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INSECTICIDES FOR CONTROL OF BARK BEETLES THAT SPREAD DUTCH ELM DISEASE

by Gerald N. Lanier, John F. Sherman, Robert J. Rabaglia, and Alan H. Jones

Abstract. Chlorpyrifos, carbaryl and methoxychlor were compared for the following uses against elm bark beetles: 1, elimination of broods in infested elm wood; 2, exclusion of colonization of uninfested elm logs; 3, toxicity to beetles "landing" on treated elm bark; 4, prophylaxis against twig feeding. Chlorpyrifos killed virtually 100% of the beetle broods, completely excluded colonization of uninfested logs and was toxic to 90% or more of the beetles exposed for 10 seconds to bark sprayed 6 weeks earlier. Methoxychlor ranked second in inflicting mortality on beetle brood and it excluded colonization of green logs, but it was marginally toxic to "landing" beetles. Although less toxic than chlorpyrifos, methoxychlor was superior for suppressing twig-feeding by European elm bark beetles. Carbaryl ranked third in effectiveness in all of these tests.

We conclude that chlorpyrifos applied at 0.5% can be an alternative to burning or burying elm wood and that the effects of trap trees can be considerably enhanced by this treatment. Healthy elms can be made prophylactic to branch-feeding or overwintering native elm bark beetles by treatment with chlorpyrifos. However, owing to its repellancy, methoxychlor remains the insecticide of choice to protect healthy elms in regions where the European elm bark beetle is the dominant Dutch elm disease vector.

Dutch elm disease (DED) is caused by a fungus *(Ceratocystis ulmi)* which is spread by bark beetles (for detailed descriptions see Sinclair and Campana 1978 or Schreiber and Peacock 1979). In North America, the principal disease vectors are the European elm bark beetle *(Scolytus multistriatus)* and the native elm bark beetle *(Hylurgopinus rufipes)*. Both of these beetles breed in diseased elms and transmit spores of the fungus when emergent adults feed in healthy trees, but they differ in important aspects of their biologies (Lanier 1978). The European beetles overwinter in the bark as larvae and emerge as new adults at about the time elm leaves reach full expansion. A second generation emerges in midsummer. Native beetles overwinter principally as adults in the corky bark at the lower bole and root collars of healthy elms. Adults leave overwintering niches at about the time elms are in full flower. Hence, emergence of the native beetle precedes that of the European species by about one month. The progeny of the spring generation emerge in midsummer. Most of these feed until fall, although those that emerge before mid July may produce broods which overwinter as larvae. Both beetle species may inoculate healthy elms with the DED fungus when they feed. The European beetle feeds in twig crotches while the native beetle feeds by boring into the fissured bark of branches.

The European beetle has displaced the native species in regions where winter temperatures seldom fall below −12°C (10°F). Due to vulnerability of its overwintering larvae, European beetles are rare where extremes of −30°C (−20°F) occur. Both bark beetle species are usually present in areas where annual winter low temperatures are between −12 and −30°C.

Sanitation, the removal and destruction of elm bark beetle breeding material, has been the principal means of controlling elm bark beetle populations. A sanitation technique that eliminates diseased and unwanted elms by injecting them with cacodylic acid (Rad-E-Cate 35®) has proven to be inexpensive and effective, especially in green spaces where actual removal of trees is usually unnecessary (O'Callaghan et al. 1980, Lanier 1982). The potential uses of insecticides to augment or as an alternative to these approaches have not been developed.

One of the principal prescriptions for control of DED has been the application of toxicants for prophylactic protection of healthy trees against feeding by bark beetles. Since DDT was banned in 1968, methoxychlor has been the only insecticide widely used for this purpose. Based on Canadian research (Gardiner and Webb 1980), chlorpyrifos (Dursban 2E®, Dow) has been registered for use against overwintering native elm bark beetles. Recently, carbaryl (Sevin-XLR®, Union Carbide) was registered for "elm bark beetles" without reference to species or the activity against which application is to be directed (Union Carbide 1983 Chemical Guide).

Studies that compared various insecticides have uniformly concluded that chlorpyrifos and carbaryl were more toxic than methoxychlor to European elm bark beetles (Barger 1978; Page and Green 1978; Rabaglia 1980; Brown and Eads 1982). However, methoxychlor was observed to have a potent repellant effect (Doane 1962) and to be more durable on plywood surfaces than carbaryl and chlorpyrifos (Barger 1978). Lack of complete twig protection in methoxychlor-treated trees was shown to be mainly the result of incomplete coverage (Cuthbert et al. 1973). Poor coverage and inappropriate timing of sprays may be the principal reasons that municipal DED control programs that used spraying to augment sanitation were not more effective than those that relied entirely upon sanitation (Cannon and Worley 1976).

With the general objective of improving the performance of DED control programs while reducing their costs, we conducted studies of the effectiveness of methoxychlor, carbaryl and chlorpyrifos, applied as they might operationally be used.

Materials and Methods

Insecticides used in these tests were aqueous preparations of the following: methoxychlor 25EC, carbaryl (Sevin-SL®), chlorpyrifos (Dursban 2E®).

Bark beetles used in laboratory bioassays were reared from naturally infested elm logs cut in Syracuse, NY. In most instances, beetles were utilized within 24 h of their emergence from brood material; when insufficient emergence made it necessary to use stored (at 3°C) beetles, all beetles were pooled before being distributed randomly among the various treatments.

Wild juvenile elms or logs cut from them were sprayed with 3 gal. capacity Smith P12® sprayers. All of the trees utilized were believed never to have been treated with insecticides prior to our experiments. The insecticides were evaluated in four types of tests. Experiment 1 ascertained the relative effectiveness of 2% methoxychlor, 1% carbaryl, and 0.5% chlorpyrifos against last stage larvae of the European elm bark beetle. Elm logs were sprayed to runoff. Each treatment used a group of 4 logs 30cm long and 10-17cm diameter. After treatment, logs were held at laboratory temperature in cardboard containers that were opened daily (except weekends) to remove all emerged beetles. The viability of beetles that were collected alive was assessed after holding them in moist chambers for 24 h.

As a comparison to the laboratory treatments, we collected four samples of native beetle-infested material that was operationally sprayed with 0.5% chlorpyrifos in Williamstown, MA and compared emergence from this material to that from unsprayed brood wood.

Experiment 2 examined effectiveness of the aforementioned insecticide preparation in preventing colonization. Logs (size as in Experiment 1) cut from 4 healthy saplings were grouped and treated as in Experiment 1. Logs were exposed (standing, western exposure) to the weather on the roof of a college building until they were tested. Individual logs from each group were assayed after 24 h, 5 weeks, 10 weeks, and 20 weeks of exposure. For assays, 15-50 unsexed European elm bark beetles were placed in containers with the individual logs and mortality was assessed after 24 h. Brood success and colonization were determined by collecting brood adults as they emerged and by removing the bark from the logs when no further emergence was evident.

Experiment 3 determined the effects of exposing European and native elm bark beetles for 10 sec., 1 min. and 3 h on bark discs cut from spent brood logs sprayed with 2% active ingredient of the above insecticides. Assays were made at 24 h, and after 1, 3, 6 and 10 weeks. Beetles in lots of 10 each were confined on the sprayed surface of bark discs for the prescribed periods then held in moist chambers and examined for morbidity at 3 h and 24 h following exposure.

Experiment 4 compared the effectiveness of 2% methoxychlor and 0.5% chlorpyrifos and 2% carbaryl in preventing twig crotch feeding by European beetles. In October 1978 carbaryl and methoxychlor were each sprayed on the crown of one elm sapling. These treatments were repeated with five saplings each on May 10, 1979. On May 20, 1983 three elm saplings each were sprayed with chlorpyrifos and methoxychlor. These treatments were repeated on different groups of trees on August 4, 1983. In 1978 and 1979 one unsprayed elm served as a control for each test while in the 1983 tests there were three controls for each experiment. After 24 h and periodically through 11 weeks, 10 twig crotches were harvested from each tree and confined in petri dishes with 20 newly emerged European elm bark beetles. Ends of the twigs were dipped in molten paraffin so that beetles would not feed at the cuts. After 24 h, beetle mortality was assessed and the twigs were microscopically examined to score the numbers of bark abrasions (bites) and penetrations to the xylem.

Results

Treatment of infested brood wood (Experiment 1). Chlorpyrifos killed 99.8% of the beetles that emerged from treated logs. Yield of the chlorpyrifos-treated logs was 4.5 beetles/dm^2 compared to 35.6 beetles/dm^2 for the untreated control (Table 1); this indicates that most of the brood in the chlorpyrifos-treated bolts died in the bark. Carbaryl and methoxychlor killed 66-80% of the emergent adults, but only methoxychlor (18.8 beetles dm^2) seems to have caused preemergence mortality (Table 1).

Since treated logs were held in closed containers it is possible that chlorpyrifos vapors caused a greater rate of mortality than could be expected under field conditions. However, no native beetles emerged from the samples of brood material that were operationally sprayed with chlorpyrifos at Williamstown, MA whereas thousands of new adults emerged from untreated material.

Protection of elm wood from colonization (Experiment 2). Chlorpyrifos and methoxychlor prevented colonization of uninfested elm logs for at least 10 weeks following treatment, whereas carbaryl-treated logs were infested by beetles confined with them after just 5 weeks of weathering (Table 2). After 20 weeks of weathering all logs were too dry to be suitable for breeding. Had they been suitable, mortality rates indicate that the methoxychlor-treated logs could have been colonized whereas the chlorpyrifos-treated log was still lethal (Fig. 2).

Table 1. Effects of insecticides on broods of European elm bark beetles in logs.

Treatments (4 each)	*Means and standard errors*[1] *Beetles emerged per dm^2 bark surface*	*Mortality of emerged adults*[2]
Chlorpyrifos	4.5 ± 2.3a	99.8 ± 0.2a
Methoxychlor	18.8 ± 6.4b	80.2 ± 2.7ab
Carbaryl	32.3 ± 9.2b	65.9 ± 15.4b
Control	35.6 ± 6.0b	12.4 ± 1.4c

[1] Means in a column followed by different letters are significantly different (Student-Newman-Keals test, P ◄ 0.05)

[2] Percent of the beetles dead within 24 h of their emergence.

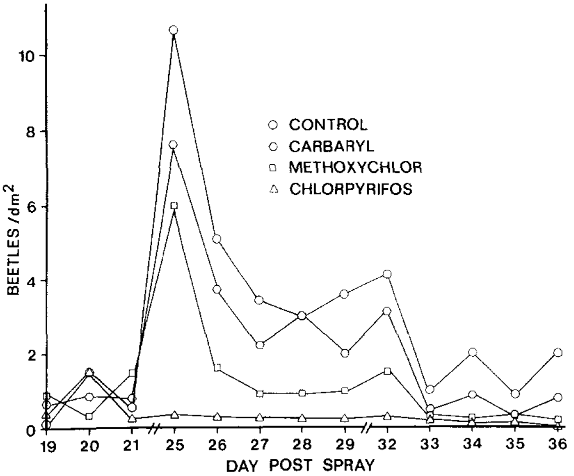

Figure 1. Control of European elm bark beetle broods (Experiment 1). Daily emergence of beetles per dm^2 bark surface of brood wood unsprayed or sprayed with various insecticides.

Lower mortality in the methoxychlor and chlorpyrifos treatments at weeks 0 and 5 than at week ten may have resulted from the beetles avoiding contact with the logs.

Table 2. Effects of insecticides on colonization of elm logs by European elm bark beetles.[a]

Treatment	*Numbers of egg galleries and (brood)*			
	0[b]	*5*	*10*	*20*
Chlorpyrifos	0	0	0	0
Methoxychlor	0	0	0	0
Carbaryl	0	4(479)	15(509)	0
Control	12(1000[c])	4(123)	12(677)	0

[a] Fig. 2 shows mortality of colonizing adults.

[b] Weathering period (weeks) between insecticide treatment and introduction of colonizing adults.

[c] Brood adults, pupae and larvae (all or almost all fully grown).

Effects of brief exposures to insecticide treated elm bark (Experiment 3). The remarkable toxicity of chlorpyrifos to both European and native elm bark beetles is best illustrated in Table 3. Confinement on chlorpyrifos-treated bark for only 10 sec was lethal to almost all European beetles through week 6 (Fig. 3) and most native beetles through week 10. Both species were killed after 3 h exposure to carbaryl- and methoxychlor-treated logs, but these insecticides were rather ineffective in killing beetles exposed for shorter periods.

Insecticides for protecting twig crotches against feeding (Experiment 4). In the 1978 and 1979 experiments methoxychlor was consistently superior to carbaryl for protecting twig crotches from beetle feeding (Fig. 4A). The excellent performance of methoxychlor was repreated in August 1983 but all trees treated in May 1983 showed a curious increase in susceptibility to feeding 5-7 weeks after treatment (Fig. 4B). This trend in feeding activity corresponds with the period of maximum growth and, possibly, the maximum production of feeding stimulants (Doskotch et al. 1970). Dilution of the insecticide by expansion of the twig substrate and sampling of tissue produced after the trees were sprayed may also have been factors in the elevated rates of feeding at weeks 5 and 7.

In contrast to their relative effectiveness for protection of twigs from feeding, chlorpyrifos usually killed more insects than methoxychlor (Fig. 5). This disparity between mortality and feeding rate appears to result from repellancy of methoxychlor. Within a few minutes of their being placed with control twigs or those from chlorpyrifos-treated trees, beetles began to feed on the twigs. At the same time, the beetles confined with the methoxychlor-treated twigs appeared to be hyperactive and to avoid contact with the twigs.

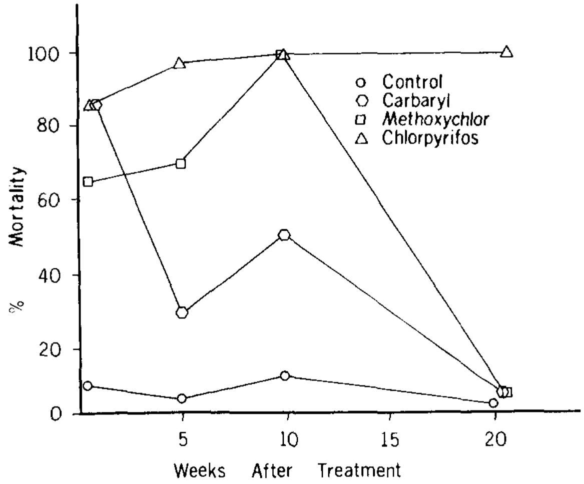

Figure 2. Preventing infestation of elm logs (Experiment 2). Percent mortality among European elm bark beetles caged with elm logs 0-20 weeks after they were sprayed.

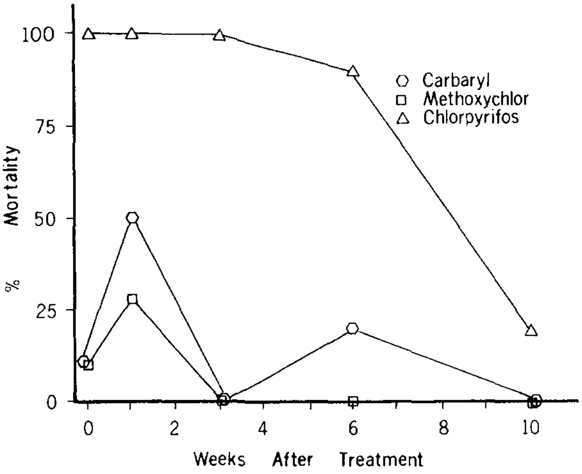

Figure 3. Mortality of elm bark beetles walking on sprayed elm bark (Experiment 3). Percent mortality among European elm bark beetles confined for 10 seconds on bark untreated or sprayed with various insecticides plotted against number of weeks after treatment.

Discussion and Conclusions

The use of chlorpyrifos as a prophylactic against native elm bark beetles overwintering in the lower boles or feeding in branches of healthy elms is well established. Our study shows that this chemical can also eliminate broods of native and European elm bark beetles as well as protect uninfested material from colonization. An exposure of only 10 sec on chlorpyrifos-treated bark was still lethal to both bark beetle species after 6 weeks. This suggests that almost all elm bark beetles that land on a treated tree would be killed, whether or not they attempted to penetrate the bark. Carbaryl and methoxychlor sprayed on infested material caused significant brood mortality but neither of these chemicals had the potency of chlorpyrifos.

Methoxychlor was superior to chlorpyrifos and carbaryl for protecting twigs from feeding by the European elm bark beetle. Unfortunately, the extraordinary mortality caused by chlorpyrifos on corky bark bolts was not evident on the smooth live bark of twigs. Beetles frequently fed on twigs of chlorpyrifos-treated trees before they were

Table 3. Percent of elm bark beetles moribund or dead[a] following various exposures to elm bark treated with insecticides.[b]

Week post treatment	*Exposure duration*	*Carbaryl*	*Methoxychlor*	*Chlorpyrifos*	*Control*
European elm bark beetle, *Scolytus multistriatus*					
Week 0	10 sec.	10/10	10/10	10/100	0/0
	1 min.	30/30	30/40	30/100	0/20
	3 hrs.	100/100	100/100	90/100	0/30
Week 1	10 sec.	0/50	0/30	100/100	0/0
	1 min.	0/1	0/0	80/100	0/0
	3 hrs.	100/100	100/90	100/100	0/0
Week 3	10 sec.	0/0	0/0	0/100	0/0
	1 min.	0/10	0/0	0/50	0/0
	3 hrs.	100/80	70/50	100/100	0/0
Week 6	10 sec.	0/20	0/0	0/90	0/0
	1 min.	0/40	0/0	0/100	0/0
	3 hrs.	100/100	90/100	100/100	0/0
Week 10	10 sec.	0/0	0/0	0/20	0/0
	1 min.	0/0	10/10	40/100	0/10
	3 hrs.	80/90	90/100	100/100	10/20
Native elm bark beetle, *Hylurgopinus rufipes*					
Week 0	10 sec.	0/40	10/60	100/100	0/30
	1 min.	0/50	0/30	100/100	0/60
	3 hrs.	70/80	40/80	100/100	0/40
Week 1	10 sec.	0/0	0/20	100/100	0/0
	1 min.	xx[b]	xx	100/100	xx
	3 hrs.	xx	xx	xx	xx
Week 3	10 sec.	0/0	0/0	0/20	0/0
	1 min.	0/0	0/0	20/80	0/20
	3 hrs.	20/40	0/0	100/100	0/20
Week 6	10 sec.	xx	xx	xx	xx
	1 min.	xx	0/0	20/100	0/20
	3 hrs.	xx	xx	xx	xx
Week 10	10 sec.	0/40	10/100	100/100	10/10
	1 min.	10/20	0/50	10/70	0/20
	3 hrs.	50/80	80/80	100/100	0/20

[a] Ten beetle replicates at each exposure after 3 hr/24 hr recovery period. E.g., 30/100 = 30% moribund or dead 3 hr after exposure, 100% moribund or dead 12 hr after exposure.

[b] Owing to insufficient supply of beetles only 5 *H. rufipes*/exposure were tested during weeks 1, 2 and 3; xx indicates no test was made. Other tests used 10 beetles each.

killed, whereas methoxychlor appeared to repel beetles from twigs even when it was not sufficiently toxic to kill them.

The twig assays illustrated an important weakness in the spraying of elm crowns to prevent inoculation of DED fungus: new growth is not protected and most of the twig feeding occurs in tissue that is partly (crotches formed by new and old twigs) or entirely (bases of leaf petioles) new growth (Rabaglia and Lanier 1983).

Our tests, together with previously published information, suggest the following uses of insecticides in DED control programs:

Elimination of overwintering adult native elm bark beetles. Chlorpyrifos applied to the lower boles and root collars of healthy elms can eliminate overwintering beetles. A 0.5% spray applied in early spring (March-early April) or in the fall is effective through two winters (Gardener and Webb 1980). This operation can be done with a back pack sprayer but commercial equipment would be desirable for large operations.

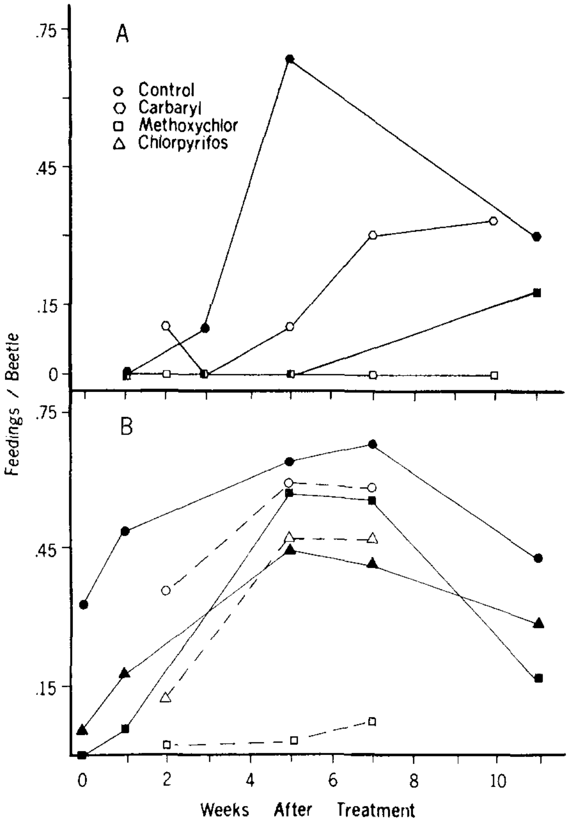

Figure 4A,B. Feeding on unsprayed and sprayed twigs (Experiment 4). Penetrations to the xylem per European elm bark beetle confined for 24 h with elm twig crotches cut at various times after treatment. A, open symbols represent treatments in October 1978 and darkened symbols represent treatments in May 1979. Controls (not shown) ranged from 0.50-0.80 in 1978 and 0.60-0.90 in 1979. B, darkened and open symbols respectively represent treatments in May and August 1983.

Prevention of feeding by native elm bark beetles. Native elm bark beetles feed in rough-barked limbs in the late summer after their emergence from elm wood and prior to moving to the lower parts of the tree to overwinter. Additional feeding occurs in the spring prior to dispersal to breeding material. Our results indicate that application of 0.5% chlorpyrifos to entire trees would kill almost all elm bark beetles (including the European species) landing on the corky bark during the year of treatment.

Killing of native and European elm bark beetle broods. DED control programs normally prescribe burning or burying beetle-infested elm wood to eliminate bark beetles that would spread the DED fungus. These operations are expensive and waste wood that could be used for timber and fuel. Chlorpyrifos applied at 0.5% would be as effective as brood wood destruction in controlling native and European elm bark beetles. Standing brood trees might be effectively sprayed with commercial equipment if removal of the tree is unnecessary or when felling is delayed. Wood from removed trees could be sprayed and stockpiled for use. Carbaryl and methoxychlor might also be employed for this use, but beetle kill would not be as complete as on wood treated with chlorpyrifos.

Prevention of colonization of green elm wood. Wood cut from healthy elms and uninfested portions of diseased trees will not be colonized if it is sprayed with 2% methoxychlor or 0.5% chlorpyrifos. Trees cut from right-of-ways or for firewood will be protected until the inner bark degrades to the point that it is no longer suitable for beetle breeding.

Augmenting the effect of trap trees. Elms killed with the herbicide cacodylic acid (Rad-E-Cate 35®, Vineland Chemical Co., Vineland, NJ) attract native and European elm bark beetles which bore into them but fail to breed owing to herbicide-induced drying of the bark (O'Callaghan et al. 1980; Lanier 1982). Recent work in Europe

(O'Callaghan et al. 1984) and New York (Lanier and Jones 1984) demonstrated that beetles are attracted to trap trees for several months after they stop boring into them. Chlorpyrifos sprayed as a 0.5% solution should kill almost all beetles that land on these trees. Attraction of the European beetle can be intensified and prolonged by baiting trap trees with Multilure (Pearce et al. 1975) (Hercon® and Conrel® baits, respectively sold by Healthchem, New York, New York; Albany International, Needham, MA) (Lanier and Jones 1984). Spraying trap trees to a height of about 5 m may be sufficient because most European beetles (Cuthbert and Peacock 1975) and probably [based on observations (Lanier unpublished) that attacks predominate on the lower bole] native beetles, land at 3-4 m height.

Preventing twig feeding by European elm bark beetles. European elm bark beetles transmit the DED fungus when they feed in twig crotches of healthy elms during their dispersal in search of breeding material. Elms are most susceptible to infection during their rapidly growing phase. Therefore, prophylactic sprays are made shortly before bud break so that twigs are protected against feeding by the spring beetle generation which usually begins to fly at about the time leaves begin to expand. Methoxychlor applied as a 2% solution is very effective as a feeding repellant, but tissue produced after spraying is not protected. Since contact toxicity of methoxychlor was limited in our tests, it seems that beetles landing on treated surfaces may be stimulated to keep moving until they find unprotected tissues. These phenomena, along with difficulties of coverage and timing, may account for marginal effectiveness of most municipal programs that spray methoxychlor to protect elms from DED (Cannon and Worley 1976). Chlorpyrifos is more toxic than methoxychlor but it does not repel feeding by European beetles which, unfortunately, may reach the twig xylem before being killed. Our results suggest that a mixture of chlorpyrifos and methoxychlor might be optimal for prophylaxis against inoculation of elms with the DED fungus where both vector species occur, or where the European elm bark beetle is predominant. Chlorpyrifos is sufficient for excellent protection where the native beetle is the major DED vector.

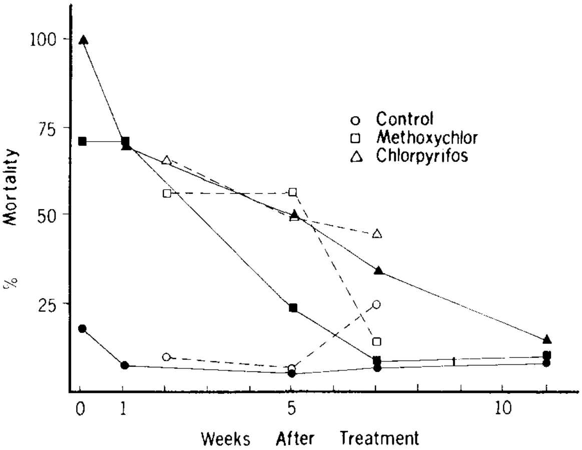

Figure 5. Percent mortality of European elm bark beetles confined with unsprayed or sprayed elm twigs (Experiment 4). Darkened and open symbols represent treatments in May and July 1983, respectively.

We conclude that insecticide applications can reduce costs and increase the effectiveness of DED control programs. Chlorpyrifos application could be substituted for destruction of infested, diseased, or cut green elm wood. Chlorpyrifos-treatment could also greatly increase bark beetle mortality inflicted by cacodylic acid-treated trap trees, especially when they are baited with Multilure, the commercial aggregation pheromone of the European elm bark beetle. Chlorpyrifos is more effective as a prophylactic against the native than the European elm bark beetle. The traditional use of methoxychlor to prevent twig feeding by the European elm bark beetle is affirmed, but this may be the least cost-effective of the operations we suggest.

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Professor, Technical Assistant, Graduate Research Assistant, and Technical Assistant, respectively.
State University of New York,
College of Environmental Science and Forestry,
Syracuse, New York 13210

ABSTRACT

FUNK, R. and R. RATHJENS. 1983. **Fertilizers and how they work.** Weeds, Trees & Turf 22(10): 26-28, 32, 34, 36, 38.

Plants require at least 16 elements for proper growth and development. Three of the elements (carbon, hydrogen, and oxygen) are provided by air and water; the other essential elements are obtained from the soil. The macronutrients (nitrogen, phosphorus, potassium, calcium, sulfur, and magnesium) are used in greater quantities than the other mineral elements absorbed from the soil. Nitrogen, phosphorus, and potassium are often called the primary nutrients because of the amount used by plants and their importance in supplemental fertilizers. The micronutrients (iron, manganese, copper, zinc, boron, molybdenum, and chlorine) are required in smaller quantities but are not less important. The so-called "acid-loving" plants have a relatively high requirement for certain micronutrients, and chlorosis caused by an iron deficiency is a common ailment when these plants are grown in alkaline soils (over pH 7.0). Because of reserves normally found in the soil, the addition of supplemental micronutrients is not often necessary unless the soil is excessively alkaline or sandy.