Toxicity of Selected Insecticides Applied to Western Spruce Budworm[1,2,3]

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ABSTRACT

The contact toxicity of 100 insecticides to last stage larvae of *Choristoneura occidentalis* Freeman was tested by topical application in a 10-yr series of screening experiments. Pyrethroids were generally the most toxic group of chemicals tested. Compounds more toxic than the standard, mexacarbate, at LD_{90} were: bioethanomethrin, (+) *cis*-resmethrin, (+) *trans*-resmethrin, (+) *cis*-phenothrin. ENT 29117 (5-benzyl-3-furylmethyl (1R,3S,E) 2,2-dimethyl-3-(2-oxo-3-tetrahydrothiophenylidenmethyl) cyclopropanecarboxylate), resmethrin, and NRDC 143 (3-phenoxybenzyl (±) -3-(2,2-dichlorovinyl-2,2-dimethylcyclopropanecarboxylate). Mexacarbate spray was tested on the western spruce budworm at selected developmental stages. First instars were least susceptible at both LD_{50} and LD_{90}; instars 3–5 and 6th instars weighing less than 110 mg were most susceptible. Since long-term laboratory rearing of insects did not change their responses to 3 representative chemicals periodically tested during this series of experiments, the results represented a valid estimate of relative toxicity.

The western spruce budworm, *Choristoneura occidentalis* Freeman, is the most widely distributed and most destructive forest defoliator in western North America (Carolin and Honing 1972). This insect attacks numerous conifers, including Douglas-fir, *Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco, grand fir, *Abies grandis* (Dougl.) Lindl., and white fir, *Abies concolor* (Gord. and Glend.) Lindl. Epidemics cause growth loss, topkilling, and, in some instances, tree death. Also, this insect has become a pest of natural regeneration by reducing the seed crop of its principal host trees (Carolin and Honing 1972).

Reported here is an investigation of the response of the western spruce budworm to selected insecticides conducted over a 10-yr period. The relative contact toxicity of 100 insecticides was tested by using a nondiapausing laboratory colony now in its 51st generation. As a quality-control indicator, we also studied the effects of long-term laboratory culture on the susceptibility of larvae to selected insecticides. One of the 100 insecticides tested was mexacarbate, which is registered for use against the western spruce budworm by the U.S. Environmental Protection Agency (Anon. 1974). In addition to topical activity, we determined the relative susceptibiilty of selected developmental stages to mexacarbate spray to provide data for estimating the best time for spray application.

MATERIALS AND METHODS.—*Insecticides and Formulations.*[4]—Fifty-two of the insecticides topically applied to 6th instars were organophosphorous, 28 were carbamates, 16 were pyrethroids, 3 were chlorinated hydrocarbons, and 1 was the extract of a marine annelid. Those without approved common names were: Abate® (*O,O*-dimethyl phosphorothioate *O,O*-diester with 4,4′-thiodiphenol); Bayer 93820 (methyl-(2-isopropanoxycarbonylphenyl) phosphoramidothioate); Butacarb® (3,5-di-*t*-butylphenyl methylcarbamate); C-9643 (2-(4-methyl-1,3-dioxolan-2-yl) phenyl methylcarbamate); C-10015 (2-(4,5-dimethyl-1,3-dioxolan-2-yl) phenyl methylcarbamate); CGA-13608 (*O*-(methyl-2-propinylamino) phenyl methylcarbamate); Cyanox® (*O*-*p*-cyanophenyl *O,O*-dimethyl phosphorothioate); Endod (extract of *Phytolacca dodecandra*); ENT 29117 (5-benzyl-3-furylmethyl (1R,3S,E) 2,2-dimethyl-3-(2-oxo-3-tetrahydrothiophenylidenmethyl) cyclopropanecarboxylate); GC-6505 (*O,O*-dimethyl *O*-(4-methylmercaptophenyl) phosphate); Landrin® (3,4,5-trimethylphenyl methylcarbamate, 75%, and 2,3,5-trimethylphenyl methylcarbamate 18%); Lauroyl trichlorfon (*O,O*-dimethyl 2,2,2-trichloro-1-dodecanoyloxyethylphosphonate); Mobam® (benzo [b] thien-4-yl methylcarbamate); *N*-acetylaminocarb (4-dimethylamino-*m*-tolyl-*N*-acetyl methylcarbamate); NC-6897 (2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate); NRDC 143 (3-phenoxybenzyl (±)-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate); Ortho-11775 (*m*-(1-methylpropyl) phenyl-*N*-phenylmercapto methylcarbamate); Ortho-12307 (*m*-(1-methylpropyl) phenyl-*N*-*p*-tolylmercapto methylcarbamate); Ortho-13907 (1-Naphthyl-*N*-formylmethylaminomercapto methylcarbamate); Ortho-14070 (*m*-(1-methylpropyl) phenyl-*N*-formylmethylaminomercapto methylcarbamate); Ortho-14589 (*m*-(1-methylpropyl) phenyl-*N*-acetyl methylaminomercapto methylcarbamate); Ortho-14647 (*O,S*-dimethyl-dodecanoylphosphoramidothioate); Ortho-14721 (*O,S*-dimethyl 10-undecanoylphosphoramidothioate); Ortho-15223 (*O,S*-dimethyl methoxyacetylphosphoramidothioate); Ortho-15527 (*O,S*-dimethyl formylphosphoramidothioate); Ortho-16675 (*m*-(1-methylpropyl) phenyl-*N*-ethylmercapto methylcarbamate); Ortho-17033 (2,3-dihydro-2,2-dimethyl benzofuranyl-7-*N*-ethylmercapto methylcarbamate); Ortho-18121 (*O*-methyl, *S*-carboethoxymethyl-2-propyl phosphoramidothioate); Ortho-18373 (*N*-2,3-dihydro-2, 2-dimethyl

[1] Lepidoptera: Tortricidae.
[2] Received for publication July 14, 1975.
[3] This paper reports research involving insecticides. It does not report recommendations for their use nor does it imply that any uses described here have been registered. All uses of insecticides must be registered by appropriate State or Federal agencies or both before they can be recommended.
[4] Technical grade insecticide samples were provided by American Cyanamid Co., Chemagro Corp., Chevron Chemical Co., Dow Chemical Co., E. I. Du Pont de Nemours and Co., Ciba-Geigy Agricultural Chemicals, Fisons Ltd. Agrochem. Div., I.C.I. Plant Protection Ltd., McLaughlin Gormley King Co., Mobil Chemical Co., Niagara Chemical Division of FMC Corp., Pennwalt Corp., S. B. Penick and Co., Shell Development Co., Stauffer Chemical Co., Sumitomo Chemical Co., and Union Carbide Corp.

benzofuranyl-7-methylcarbamate sulfide); Padan® (*S,S'*-[2-(dimethylamino) trimethylene]bis-(thiocarbamate), hydrochloride); R-15396 (4-[*O,*-(*O,O*-diethylphosphorothionyl)]benzaldoximino-*N'*-*n*-propylcarbamate); R-15996 (4'-(diethoxyphosphinothioyl) benzaldoxine 4-morpholinecarboxilate); R-17543 (*S*-methyl ethylthiophosphonylbenzamidine); R-17767 (*N*-(*O,S*-dimethylphosphorothioyl) acetamidine); R-20625 (*O*-(acetoneoximino), ethyl-(2,4,5-trichlorophenyl)-thiophosphonate); R-21277 (*S*-isopropyl, ethylphosphono-trithioyl methylphthalimide); R-21279 (5-*t*-butyl ethylphosphono-trithioyl methylphthalimide); R-22607 (*O* (1-carbomethoxyl-1-propen-2-yl)-*S*-ethyl-ethanephosphonodithioate); R-28585 (*N*-(*S*-methyl-*O*-methylphosphoro), *O*-ethyl formimidate); R-23090 (*O*-cyclopentyl, ethyl-*S*-propargylphosphonodithioate); R-24413 (*O*-benzyl, ethyl-*S*-propargylphosphonodithioate); R-26664 (methylthioglyoxylonitrileimine methylcarbamate); R-26990 (3-methyl-4[*N*-(*O*-ethylpriopinomidio)] phenyl methylcarbamate); R-30954 M (mixture of phosmet and *O,O*-dimethyl-*O*-(1-methyl-2-phenylvinyl) thiophosphate); Salithion (2-methoxy-4*H*-1,3,2-benzodioxaphosphorin 2-sulfide); Surecide (*O*-*p*-cyanophenyl *O*-ethyl phenylphosphonothioate); TD-5032 (hexamethylditin); TD-8550 (*S*-(*N*-carbomethoxy, *N*-methylcarbamylmethyl) dimethyl phosphonothiothionate. Endod and Padan were formulated in 50% ethanol, the other compounds in acetone. Mexacarbate was dissolved and serially diluted in Dowanol TPM for spray chamber testing.

All solutions were prepared on the basis of wt/vol concn of the active ingredient. Serial dilutions were made in the appropriate solvent from stock solutions prepared fresh daily. We tested 4–5 concentrations of each insecticide. Control groups treated with solvent only were included in each of at least 3 replicates of each insecticide.

Treatment Procedures.—Topical Application.—Sixth instars treated by topical application were segregated into groups of 10 in weight classes from 60–110 mg. The insects were distributed among the different concentration levels to equalize the weight range and avg weight for each concentration. During testing, they were kept in sterile plastic petri dishes (100×20 mm) lined with filter paper. After being anesthetized by CO_2, each insect was treated with 1 μl of insecticide solution/100 mg body weight. An ISCO model M microapplicator with ¼ cc tuberculin syringe with a 27-guage hypodermic needle was used to apply the insecticide to the thoracic dorsum of each larva.

Testing was divided into numerous series of experiments in which each group of insecticides was tested simultaneously with a mexacarbate standard. Since western spruce budworm normally diapause in nature, we decided to test the assumption that the responses of diapausing and nondiapausing larvae were similar. In addition, use of nondiapausing larvae from so many generations required tests to determine whether the responses of different generations differed. Therefore, quality control experiments were conducted throughout the screening period. DDT, mexacarbate, and pyrethrins were routinely tested by topical application on selected generations from the nondiapausing laboratory colony. These were designated by generation number and the letters 'ND'. Larvae from normal diapausing (D) laboratory colonies and from field collections (P) also were tested. D colonies were designated by generation number and year their ancestors were collected in the field, e.g., F_2-64, F_3-64, etc.

Spray Application.—The contact toxicity of mexacarbate in spray form was tested on all 6 larval stages and the pupal stage. Test insects were selected from the 36th and 37th ND generations. Sixth instars were divided into 2 groups: immature larvae weighing from 70–110 mg, and mature larvae weighing more than 110 mg. Pupae were divided into 3 different groups: pharate pupae (Hinton 1958) in stage III, newly molted pupae, and tanned pupae in which adult pigmentation was visible in the wing pads (pharate adults). Stage III describes last instars which cannot walk or right themselves but vigorously twist their abdomens from side to side when disturbed (Pipa 1963); it is terminated by larval-pupal ecdysis. Larval stages were determined by comparing test insects to those of known instar as identified by head capsule measurements (Lyon et al. 1972). The sex of immature 6th instars was determined by the procedure of Page et al.[5]

Insects of each stage used in the spray tests were segregated into groups of 10 in filter-paper-lined, sterile plastic petri dishes (100×20 mm). Lug vents were removed from the tops of dishes holding 1st to 3rd stage larvae to prevent their escape. During spray treatment, the insects were held in paper lids (100× 20 mm); immediately afterward they were returned to the petri dishes. Each lid was used once, then discarded.

Treatment was performed in a modified Potter spray tower. A constant volume of mexacarbate in TPM, 0.3 ml, was introduced into the spray tower for each test group. Tests of each group were replicated 3–7 times. Pressure for atomization was maintained at 10 lb/in^2. The spray deposit in the chamber was assessed by weighing the spray impinging on filter paper 9-cm diam. Deposit weights were determined at least 5 times during each day's test. Spray deposit averages for each day's test ranged from 0.097–0.315 μl/cm^2 (or 1.04–3.30 gal/acre). Average deposit for the entire test was 0.120±0.011 μl/cm^2 (mean ±SE) (1.26 gal/acre).

After treatment, all larvae were fed an artificial diet (Lyon et al. 1972). Mortality was tallied 7 days after treatment, and the data were analyzed by probit analysis.[6]

RESULTS AND DISCUSSION.—Pyrethroids were generally the most toxic group of chemicals tested against the western spruce budworm (Table 1). Bioethano-

[5] Page, M., R. L. Lyon, and L. Greene. A simple method for sexing early larval western spruce budworm, *Choristoneura occidentalis* Freeman. (Manuscript in preparation).

[6] A computer program for probit analysis prepared by Gerald W. Walton, U.S. Forest Service, Upper Darby, PA, was used in analyzing data collected before 1972. Tests conducted in 1972 and subsequent years were analyzed with the computer program of Daum (1970).

Table 1.—Toxicity of insecticides topically applied to last instar western spruce budworm.

Insecticide[a]		No. treated	Slope ± SE	LD_{50}[b]	95% fiducial limits	LD_{90}[b]	95% fiducial limits	Toxicity ratio[c]
Bioethanomethrin	(P)	258	3.72±0.16	0.091	0.087– 0.095	0.20	0.19– 0.22	14
(+) *cis*-resmethrin	(P)	340	2.86±0.36	.12	.10 – .15	.35	.27– .51	8.0
(+) *trans*-resmethrin	(P)	379	2.97±0.33	.24	.20 – .28	.65	.53– .87	4.3
(+) *cis*-phenothrin	(P)	340	2.64±0.36	.25	.20 – .33	.78	.56– 1.3	3.6
ENT-29117	(P)	520	2.20±0.22	.22	.18 – .25	.83	.67– 1.1	3.4
Resmethrin	(P)	459	2.44±0.30	.26	.21 – .33	.89	.67– 1.3	3.1
NRDC 143	(P)	220	2.98±0.11	.41	.38 – .43	1.1	1.0 – 1.2	2.5
(+) phenothrin (80% d-*trans*, 20% d-*cis* isomers)	(P)	500	2.44±0.38	.36	.17 – .74	1.2	.64– 16	2.3
(+) *trans*-phenothrin	(P)	339	2.64±0.43	.40	.31 – .50	1.2	.86– 2.2	2.3
fospirate	(OP)	90	4.35±0.15	.60	.57 – .62	1.2	1.1 – 1.2	2.3
Mexacarbate	(C)	2639	3.03±0.46	1.1	.79 – 1.4	2.8	2.0 – 5.4	1.0
Chlorpyrifos-methyl	(OP)	240	5.45±1.14	1.7	.43 – 4.5	2.9	1.8 –380	0.97
Phenothrin (mixed d, l isomers)	(P)	370	2.68±0.22	1.2	1.0 – 1.3	3.6	3.0 – 4.5	.78
Salithion	(OP)	380	4.87±0.43	2.0	1.8 – 2.2	3.6	3.3 – 4.2	.78
Pyrethrins	(P)	370	2.28±0.18	1.0	.88 – 1.2	3.7	2.9 – 5.7	.76
Chlorphoxim	(OP)	159	4.34±0.17	2.0	1.9 – 2.1	3.9	3.6 – 4.3	.72
Aminocarb	(C)	120	2.49±0.49	1.3	.023– [d]	4.3	.68–140	.65
Phoxim	(OP)	539	4.14±0.78	2.3	1.5 – 3.3	4.8	3.4 – 14	.58
Chlorpyrifos	(OP)	140	4.23±0.33	2.7	2.4 – 2.9	5.3	4.8 – 6.1	.53
Fenitrothion	(OP)	150	4.24±0.85	3.4	2.5 – 4.8	6.8	5.2 – 17	.41
R-26990	(C)	280	2.85±0.59	2.8	.40 – 9.6	7.8	3.7 – [d]	.36
GC-6506	(OP)	539	4.01±0.32	3.8	3.5 – 4.1	7.9	7.0 – 9.3	.35
N-acetyl aminocarb	(C)	459	2.23±0.26	2.4	1.9 – 2.8	8.9	7.4 – 12	.31
Dichlorvos	(OP)	260	[e]	3.9	[d]	9.5	[d]	.29
Cyanox	(OP)	240	4.19±0.36	5.4	4.9 – 5.9	11	9.7 – 12	.25
Naled	(OP)	150	3.80±0.21	5.3	4.9 – 5.7	12	11 – 13	.23
Methidathion	(OP)	260	3.96±0.11	7.9	7.7 – 8.1	17	16 – 17	.16
Ortho-17033	(C)	300	2.92±0.33	7.0	6.0 – 8.1	19	16 – 22	.15
Bayer-93820	(OP)	240	4.07±0.03	9.0	8.9 – 9.0	19	18 – 19	.15
Leptophos	(OP)	300	3.88±0.46	9.9	8.6 – 11	21	18 – 27	.13
Surecide	(OP)	280	3.14±0.37	8.1	6.8 – 9.4	21	17 – 27	.13
Ortho-14647	(OP)	280	2.87±0.29	8.2	7.1 – 9.2	23	19 – 29	.12
(+) *trans*-allethrin	(P)	350	2.14±0.08	6.3	5.9 – 6.8	25	22 – 29	.11
R-22607	(OP)	400	4.19±0.35	12	11 – 13	28	22 – 29	.11
Phosphamidon	(OP)	279	2.33±0.12	7.9	7.2 – 8.6	28	25 – 32	.10
R-23090	(OP)	300	5.32±0.53	16	15 – 17	28	25 – 32	.10
R-24413	(OP)	300	4.77±0.53	18	17 – 20	34	30 – 41	.082
Lauroyl trichlorfon	(OP)	319	2.09±0.09	8.4	7.2 – 9.5	34	28 – 45	.082
Methamidophos	(OP)	290	2.34±0.38	10.	7.4 – 14	38	25 – 71	.074
TD-5032	(OP)	60	4.39±0.00	20.	20 – 20	38	38 – 38	.074
Diazinon	(OP)	280	3.35±0.51	19	15 – 23	45	35 – 69	.062
Bromophos	(OP)	240	3.55±0.36	20.	17 – 23	46	39 – 58	.061
TD-8550	(OP)	240	3.89±0.58	22	18 – 26	46	37 – 65	.061
Methomyl	(C)	410	0.93±0.10	2.3	1.1 – 3.3	54	24 –200	.052
Pirimiphos-methyl	(OP)	280	3.97±0.66	26	21 – 33	55	42 – 85	.051
R-21277	(OP)	200	3.17±0.38	22	18 – 26	55	44 – 76	.051
Allethrin	(P)	210	2.32±0.15	16	15 – 18	58	50. – 70.	.048
Acephate	(OP)	240	3.68±0.46	27	22 – 31	60.	51 – 76	.047
Ortho-14721	(OP)	260	2.13±0.45	15	9.4 – 21	61	41 –130	.046
Dimethoate	(OP)	200	3.28±0.24	26	24 – 29	65	57 – 76	.043
Fenthion	(OP)	120	2.06±0.33	16	12 – 23	66	42 –150	.042
Trichlorfon	(OP)	319	2.44±0.27	20.	11 – 27	67	40. –180	.042
Tetramethrin	(P)	240	2.07±0.19	16	14 – 19	69	56 – 90.	.041
R-28585	(OP)	280	3.40±0.39	29	24 – 34	69	56 – 92	.041
Tetrachlovinfos	(OP)	240	2.87±0.62	26	1.7 –150	72	33 – [d]	.039
NC-6897	(C)	300	2.00±0.20	17	17 – 21	75	55 –110	.037
Carbaryl	(C)	310	2.20±0.22	20.	15 – 27	76	52 –150	.037
DDT	(CH)	300	1.92±0.37	17	9.9 – 24	79	52 –170	.035
Malathion	(OP)	360	2.69±0.23	29	24 – 34	88	69 –180	.032
Ortho-15223	(OP)	238	2.55±0.43	30.	23 – 39	96	68 –180	.029
Metalkamate	(C)	210	2.08±0.28	24	20 – 32	100	74 –180	.028
Landrin	(C)	580	2.29±0.22	31	27 – 36	110	86 –160	.025
Ortho-16675	(C)	360	2.77±0.53	38	12 –120	110	54 – [d]	.025
d-*trans*-dimethrin	(P)	240	2.33±0.45	32	20 – 42	110	80. –200	.025
Pirimiphos-ethyl	(OP)	280	3.61±0.81	49	.63 –210	110	61 – [d]	.025
Mobam	(C)	150	1.89±0.40	25	15 – 37	120	74 –330	.023

Table 1.–(Continued)

Insecticide[a]		No. treated	Slope ± SE	LD_{50}[b]	95% fiducial limits	LD_{90}[b]	95% fiducial limits	Toxicity ratio[c]
Ortho-15527	(OP)	240	2.81±0.28	41	35 – 47	120	95 –150	.023
R-20625	(OP)	239	2.49±0.41	36	26 – 46	120	88 –190	.023
Ortho-13907	(C)	320	1.70±0.16	21	17 – 25	120	90. –170	.023
Phosalone	(OP)	339	3.68±0.37	53	47 – 60	120	100 –140	.023
Ortho-11775	(C)	270	2.19±0.37	33	23 – 46	130	81 –280	.022
Ortho-14589	(C)	280	1.38±0.16	16	12 – 20.	130	95 –230	.022
Carbanolate	(C)	299	1.88±0.24	27	20. – 34	130	92 –210	.022
Ortho-18121	(OP)	280	2.54±0.30	43	36 – 53	140	100 –210	.020
Ortho-12307	(C)	161	1.71±0.29	26	18 – 33	140	94 –300	.020
R-21279	(OP)	240	2.93±0.17	53	48 – 57	140	130 –170	.020
Phosmet	(OP)	400	2.07±0.15	35	31 – 40.	150	120 –190	.019
Dimethrin	(P)	239	3.06±0.45	65	53 – 79	170	130 –260	.016
Ortho-14070	(C)	320	1.56±0.16	30	25 – 36	200	140 –330	.014
Padan	(C)	300	2.31±0.12	60	55 – 65	220	190 –250	.013
Carbophenothion	(OP)	239	2.57±0.37	75	60. – 92	240	170 –390	.012
Carbofuran	(OP)	300	0.79±0.11	6.0	4.6 – 8.6	250	96 –1300	.011
Abate	(OP)	475	1.93±0.19	67	55 – 79	310	240 –440	.0090
R-26664	(C)	339	0.84±0.25	57	29 –140	1900	450–330000	.0015
CGA-13608	(C)	50	—	ca. 100				
Dioxacarb	(C)	40	—	ca. 100				
Ortho-18373	(C)	50	—	>100				
Methoxychlor	(CH)	50	—	>100				
C-9643	(C)	20	—	>100				
R-17543	(OP)	59	—	>100				
R-30956M	(OP)	50	—	>100				
R-17767	(OP)	59	—	>100				
R-15996	(OP)	80	—	>100				
Dimetilan	(C)	50	—	>100				
Disulfoton	(OP)	50	—	>100				
C-10015	(C)	20	—	>100				
Propoxur	(C)	40	—	>100				
Endod	(E)	48	—	>100				
Chlordimeform	(CH)	50	—	>100				
Butacarb	(C)	50	—	>100				

[a] C = carbamate, CH = chlorinated hydrocarbon, E = extract of annelid, OP = organophoshate, P = pyrethroid.
[b] μg/g body weight.
[c] Toxicity at LD_{90} relative to mexacarbate = LD_{90} mexacarbate/LD_{90} candidate.
[d] Data too heterogeneous to provide useful 95% confidence limits.
[e] Data too heterogeneous to determine slope using probit analysis. Curve fitted by eye.

methrin, the most toxic insecticide tested, was 14 times more toxic at LD_{90} than the standard, mexacarbate. The least toxic pyrethroid, dimethrin, was 61 times less toxic than mexacarbate at LD_{90}. At LD_{50}, the (+)-*cis* isomer of resmethrin was 2 times more toxic than the (+)-*trans* isomer, a difference within the range reported by Jao and Casida (1974) and Robertson and Lyon (1973) for other Lepidoptera. The (+)-*cis* isomer of phenothrin was 1.6 times more toxic than the (+)-*trans* isomer at LD_{50}, in contrast to the greater toxicity of the (+)-*trans* isomer of the armyworm, *Pseudaletia unipuncta* (Haworth) (Fujimoto et al. 1973).

Fospirate was the most toxic organophosphorous compound tested, and the only one more toxic than mexacarbate; at LD_{90}, it was about twice as toxic as mexacarbate. The least toxic organophosphorous compounds killed less than 50% at the highest dose level tested (100 μg/g body weight). The structure activity relationships of organophosphorous compounds followed the usual pattern (Fest and Schmidt 1973). Conversion of P=S to P=O (e.g., chlorpyrifos-methyl to fospirate) increased activity. Dithiophosphorous compounds were less toxic than monothiophosphorous compounds. Methyl esters were more toxic than ethyl esters. Modification of structures by acylation with long-chain acids increased activity (e.g., lauroyl trichlorfon vs. trichlorfon; Ortho-14647 vs. acephate), possibly indicating increased fat solubility and cuticular penetration.

Mexacarbate was the most toxic carbamate tested. We found no significant differences, at the 5% confidence level, in the response of the numerous groups of insects treated with this chemical during the screening series. Therefore, results of all mexacarbate screening are shown by a combined curve in Table 1. The usual relationship of structures complementary to the active site of acetylcholinesterase of insects in general applied to the western spruce budworm. Lipophilic groups in the molecule increased toxicity (e.g., mexacarbate and aminocarb). Less comprehensive studies by Miskus et al. (1968) suggested a similar conclusion. Any modification of the nitrogen-hydrogen moiety of the carbamate group lowered toxicity (e.g., carbaryl vs. Ortho number, metalkamate vs. Ortho 11175, Ortho-14589, etc.).

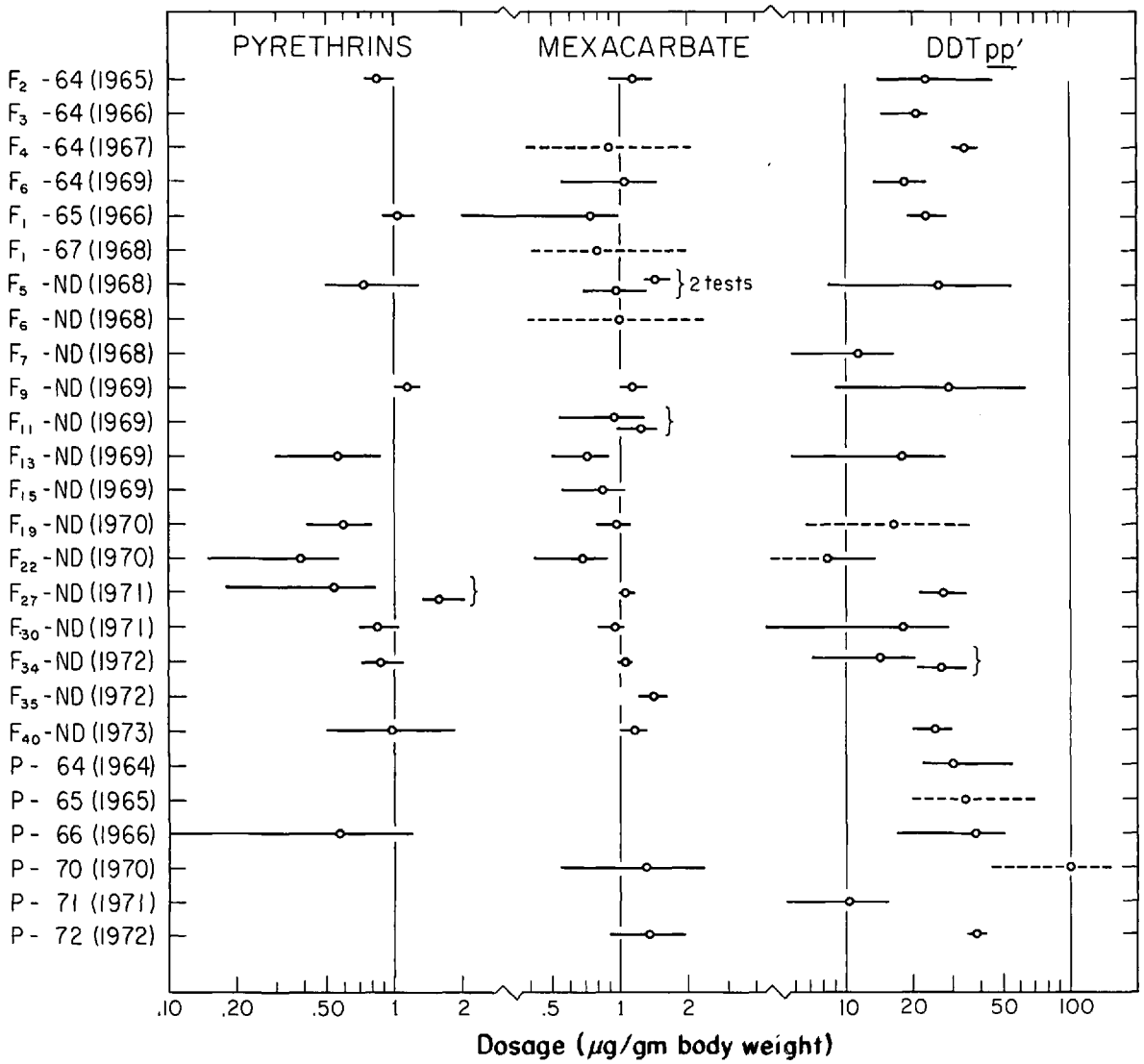

FIG. 1.—LD_{50} and 95% confidence limits for pyrethrins, mexacarbate, and DDT applied topically to 6th-stage western spruce budworm from diapause and nondiapause laboratory colonies, 1964–73. Dashed lines indicate that no confidence limits could be provided. Dosage: μg/g body weight.

Of the chlorinated hydrocarbons tested, only DDT was toxic by contact. Neither methoxychlor nor chlordimeform were toxic, giving 36 and 0% mortality, respectively, at the highest dose level tested (100 μg/g body weight).

Use of the nondiapausing laboratory colony over an extended period was justified by the results of quality-control experiments. We found no significant change in the pattern of response to DDT, mexacarbate, and pyrethrins throughout the period of rearing the ND colony (Fig. 1). Furthermore, there were no consistent differences in response between D and ND colonies, nor between these colonies and parent insects collected from the field and tested directly. We were unable to explain the occasional significant differences in LD_{50} and LD_{90} values. We concluded that our data represent a valid estimate of the contact toxicity of a broad spectrum of insecticides.

The responses of insects at selected developmental stages to mexacarbate spray were clustered in 3 groups at LD_{50} (Table 2). Instars 3–5 and immature 6th instars were most susceptible; 2nd instars, mature 6th instars, and pupae (pharate, untanned, and tanned) were susceptible to an intermediate degree; and 1st instars were least susceptible. At LD_{90}, 4th, 5th, and immature 6th instars were most susceptible; 2nd and 3rd instars, mature 6th instars, and pupae were intermediate in susceptibility; and the 1st instars were least susceptible. Female immature 6th instars were significantly more susceptible than males at LD_{50}. At LD_{90}, however, the sexes did not differ in response. These responses of the western spruce bud-

Table 2.—Toxicity of mexacarbate spray applied to western spruce budworm of various developmental stages.

Developmental stage and no. insects treated	Dose level	Lower 95% fiducial limit	Median[a]	Upper 95% fiducial limit	Probit slope ± SE
1st instar (473)	LD_{50}	1.6	2.6	14	1.40±0.41
	LD_{90}	6.3	21	3800	
2nd instar (625)	LD_{50}	0.37	0.54	0.84	1.56±0.29
	LD_{90}	1.8	3.6	15	
3rd instar (656)	LD_{50}	0.04	0.12	0.20	1.13±0.25
	LD_{90}	0.84	1.6	8.2	
4th instar (588)	LD_{50}	0.09	0.14	1.2	1.99±0.34
	LD_{90}	0.46	0.64	1.2	
5th instar (655)	LD_{50}	0.18	0.22	0.25	2.97±0.30
	LD_{90}	0.49	0.58	0.74	
6th instar, immature[b] both sexes (554)	LD_{50}	0.18	0.20	0.23	2.95±0.24
	LD_{90}	0.48	0.55	0.66	
Males (248)	LD_{50}	0.20	0.23	0.26	3.41±0.37
	LD_{90}	0.46	0.55	0.72	
Females (226)	LD_{50}	0.11	0.16	0.19	2.48±0.44
	LD_{90}	0.40	0.51	0.79	
6th instar, mature[c] (408)	LD_{50}	0.53	0.77	1.10	2.10±0.44
	LD_{90}	1.9	3.1	11	
Pupae, pharate (197)	LD_{50}	0.54	0.88	1.7	2.05±0.60
	LD_{90}	1.9	3.8	76	
Untanned (129)	LD_{50}	0.43	0.72	1.3	1.57±0.43
	LD_{90}	2.1	4.7	51	
Tanned (620)	LD_{50}	0.33	0.49	0.64	1.95±0.34
	LD_{90}	1.5	2.2	4.7	

[a] Ounces per acre.
[b] 70–110 mg body weight.
[c] Weight greater than 110 mg.

worm to mexacarbate contrast with the orderly progression of increasing tolerance with successive instars of most insects (Busvine 1971, Robertson 1972). The high tolerance of 1st instar *C. occidentalis* is analogous to that of 1st instar *Bombyx mori* (L.) treated with pyrethrins (Yoshida 1948).

The recommended time of application of mexacarbate in suppression programs is when members of the population are 4th and 5th instars (Anon. 1974). Our data confirm that these stages are among the most susceptible at both LD_{50} and LD_{90}. The strong statistical difference in the toxicity of mexacarbate between small and mature 6th instars emphasizes the importance of timing the spray application. Although small 6th instars were highly susceptible to mexacarbate, larger 6th instars were among the least susceptible. The slight differences in response noted between ♂ and ♀ 6th instars at LD_{50} would appear to have no practical impact during a suppression program because at LD_{90} both sexes were equally affected.

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