within a row and by at least one intervening row of trees to reduce effects from neighbouring plots. White spruce plots were treated with 0, 10.8, and 21.6 g AI (active ingredient) / cm DBH of carbofuran (Furadan 10G; Chemagro Ltd, Mississauga, Ont.) while black spruce plots received 0, 5, or 10 g AI / cm DBH. Lower rates were applied to the black spruce plots in 1980 because the high rate applied to white spruce plots in 1979 was associated with a high level of stress as judged by needle senescence. For both species, each carbofuran treatment was combined with ammonium nitrate treatments of 0, 224, or 448 kg N/ha. Each combination of carbofuran and ammonium nitrate levels was replicated in three treatment plots in a randomized two-factor (carbofuran and ammonium nitrate) experimental design.

Carbofuran granules were applied with a fertilizer spreader and raked into the litter in the white spruce plots on 17 May 1979. In the black spruce plots, granules were applied 14 May 1980 by means of a mechanized hoe-drill to ensure deeper incorporation into mineral soil and thus reduce the risk of bird mortality following consumption of granules (Fogal et al. 1988). Ammonium nitrate was evenly broadcast by hand within white spruce plots 12–14 June 1979 and in black spruce plots 10–14 June 1980.

Response variables

Spruce budworm larvae and pupae were counted and percent defoliation of current-year needles was estimated on three 46-cm branch samples, one from each of the lower, middle, and upper crown and averaged for each tree. Branch samples were obtained with a pruning pole equipped with a collecting basket after most larvae had finished feeding on 28 and 29 June 1979, 29 June 1980, and 9 July 1981. Defoliation of current-year needles was estimated subjectively following the Fettes method (Montgomery et al. 1982) by ranking each branch tip into one of the following classes: 0, 5, 15, 25, ..., 85, 95, or 100% defoliation. In 1980 much of the new flush of foliage had been killed by late spring frosts, so estimates of budworm defoliation for that year were not considered.

All cones from each tree were collected on 20 August 1980 and 18 August 1981, a time when seed maturation was expected to be near completion, when most insect damage would have occurred, but prior to seed fall (Fogal and Larocque 1992; Winston and Haddon 1981). Random samples of 20 cones (or all cones if less than 20) were examined for insect damage and seed yields following procedures outlined by Fogal et al. (1988). Budworm-damaged cones were curled and distorted, while cones damaged by coneworm *Dioryctria reniculelloides* Mutuura and Munroe had been excavated by the larvae and were usually covered with frass and silk. Damage by insects feeding inside cones was noted after sectioning each cone in half longitudinally and looking for insects, feeding tunnels, resin exudations, and frass. The number of sound seeds on the cut face of one section was then counted to assess seed yield (Fogal and Alemdag 1989).

One branch for counting seed-cone buds was collected from the third whorl below the leader on each tree and trees were assessed for needle senescence on 12 and 13 October 1979, 5 November 1980, and 3 November 1981. Seed-cone buds were distinguished from pollen-cone buds and vegetative buds by external characteristics (Eis 1967; Ho 1991) and by examining dissected bud primordia under a microscope (Eis 1967; Owens and Molder 1977; Fraser 1962). Needle senescence was evaluated in the field by estimating the proportion of needles that displayed yellow to brown discolouration on several branches and placing each tree into one of the following classes: (1) no needles discoloured; (2) 1-25% discoloured; (3) 26-50%; (4) 51-75%; (5) 76-99%; (6) 100%.

To reduce heteroscedasticity and to normalize the data, numbers of budworms, seed-cone buds per branch, cones per tree, and seeds

TABLE 1. ANOVA *F*- and *P*-values for carbofuran and ammonium nitrate effects and their interactions for assessment variables examined in 1979–1981 on white spruce (*Picea glauca* (Moench) Voss) seed trees treated in 1979

Assessment variable	Year	Carbofuran (C)		NH_4NO_3 (N)		C × N	
		F	*P*	*F*	*P*	*F*	*P*
Budworms per branch	1979	138.21	0.000	0.01	0.994	0.78	0.554
	1980	43.26	0.000	1.67	0.215	1.04	0.412
	1981	4.19	0.032	0.79	0.471	1.49	0.246
Percent defoliation	1979	139.35	0.000	0.95	0.404	0.21	0.929
	1981	0.27	0.764	0.09	0.912	0.52	0.719
Seed-cone buds per branch	1979	16.81	0.000	2.34	0.100	1.24	0.297
	1980	3.83	0.024	2.11	0.125	0.89	0.470
	1981	12.24	0.000	1.78	0.172	1.85	0.123
Needle senescence	1979	16.17	0.000	5.41	0.015	1.80	0.174
	1980	11.01	0.001	1.77	0.199	0.78	0.555
	1981	2.59	0.103	0.33	0.726	1.61	0.214

per cone section were transformed to $y = \ln(x + 1)$, percent defoliation and percent cones damaged by insects were transformed to $y = \text{arc sine } (x^{1/2})$, and needle senescence ratings were not transformed. A two-factor analysis of variance (SAS Institute Inc. 1985) was run on plot means of each dependent variable for each assessment year to test carbofuran and ammonium nitrate effects and their interactions. When significant differences were observed with the ANOVA, treatment means were separated using the least significant difference method (SAS Institute Inc. 1985; Steel and Torrie 1960).

Weather records

Precipitation and temperature records were provided by the Agriculture Canada Research Station at Kapuskasing, Ont. for the 1979, 1980, and 1981 field seasons. These were compared with 30-year normals for the area (Treidl 1978).

Results

White spruce

Budworm numbers were influenced by carbofuran treatments in each of the 3 assessment years but they were not influenced by ammonium nitrate and there were no interactions between insecticide and fertilizer treatments (Table 1). Because there were no fertilizer effects and no interactions between the two independent variables, carbofuran effects were averaged over all ammonium nitrate treatments (Fig. 1). In 1979, budworm numbers averaged nearly five per branch on trees that did not receive carbofuran; numbers were reduced by both rates of carbofuran. In 1980, there was an average of 15 budworms per branch on trees that did not receive carbofuran. The high rate of carbofuran caused nearly complete reduction in numbers and, at the lower rate, nearly 50% reduction was observed. In 1981, very low numbers of budworm larvae were present on untreated or treated trees and no significant reductions with carbofuran were detectable. However, there was a small but significant increase on trees that had been treated with the low rate of carbofuran.

Percent defoliation was not assessed in 1980 because of frost damage. It was reduced by carbofuran treatments in 1979, but not in 1981. Ammonium nitrate treatments did not influence defoliation in the year of treatment or subsequent assessment years. No interactions between carbofuran and ammonium nitrate treatments were evident in any year (Table 1). Defoliation on trees that did not receive carbofuran treatments averaged approximately 76% in 1979 and both application rates of carbofuran provided nearly complete protection (Fig. 1). There was little defoliation in 1981 on untreated or treated trees, reflecting the drop in numbers of insects.

Carbofuran treatments had highly significant effects on the number of seed-cone buds per branch in all assessment years, but their numbers were not influenced by ammonium nitrate treatments nor were there any interactions between insecticide and fertilizer (Table 1). Seed-cone bud production was increased by both rates of carbofuran in 1979 and 1981 (Fig. 1). In 1980, when production of seed-cone buds was relatively low, only the high rate caused a significant increase.

In 1980, we expected reasonably good cone yields, particularly on carbofuran-treated trees, as judged by our seed-cone bud counts in the fall of 1979 (Eis and Inkster 1972). However, the expected crops did not materialize, probably because of frost damage. Most of the trees had no cones at harvest, but small numbers of cones were collected from some of the trees that had been treated with both carbofuran and ammonium nitrate. In 1981, a small number of cones was again collected from some of the trees that had received carbofuran plus ammonium nitrate. There were too few cones for analyses of insect damage or seed yields.

Needle senescence was influenced by carbofuran in 1979 and 1980 and by ammonium nitrate in 1979. There were no interaction effects in any year (Table 1). Both rates of carbofuran increased the senescence ratings (Fig. 1). Fertilizer applications reduced senescence in 1979.

Black spruce

The number of budworms per branch was influenced by carbofuran in 1981, the year after treatment, but not in the treatment year; ammonium nitrate had no effect in either year, nor were there any interactions between insecticide and fertilizer (Table 2). Examination of carbofuran effects across all fertilizer treatments revealed that there was an average of eight budworms per branch on the untreated trees in the year of treatment but the number fell to a little less than one in the year after treatment (Fig. 2). The high rate of insecticide significantly reduced the number per branch in 1981.

Percent defoliation is not considered in the year that treatments were applied because of frost damage. In the subsequent year, defoliation was significantly affected by

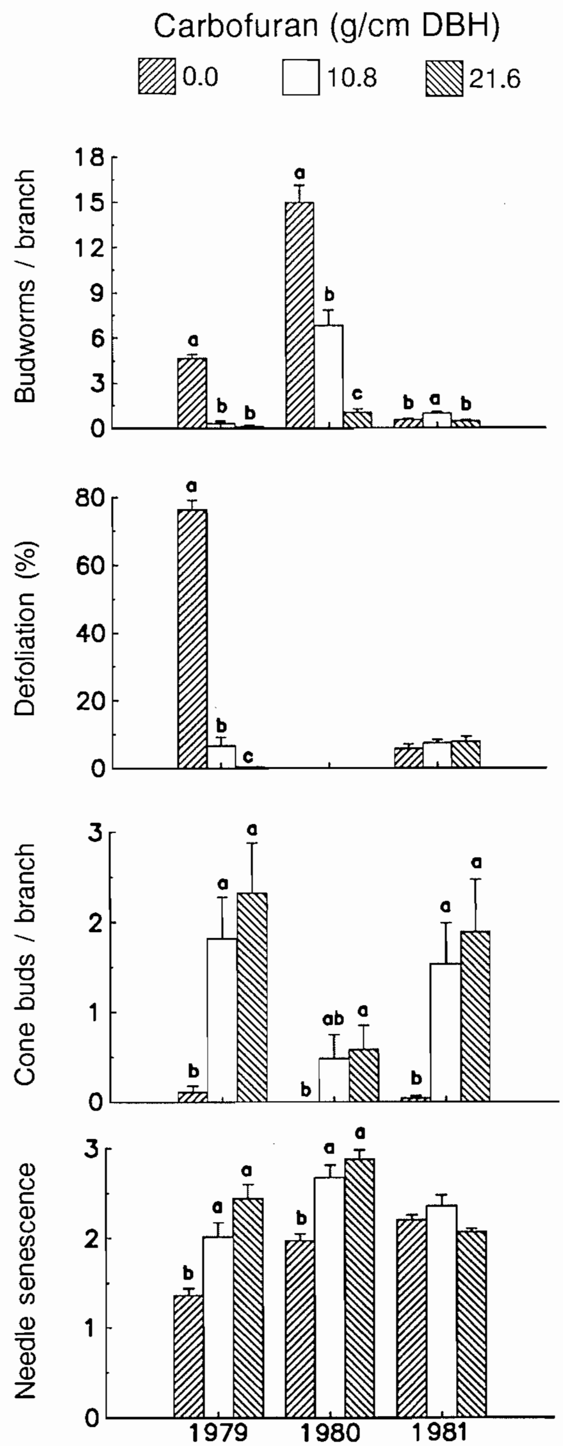

FIG. 1. Effects of carbofuran on number (mean ±1 SE) of budworms per branch, percent defoliation, number of seed-cone buds per branch, and needle senescence on white spruce (*Picea glauca* (Moench) Voss) seed trees for three seasons (1979–1981) following treatment in 1979. Bars bearing the same letter within years are not significantly different ($P = 0.05$).

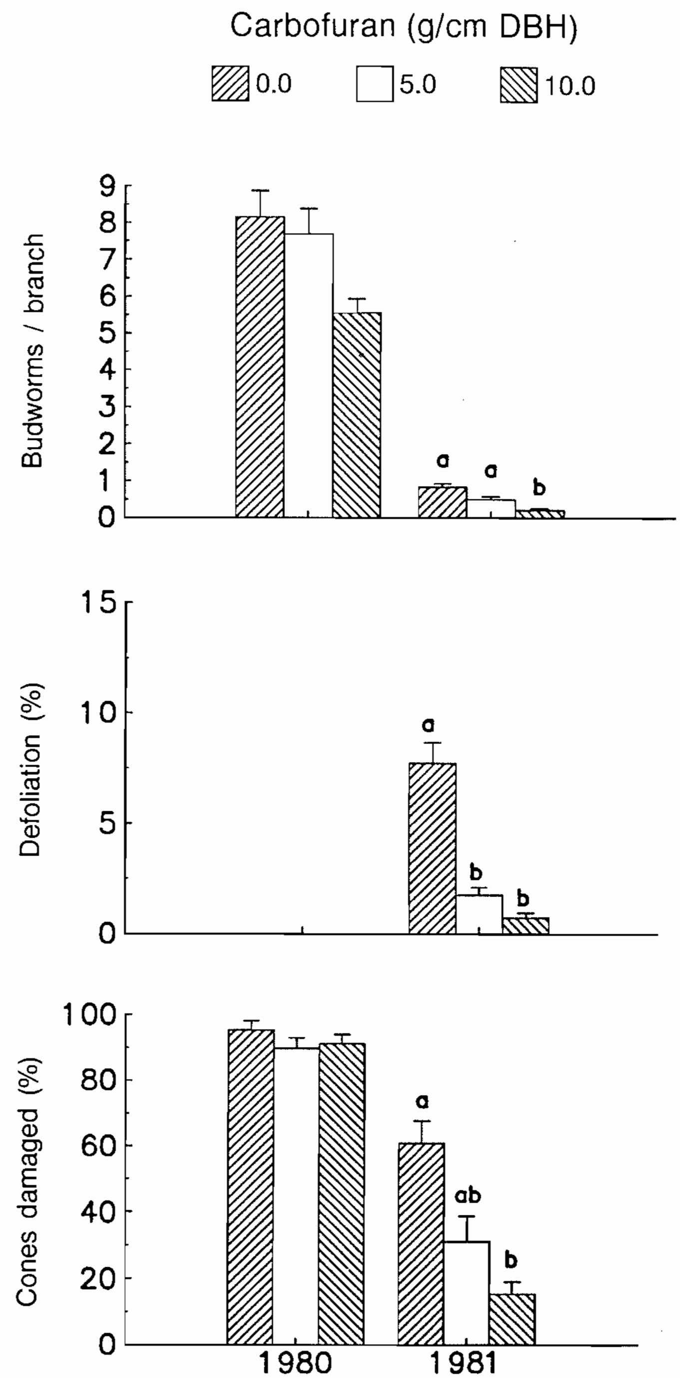

FIG. 2. Effects of carbofuran on number (mean ±1 SE) of budworms per branch, percent defoliation, and percent cones damaged on black spruce (*Picea mariana* (Mill) B.S.P.) seed trees for two seasons (1980–1981) following treatment in 1980. Bars bearing the same letter within years are not significantly different ($P = 0.05$).

carbofuran and ammonium nitrate applications but there was no interaction between them (Table 2). The average for percent defoliation of untreated trees was less than 10% reflecting the dramatic drop in the budworm population. Both rates of carbofuran effectively reduced defoliation (Fig. 2). In 1981, percent defoliation figures for the 0, 224, and 448 kg N/ha rates of ammonium nitrate averaged across all carbofuran treatments were, respectively, 4.1 ± 0.9, 1.6 ± 0.4, and 3.3 ± 0.7%. Thus, the significant effect of fertilizer detected in the ANOVA (Table 2) is seen as a reduction in feeding with 224 kg N/ha.

Treatments had no statistically significant influence on production of seed-cone buds (Table 2). Among all treatment

TABLE 2. ANOVA *F*- and *P*-values for carbofuran and ammonium nitrate effects and their interactions for assessment variables examined in 1979–1981 on black spruce (*Picea mariana* (Mill.) B.S.P.) seed trees treated in 1979

Assessment variable	Year	Carbofuran (C) *F*	Carbofuran (C) *P*	NH_4NO_3 (N) *F*	NH_4NO_3 (N) *P*	C × N *F*	C × N *P*
Budworms per branch	1980	2.93	0.092	0.55	0.592	0.68	0.617
	1981	7.33	0.008	0.36	0.703	0.39	0.815
Percent defoliation	1981	34.51	0.000	4.22	0.041	1.11	0.396
Seed-cone buds	1980	1.32	0.271	2.50	0.087	0.72	0.577
per branch	1981	0.21	0.809	1.38	0.256	0.56	0.694
Cones per tree	1980	0.07	0.934	0.44	0.651	1.44	0.281
	1981	1.22	0.330	1.18	0.341	1.81	0.192
Percent cone insect	1980	1.05	0.379	1.25	0.322	0.41	0.801
damage	1981	4.66	0.032	2.06	0.170	0.74	0.580
Seeds per 10 cone	1980	0.09	0.915	0.46	0.644	0.44	0.780
sections	1981	1.67	0.230	1.93	0.187	4.11	0.025
Needle senescence	1980	0.01	0.986	2.26	0.318	0.21	0.929
	1981	1.24	0.324	0.82	0.462	0.64	0.643

combinations, the average number per branch ranged up to two in 1980 and three in 1981.

The average number of cones per tree across all treatments was 39 ± 9 in 1980 and 28 ± 8 in 1981. According to the results of the ANOVA, the number of cones per tree was not influenced by fertilizer or carbofuran treatments (Table 2).

Carbofuran affected cone damage by insects in 1981 but not in 1980. Ammonium nitrate had no effects in either year. There were no interaction effects (Table 2). Examination of carbofuran effects, in 1981, reveals that the high carbofuran treatment reduced cone damage to 15% compared to 60% on trees that did not receive carbofuran (Fig. 2).

Seed counts and senescence were not influenced by treatments (Table 2).

Discussion

The decrease of the budworm population in both plantations in 1981 may have been related to late spring frosts in 1980. Much of the new foliage was killed, forcing larvae to feed on older foliage. With the exception of needle mining by early instar larvae, the budworm has a strong preference for current-year foliage of its host trees. Feeding on second-year or older foliage increases larval mortality (Heron 1964), retards development, and reduces fecundity (Blais 1953). Thus, it is likely that loss of current year foliage to frost in 1980 is responsible for some of the population reduction in 1981.

Soil application of carbofuran controlled the spruce budworm and provided foliar protection for the year of treatment and the year after, but did not persist into the 3rd year in white spruce. For black spruce, carbofuran was not effective in the year of treatment, but was effective the year after. The positive response of white spruce in the year of application could have been facilitated by the 27 mm of rainfall that occurred within 48 h following treatment and by abnormally high precipitation occurring during June (132 vs. a normal of 82 cm) and July (112 vs. 93 cm). Rainfall likely assisted in the release of carbofuran from granules, movement in the soil, and uptake by the trees. Conversely, the lack of response by black spruce in 1980 was associated with an absence of rainfall during a 2-week period following application and abnormally low total precipitation during June (46 vs. a normal of 82 cm) and July (78 vs. 93 cm). Moisture deficiency could have limited carbofuran distribution in the soil and uptake by the trees. This is supported by studies showing that a liquid formulation of carbofuran is more effective than a granular formulation during the year of application for black spruce (Fogal et al. 1988) and red pine (*Pinus resinosa* Ait.) (Rush et al. 1987).

Cone damage by insects was reduced by granular carbofuran treatments in the black spruce experiment but this protection provided no increase in seed yields. In a different experiment in a nearby black spruce plantation where liquid and granular carbofuran formulations were compared, seed counts per cone were increased 153% by the liquid formulation at 5 g AI / cm DBH in the year after treatment (Fogal et al. 1988). Thus, carbofuran does have the potential to increase seed yields. Several studies have indicated that insecticide treatment may not always result in an increase in seed yield in spite of the reduction in apparent insect damage to cones (Fogal and Plowman 1989). Other factors including poor pollination and climatic effects may reduce seed set to the point where little increase in seed yield is possible as a result of protection with insecticide.

Significant increases in numbers of seed-cone buds per branch occurred on white spruce with carbofuran treatments. Increases in seed-cone production might be expected when foliage is protected because reduction of seed-cone bud production is one of the earliest consequences of severe defoliation by spruce budworm (Woodwell 1962). It is also possible that carbofuran had a direct effect on initiation and development of reproductive buds. This is suggested because the number of seed-cone buds was higher on carbofuran-treated white spruce trees in 1981 when insect numbers and defoliation were very low and no effects on defoliation could be detected. In addition, white spruce did display increased needle senescence associated with carbofuran treatments in the year of treatment and the year after, suggesting a direct effect on tree physiology, but the effects did not persist into the 2nd year after treatment. Other research has shown that carbofuran can have direct effects on plant development; it stimulates growth (Apple 1971; Belanger et al. 1985; Daynard et al. 1975; Lee and Chapman 1977) and can also stimulate sexual reproductive development (Daynard et al. 1975;

Pless et al. 1971). Other carbamate compounds with high plant sex-promoting activity are known (Yanosaka et al. 1989). Loblolly pine (*Pinus taeda* L. growth is inhibited by carbofuran treatments (DeBarr and Marx 1984) and treatments that reduce growth of conifer trees tend to favour sexual development (Pharis et al. 1987).

Ammonium nitrate treatments did not influence budworm numbers or defoliation by the budworm in white spruce. However, defoliation of black spruce was significantly reduced 1 year after treatment by 224 kg N/ha, but not by the higher rate of 448 kg N/ha. The response of forest insects to the addition of fertilizers to soil varies considerably. Insect damage and populations may increase or decrease depending on the type or quantity of fertilizer and with the feeding habits of the insect (Stark 1965). For forest-defoliatng insects there may be an optimum level of nitrogen nutrition that predisposes trees to suffer less damage compared with trees on either side of the optimum (Popp et al. 1986). This may explain why 224 but not 448 kg N/ha decreased defoliation in our black spruce experiment.

We were unable to detect a stimulatory effect of ammonium nitrate on production of seed-cone buds per tree in either black or white spruce. However, in white spruce, the only cone-bearing trees were those that had been treated with ammonium nitrate plus carbofuran. A reproductive response of conifer trees to soil-applied ammonium nitrate is dependent on timing, soil nutrient and water conditions, and temperature prevailing at the time treatments are applied (Barnes and Bengsten 1968; Gregory et al. 1982; Owens and Blake 1985). Cone production can be stimulated by ammonium nitrate treatments in white and black spruce, but the response depends on the rate and time of application, tree size, and spacing (Holst 1961; Smith 1986). Our lower rate of application fell within the optimum range, and tree size and spacing were above the minima required for a response to ammonium nitrate. Ammonium nitrate should be applied in advance of the time when reproductive buds are initiated (toward the end of shoot elongation) in spruce and fir trees to ensure sufficient uptake for stimulating reproductive bud initiation (Ebell 1972; Owens and Blake 1985). Our treatments were done in mid-June. This may not have been early enough for white spruce but should have been early enough for black spruce, which begins shoot development later than white spruce. However, low rainfall in 1980 may have prevented sufficient uptake of ammonium nitrate early enough in the season in our black spruce experiment.

In both experiments, either the timing was off or the trees were not in the appropriate physiological condition to allow an increase in the expression of sexual reproductive development in response to ammonium nitrate treatments. Nonetheless, ammonium nitrate treatments did reduce needle senescence in the white spruce experiment. Needle senescence and abscission are means by which woody plants achieve maximum efficiency in element utilization (Del Arco et al. 1991; Larson and Tenow 1980). They are sensitive to nutritional and physiological stress and optimizing nitrogen nutrition tends to retard abscission (Addicott 1968). Trees in the black spruce experiment also responded to the fertilizer treatment with reductions in insect defoliation at the low application rate. These responses suggest that ammonium nitrate has the potential to increase the efficacy of carbofuran treatments and perhaps reduce the loss of foliage associated with the use of carbofuran.

The persistent insecticidal activity of carbofuran plus the possibility that it may also stimulate reproductive development (Daynard et al. 1975; Pless et al. 1971) enhances its potential for use on spruce seed trees. However, carbofuran, especially in the granular form, is toxic to wild birds (Fogal and Lopushanski 1988); application as a flowable formulation to soil or by stem incorporation (Fogal and Plowman 1989) may reduce this risk. In addition, other carbamate insecticides with lower vertebrate toxicity and higher insecticidal activity are known (Vialaneix et al. 1991) and certain carbamate compounds can promote sexual reproductive development in plants (Yanosaka et al. 1989). Thus it may be possible to develop a relatively low risk chemical that will promote sexual reproductive development and provide protection for the subsequent cone crop in spruce seed trees.

The virtual absence of an interaction effect between carbofuran and ammonium nitrate applications for all but one of the variables over the assessment years on spruce trees used in the experiments described herein suggests that expected responses can occur when the two management agents are applied together. However, with different application times or different site and climatic conditions that permit a sexual reproductive response to fertilizer application, interactions between fertilizer and insecticide may occur.

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