

SCOPE AND LIMITATIONS OF CARBENDAZIM•H₂PO₄ INJECTIONS IN DUTCH ELM DISEASE CONTROL ¹

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Since Dutch elm disease (DED) was first discovered in North America in 1929 and its full impact on our native elms became obvious, many control methods have been developed and implemented in an effort to save the elm. At first, attempts were made to eradicate the disease; when the attempts failed and it became apparent that DED was here to stay, efforts were made to restrict the spread of the disease by quarantine and sanitation measures. The quarantine measures were designed essentially to prevent movement of elm material from a diseased region to a non-diseased region. Sanitation measures were designed to reduce the populations of elm bark beetles (the insects responsible for transmitting the disease-causing fungus from infected to healthy elms) by removal and destruction of all elm material that was suitable for bark beetle breeding purposes. Despite these measures, the disease continued its rapid spread. Insecticide spray programs (first with DDT and later methoxychlor) were initiated but for the most part these failed when DDT was banned and an effective and ecologically safe substitute could not be found. To date, none of these measures, when used alone, has proved successful over the long run. Countless cities, towns, villages and countrysides have lost most of their elms to the disease. In North America DED now extends from the Atlantic to the Pacific.

Most of the early control measures were designed to reduce losses of elms within a designated control area, wherein all elms were considered equal. Therefore, once an elm became infected, regardless of its value, it was slated for removal. No elm, regardless of its historic or aesthetic value, could be protected with any assurance. However, with the development of solubilized carbendazim and various in-

jection techniques, it is now generally recognized that much more can be done to save high-value elms. Proper injection of solubilized carbendazim can prevent infection of healthy elms or arrest the disease in recently infected elms. There is, however, much controversy regarding the scope and limitations of the chemical and the injection technique, because of the lack of standardization of experiments and variation in experimental materials and conditions resulting from wide geographic separation of experiments. The purpose of this paper is to attempt to clear up some of the controversy and bring into perspective the role of solubilized carbendazim injections in the overall DED control program.

Solubilized Carbendazims

There are many ways to solubilize carbendazim (Buchenauer and Erwin 1971, Kondo et al. 1973, McWain and Gregory 1971, Gibbs and Clifford 1974) but the different soluble salts that result do not necessarily all possess the same properties. For example, some are more soluble, some more fungitoxic, some more phytotoxic, and some more stable, just to mention a few differences. We have shown that the various soluble carbendazim salts have different levels of fungitoxicity at equal concentrations (Kondo et al. 1973). Janutolo and Stipes (1976) clearly show differences in survival of *C. ulmi* conidia when these are exposed to carbendazim, carbendazim•HCl and carbendazim•H₂PO₄ at equal concentrations. This strongly suggests that although the salts are similar in that they are all carbendazim derivatives, they differ substantially in certain respects.

Although the side effects of the different salts have not been examined, it is reasonable to assume that these will differ as well. A lack of ap-

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preciation for these differences has resulted in some confusion. Therefore, it is important to employ the generic name of the chemical compound i.e., benomyl, carbendazim•HCl, carbendazim•H₂PO₄, at all times when comparing experimental results. Researchers have attempted to keep confusion to a minimum by always referring to the generic name or by stating exactly the way in which the compound was formulated. Our work involves the use of carbendazim•H₂PO₄ only. This chemical is known commercially as Lignasan-BLP and is fully registered in Canada and the United States for Dutch elm disease control.

Field Tests with Carbendazim•H₂PO₄

Extensive research involving over a thousand mature field elms has been carried out over the past 6 years by researchers at the Canadian Forestry Service, Great Lakes Forest Research Centre and the Faculty of Forestry, University of Toronto. This research has shown that healthy elms can be protected from infection if properly root injected or root-flare injected with adequate amounts of carbendazim•H₂PO₄, and that there is a good chance of arresting disease symptoms if the correct amount of chemical is properly root injected as soon as symptoms appear (Kondo and Huntley 1973, Kondo 1977).

From 1971 to 1974, 438 elms were injected with carbendazim•H₂PO₄ and extensively monitored by trained crews supervised by Great Lakes Forest Research Centre research staff (Kondo 1977). Approximately 50% of these elms were sampled at one time or another for chemical distribution during the last six years. Table 1 shows the results of the experiments after six years of monitoring these elms. Losses shown in the table are based on the condition of the trees at least one year after treatment. It is evident that no healthy elm that was root injected or root-flare injected became naturally infected during the period of chemical effectiveness. This period was determined from extensive bioassay and chemical analysis of samples obtained from elms injected with carbendazim•H₂PO₄ over a six-year period. The period of chemical effectiveness was established as two growing seasons for root injection and one growing

season for root-flare injection. Four hundred control elms associated with the treated elms became infected at a rate similar to the natural infection rate for that particular area. This varied from approximately 5% to 40%, depending on the year and the area.

Table 1 also shows that of 119 diseased elms with a Disease Index (DI) (Kondo and Huntley 1974) of less than 50 that were root injected, only nine were lost to DED over a six-year period. Detailed examinations revealed that all nine of these elms had little chemical distribution. Eight of the losses were attributed directly to poor injection techniques by one crew early in the injection season in 1973 and the other loss was attributed to little or no chemical uptake owing to the wetness of the site.

Table 1 shows that treatment of diseased elms with a DI greater than 50 usually results in high losses even during the period of chemical effectiveness. Generally the diseased elm appears to respond to treatment in the first year but gradually declines in spite of repeated injections. However, if enough chemical solution is injected yearly into the diseased elm through severed roots, the tree can be kept alive, although each year more of the elm succumbs to the disease. Eventually the elm reaches a point at which it has little or no aesthetic value owing to the yearly necessity of pruning back branches with DED symptoms.

Root-flare injections of diseased elms with a DI of less than 50 usually resulted in relatively high losses during the period of chemical effectiveness in spite of repeated yearly treatment. Eleven of the 19 diseased elms were lost within the period of chemical effectiveness. No root-flare injections of diseased elms with a DI greater than 50 were carried out.

With root-flare injection of healthy elms there was no apparent infection of treated elms during the period of chemical effectiveness. Injected elms that were not re-injected gradually returned to the degree of susceptibility of natural infection considered normal for that particular area after the period of chemical effectiveness. In general, by the second or third year after injection, the rate of natural infection of these formerly protected elms had approached a level similar to that of

Table 1^a. Condition of elms^b injected with MBC-P during the period of chemical effectiveness.

Year treated	Injection method	No. of elms treated			Total no. of treated	No. of elms lost ^c to DED during period of chemical effectiveness ^d		
		Healthy		Diseased		Healthy	Diseased	
		DI=0	DIX50	DIX50		DI=0	DIX50	DIX50
1971	(a) root	12	—	1	13	0	—	1
1972	(a) root	—	31	49	80	—	0	18
1973	(a) root	40	80	23	143	0	8 ^e	18
	(b) flare	—	10	—	10	—	7	—
1974	(a) root	29	8	1	38	0	1 ^f	1
	(b) flare	145	9	—	154	0	4	—
Totals		226	138	74	438	0	20	38

^aTable reproduced from Kondo (1977).

^bData from Central Ontario.

^c"Lost" means the elm had little aesthetic value, owing to DED; however, the elm was not necessarily dead.

^dPeriod of chemical effectiveness (a) Root injection-2 years (year of injection plus the following year). (b) Flare injection-1 year (the year of injection only)

^eThe eight losses were traced to poor chemical distribution resulting from poor injection techniques employed by one crew during a three-day period.

^fLoss resulted from little or no chemical uptake because of the site on which the elm was located.

untreated elms in the vicinity. Thus, the importance of a continued reinjection program cannot be overemphasized, once the decision is made to inject the elm.

Many cases of arrest of DED symptoms following root injection of carbendazim•H₂PO₄ in diseased elms with a DI of less than 50 at the time of treatment have been documented. These elms continue to be monitored for recurrence of the disease. In each case of total remission of the disease, the arrest of symptoms occurred in the initial year of treatment. Subsequent re-injections in some cases were undertaken as a precaution against re-infection when these elms were situated in areas of high disease incidence.

Difficulties in Comparing Research Data

Correlation of all available carbendazim injection research data from the United States, Canada and the United Kingdom is extremely difficult, if not impossible, because of the lack of standardization in experimental design. Further problems arise from unavoidable variation in experimental materials and conditions resulting from wide geographic separation of these ex-

periments. If one were to examine the available field data superficially, it would appear that the research data are variously supportive, non-supportive, or even contradictory. However, closer examination suggests that these unavoidable variations in experimental material and conditions probably account for most of the apparent discrepancies in the efficacy data of the carbendazim salts. The problem has been complicated further by the fact that some of the research findings have been extrapolated into greatly differing geographic locations without any consideration of these unavoidable variations.

Some of the more obvious unavoidable variations in experimental material are:

- 1) *different elm species and variability within a species*
- 2) *site and climatic differences*
- 3) *different species of elm bark beetle*
- 4) *variation in C. ulmi strains*

1) Elm species and variability within a species can greatly influence the outcome of carbendazim•H₂PO₄ injection and one would expect that the same would hold true with injections of other soluble salts of carbendazim. We have

found that injection of the more resistant elm species such as Siberian elm (*Ulmus pumila* L.) invariably results in total remission of Dutch elm disease. Similarly Gibbs and Dickinson (1975) suggest that there is evidence that the Wych elm (*U. glabra* Huds.) and the smooth-leaved elms including the Wheatley elm (*U. carpiniifolia* var. *Sar-niensis*) are more resistant to the disease than English elm (*U. procera* Salisb.) and it appears that the more resistant the elm the greater the benefits from carbendazim•HCl injection. Unfortunately no research data are available concerning variation in resistance in American elm (*U. americana* L.) and the relative rates of success or failure with carbendazim•H₂PO₄ or •HCl injection.

2) Site and climatic differences can greatly influence the outcome of carbendazim•H₂PO₄ injection (Kondo et al. 1973). Our injection data of the past six years generally confirm the observation that weather and site greatly affect uptake of chemical solution. There appears to be a strong relationship between the rate of uptake of the chemical and subsequent chemical distribution in the injected elm and factors that normally affect the transpiration rate such as temperature, wind, humidity and time of day. In most cases the best uptake was observed on sunny, windy days and the poorest uptake on cold, rainy days. During the night the rate of uptake of the solution declined. However, the long-term availability of water to elms greatly overrides short-term weather conditions as a factor influencing uptake and distribution of chemical solution. Consequently, chemical uptake and distribution in elms can vary greatly from one geographic location to another.

Gibbs and Dickinson (1975) report that in the UK there was no simple relationship between uptake rate of carbendazim•HCl and conditions that favor high transpiration. They frequently found better uptake on overcast days, even when there was a slight drizzle, than on hot sunny days. This strongly suggests that long-term availability of water to the elm greatly overrides short-term weather conditions. For instance, we have observed that following a prolonged period of drought, elms take up large quantities of carbendazim•H₂PO₄ solution even during short periods

of heavy rainfall during the injection.

Our findings further suggest that root and root-flare injection of carbendazim•H₂PO₄ into elms that are not under moisture stress results in better chemical distribution than does injection into elms that are under moisture stress, although the rate of uptake is superior with elms under stress. This supports our findings that injection in general should involve a minimum injection time of 24 hours.

3) Species of elm bark beetle would be expected to influence greatly the outcome of injection of salts of carbendazim because of the nature of the infection. In North America there are two principal insect vectors of the fungus, namely, the smaller European elm bark beetle, *Scolytus multistriatus* (Marsh.), and the native elm bark beetle, *Hylurgopinus rufipes* (Eichh.). Adults of the native bark beetle overwinter in niches bored in the bark of living elm trees along the main tree trunk. When adults contaminated with *C. ulmi* spores bore too deeply and penetrate the xylem tissue, the tree may become infected. Invariably when this occurs the infection becomes systemic. Also, because the native beetle normally feeds on larger branches with rough bark, there is a high risk that an infection will become systemic.

On the other hand, the European elm bark beetle normally feeds on smaller branches and twigs and therefore a large number of *C. ulmi* infections remain localized and never become systemic. Parker et al. (1941) have found that a great many infections made by the feeding activity of the European beetle do not result in a systemic infection. They report that there was evidence that the fungus sometimes died in infected elms and that sometimes the infected twigs died before the fungus became systemic.

It has been suggested by various researchers that control of DED with solubilized carbendazim is difficult when the infection becomes systemic (Kondo and Huntley 1973, Smalley et al. 1973, Gibbs and Clifford 1974, Van Alfen and Walton 1974). Therefore, control of DED with solubilized carbendazim by infection from the native beetle may be more difficult than in areas where the chief vector of the disease is the European beetle. Gibbs and Dickinson (1975) have

speculated that failure of injections of technical carbendazim•HCl in one natural infection experiment may have resulted because of the enormous amount of feeding by the European beetle and in some cases abortive breeding activity in the trunk and main branches.

In central Ontario, the principal insect vector is the native elm bark beetle; therefore, injections of carbendazim•H₂PO₄ must be undertaken more carefully to obtain the correct dosage and distribution of the chemical. Low concentrations (250.0 ppm) of carbendazim•H₂PO₄ are root or root-flare injected. Dilution of the chemical in the smaller branches and twigs is not important because most of the infection occurs in the larger branches or the trunk of the tree.

4) Variation of *C. ulmi* strains may also influence the outcome of injection of salts of carbendazim into elms because of the possibility that carbendazim-resistant strains of *C. ulmi* will develop.

Recently, reports on tolerance to carbendazim and its soluble salts in isolates of *C. ulmi* have appeared in the literature (Brasier and Gibbs 1975, Janutolo and Stipes 1976, Schreiber and Townsend 1976, Campana and Schafer 1977). Development of tolerance in *C. ulmi* under laboratory conditions after continuous exposure to sublethal concentrations of carbendazim•HCl has been reported by Brasier and Gibbs (1975) and Campana and Schafer (1977). Campana and Schafer suggest that tolerance acquired by strains of non-sexual origin is often temporary whereas strains from spores of sexual origin apparently represent a genetic change toward tolerance. Brasier and Gibbs reported that selected carbendazim-tolerant strains of *C. ulmi* were totally inhibited at concentrations of 5 ppm and that attempts to select strains tolerant to 10 ppm were unsuccessful. On the other hand, Schreiber and Townsend (1976) reported finding six isolates from a total of 26 isolates of *C. ulmi* occurring naturally which were capable of growth on agar amended with carbendazim•HCl concentrations ranging from 1 to 1000 ppm. They reported that the chemical tolerance of *C. ulmi* to carbendazim•HCl occurred naturally, and did not arise following exposure to carbendazim compounds.

We have been conducting similar investigations with carbendazim•H₂PO₄ for a number of years to monitor possible development of tolerant strains of *C. ulmi* in the field. Also, under laboratory conditions we have attempted to develop strains highly tolerant to carbendazim•H₂PO₄. On a continuing basis isolates of *C. ulmi* from elms injected with the chemical that finally succumbed to DED have been screened for tolerance. Also, isolates of *C. ulmi* from the immediate vicinity of long-term (six years) carbendazim•H₂PO₄ injection field experiments have been regularly screened for tolerance to the chemical. These isolates have been screened and compared with isolates collected from "wild" areas where no form of carbendazim has been used. To date, after examining many hundreds of strains both on carbendazim•H₂PO₄ amended malt agar plates and in shake culture tubes in Wilson's media, we have been unable to find or develop strains of *C. ulmi* exhibiting tolerance to carbendazim•H₂PO₄ at concentrations greater than 50 ppm. Natural variation in tolerance among the various strains collected ranged from 0.5 to 10 ppm. These findings appear to be in disagreement with the work of Schreiber and Townsend, but in agreement with that of Brasier and Gibbs. This discrepancy may have resulted because of a difference in the chemical formulations of carbendazim employed in the experiments.

Discussion

Dekker (1976) suggests that under natural conditions the type and abundance of the pathogen spore production may be very important in the buildup of a resistant population and that this is the reason why pathogens which produce large numbers of aerial spores such as *Aspergillus* and powdery mildews have developed resistant strains to carbendazims. On the other hand, the use of benomyl and thiophanate-methyl in controlling strawberry wilt caused by a slow-spreading pathogen that does not produce aerial spores, has not shown evidence of increased resistance in the field although fungicide-resistant strains were obtained in the laboratory. Dekker further suggests that if complete elimination of the pathogen by a fungicide is

difficult to achieve as with wilt diseases, competition by the wild type strains may counteract the spread of the resistant mutants if they should develop. Brasier and Gibbs (1975) support Dekker's thesis and state that in the case of DED it is unlikely that selection pressures will ever be great enough in the field for the development of highly tolerant *C. ulmi* strains since only a very small portion of elms will ever be treated with the chemical. Certainly our work to date strongly supports this thesis; however, we will continue to monitor *C. ulmi* strains in the field as a precaution.

From the foregoing it should be apparent that control of DED with injections of soluble formulations of carbendazim is not as easy as drilling a few holes or severing a few roots and injecting the chemical solution into the elm in a haphazard manner. These chemicals, which we could call first generation injection compounds, pose many problems. If carbendazim salts were active materials within the elm, then we would not have to rely so heavily on injection techniques. However, this is not the case; carbendazim salts are "passive" and hence we must rely on injection techniques to obtain the desired chemical distribution and resultant effect. For these reasons, the use of carbendazim•H₂PO₄ is restricted in Canada to trained individuals. The Ontario Shade Tree Council trains individuals and certifies them as competent in the use of this chemical following an intensive one-week injection course in the field.

As the use of carbendazim•H₂PO₄ injection becomes more widespread, certain aspects of the technique will become clearer.

1) There will be an initial period during which there is a high rate of success, followed by a period of increased failures as untrained or improperly trained individuals enter the elm injection field.

2) It will become obvious that the rate of uptake of chemical solutions in American elm differs in various geographic locations in North America. It appears that the more rapid the uptake, the poorer the chemical distribution, unless injection is extended over at least a 24-hour period at more dilute concentrations (250 ppm).

3) It will become very clear that the *in vivo* mode of action of carbendazim•H₂PO₄ in elms is one of the least understood areas in Dutch elm disease research today. To my knowledge, little or no basic research is being carried out to determine *in vivo* mode of action. We assume that because a chemical compound is fungitoxic *in vivo* and can be detected in certain parts of the elm at certain concentrations, it must be acting *in vivo* solely as a fungitoxicant. However, examination of the accumulating research data from the field suggests that the chemical injected into the elms may have several modes of action. It is very obvious that the fungitoxic property of carbendazim alone is insufficient to account for the high rate of success.

Conclusions

The past failures of efforts to control DED have resulted from the belief that a single control measure was all that was required. If we are to learn from our past mistakes, surely we must not rely on a single control measure, be it an insecticide spray program or a systemic fungicide injection program. Instead we should attempt to control DED in communities by means of a concerted attack using all the techniques currently available. Injection is a time-consuming and costly operation when it is properly undertaken; therefore, it should be considered only as a small part of an integrated DED control approach, and should be restricted to high-value elms. Consequently, it is important to undertake and maintain such practices as sanitation, controlled application of insecticides, and pruning of elms on a regular basis.

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ABSTRACTS

Van Haverbeke, D.F. 1976. **Forest genetics and tree improvement**. p. 154-159. *In* Shelterbelts on the Great Plains. Proc. Symp. [Denver, Colo., April 1976] Great Plains Agric. Council. Publ. 78, 218 p.

Interest in forest tree breeding and improvement has been stimulated from two directions: the almost phenomenal success story of the breeding of hybrid corn, and the stress placed on tree breeding at the Third World Forestry Congress in Helsinki, Finland in 1950. Today, many federal and state agencies, universities, and private and industrial organizations are actively engaged in forest genetics and tree improvement programs. The improvement of trees involves the same genetic principles as does the improvement of agronomic crops, except there are some obvious differences unique to trees — long life and large size. Experimental taxonomy, provenance testing, selection, progeny testing, seed orchards, and seed certification are discussed.

Peterson, G.W. 1976. **Disease of Russian-olive caused by Botryodiplodia theobromae**. Plant. Dis. Rep. 60(6): 490-494.

Russian-olive, an exotic species native to southern Europe and western and central Asia, has been planted in the Great Plains for over 60 years. Early reports of performance in state and federal experiment stations in the Great Plains indicated that Russian-olive was highly adapted to Plains conditions, and was free of serious diseases and insect pests. *Botryodiplodia theobromae* has been identified as a cause of widespread mortality of Russian-olive in shelterbelts in Nebraska and other Great Plains States. Typically, bark, cambium, and phloem tissues are killed in strips along main stems and major branches. Necrosis is rapid along stems but slow around them, thus complete girdling may take several years.