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1. INTRODUCTION

The white-pine weevil (Pissodes strobi Peck.) currently is the major insect pest of plantation white pine (Pinus strobus L.) and certain spruces (Picea spp.) in eastern Canada, particularly since DDT no longer is recommended for its control. During the past few years in Ontario, unsatisfactory protection levels have resulted with aerial applications of methoxychlor, a less hazardous material than DDT, but also of the chlorinated hydrocarbon family of insecticides. Howse and Sippell (1970) have shown that methoxychlor, applied by aircraft at 2 - 2.5 lbs./acre, reduces weevil damage by only 67 - 75%. The alternative method currently used for weevil "control[1]" is costly and time consuming hand-clipping of infested leaders, a technique practical only in very young plantations.

In December, 1970, a meeting (attended by staff of the Forest Protection Section, Ontario Department of Lands and Forests, the Great Lakes Forest Research Centre and the Chemical Control Research Institute) was held to discuss the implementation of an appropriate field research program on weevil control. The priority objective agreed upon was to obtain optimal population reduction using insecticides causing minimal disturbance to the

[1] Weevil control generally is considered by both foresters and growers to be achieved when the incidence of leader infestation has been reduced to less than 5%.

environment. The program was designed as follows:

1. Laboratory evaluations of candidate insecticides by C.C.R.I. for toxicity to adult weevils provided by G.L.F.R.C.
2. Selection of several insecticides by C.C.R.I. for field evaluation by ground application in 1971.
3. Continuation of laboratory toxicological studies in 1971 (Nigam, 1971), and possible experimentation with new insecticides/new application techniques using aircraft by 1972.
4. Continuation of aerial applications of methoxychlor to threatened stands by Ont. L. & F. in collaboration with G.L.F.R.C. as described by Howse and Sippell (1970) until an alternative compound/technique is available.

2. MATERIALS AND METHODS

Preliminary surveys indicated high population levels of the white-pine weevil (>20% of trees attacked) in 1971 at the Orr Lake Forest, approximately 14 miles northwest of Barrie, Simcoe County. Twenty-seven treatment plots, each approximately 0.4 acre in size, were established in plantation compartments 73-76. The number of trees, number of 1970 weeviled-leaders, tree heights and DBH's were recorded in each plot.

Four insecticides (acute dermal toxicities are given in Fig. 1) and two spray adjuvants (extenders) were selected for the applications:

(a) Dursban® (0,0-diethyl 0-(3,5,6-trichloro-2-pyridyl) phosphorothioate). Dow Chemical Co.

(b) Gardona® (2-chloro-1-(2,4,5-trichlorophenyl) vinyl dimethyl phosphate). Shell Chemical Co.

(c) Lindane (1,2,3,4,5,6-hexachlorocyclohexane, 99% or more gamma isomer). Niagara Chemicals.

(d) Methoxychlor (1,1,1-trichloro-2,2-bis (p-methoxyphenyl) ethane). Niagara Chemicals.

(e) Pinolene® (di-1-p-Menthene). A product of Miller Chemical and Fertilizer Corp.; sample provided by Green Cross Products.

(f) Target E® (industrial invert disaccharide mixture). Agway Inc.

The probable order of residual persistence in the environment of these compounds is: lindane > methoxychlor > Dursban > Gardona.

Two experiments were designed to (1) compare efficacy of treatments, and (2) to determine the importance of correct timing of sprays, particularly with reference to methoxychlor, the insecticide currently most widely used for control of the white-pine weevil in Canada and the United States. The frequency of observations of both adult weevils and feeding punctures were used as criteria for timing of sprays. Adults were first seen on May 6; at that time only very few feeding punctures (Fig. 2) were evident. Sprays were applied May 8 - 14, the period selected as optimal since only a few eggs were deposited during this time. A second set of treatments was made on May 27 to plots previously sprayed with Gardona and methoxychlor to compare efficacy of one versus two applications, and to determine the effect of (purposely) late applications of methoxychor.

All sprays were applied by hydraulic sprayer (Fig. 3). A two-man crew moved up and down tree rows directing the spray stream at the upper whorl of branches and soaking the leader of each tree to the dripping point. Two to four rows were sprayed during each pass, and all leaders were sprayed from opposite directions for optimum coverage (e.g. once along a north-south line from the west, and again 2 - 4 rows over from the east). Spraying occurred only during early morning or early evening during optimum conditions of wind, temperature and humidity.

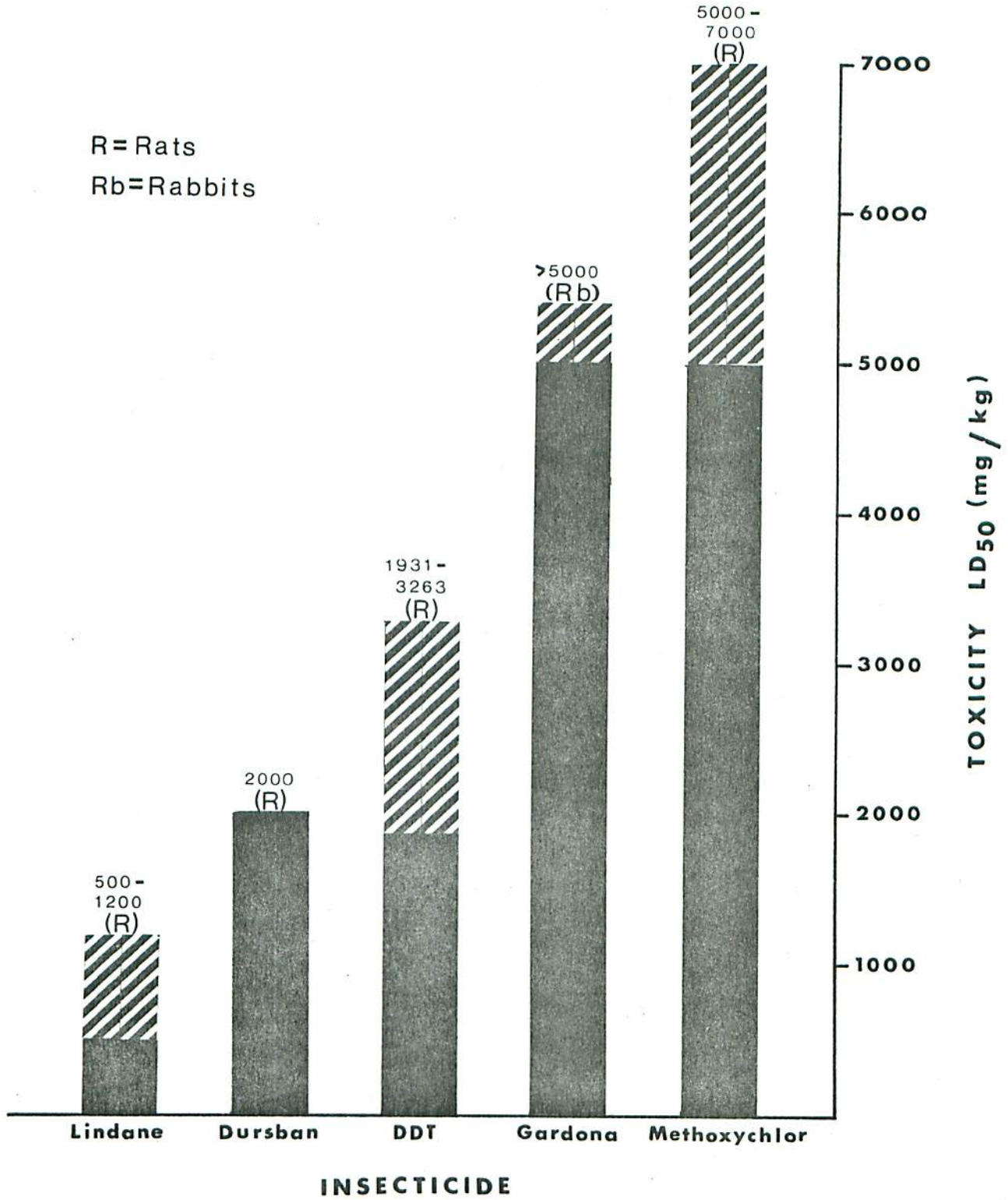

Figure 1. Acute dermal toxicity values of insecticides selected for field experimentation compared with values for DDT (after Kenaga and Allison 1969). Hatching of bars signifies range of LD_{50} values.

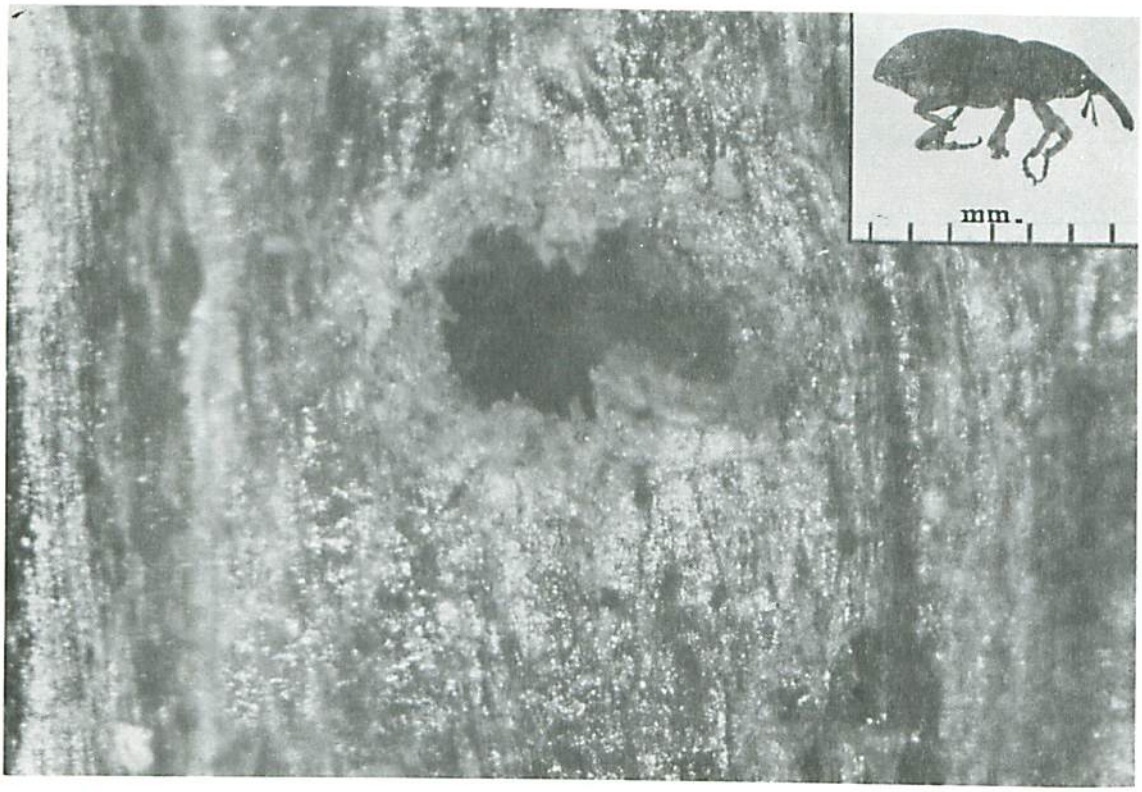

Figure 2. Feeding puncture (diam. approximately 1 mm.) on bark of white pine leader caused by the white-pine weevil.

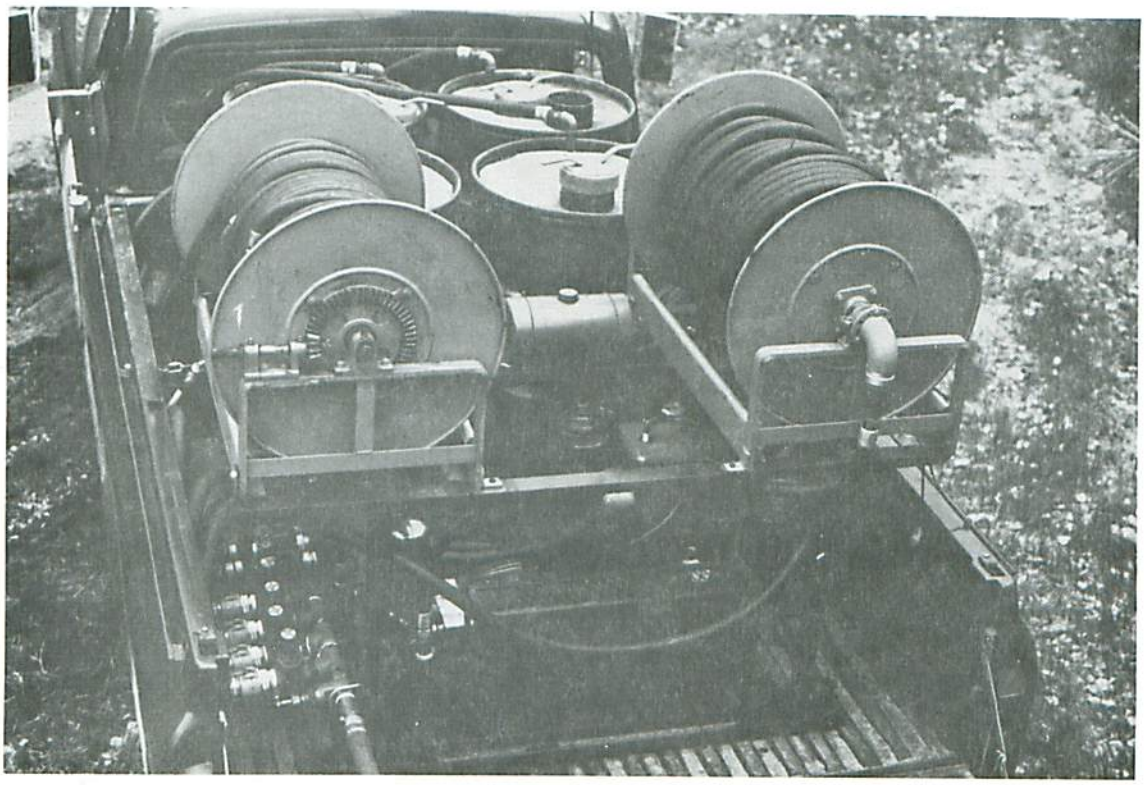

Figure 3. Experimental hydraulic sprayer used for all applications at the Orr Lake Forest. The system included 4 - 45 gal. mixing tanks, 150 ft. of high-pressure delivery hose, a Magikist Model M38E pump, and a John Bean Spraymaster Deluxe Spray Gun.

Post-treatment assessments were made August 30-31, 1971, by observing and recording the numbers of weeviled leaders in all treatment plots.

Details pertaining to treatment plots, insecticide formulations and dosages, and weather conditions during spray applications are found in Tables I and II.

TABLE I. Descriptions of treatments and treatment plots at Orr Lake.

TREATMENT				PLOT					
	Chemical, label formulation	Approx. dosage/ acre (active)	Date (May)[1]	No.	Vol. spray mix emitted (gal)	No. Trees	Tree HT (ft) Range	Tree HT (ft) Avg.	DBH (in.)
			EXPERIMENT 1						
I	Methoxychlor 25 EC	2 lb.	13 E	1	29	361	4-18	12.9	2.5
			13 E	2	36	305	3-18	11.8	2.1
II	Methoxychlor 50 WP/ Target E	2 lb.+ 4 gal.	14 M	18	37	402	7-26	18.9	3.6
			14 M	20	28	330	5-24	15.3	3.2
III	Gardona 20 EC	0.5 lb.	8 E	10	62	306	3-24	12.7	2.7
			8 E	19	50	389	7-24	16.7	2.9
IV	Gardona 20 EC	0.5 lb. (twice)	9 E	8	45	302	6-20	13.0	2.9
			27 E		43				
			9 E	17	37	370	5-24	18.9	3.6
			27 M		37				
V	Lindane 25 WP	1 lb.	13 M	6	55	393	10-20	15.6	3.6
			12 E	9	50	309	6-18	12.5	2.4
VI	Lindane 25 WP/ Target E	1 lb.+ 4 gal.	13 M	5	39	323	4-18	12.7	2.3
			13 M	7	44	417	3-18	11.4	2.2
VII	Dursban 2.4 lb./gal EC	0.5 lb.	10 E	12	55	305	8-24	13.6	2.9
			10 E	13	59	428	4-20	11.1	2.5
VIII	Dursban 2.4/ Target E	0.5 lb.+ 4 gal.	11 E	3	45	309	5-18	12.3	2.1
			11 E	15	44	342	6-20	13.8	3.2
IX	Dursban 2.4/ Pinolene	0.5 lb.+ 0.2 gal.	10 E	11	45	310	6-25	13.2	2.5
			11 M	14	36	316	5-20	12.5	2.8
X	Untreated Check	-	-	4	-	351	4-16	13.2	1.0
		-	-	16	-	329	8-22	13.7	1.1
			EXPERIMENT 2						
XI	Methoxychlor 25 EC	2 lb.	13 E	25	12	100	3-24	16.6	1.3
XII	Methoxychlor 25 EC	2 lb.	27 E	24	22	100	3-24	11.2	0.8
XIII	Methoxychlor 25 EC	2 lb. (twice)	13 E	26	10	100	3-24	13.8	1.1
			27 E		20				
XIV	Methoxychlor 50 WP/ Target E	2 lb.+ 2 gal.	14 E	21	12	100	3-24	15.6	1.2
XV	Methoxychlor 50 WP/ Target E	2 lb.+ 2 gal.	27 E	22	19	100	3-24	13.2	0.8
XVI	Methoxychlor 50 WP/ Target E	2 lb.+ 2 gal. (twice)	13 E	23	10	100	3-24	15.8	0.8
			27 E		20				
XVII	Untreated Check	-	-	27	-	100	3-24	12.2	1.1

1 - E = Evening Application
M = Morning Application

TABLE II. Weather records during treatments at Orr Lake.

	TREATMENT	PLOT NO.	WEATHER			
			Temp. °F	RH %	Wind (mph)	Sky
		EXPERIMENT 1				
I	Methoxychlor 25 EC	1	61	44	0-5	clear
		2	61	44	0-5	clear
II	Methoxychlor 50 WP/	18	42	69	5-10	clear
	Target E	20	56	40	5-10	clear
III	Gardona 20 EC	10	55	65	0-2	clear
		19	60	51	0-5	hazy
IV	Gardona 20 EC	8	63	44	0-5	partly overcast
			56	69	5-10	" "
		17	65	41	0-5	overcast
			52	69	5-10	clear
V	Lindane 25 WP	6	35	80	2-5	clear
		9	42	65	5-15	overcast
VI	Lindane 25 WP/	5	55	45	5-10	clear
	Target E	7	50	49	5-15	clear
VII	Dursban 2.4 lb./gal EC	12	68	32	5-15	clear
		13	64	37	0-5	clear
VIII	Dursban 2.4/	3	72	42	2-5	overcast
	Target E	15	73	31	2-5	" "
IX	Dursban 2.4/	11	52	58	0	clear
	Pinolene	14	72	34	0-5	hazy
X	Untreated Check	4	-	-	-	-
		16	-	-	-	-
		EXPERIMENT 2				
XI	Methoxychlor 25 EC	25	57	43	0-5	clear
XII	Methoxychlor 25 EC	24	52	73	0	overcast
XIII	Methoxychlor 25 EC	26	56	53	0-10	overcast
			52	73	0	hazy
XIV	Methoxychlor 50 WP/Target E	21	56	45	5-20	clear
XV	Methoxychlor 50 WP/Target E	22	50	73	0	overcast
XVI	Methoxychlor 50 WP/Target E	23	57	36	5-20	clear
			51	73	0	overcast
XVII	Untreated Check	27	-	-	-	-

3. RESULTS

For convenience, results have been summarized in Table III. The F-, t-, and mean comparison tests were used in the statistical analyses.

TABLE III. Results of spray trials for control of the white-pine weevil at Orr Lake, 1971.

	Treatment	Total Dosage Act. ingr. (lb.) acre[1]	No. Applic.	No. Trees	1970 No. Weeviled	1970 %	1971 No. Weeviled	1971 %	Infestation Change (Reduction %)[2] Between years (70-71)	Between trtmts. +CK (71)
				EXPERIMENT 1						
I	Methoxychlor EC	2.0	1	666	169	25	17	3	90**	91**
II	Methoxychlor WP	2.0	1	732	143	20	15	2	90**	92**
III	Lindane WP	1.0	1	700	169	24	73	10	57**	63**
IV	Lindane WP/Target E	1.0	1	740	193	26	33	4	83**	83**
V	Gardona EC	0.5	1	695	152	22	45	6	70**	77**
VI	Gardona EC	1.0	2	672	162	24	7	1	96**	96**
VII	Dursban EC	0.5	1	733	210	29	81	11	61**	59**
VIII	Dursban EC/Target E	0.5	1	651	174	27	85	13	51**	57**
IX	Dursban EC/Pinolene	0.5	1	626	163	26	42	7	74**	79**
X	Untreated Check	-	-	680	193	28	198	29	(+)3 n.s.	-
				EXPERIMENT 2						
XI	Methoxychlor EC	2.0	1	100	48	48	2	2	96**	96**
XII	Methoxychlor EC	2.0	1(late)	100	40	40	9	9	78**	80**
XIII	Methoxychlor EC	4.0	2	100	59	59	0	0	100**	100**
XIV	Methoxychlor WP/ Target E	2.0	1	100	47	47	9	9	81**	80**
XV	Methoxychlor WP/ Target E	2.0	1(late)	100	45	45	20	20	56**	57**
XVI	Methoxychlor WP/ Target E	4.0	2	100	42	42	5	5	88**	89**
XVII	Untreated Check	-	-	100	62	62	46	46	26	-

1. Target E @ 4 gal.; Pinolene @ 0.2 gal.
2. As expressed by number of weeviled leaders (%)
   ** difference significant at 1% level
   n.s. difference not significant

4. DISCUSSION

Population levels of the white-pine weevil in the Orr Lake plantations were very high during 1970 and 1971, and were considered to be representative of the current condition of weevil infestation at many other locations in southern Ontario. As in the past, applied chemical controls are essential now, and will be in the future, to maintain the quality of stem growth required by both private and provincial growers.

The results of these initial spray treatments of the current research program have shown that (1) the insecticide used for weevil control in Ontario, methoxychlor, will provide excellent protection of leaders when applied at aircraft rates (2 lbs./acre) but by hydraulic ground sprayer at greatly increased total volumes (2 lbs./100 gal. water/acre), and that (2) timing of spring spray applications must be closely correlated with the commencement of adult activity. Also, carefully applied and well-timed Dursban or Gardona applications (at only 0.5 lbs./acre in 100 gal. water) will significantly reduce weevil attack. The results using either of these latter two insecticides, however, were significantly poorer than those results obtained using methoxychlor. The differences are directly related, apparently, to the obvious discrepancies in dosages (i.e. 0.5 lb. vs. 2.0 lb.) indicating increased amounts

of either insecticide may provide equivalent levels of control. Similarly, lower concentrate methoxychlor sprays (e.g. 1-1.5 lb./acre) may also provide protection equivalent to those levels achieved with sprays at 2 lb./acre. An appraisal of the 1971 spray treatments, including brief discussions of problems dealing with timing and coverage, follows herewith.

Methoxychlor. Both formulations (emulsifiable concentrate and wettable powder) of this insecticide afforded excellent protection of trees treated early during the adult activity period (treatments I, II, XI). Nearly five times more weeviling occurred in those trees sprayed two weeks late (treatment XII). Two applications of methoxychlor (treatment XIII) gave 100% control, but a total of 4 lbs./acre was required to achieve this level.

Lindane. Considerably less than the required dosage of 1 lb./acre reached treatment trees because of poor agitation during applications. Accordingly, this insecticide could not be used as the standard treatment as originally intended. The high percentage of weeviling, therefore, is misleading and cannot be considered indicative of results to be expected from properly applied sprays. The level of population reduction more likely would be similar to the results obtained with the forementioned methoxychlor spray. The use of lindane currently is not recommended for weevil control in Ontario, and expectations are that its future use for this purpose will decrease in other Canadian provinces and in the United States.

Gardona. The results of the single application of Gardona (treatment V) were significantly less effective than either of the similarly-timed methoxychlor treatments in Experiment 1. Two applications of Gardona (treatment VI), however, gave excellent protection against weevil attack. Expectations are that a single, more concentrated application (e.g. 0.75 to 1.0 lb./acre), would afford protection at this level.

Dursban. Applications of Dursban (treatment VII) significantly reduced weevil attack in treated plots. The level of infestation after treatment, however, was still greater than 10%. As for treatments with Gardona, slightly more concentrated sprays would be required to reduce infestations to those levels achieved with methoxychlor sprays.

Target E. The major ingredient in this proprietary compound is industrial cane molasses. Unpublished data and personal communication from Dr. N. L. Gauthier of Agway Inc., Syracuse, New York, indicate that, when added to insecticide sprays, this ingredient has promoted anti-drifting of spray droplets and, may, at the same time, serve as residue extender for some insecticides. It may also act as an attractant to certain pests of forests and agricultural crops. Target E was selected as an adjuvant in the white-pine weevil spray trials mainly to investigate its properties as an extender of spray residues.

Because of the mixing problems experienced during the lindane applications (treatment III), a valid comparison again is not possible for similar sprays with the Target E additive. Control levels achieved, however, with this treatment (IV) were excellent and insignificantly different from the methoxychlor treatments. No significance was found between the Dursban sprays (e.g. comparison of treatments VII and VIII), and no improvement in toxicological properties was noted when added to methoxychlor sprays (treatments XI and XIV).

Although results of spray trials with Target E were rather disappointing, two beneficial attributes were noted: (1) the dark color of the spray stream was extremely helpful in directing droplets to the leaders of taller trees during marginal wind conditions, and (2) the shiny appearance of the leaders after treatment was useful in visual assessments of deposit accuracy for several days thereafter.

Pinolene. Documentation provided by Mr. J. F. Stewart, Green Cross Products, Montreal, has shown that this terpene polymer has significantly enhanced several insecticide sprays for control of white-pine weevil. Also known as Nu Film 17^{R}, its major attribute of interest involves the extension of short-residue insecticides.

When added to Dursban sprays (treatment IX), results in terms of weevil control were about twice as effective as the

applications of Dursban alone (treatment VII). The level of control achieved, however, was considered to be inadequate due most likely to the very dilute rate of application of the insecticide (0.5 lb./acre).

Timing. Adult feeding, mating, and oviposition of the white-pine weevil may extend from late April to mid-summer depending upon weather conditions and geographical location. A review of the literature has indicated that spring applications of insecticides usually provide optimum tree protection, although late summer applications for control of adults emerging from infested shoots have been successful also (Connola and Smith 1964). The major difficulty has been inaccurately predicting these peak adult activity periods for the prevention of oviposition and subsequent feeding by larvae.

Although some oviposition had occurred during the spray period (May 8-14), it was apparent that all early spring applications occurred prior to the peak of adult activity. Where second applications were made with Gardona (treatment VI) and methoxychlor (treatments XIII, XVI) on May 27, it was evident from the increased protection levels obtained that considerable activity was still underway. Late applications of methoxychlor (treatments XII, XIV) indicated the obvious: from two to five times more weeviling occurred because of prior egg deposition and larval emergence.

The problem of properly timing sprays to span the period of peak adult activity remains as one of the two important

criteria in weevil control, particularly in applications of short-residue insecticides. Only with extender-type adjuvants for existing contact insecticides and/or with new systemic insecticides can this problem be surmounted.

Jaynes and MacAloney (1958) have adequately summarized the importance of well-timed and effective insecticide sprays: "A new plantation must be watched closely. Apply treatment as soon as weeviling reaches 2 to 5 percent in any one year. Treat again when 10 percent of the trees are weeviled in one season, to prevent a rapid buildup of the weevil and loss of good treetops. There is usally a 3-to 6-year period before weeviling approaches the 10-percent point, with a resulting 6 to 12 years of protection following the two treatments. During this time, enough trees will develop straight 16-foot butt logs to form a well-stocked stand."

Coverage. Equally important, is the coverage of any insecticide to the leader. Potts' (1958) statement, in reference to stomach poisons, is still appropriate for contact insecticides used today: "Better control of...snout beetles is obtained with droplets of smaller size than are needed for large insects and gross feeders. ...a white-pine weevil adult makes a 0.8-millimeter hole in the bark in the process of feeding, and 1,000 or more droplets...are required per square inch of bark to effect good control, because female weevils must be killed quickly before they lay eggs."

The drench effect obtainable with hydraulic equipment obviously meets this requirement, especially when two applications are made to each leader as was the case with all treatments presented in this report. Similar results can be expected with mist blower applications (Connola 1961). The coverage problem applying insecticides by aircraft (low volume, high concentrate spray mixtures) might explain, at least partially, the inadequate control levels attained during recent years in Ontario with methoxychlor. A one-direction, low-volume swath could very well provide inadequate spray deposit, particularly on the vertically-oriented leader. In early work on aerial applications of DDT by fixed-wing aircraft, Connola, McIntyre and Yops (1955) and Kirby, Harnden and MacLeod (1962) have shown that good control levels can be achieved at rates of 4 lbs. DDT/4 gal. diluting solvent/acre. By contrast, current aerial applications in Ontario using methoxychlor are at 2-2.5 lb./2 gal. water/acre.

5. SUMMARY AND CONCLUSIONS

Ground applications of methoxychlor with hydraulic equipment will provide good control of the white-pine weevil when applied prior to adult feeding and oviposition during late April or early May. Not more than 2 lbs./acre is required to obtain population reduction levels in the range of 90-100%. Two applications, spaced at 10-14 day intervals, provide better control than a single application, and good coverage of spray to the leader is a prerequisite to any successful application. Late applications will give only mediocre to poor control.

Very dilute hydraulic sprayer applications of Gardona and Dursban (0.5 lb./acre) provided good protection of leaders. Slightly more concentrated spray mixtures of either of these insecticides and/or the addition of a good extender-spreader-sticker should provide control at levels similar to those attained with methoxychlor treatments.

6. ACKNOWLEDGEMENTS

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