EFFECT OF APPLICATION EQUIPMENT ON THE DISTRIBUTION OF CHLORPYRIFOS APPLIED FOR DUTCH ELM DISEASE VECTOR CONTROL

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Abstract *Proc. ent. Soc. Ont.* 119:63-68

Chlorpyrifos (0.5%) was applied to mature elm trees with either a hydraulic sprayer or a mist blower, and the deposition of chlorpyrifos on bark samples measured by high performance liquid chromatography (HPLC). Neither apparatus provided uniform deposition, and the upper crowns, trunks and major branches of most of the trees were poorly covered. The mist blower and hydraulic sprayer both oversprayed portions of the lower and middle crowns. Our results indicate that improvements in application equipment and technique are needed, and that chlorpyrifos concentration should be independently evaluated with each type of application equipment to achieve an effective deposit.

Introduction

The objective of modern management programs for Dutch elm disease (DED), *Ceratocystis ulmi* (Buisman) C. Moreau (Ascomycetes: Ophiostomataceae), is to prevent infection of high-valued individual elm trees, with control efforts directed and timed according to the activities of the bark beetle vectors (Euale *et al.* 1978, 1980; Peace 1954). In Ottawa, both the native elm bark beetle, *Hylurgopinus rufipes* (Eichhoff), and the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham) (Coleoptera: Scolytidae) are vectors of DED. The insect activities of importance in DED control are the overwintering of adult beetles on the rough lower bark of the trunk, followed by upward migration on the bark in the spring, and feeding on twig crotches in the upper crown.

Chlorpyrifos has been recommended for use against elm bark beetles as part of an integrated program to control DED (Euale *et al.* 1980). Label specifications on a formulation of chlorpyrifos approved for this use, Dursban 4E, state that an aqueous dilution of 0.48% chlorpyrifos should be applied to the bottom 2.5 m of the trunk to prevent overwintering, and/or to the crown of the tree to prevent branch and twig feeding. The applicator is instructed to use a sprayer which will "give thorough coverage to the tree crown", and to "wet the trunk thoroughly, but do not spray to run off" with either a mist blower or hydraulic pressure sprayer.

The operating principles of these two types of application equipment are quite different. The mist blower applies a concentrated pesticide solution dispersed as fine droplets in a broad column of high velocity air, while the pressure sprayer applies a dilute formulation in a compact stream of large droplets. To compensate for these differences in pesticide deposition, Johnson and Zepp (1979) recommended that methoxychlor be applied in different dilutions depending upon the type of application equipment.

At a range of 15-20 metres or more, it is difficult for the spray operator to judge coverage visually. Although anecdotal, observations by the National Capital Commission, Ottawa, (Perumal, unpublished) and the Parks Department in Fredericton, New Brunswick, (O. Urquhart, personal communication 1978) indicate that an experienced operator applies as much as 10-fold more solution per elm tree with an hydraulic sprayer than with a mist blower. Thus, if label instructions for chlopyrifos dilution are followed, either the hydraulic sprayer may apply an excess of material or the mist blower may provide inadequate coverage.

The purpose of our study was to compare the two methods of application by examining the distribution of chlorpyrifos and uniformity of dosage obtained on mature elm trees. A chemical assay for chlorpyrifos was employed. This is faster and less expensive than a bioassay, but can be correlated with bioassay results against the target insects (Barger *et al.* 1973). It was also possible to compare the insecticide coverage, or the percentage of samples bearing a dosage at or above the label-specified effective dosage.

Materials and Methods

Insecticide application

Six healthy mid-sized elm trees, *Ulmus americana* L. (Ulmaceae), 10-20 metres high and of roughly equal bulk and age were selected from among trees growing along the Eastern Parkway in Ottawa, Ontario. The trees were in a park-like setting, readily accessible on all sides, and were subject to routine low-priority maintenance. Two ball-shaped, two cone-shaped and two umbrella-shaped trees were selected. The mist blower was an FMC Model 100 (trailer) (FMC of Canada Ltd., Burlington, Ontario) and the hydraulic sprayer was an FMC Model 2020MT with a Spray Master Deluxe Model 785 gun and a No. 12 disc, operated at 450 psi. Insecticide applications were made by trained operators on a clear day in July, with winds less than 10 km/h. The operators were given no special instructions on application technique and applied the material from all sides of the trees, as permitted by the maneuverability of the equipment. Chlopyrifos was applied as an 0.5% aqueous dilution of Dursban 4E (Dow Chemical Canada Inc., Sarnia, Ontario, PCP No. 10637).

Sample collection

The sampling design was adapted from one used by Barger *et al.* (1973). Each of the six trees in the study was divided into ten sample zones according to height and wind direction (Fig. 1), and two types of bark samples were distinguished: the thin, young bark in the crotches of 2-3 year old twigs in the crown exterior (zones 1-2A, 1-2B, 1-2C), and the mature, rough bark of the major interior branches (zones 1-2D) and lower trunk (zones 1-2E). The saddle-shaped portion of bark in the twig crotch was excised with a specially fabricated hand-operated punch (similar to a hand-operated paper punch), and bark disks (ca. 3 mm thick) from the major branches and trunk were removed with an 11.1 mm diameter brass cork borer. To control for any previous insecticide applications, a pooled sample of ten twig crotches or ten bark disks was collected from each sample zone before spray application. As soon as the bark appeared dry following the spray application, three pooled samples were again collected from each zone.

HPLC assay

Acetonitrile was added to each sample of 10 twig crotches (1.0 ml) and 10 bark disks (2.0 ml) in polypropylene-capped vials. The free acetonitrile in each sample was withdrawn after 48 hours and filtered through a 0.5 µmillipore filter. An aliquot of 20 µl was injected onto a high performance liquid chromatography (HPLC) column (Altex, 10 µLichrosorb C-10, 250 x 4.6 mm ID, temperature: ambient, flow rate: 1 ml/minute, detector: 254 nm UV) and eluted with acetonitrile:water, 3:1. Chlorpyrifos concentration was quantified by comparison of the peak height at the appropriate retention time to the values obtained using technical chlorpyrifos (Dow Chemical Canada Inc.).

The surface area of the saddle-shaped samples of bark from the twig crotches was difficult to determine, and chlorpyrifos yield was expressed on a weight/weight basis in µg/g dry weight after solvent extraction. Because bark disks of uniform surface area were obtained from the major branches and trunk, pesticide dosage on these samples was expressed in µg/cm.

Correlation of chlorpyrifos deposition to label specifications

Pesticide label specifications are written under the direction of Agriculture Canada, and describe the necessary concentration in solution of the active ingredient and the appropriate application method to control the target insects. In order to compare the deposition of chlorpyrifos with the two application methods, we assumed that the dosage of chlopyrifos needed for DED vector control was that obtained by precisely following label directions. Our operational definition of the label-specified effective dosage was the surface concentration of chlorpyrifos achieved by applying a 0.5% mixture of chlorpyrifos in water until the bark was thoroughly soaked, but not draining.

To correlate field deposition of chlopyrifos with the label-specified dosage, short sections of elm branches, having either mature rough bark or 2 to 3-year old twig crotches, were sprayed with Dursban 4E in water (0.5% chlorpyrifos in solution). A small air-powered sprayer normally used to spray chromatography plates was used, and spray was applied in a crossed pattern of parallel strokes from a range of approximately 15 cm until the bark surface was thoroughly soaked, but not draining.

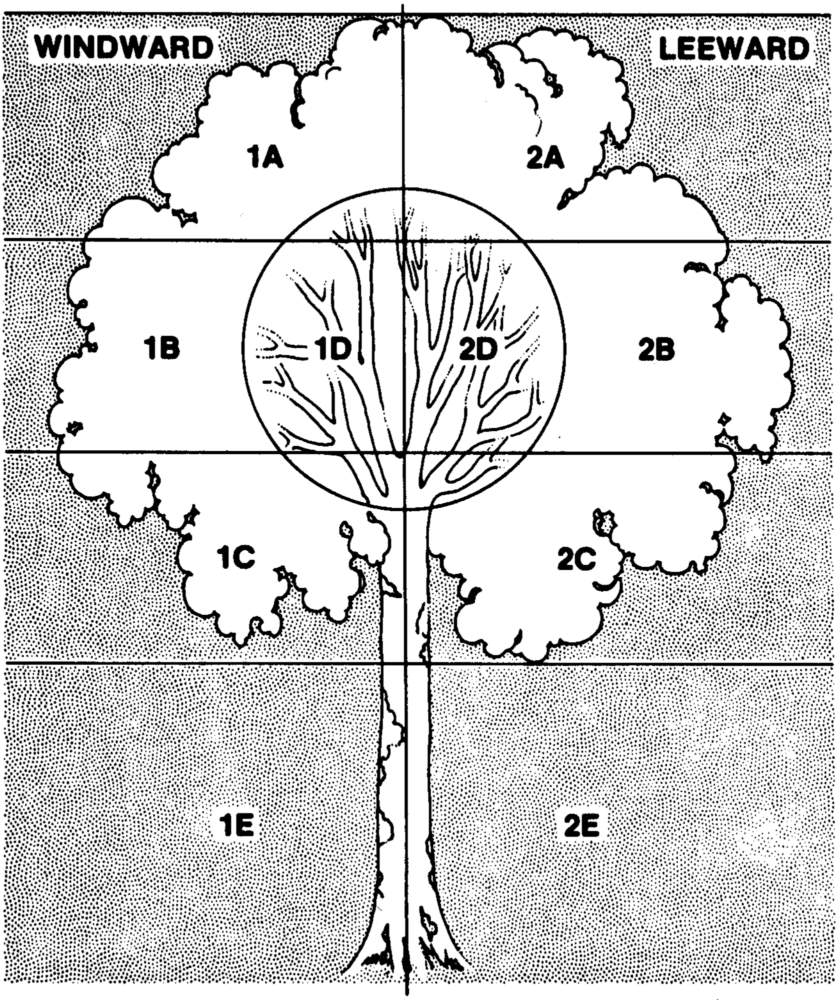

FIGURE 1. Location of chlorpyrifos sample zones on elm trees. Trees were divided into windward (1) and leeward (2) sides. Bark samples were excised from twig crotches in the upper (A), middle (B), and lower crown (C). Samples of rough bark were taken from the major branches (D), and lower trunk (E).

The branches were allowed to dry for 1 hour, then sampled and analyzed as described above. Measured chlorpyrifos dosages on five replicates agreed within 10%, with an average value of 30 μg/g dry weight for the twigs and 60 $\mu g/cm^2$ for rough bark. These mean values were considered to represent the label-specified effective dosage.

Quantitative accuracy of HPLC assay

A fortification study was conducted to determine the actual recovery of chlorpyrifos with the analytical method. Twig samples and bark disks were collected as described above from unsprayed elm trees. A series of five standard chlorpyrifos solutions ranging in concentration from 0.29 mg/ml to 4.85 mg/ml in acetonitrile was prepared. Rough bark samples were covered with 2.0 ml of each of the five standard solutions, and twig crotch samples were covered with 1.0 ml. After 48 hours, the remaining free acetonitrile was analyzed by HPLC and the concentration of chlorpyrifos compared to that of the standards. The mean yield of chlorpyrifos, measured at 254 nm UV, was 85 ± 10%.

Data analysis

Data were subjected to analysis of variance (ANOVA) (Nie *et al.* 1975). In our primary model, crown shape, orientation to the wind, sample zone, and sprayer type were independent variables and measured chlorpyrifos deposition the dependant variable. With the twigs from the exterior crown, a revised model was developed to reclassify the factors related to tree size and crown shape in terms of the spray operation. In this revised model, the area of each zone as seen by the operator was classified in one of three size catagories (<100m^2, 100-200m^2, >200m^2), and the square of the distance from the sprayer nozzle to the midpoint of the sample zone (assuming a nozzle position of *ca.* 1.75 m above the ground and 8 m from the trunk) was included in the analysis.

Results and Discussion

The advantages of our HPLC method over other chemical assays for chlorpyrifos are simplicity, speed, and use of the commonly available 254 nm UV detector. With this method, we determined the label-specified effective dosage of chlorpyrifos to be 30 μg/g for bark samples from the twig crotches and 60 μg/cm^2 for samples of rough bark from the trunk and major branches. The dosage on rough bark, when corrected by the 85% yield factor, is close to the chlorpyrifos concentration of 85 μg/cm^2 for rough bark obtained with a standard gas chromatography method (Euale *et al.* 1980). Although not addressed in our study, where efficacy data is required chemical assays can be correlated with bioassays to relate insecticide application rate and deposition to insect mortality (Barger *et al.* 1973).

TABLE I. Chlorpyrifos deposits on twig and rough bark from elms treated with either a mist blower or hydraulic sprayer.*

Application Method	Crown Shape	Twig Crotches (mg/g) Zone A	Zone B	Zone C	Rough Bark (mg/cm2) Zone D	Zone E
Mist Blower	Ball	0 ± 0	72 ± 135	273 ± 292	22 ± 25	59 ± 31
	Cone	284 ± 169	317 ± 250	563 ± 257	38 ± 30	43 ± 38
	Umbrella	15 ± 24	114 ± 159	394 ± 296	27 ± 23	37 ± 27
Hydraulic Sprayer	Ball	2 ± 5	214 ± 309	526 ± 238	38 ± 21	74 ± 17
	Cone	234 ± 342	463 ± 309	763 ± 238	69 ± 38	96 ± 19
	Umbrella	19 ± 46	240 ± 170	605 ± 241	69 ± 28	76 ± 45

* Mean (± SD) of 6 samples from each zone, each sample containing ten pieces of bark.

With both types of application equipment, there was a great deal of variation in the deposition of chlorpyrifos on twig crotches from the outer crown, and on the rough bark (Table I). The lowest dosages were found on the twig crotches from the upper third of the crown (zone A). With the rough bark, chlorpyrifos dosage was lowest on the major branches (zone D), generally with the mist blower application.

Deposition of chlorpyrifos on bark in the twig crotches was significantly (P ≤0.01) affected by crown shape, the sample zone on the tree, and the type of application equipment (Table II). The revised ANOVA model indicated that the area of the sample zone and the distance from the applicator to the sample zone were also significant factors. Orientation with respect to the direction of the wind, minimal during the insecticide application, had no significant effect on chlorpyrifos dosage.

The significance of distance to the spray zone and zone area indicates that operators of the hydraulic sprayer and the mist blower did not successfully compensate for these factors. As a result, higher zones were poorly covered, as were trees with bulkier crowns, and lower zones were often oversprayed relative to the specified effective dosage. We observed that operators of both types of equipment could not judge from a distance when the bark was thoroughly soaked, but not draining. Operators also tended to aim toward the bulk of the crown, and were reluctant to spray the trunk down to the groundline. Scattering, foliage density, spray obstruction, and angular orientation to the target could also be expected to affect insecticide deposition.

TABLE II. Analysis of variance (ANOVA) of factors affecting chlorpyrifos dosages on elm twigs and rough bark.

		F-ratio	
	Variables	**Twig Crotch Samples**	**Rough Bark Samples**
Primary Model	Crown Shape	15.367*	0.245
	Sample Zone	40.381*	8.127*
	Wind Direction	0.177	1.960
	Sprayer Type	7.886*	24.588*
	4-way interaction	3.497	11.901*
Revised Model	Distance to Zone	6.457*	—
	Area of Zone	8.501*	—
	Sprayer Type	17.842*	—
	Wind Direction	0.005	—

*Significant at $P \leq 0.01$ level.

There were significant differences in the chlorpyrifos dosages obtained with the two types of equipment (Table II). In terms of coverage, or the percentage of samples bearing doses equal to or above the label-specified effective dosage, there was greater variation between twigs from different trees treated with the mist blower, and poorer coverage of the trunk and major branches, than was the case with the hydraulic sprayer application (Table III).

TABLE III. Measured coverage (C) on elm trees treated with 0.5% chlorpyrifos in solution, and estimated coverage with 0.25% ($C^{0.5}$), 1.0% (C^2), and 1.5% (C^3) chlorpyrifos. Coverage is expressed as the percentage of samples bearing deposits equal to or greater than the label-specified effective dosage.

		Twig Crotches			Rough Bark		
Application Method	**Crown Shape**	**C**	**$C^{0.5}$**	**C^2**	**C**	**$C^{0.5}$**	**C^3**
Mist Blower	Ball	35%	29%	35%	25%	0%	67%
	Cone	100	94	100	27	0	73
	Umbrella	67	50	72	27	0	73
Hydraulic Sprayer	Ball	50	50	56	58	0	83
	Cone	81	75	81	80	0	100
	Umbrella	63	63	69	58	8	100

Assuming the same spray deposition, we can estimate the effects on coverage of increasing or reducing chlorpyrifos concentration in solution (Table III). With both types of application equipment, doubling the chlorpyrifos concentration should only slightly improve twig coverage in the crown. Thus, modifications of the equipment or technique which would compensate for the effects of distance and zone area are more likely to produce significant improvements in crown coverage. Alternatively, a reduction in the concentration of active ingredient should be associated with a drastic reduction in coverage of the rough bark on the trunk and major branches. Theoretically, the concentration of chlorpyrifos used in the mist blower would have to be tripled to 1.5% to provide coverage roughly equivalent to that produced by an 0.5% chlopyrifos solution with the hydraulic sprayer. At the label-specified rate, it appears that a hydraulic sprayer should be used for applications to rough bark.

We noted several operational factors that affected the spray applications. The trailer mist blower was less maneuverable than the hydraulic sprayer, and two operators, a driver and a sprayer, must coordinate their efforts. The mist blower operator tended to direct the spray in a vertically oscillating pattern from the top to the bottom of the tree, making it difficult to compensate for distance or to recognize sprayed and unsprayed areas. It would be preferable for the operator to avoid rapid movements and work in a systematic spiral pattern down the tree. The towing vehicle should be light and fitted with broad tires to minimize soil compaction. These improvements in technique may allow the potential advantage of higher efficiency of the mist blower to be achieved. It is also possible to use a small hydraulic sprayer in conjunction with a mist blower to cover the trunk and major branches. With respect to these lower portions of the tree, the Dursban 4E label addresses the maneuverability issue by specifying use of a back pack mist blower, rather than a trailer, for trunk applications.

With the hydraulic sprayer, improvements are required in coverage of the upper crown and in reducing the amount of excessive spray. Reducing the operating distance by working from an elevating device, such as a bucket truck, should improve performance.

With both types of application equipment, success depends on the skill and diligence of the operator. Both supervisory and analytical spot checks may be required to ensure that the best techniques are employed. HPLC analysis offers a simple and inexpensive means of evaluating insecticide deposition in relation to label specifications.

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