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ENTOMOLOGY

Effects of Late Spring Frosts in 1980 on Spruce Budworm and its Host Trees in the Laurentian Park Region of Quebec.—Late spring frosts occasionally kill new shoots on balsam fir (*Abies balsamea* [L.] Mill.) and white spruce (*Picea glauca* [Moench] Voss), and can affect spruce budworm (*Choristoneura fumiferana* [Clem.]) populations (Blais, For. Chron. 33:364-372, 1957). In the spring of 1980, frost damage to new shoots on fir and white spruce was very extensive in various forest regions of Quebec. Observations of effects on the trees and on budworm populations (then at outbreak levels) were made in the spring and summer of 1980 in connection with this phenomenon in Laurentian Park, a mountainous region covering 15 000 km² north of Quebec City. Since 1972, this region has been under budworm attack; at elevations below 700 m, insect populations have remained high, whereas at elevations above 700 m (about 40% of the study area), populations declined in 1978 and have remained at a low level since then. By the end of 1979, impact of the budworm on the forest was considerable; an average of 12% of the balsam fir of merchantable size in 37 study plots in the region were dead, whereas 35% of the living trees had lost more than 75% of their foliage (Blais, Laurentian Forest Res. Cent. Inf. Rep. LAU-X-43, 1980).

Temperatures in May 1980 at the Quebec airport (about 40 km south of Laurentian Park) were close to normal; mean for the month was 11.5° C, whereas mean for the normal is 10.6° C. Temperatures in Laurentian Park are lower because of the higher elevation, but temperatures in May for that region were presumably close to normal because budworm emergence from hibernacula, early larval development, bud bursting, and shoot elongation on spruce and fir occurred about the same time as in previous years. During the 1st wk in June at elevations below 700 m, shoots on fir and spruce measured about 1.5–2 cm, and budworm larvae were mostly in the third instar; populations varied somewhat among localities but averaged about 18 larvae per 45-cm branch. Loss of current foliage resulting from such population levels ranged from 25 to 70%. At elevations above 700 m, larvae were in the second instar, and buds on fir and white spruce were starting to open; budworm populations were scarce and averaged about two larvae per 45 cm branch.

Meteorological records at the Montmorency Experimental Forest Station in the park at an elevation of 620 m reveal that frosts are not uncommon at this locality in late May and early June. However, in 1980, some unseasonably low temperatures were recorded for that time of year. Minima of -25° C, -5.5° C, and -2.5° C were registered for 24, 29, and 30 May respectively, and of -2.0° C and -3.0° C for 6 and 9 June respectively. The very low minimum temperatures on 29 May, and especially on 9 June, when vegetation and insect development was more advanced, were probably mainly responsible for the frost damage observed later.

TABLE 1
Average number of shoots, percentage of frozen shoots, average number of larvae, and percentage of dead larvae for five 45 cm balsam fir branches by observation point.

Observation Point	Average no. of shoots per 45-cm branch	Percentage of frozen shoots	Average no. of larvae/45 cm branch	Percentage of dead larvae
1	105	91	19	20
2	123	55	13	16
3	101	32	13	8
4	140	19	11	0
5	118	22	20	20
6	129	18	24	7
7	102	99	29	48
8	127	41	19	15
Average	118	46	18	17

On 12 and 13 June, observations were made in eight localities 1–5 km apart, in and around the Montmorency Experimental Forest. One 45 cm branch tip was obtained with pole pruners from the mid-crown of each of five balsam fir trees (approximately 12 m in height) from each locality. All new shoots were counted on these branches and classified as frozen or intact; all budworm larvae were counted and classified as living or dead. At the time of sampling, insect development was at peak L_3 with a few L_2 and L_4; average shoot length measured 1.6 cm (Table 1). Percentages of frozen shoots varied considerably among localities and ranged from 19 to 99, with an average of 46 for the eight localities. Percentages of dead larvae varied among localities with a range of 0–48 and an average of 17. It is noteworthy that relatively few larvae were killed by the freezing temperatures.

Observations made in August and September 1980 indicate that frost damage to fir and spruce was most pronounced in the western half of the park. Moderate to severe frost damage occurred in an area of 8 200 km^2 west of highway 175, linking Quebec City to Chicoutimi. East of this highway and south of the park, frost damage was light to nil.

Fir and spruce can sustain the loss of much or all of the foliage growth produced in one season without any serious consequence to the trees. However, a very large proportion of the fir, especially at elevations below 700 m, was in a greatly weakened condition because of repeated defoliation by budworm. The complete loss of the current year's foliage, through the combined action of frost and feeding by the insect, will hasten tree mortality in those sectors where the infestation persists and where defoliation by budworm would only have been moderate (25–70%) in 1980. In sectors where little defoliation would have occurred because of greatly reduced insect populations, the loss of the 1980 foliage growth through frost will cause some trees to die that otherwise would have recovered.

The egg-mass survey conducted by employees of the Quebec Department of Energy and Resources reveals that budworm populations will be sufficiently high to cause severe defoliation in 1981 in most sectors where the budworm infestation has been persisting in Laurentian Park. This indicates that late spring frosts in 1980, although they caused considerable damage to foliage and may hasten the mortality of weakened trees, did not seriously affect budworm populations. — J.R. Blais, Laurentian Forest Research Centre, Ste. Foy, Que.

The Potential for Selection for Freezing-Tolerance in an Ontario Population of *Scolytus multistriatus* (Coleoptera: Scolytidae).—In Ontario there are two main insect vectors of Dutch elm disease: the native elm bark beetle, *Hylurgopinus rufipes* (Eichh.), and the smaller European elm bark beetle, *Scolytus multistriatus* (Marsh.). The latter was first reported near Windsor in 1948 (Watson, Can. Dep. Agric., Div. Entomol., Bi-mon. Prog. Rep. 4(5):2, 1948).

By 1957 the northern limit of *S. multistriatus* corresponded to a line drawn between Sarnia and Hamilton, and by 1974 its range extended from Midland on Georgian Bay, north of Lake Simcoe and east to the Ontario-Quebec border in a narrow strip along the St. Lawrence Seaway. Also in 1974, successful establishment of *S. multistriatus* was recorded in Ottawa, 40–50 km north of its previously known range.

In 1970, *S. multistriatus* was found for the first time in Sault Ste. Marie where it was breeding in a single elm (Thomas, Bi-mon. Res. Notes 27:1, 1971), and by 1971 two additional sites were reported (Sippell et al., Annu. Rep. Forest Insect and Dis. Surv., Can. For. Serv., p. 61, 1971). Since these finds were 250 km north and west of the known distribution in Ontario, and 190 km north of any known infestation in Michigan, it was assumed that they were accidental and that the beetle would not become established.

Cold-hardiness tests conducted at the Great Lakes Forest Research Centre in the late 1960s and early 1970s indicated that *S. multistriatus* would be restricted in its northward spread by its inability to survive at temperatures of -30° C or lower (Sullivan, Great Lakes Forest Res. Cent., pers. comm.). Sault Ste. Marie is located just south of the -30° C isotherm and occasionally experiences temperatures of -35° C. Consequently, Sullivan felt that, although small pockets of *S. multistriatus* might be found because of the protection afforded by snow cover, the population would frequently experience stress temperatures that would limit its potential as a vector in northern areas.

However, in 1978 and again in 1979, large numbers of *S. multistriatus* were caught in Sault Ste. Marie on multilure-pheromone traps (Euale et al., Great Lakes Forest Res. Cent. Rep. 0-X-307, 1980). Furthermore, a random sample of 38 diseased trees taken in January 1980 to determine the number of overwintering elm bark beetle galleries/m^2 in brood elms revealed substantially more overwintering *S. multistriatus* than *H. rufipes* larvae (Table 1). Although this does not mean that there are more *S. multistriatus* than *H. rufipes* in Sault Ste. Marie, it does suggest that the *S. multistriatus* population is increasing. Hence, a study was begun to determine if the cold hardiness of *S. multistriatus* has increased by natural selection through exposure to low temperatures.

TABLE 1

Bark beetle galleries/m^2 in brood elms

		Unsuccessful galleries		Successful galleries	
No. of trees sampled	Total area sampled (m^2)	*S. multistriatus* /m^2	*H. rufipes* /m^2	*S. multistriatus* /m^2	*H. rufipes* /m^2
38	21.9	0.18	0	0.82	0.09

Trap logs baited with pheromones were set out in Sault Ste. Marie in August to attract *S. multistriatus* adults. The progeny of these adults in the trap logs were brought into the laboratory in early March and held at -2° C until required for testing.

Larvae were removed, as required, from the trap logs and then warmed sufficiently to determine that they were alive. Live larvae were placed on filter paper in a petri-plate that was then refrigerated on a bed of crushed ice in an insulated container until the supercooling point of the larvae could be determined.

The cooling rate for tests ranged from 0.5°C to 2.0°C per minute in an alcohol-dry ice bath (Sullivan, Can. Entmol. 97:978-993, 1965), in accordance with the standard proposed by Salt (Can. J. Zool. 44:655-659, 1966) for determining biological supercooling points. The temperature at which freezing occurred was determined by the rebound in the cooling curve caused by the release of latent heat as the insect tissue froze and was recorded on a potentiometer. Tested specimens were incubated at 20°C and 50% RH for 24 h to determine if they had been susceptible to freezing. Those specimens that showed no adverse effects of freezing were selected for further incubation in elm bark.

Elm bark, which would have been acceptable for infestation by adult beetles, was removed from diseased and dying trees. Holes were drilled from the phloem side into the bark to accommodate the supercooled larvae. Care was taken to ensure that the holes drilled were not too large, but would accommodate the test specimens without injury. After drilling, the shredded phloem remained attached to the area surrounding the drill hole and provided excellent material for packing and sealing the implanted larvae in the bark. The bark was then incubated at 20°C and 50% RH for 6 wk and the incubated samples were checked regularly for adult emergence.

The mean supercooling point for the 49 *S. multistriatus* tested was -27.58 ± 1.61°C (range -24.0 to -32.2°C), which was similar to the mean -28.9 ± 0.24°C reported by Sullivan (pers. comm.) for a sample of 1970-1971 overwintering larvae. In Sullivan's experiment 5.2% of the supercooled specimens recovered some body movement. Six pupated but were unable to shed their larval skin and none developed to the adult stage. Consequently, Sullivan considered the species susceptible to freezing.

In the tests reported here, 31 of the 49 larvae, or 63%, recovered some body movement. Twenty-nine were selected for incubation in elm bark and of these, 18 became desiccated and died, one could not be found, and 10 became adults. However, only one of the 10 adults appeared to be normal; the remainder exhibited varying degrees of abnormality. Of 29 control larvae (i.e., larvae that were not supercooled) similarly incubated in elm bark, 11 became desiccated and died, three were missing, and 15 became adults. Eleven of the 15 adults emerged. The four adults that did not emerge showed malformations similar to those of the adults that developed from supercooled larvae. It is clear that the experimental technique caused larval desiccation and malformations.

Past experience in rearing *S. multistriatus* has shown that healthy individuals normally develop to emerging adults in rearing material with relatively low moisture content. However, in this experiment it was clear that the technique was causing larval desiccation. Initially the elm bark was moistened with an atomizer, but this practice was abandoned because of fungus contamination. It therefore appears that the supercooled larvae are more susceptible to dehydration than normal larvae. Work is under way to devise a method that will allow supercooled larvae to develop normally in moist elm bark and it is expected that under such conditions healthy adults will emerge from supercooled larvae.

The greater survival of the 1979-1980 supercooled larval population (63%) than that of the 1970-1971 population (5.2%), even though the mean supercooling points for the two populations were about the same, represents an increase of 57.8% in larvae recovering some body movement. The fact that 34% of these larvae pupated and became adults suggests that, under natural, favorable brood conditions, healthy adults may develop from supercooled larvae. The implication of this work is that *S. multistriatus* may, through natural selection as a result of continual stress from a cold climate, be developing tolerance to freezing. If so, *S. multistriatus* may become established throughout the range of elm in Canada. Because supercooling is a product of both temperature and time (Salt, Can. J. Res., D., 28:285-291, 1950), time also must be considered if laboratory-determined supercooling points are to be related to field conditions. Further work is under way to determine the effect of prolonged supercooling on survival and development.—D.B. Roden, Great Lakes Forest Research Centre, Sault Ste. Marie, Ont.

Effect of Additives on the Persistence of Aminocarb in Conifer Foliage.—Aminocarb (Matacil®), 4-dimethylaminon-tolyl N-methylcarbamate has been used operationally since 1973 for the control of spruce budworm (*Choristoneura fumiferana* [Clem.]) in Canada with few adverse environmental effects (Buckner et al., Chem. Cont. Res. Inst. Inf. Rep. CC-X-91, 1975). Usually the chemical is used as an oil formulation at an operational dosage of 0.070 kg A.I./ha. Under the present conditions of forest spraying, only a small portion of the released aminocarb penetrates the forest canopy and reaches the foliage. The deposited chemical can dissipate from the foliage by various physical and biological processes yielding a low residual half-life (Sundaram et al., Chem. Cont. Res. Inst. Inf. Rep. CC-X-116, 1976). The effectiveness of the sprayed insecticide is dependent upon the appropriate residual activity and hence is related to foliar half-life. While the active ingredient is responsible for insecticidal activity, the additives in the formulation can play a significant role in maintaining a desirable half-life in the forest environment. At present, little factual information exists in correlating foliar stability and efficacy of an insecticide. Our present understanding of the efficacy of the additives is superficial. Consequently, there is a need to investigate the usefulness of some solvents and diluent oils in enhancing the half-life of the chemical in foliage, thereby increasing its biological activity. This paper presents results, obtained under field conditions, of the effects of different additives on foliar penetration, persistence, and half-life characteristics of aminocarb in conifer foliage.

In this study technical Matacil® was admixed with various additives as shown in Table 1 to yield a 2% solution (wt/vol) of the insecticide. Each formulation was sprayed on a single white spruce tree, *Picea glauca* (Moench) Voss, on a tree farm near Shawville, Quebec, using the technique and device reported earlier by Sundaram and Hopewell (Forest Pest Manage. Inst. Inf. Rep. FPM-C-6, 1977.) Eight spruce trees of near-uniform size and shape (1.9–2.2 m in height and 7.5–8.0 cm d.b.h.), and with abundant foliage were selected for the experiment and numbered. Trees S1 to S7 each received separately 2.0 mL of the formulation corresponding to F1 to F7, listed in Table 1, and tree S8 served as the untreated control.

Table 1

Trees and formulations

Formulation	Additive containing 2% (wt/vol) of aminocarb[a]	Tree sprayed
F1	Acetone	S1
F2	Nonylphenol[b]	S2
F3	Fuel oil No. 2[c]	S3
F4	Arotex® 3470[d]	S4
F5	Nonylphenol:Fuel oil No. 2 1:1 (v/v)	S5
F6	Nonylphenol:Arotex® 1:1 (v/v)	S6
F7	Nonylphenol:Fuel oil:Arotex® 1:14:5[e]	S7
—	Untreated control	S8

[a] Tech. material supplied by Chemagro Chem. Co.
[b] Fisher Sci. Co. 7956-P.
[c] Supplied by Texaco Oil Co.
[d] Density 0.94; supplied by Texaco Oil Co.
[e] Nearly similar to the operational spray formulation used in early 1974.

The surface of a conifer needle is uneven and waxy because of the presence of highly cross-linked polymeric cutin that is lipophilic. Deposited aminocarb, being apolar, will produce two types of residues: deposits on the surface and deposits in the needle tissue. These are referred to in this paper as surface and tissue deposits or residues.

Samples of foliage were taken 1 h (0 day), 3, 7, 12, 18, 25, 35, 45, and 60 days thereafter. Aminocarb present on the conifer needles (surface residues) was removed by washing 20 g aliquots of foliage with 4 x 50 mL of acetonitrile. Deposits inside the needle tissues (tissue residues) were obtained by Sorvall homogenization of the same foliage followed by extraction with 2 x 100 mL of acetonitrile. The extracts were further cleaned, the residues were quantified by gas-liquid chromatography as described by Sundaram and Hopewell (loc. cit.), and the aminocarb concentrations were expressed in ppm of oven-dry foliage weight.

The influence of different solvents and solvent mixtures on the surface residues, tissue residues, penetration, and persistence of aminocarb in conifer foliage is summarized in Table 2. Foliar samples from the untreated control tree did not show any detectable levels of aminocarb (detection limit 0.05 ppm).

Acetone solutions of aminocarb (F1) gave poor surface and tissue deposits. The insecticide dissipated rapidly, giving a "half-life" (T½), i.e., time (days), after which only one-half of the initial residue concentration was detected, of 8.8 days. Half-lives were calculated by fitting the data to the exponential decay model and significant differences were estimated by analysis of variance. Acetone, being a polar and volatile liquid of low viscosity, is a poor solvent to enhance the dispersibility, coverage, and retention of aminocarb on the waxy surface of foliage.

Nonylphenol, a pale, brown, viscous liquid, is a mixture of monoalkyl phenols, predominantly *para* substituted, and containing randomly branched nonyl groups as side chains. It is used as an adjuvant in commercial aminocarb (Matacil®) formulations and also acts as a nonionic surfactant because of the presence of hydrophobic and hydrophilic ends in the molecule. From the residue data (Table 2, S2) it is apparent that, apart from the minor difficulties encountered in metering, mixing, and spraying (nozzle plugging), the nonylphenol solutions of aminocarb (F2) gave excellent deposition levels and enhanced the penetration and stability of the active ingredient on the needles. This is evident from the relatively high surface and tissue residues as well as the total foliar residue levels that showed considerable persistence (T½ 15.3 days), compared to the other solvents and solvent mixtures studied. Knowledge of the ability of solvents to facilitate and enhance dispersion, foliar penetration, and persistence of aminocarb (thus improving efficacy of insecticides) is still sketchy. However, the present results indicate that the structure of nonylphenol, with its hydrophobic and hydrophilic ends and aryl ring, may have considerable influence on insecticide retention, penetration, and persistence in conifer foliage. Following impaction on the spruce needle, the solvent molecules, because of their polarity, orient toward the cuticular surface, reducing interfacial tension. This reduction facilitates wetting and spreading of spray droplets over the needle (Gould, R.F., ed., Pesticide formulations research, Amer. Chem. Soc., Washington, D.C., 1969). At the same time, the solute molecules, being apolar, uniformly distribute themselves on the surface of the needle and diffuse from the spray droplet into the lipophilic cutin, forming a solid solution. This process facilitates the penetration of solution through the cuticular layer and incorporation as tissue deposits. Inside the tissue, aminocarb tends to resist a rapid physicochemical degradation and the result is a slow decrease of tissue residues so that a small fraction (0.9 ppm) was persistent even after a 60-day interval.

Two petroleum distillates, fuel oil No. 2 (F3) and Arotex® 3470 (F4), showed approximately the same deposition and dissipation characteristics. The former, because of its aromatic content, has some agreeable properties such as increased foliar penetrability, adhesion, and resistance, when compared to the latter (T½ 11.0 vs 9.2 days). With respect to foliar adsorption, spreadability, and cuticular diffusion, these two oils exhibited intermediate properties between acetone on one hand and nonylphenol on the other (Table 2), because of their high paraffinic content and lack of polarity.

Dispersion of aminocarb in a solution of nonylphenol and fuel oil as formulating agent (F5) gave equally superior deposition concentration on needles compared to the use of pure nonylphenol (F2). Dominant factors that influenced residual effectiveness (T½ 14.4 days) in this spray are minimum evaporation loss (authors' unpublished data) and foliar leaching caused by rain (addition of an oil component further reduced the water-solubility), firm adhesion of the droplets to leaf surface, and penetrability of the toxicant molecules below the cuticular layer of conifer needles. The ingredients used in the formulation are economical and the solvent system considerably increased the penetration and foliar life (T½ 14.4 days) of aminocarb compared to the use of fuel oil alone. Also, the solubility of aminocarb in the solvent mixture was greater than in pure fuel oil.

The solution mixture containing nonylphenol and Arotex® (F6) was not as effective as the nonylphenol/fuel oil system as shown by a lower T½ value. Arotex®, being a light petroleum distillate rich in aliphatics, lacked the adhesion characteristics of fuel oil, resulting in evaporation of the targeted formulation, thus reducing the residual effectiveness (T½ 12.1 days) compared to the nonylphenol/fuel oil (T½ 14.4 days) solvent system.

The last formulation (F7) was prepared according to the recipe used for Matacil® in an experimental spray program undertaken previously (Sundaram et al., 1976, loc. cit.). The residue pattern, persistence, and T½ (11.5 days) observed for this spray formulation (F7) were basically the same as nonylphenol/Arotex® mixture. The use of petroleum distillates alone, which are less hydrophobic than nonylphenol, markedly diminished the cuticular penetration and persistence of the active material compared to the formulations containing both the ingredients.

The results of the present investigation indicate a relationship between the chemical nature of the solvents/diluent oils and foliar half-life of the active ingredient. Although only one tree was used to study each formulation, all treatments were done under the same weather conditions (temperature 16° C, windspeed 1.37 m/sec, relative humidity 73%, and barometric pressure 70.2 cm Hg). A change in the weather conditions is expected to alter the efficiency of foliar deposition,

TABLE 2

Aminocarb concentration* (ppm) in oven-dry foliage

Days after spraying	Tree sprayed																				
	S1[a]			S2[b]			S3[c]			S4[a]			S5[b]			S6[c]			S7[c]		
	Sur.	Tis.	Total	Sur.	Tis.	Total	Sur.	Tis.	Total	Sur.	Tis.	Total	Sur.	Tis.	Total	Sur.	Tis.	Total	Sur.	Tis.	Total
0	14.0	0.7	14.7	25.6	3.2	28.8	19.7	1.5	21.2	17.8	1.1	18.9	23.7	3.0	26.7	21.8	3.1	24.9	21.3	2.2	23.5
3	11.0	1.1	12.1	23.0	4.1	27.1	16.2	1.9	18.1	14.2	1.5	15.7	20.5	3.7	24.2	18.9	3.4	22.3	18.2	3.6	21.8
7	6.9	0.9	7.8	14.9	3.4	18.3	11.2	1.6	12.8	10.8	1.1	11.9	9.9	3.1	13.0	9.4	2.5	11.9	11.4	2.8	14.2
12	3.9	0.8	4.7	9.2	2.7	11.9	7.2	1.2	8.4	6.9	0.7	7.6	8.5	2.2	10.7	7.5	1.7	9.2	8.1	2.0	10.1
18	2.3	0.6	2.9	6.7	2.0	8.7	4.4	0.9	5.3	4.2	0.5	4.7	5.9	1.7	7.6	4.7	1.4	6.1	5.5	1.7	7.2
25	1.2	0.4	1.6	3.4	1.7	5.1	2.3	0.6	2.9	1.9	0.3	2.2	3.3	1.3	4.6	2.8	0.8	3.6	2.9	1.4	4.3
35	0.9	0.2	1.1	3.2	1.3	4.5	1.7	0.4	2.1	1.1	0.3	1.4	3.0	1.0	4.0	2.3	0.6	2.9	2.1	1.0	3.1
45	0.4	0.1	0.5	1.9	1.1	3.0	1.1	0.3	1.4	0.5	0.2	0.7	2.2	0.6	2.8	1.4	0.4	1.8	1.5	0.6	2.1
60	0.1	N.D.	0.1	0.9	0.9	1.8	0.2	0.2	0.4	0.1	0.1	0.2	0.7	0.4	1.1	0.3	0.3	0.6	0.3	0.2	0.5
T½† (days)	8.9	12.3	8.8	13.0	26.0	15.3	9.8	17.0	11.0	8.2	16.1	9.2	13.5	17.8	14.4	10.9	16.1	12.1	10.6	15.0	11.5

Sur. = surface residue

Tis. = tissue residue

N.D. = not detectable and the detection limit was 0.05 ppm.

* Values represent the mean of two determinations; for each tree the standard deviation was less than 10%.

† Values represent half-life for residues.

[a] Half-life for surface and total residues for trees S1 and S4 are not significantly different, whereas for the tissue residues it is different ($P \leq 0.08$).

[b] Same observation as above, for trees S2 and S5.

[c] No significant difference was found among the three formulations F3, F6, and F7 concerning the half-lives for the three types of residues.

possibly affecting the foliar persistence of the chemical as well. However, it is assumed that any such changes in persistence would equally affect all foliar residues, thus maintaining the relative significant differences between half-lives of different formulations. Although extrapolation of the present results to other insecticide formulations to make a generalization on deposition efficiency and foliage half-life is not possible at this time, some salient points emerge from the present study:

1. Environmental stability of an insecticide is influenced by additives in the formulation.
2. There appears to exist a structure/activity relationship between the solvent type and foliar stability. The chemical nature of the solvents/diluent oils appears to influence foliar deposition, spreading, wetting, adhesion, penetration, and retention of the active ingredient.
3. Tissue deposits decrease more slowly with time than surface residues.
4. Arotex® 3470 appears to behave like acetone with respect to surface and total foliar residues but causes greater foliar penetration and retention, resulting in higher tissue residues.
5. Nonylphenol yields the highest tissue residues among all the additives studied, although the surface and total residues are similar to those found with 1:1 (v/v) mixture of nonylphenol and fuel oil.
6. Formulations F3, F6, and F7 behave similarly with respect to the half-lives of surface, tissue, and total foliar residues of aminocarb. This behavior suggests that these formulations probably have similar physicochemical properties that play an important role in foliar absorption and retention.
7. Use of appropriate additives is likely to result in increased efficacy, contributing to reduction in application dose, cost, and environmental hazards associated with the release of large quantities of toxicants.

Further research should be conducted to explore ways and means by which the field of formulation science could be exploited fully for the forest pest control programs in Canada.—K.M.S. Sundaram and A. Sundaram, Forest Pest Management Institute, Sault Ste. Marie, Ont.

TREE PHYSIOLOGY AND ANATOMY

Effects of Temperature on Strobilus Production in Gibberellin-treated Seedlings of Western Hemlock.— This paper describes the effects of air temperature during initiation of strobili in 3-yr-old seedlings of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) subjected to gibberellin and drought treatments in controlled environments. The influence of environmental variables, such as temperature, on strobilus production has been studied mainly through retrospective analysis of cone crops and climatic records. It is now possible to examine these variables experimentally by superimposing their effect upon artificially enhanced reproductive development in trees small enough to be accommodated in controlled environments. The role of temperature is of particular interest, not only in natural climates, but also in the operation of controlled-environment seed orchards, such as are envisaged for western hemlock in British Columbia.

Until recently, methods for enhancing strobilus production depended on mechanical or chemical treatments such as girdling and fertilization. In general, their effectiveness was limited to older trees. Reliable induction of strobili in juvenile conifers was not attained until research had been conducted on gibberellins (Ross and Pharis, Physiol. Plant. 36:182-186, 1976). Recent work has established the gibberellin mixture $A_{4/7}$ as being particularly effective for the enhancement of strobili production in young plants of western hemlock (Ross et al., in press).

This experiment was conducted on 3-yr-old seedlings reared in plastic pots in a shadehouse. At the time of treatment, all plants, except those to undergo water stress, were in 15-cm-diameter pots containing equal amounts of peat and sand. Seedlings to undergo water stress remained in 10-cm-diameter pots. Treatments included four temperature regimes, with daytime (6 h) temperature of 20°C. These treatments were provided by Conviron growth rooms; fluorescent (v.h.o. Cool-white) lamps provided illumination at plant level of approximately 10 000 lx. All but one plant subjected to 35°C treatment died and are excluded from the main discussion of this paper. Two induction treatments were applied within each growth room: 100 ppm gibberellin A_4 + A_7 mixture ($A_{4/7}$) (Supplied by Imperial Chemical Industries Ltd., England. Test sample indicated A_9 6.4%: A_4 55.6%: A_7 38.0% [Pharis, pers. comm.]), and 100 ppm $A_{4/7}$ combined with soil moisture deficit. Gibberellins were dissolved in a few mL of ethanol, and made up to 100 ppm with distilled water, plus 0.1% wetting agent (Aromox $C_{12}W$). A comparable mixture of ethanol, wetting agent, and water was applied to control plants. Gibberellin and control solutions were sprayed on test groups of five seedlings in each room at weekly intervals, beginning 23 May 1979 and ending 25 July 1979. Plants were sprayed until all foliage was wet.

All plants, other than those under water stress, were given a soil dressing of 10 g of calcium nitrate every 2 wk during the 7-wk treatment period. Stressed plants received 5-g dressings at the same intervals) the nitrate application was reduced for these plants because containers were smaller and leaching was expected to be negligible under restricted watering regimes).

Unstressed plants were surface-watered every 2 days; stressed plants were watered according to internal (plant) moisture potential estimated from weight loss of pots and previously determined relationships between soil moisture content and internal (plant) moisture potential (Brix, pers. comm.). Upper and lower weight limits were designated for each pot and were checked weekly to maintain weights in this range. The potential remained in the range -1000 to -2100 Pa (-10 to -21 bar) for stressed plants in this experiment. At the end of the treatment period (26 July 1979) the plants were transferred to an unheated shadehouse to overwinter. Production of strobili was recorded 1 April 1980.

The efficacy of $A_{4/7}$ was clearly shown in this experiment. When summed across the three lower temperatures, nine seedlings treated with $A_{4/7}$ alone and 11 seedlings treated with $A_{4/7}$ combined with water stress produced male strobili. Female strobili were produced in five seedlings among those treated with $A_{4/7}$ and in eight seedlings among those treated with $A_{4/7}$ and water stress combination. The stronger response of male strobilus production was in contrast to previously reported enhancement experiments (Ross et al., in press). The male response probably reflects the improved efficacy of $A_{4/7}$ when applied in combination with calcium nitrate and average controlled temperatures higher than outdoor temperatures.

TABLE 1

Production of male and female strobili in western hemlock seedlings (mean of 5) after gibberellin and water stress treatments under different temperatures[1]

	Temperature °C					
	20		25		30	
	Male strobili	Female strobili	Male strobili	Female strobili	Male strobili	Female strobili
$A_{4/7}$	0.2	0	15.2	6.2	22.6	15.0
$A_{4/7}$ + stress	4.2	0	8.0	2.4	55.2	31.4
Control	0	0	0	0	0	0

[1] Data from 35°C not included because of mortality. See text for survivor.

TABLE 2

Analysis of variance: male strobilus production

Source	Degrees of freedom	Mean square	Variance ratio
Gibberellin treatments	2	1903	10.6**
Temperature[1]	2	2423	13.5**
Gibberellin x temp.	4	1132	6.3**
Residual	36	180	

[1] Excludes data from 35°C treatment.
**Significant at 1% probability.

TABLE 3

Analysis of variance: female strobilus production

Source	Degrees of freedom	Mean square	Variance ratio
Gibberellin treatments	2	507	5.4*
Temperature [1]	2	991	10.6**
Gibberellin x temp.	4	388	4.1*
Residual	36	94	

[1] Excludes data from 35°C treatment.
* Significant at 5% probability.
**Significant at 1% probability.

Numbers of strobili together with analyses of variance are presented in Tables 1, 2, and 3. Apart from more abundant production of male strobili, significant effects of treatments and interactions were similar for both sexes. The effects of temperature and gibberellin treatments were pronounced. However, an effect of temperature was entirely dependent upon the application of $A_{4/7}$. Increasing temperature then resulted in pronounced increases in male and female strobili production. The induction of strobili by $A_{4/7}$ was weak at 20°C. An additive influence of drought was observed only at 30°C.

Whether the strong influence of temperature can be extrapolated to strobilus production in sexually mature trees cannot be assessed from this experiment. It is conceivable that the temperature response was peculiar to gibberellin induction. However, the importance of temperature to strobilus production has been inferred from numerous past studies of cone crops (Daubenmire, Amer. Midl. Nat. 64:187-193, 1970). Correlative observations made from meteorological and cone crop records have been supported by evidence from experimental modification of temperature through enclosure of small trees in plastic sheets (Brøndo, Medd. Nor Skogforsøkves 27:295-311, 1969). The results of this experiment are consistent with those of Tompsett and Fletcher (Physiol. Plant. 45:112-116, 1979), whose treatments of grafts of *Picea sitchensis* (Bong.) Carr. with gibberellins ($A_{4/7}$ and A_9) proved to be far more efficacious when applied to grafts in a polyethylene house. The results are thus pertinent to the concept of controlled-environment seed orchards, in which temperature and soil moisture can be controlled, and in which effective applications of gibberellins are economically feasible. While more effective, higher temperatures were clearly hazardous to seedlings, especially above 30°C, and should be applied with caution. Nevertheless, it would appear that temperatures of 20°C or less during the induction period may severely limit production of strobili in western hemlock seedlings. — D.F.W. Pollard and F.T. Portlock, Pacific Forest Research Centre, Victoria, B.C.

SILVICULTURE

Growth of Natural Tree Seedlings on a Fen Following Draining and Fertilization. — Newfoundland has extensive areas of unforested peatlands, most of which are capable of supporting forest stands. Though unforested in the strict sense, these areas often have patches of very slow-growing natural softwood seedlings. Some of the peatland sites have been drained and plantations of softwood species have been established successfully (Richardson, Nfld. Forest Res. Cent. Inf. Rep. N-X-178, 1979). Peatland afforestation is also practised in Finland, but there it is more common to drain peatland sites to improve the growth of natural tree seedlings or stands already on the site (Heikurainen, ed., Proc. Int. Symp. Forest Drainage, 1974). To determine if similar results could be achieved in Newfoundland, measurements of annual height increment were made on natural softwood seedlings growing on a drained fen. These measurements were incidental to a plantation growth experiment.

The fen, on a site near Millertown Junction in central Newfoundland, moderately exposed to prevailing westerly winds, is composed of a moderately nutrient-rich peat characterized by the vegetation association *Scirpo-Sphagnetum papillosi* (Pollett, Proc. 4th Int. Peat Congr., Vol. 3:461–468, 1972). It was ditched in September 1971 using a Parkgate tine plough to produce furrows about 38 cm deep and 43 cm wide. The furrows were spaced 2 m apart in one section and 4 m apart in another section; control areas were left undrained (Richardson et al., Nfld. Forest Res. Cent. Inf. Rep. N-X-139, 1976). Softwood seedlings — mainly black spruce (*Picea mariana* [Mill.] B.S.P.) and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) — were planted on the overturned peat strips in June 1973. In August 1973 each planted seedling was fertilized: a mixture of 71 g urea, 99 g ground rock phosphate, and 41 g potassium sulphate was scattered in a ring around each seedling at a radius of 15 cm (Richardson, 1979).

In June 1980, 15 natural black spruce seedlings and 15 natural larch (*Larix laricina* [Du Roi] K. Koch) seedlings were selected on each of five conditions: undrained, drained with furrows at 2 m spacing, planted and fertilized; drained with 2 m furrows, unplanted (and therefore unfertilized); drained with 4 m furrows, planted and fertilized; drained with 4 m furrows, unplanted. Seedlings selected on the fertilized areas were 0.5 to 2.5 m distant from a fertilizer source on the 2 m furrows, 0.5 to 3.0 m distant on the 4 m furrows. Annual height increments of these seedlings were measured for each year back to 1971 when the fen was drained (after annual height growth for that year was complete). Some natural seedlings on the drained fen had obviously seeded in since draining, but those were not included in the measurements.

Draining had a pronounced effect on the growth rates of these seedlings (Figs. 1 and 2). After 1972, annual height increments were always greater on the drained area than on the undrained. About the time of draining, most seedlings were no taller than the ground vegetation on the fen. Average heights of black spruce and larch before growth started in 1971 were 16.9 and 21.2 cm respectively on the (subsequently) drained area of the fen, and 47.1 and 40.4 cm on the undrained area. After growth ended in 1979 they were 69.1 and 112.5 cm respectively on the drained area, 68.9 and 69.5 cm on the undrained area. There were no significant differences in annual seedling

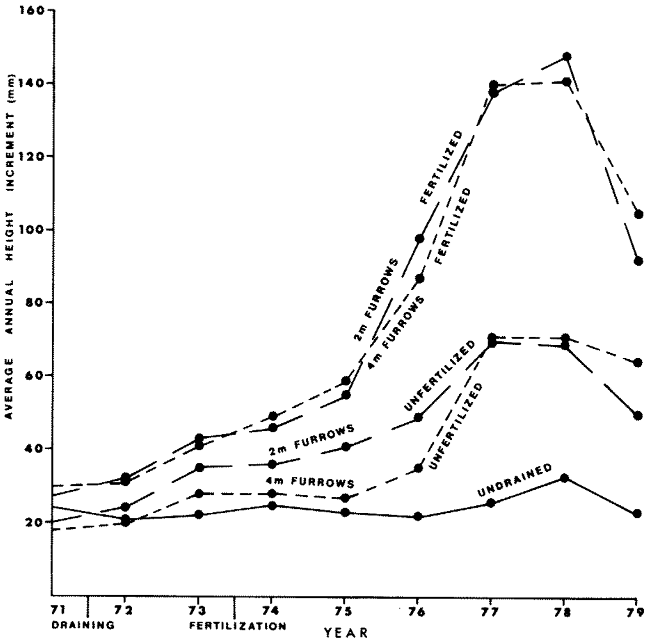

Figure 1. Average annual height increment - black spruce.

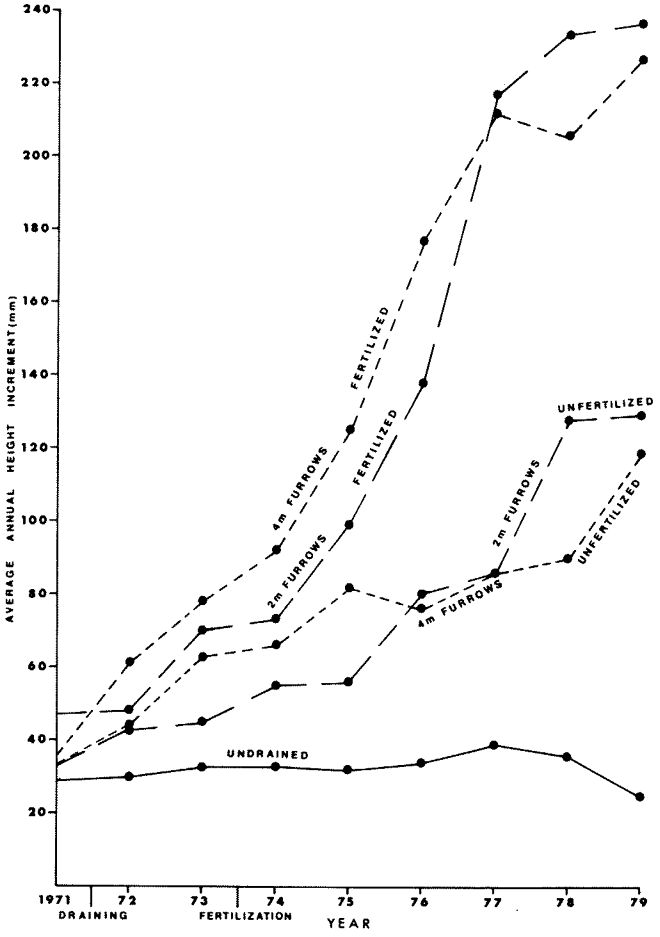

Figure 2. Average annual height increment - larch.

height increment between the 2 m and 4 m furrow spacings.

Fertilization on drained areas brought about an even greater increase in growth than did draining alone. Annual height increments from 1975 to 1979 were two to three times as great on fertilized sites as on unfertilized. However, in recent years, the planted seedlings, which are about the same height as the natural ones but not in direct competition with them, may have had a beneficial sheltering influence on the natural seedlings. This could have contributed to the large height increment differences. Larch seedlings responded more vigorously than black spruce.

Height increment of larch began to level off in 1977–79; black spruce height increment was maximum in 1977–78 and decreased in 1979. These patterns could reflect unusually warm weather during the summers of 1977 and 1978. They could also reflect the waning influence of draining and fertilization as the furrows become clogged with vegetation, and the chemicals applied are exhausted. Experiments involving drain cleaning and application of additional fertilizer are planned to elucidate this.

If fens adequately stocked with natural softwood seedlings are drained, or if natural seeding in occurs soon after draining, it is clear that productive forest growth can at least be initiated on these sites without resorting to planting. — J. Richardson, Newfoundland Forest Research Centre, St. John's, Nfld.

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