RESEARCH NOTES

Research Note No. 19
June 1976

A REVIEW OF CURRENT RESEARCH ON CONTROLS

FOR

DUTCH ELM DISEASE

by

Steven T. Bethune
Douglas J. Frederick
Martin F. Jurgensen
and
Norman F. Sloan

MICHIGAN TECHNOLOGICAL UNIVERSITY
FORD FORESTRY CENTER
L'ANSE, MICHIGAN 49946

A Review of Current Research on Controls

for

Dutch Elm Disease[1]

by

Steven T. Bethune

Douglas J. Frederick

Martin F. Jurgensen

and

Norman F. Sloan[2]

1. Supported in part by a grant from Dow Chemical Co., Midland, Michigan.

2. Respectively, Research Assistant, Assistant Professor and Associate Professors of Forestry, Michigan Technological University, Houghton, Michigan 49931.

Introduction

The first interdisciplinary meeting on Dutch elm disease (Ceratocystis ulmi (Buism.) C. Moreau) was held in Minneapolis - St. Paul, September, 1973. The most recent significant information on the causal agent, vectors and controls of this disease were summarized and discussed in the proceedings of this meeting (Burdekin and Heybroek 1975). Since 1973, a considerable amount of new information on controls has been published. The four major research areas include: (1) chemical control of the fungus, (2) chemical and biological control of bark beetles, (3) host and fungal genetics, and (4) sanitation.

It is the purpose of this brief paper to review the most recent advances in controls for Dutch elm disease. Several aspects of the disease not covered during the 1973, IUFRO meeting are also reviewed.

Chemical Control of Dutch Elm Disease

Many systemic fungicides have been investigated for possible chemotherapeutic and chemoprophylactic effects for controlling Dutch elm disease. Several chemical compounds have been tested and compared for effects on C. ulmi under laboratory conditions. The most toxic was Lignasan, followed by Actidione, Baydam 18654, benomyl and MBC chloride (all equally toxic) (Prasad and Travnich 1974). Of these, Lignasan - P has been released to commercial arborists in the province of Ontario under the control of the Ontario Shade Tree Council (OSTC). It can be injected into healthy, or partially diseased trees by two methods; root injections and lower trunk or flare injections (Kondo and Huntley 1974). These two methods can be used in conjunction on a single tree (Munro 1976).

Benomyl, and its derivatives administered using various techniques have undergone intensive investigation and show great promise for disease control. Pressure injection of benomyl or a water soluble benomyl-derived fungitoxicant has recently proven to be effective in protecting American elm (Ulmus americana

L.) from the disease (Biddle 1973; Campana et al. 1973; Campana 1975; King and Campana 1975; Prasad 1974a; VanAlfen and Walton 1974a).

Results of a study on the effects of (MBC) methyl 2-benzimidazole-carbamate, a benomyl derivative, on the viability of washed conidia of C. ulmi suggest that MBC is fungistatic at low concentrations and fungicidal at higher concentrations (Janutolo et al. 1975).

Pressurized stem injection of MBC·HCL into diseased trees at locations in Ontario and Quebec has suppressed the spread of the disease, prolonged tree life expectancy and maintained the trees in reasonable health and vigor for 2 years (Prasad 1974b). No adverse effects of high pressure injection were noted. Preparations of MBC·HCL were found less phytotoxic to shoots of Ulmus glabra Huds. (Wych elm) than MBC nitrate or bisulphate. Field trials on Ulmus x hollandica 'Belgica' (Burgsd.) Rehd. (Belgian elm) trees with MBC·HCL injected at ground level has decreased infection rates and symptom development (Gibbs and Clifford 1974).

Injection of benomyl into the soil surrounding large nursery elms has also reduced disease symptoms (Neely 1974) with little phytotoxic or other adverse effects. Roberts et al. (1973) applied benomyl as a drench to 10-month-old American elm seedlings growing in silica sand. No significant effect on height, dry weight, leaf area, or root/shoot ratio were observed. Wilson et al. (1975) found that organic matter tied up benomyl in soil mixes and inhibited growth of certain hardwood seedlings.

Foliar sprays of benomyl when applied to young American elm trees were found unsatisfactory in controlling symptoms of Dutch elm disease (Neely 1974; Holmes and McKenzie 1975).

Although the penetration and movement of benomyl into leaves is slow, appreciable amounts of the fungitoxicant seem to be absorbed through the bark, particularly the lenticels (Prasad and Travnich 1973). Prasad (1972) investigated the absorbtion of benomyl into bark by treating young and older bark with benomyl solutions. Little uptake and penetration occurred through the older bark. Movement through the young bark appeared to be related to the structure of the bark rather than to the distribution or size of the lenticels.

The fungicide Topsin M is currently being evaluated for both protective and curative measures against Dutch elm disease (Brewer and Oshima 1975).

A fungitoxicant against Dutch elm disease was recently isolated and identified in American elm seeds. It is capric acid which shows a broad spectrum of inhibition against spore germination and growth of *C. ulmi* (Doskotch et al. 1975).

Antibiotics

Antibiotics have recently been tested for possible use in prevention or therapy of Dutch elm disease. The antibiotic nystatin at high concentrations was found to be fungicidal on washed conidia of *C. ulmi* (Janutolo et al. 1975). When injected into American elms artificially inoculated with *C. ulmi*, nystatin prevented fungus growth (Costonis and Davis 1973). The Lowden formulation containing nystatin, achieved significant control when treatment and inoculation of trees occurred on the same day, but no control was achieved when treatment preceeded or followed inoculation by one week (VanAlfen and Walton 1974b).

The fungicidal activity of three new antibiotics cryptosporiopsin, scytalidin, and hyalodendrin were tested for control of *C. ulmi* and the results compared with that of nystatin, benomyl and MBC-P (a soluble phosphate salt of benomyl). Scytalidin and hyalodendrin slightly reduced the viability of *C. ulmi* in excised elm-branch sections, whereas cryptosporiopsin was ineffective (Sterner 1975).

Chemical and Biological Control of Bark Beetles

Protection of healthy elms from Dutch elm disease can be obtained through the application of various insecticides to reduce beetle feeding. A 3-year study by Lincoln (1975) showed that elms sprayed with methoxychlor had an infection rate of approximately 5 percent compared to 34 percent for unsprayed controls. Bioassay and GLC assay showed no beetle feeding on elms if methoxychlor deposits were 1.5 microgram/mm or greater on the bark surface.

The herbicide, cacodylic acid which is also toxic to bark beetles has been tested as a control for Dutch elm disease. Diets containing 900 to 4,000 ppm of cacodylic acid were effective in killing elm bark beetles in laboratory tests (Rexrode and Lockyer 1974). Preliminary results of a study by Brewer and Oshima (1975) indicate that lower numbers of beetles survive in cacodylic acid treated wood. When pressure-injected into American elm trees that had been artificially inoculated with spores of _C. ulmi_, cacodylic acid at 144g/1 was effective both in preventing beetle establishment and in destroying existing broods (Rexrode 1974). Hostetler (1975) however, reported no significant inhibitory effect on elm bark beetle brood development when cacodylic acid was injected into diseased American elms. Residues as high as 1,700 ppm caused little or no beetle mortality.

Pressure-injection of oxydemetenmethyl into American elm trees subsequently resulted in effective protection from beetle establishment and in destruction of existing brood colonies, while injection of 2, 4-D amine has proved completely ineffective in controlling beetle numbers (Rexrode 1974). Meta-Systox-R has been found effective in controlling bark beetle populations (Rexrode and Lockyer 1974).

Pheromones

According to Peacock et al. (1973) a phermone contained in the frass of virgin female elm bark beetles is responsible for the excitantturning reaction of walking male beetles in a laboratory olfactometer. However, virgin-female frass or frass extracts have failed to attract in-flight beetles in several tests (Peacock et al. 1975). The pheromone contained in virgin-female frass was compared with the aggregation pheromone in the air around virgin female elm bark beetles. GLC analysis of the two extracts revealed active chemicals in the air born extracts that were not found in the extracts of frass. Virgin-female frass is unattractive in the field because it lacks the long-range attractants required for attraction of beetles in flight. Silverstein et al. (1974) isolated and identified a combination of three chemical attractants used by the smaller European elm bark beetle. Simeone et al. (1975) recently developed an improved pheromone baited trap that attracted and caught more beetles than conventional traps and is effective for a longer period.

Antagonists

Of the various biological controls of elm bark beetle populations, parasitism by other insects is gaining renewed emphasis. Dendrosoter protuberans (Nees), a parasite of the smaller European elm bark beetle was introduced into the United States in 1964 from France. D. protuberans will overwinter successfully in Michigan (Lincoln 1975), but has had low overwintering success in Colorado (Hostetler 1975). Percent of beetles parasitized by this insect in Colorado based upon emergence for November and December was 11.3 and 19.3 percent respectively for beetle collections from American and Siberian elm (Ulmus pumila L.). For combined samples of January through March, the percent parasitized was 1.2 and 3.9 percent respectively for American and Siberian elms. A Chi square test of the average emergence of beetles and parasites in the two month-groups (i.e., November-December and January-February-March) showed the difference in ratios to be highly significant. This indicated significant mortality of D. protuberans due to some factor, possibly temperature, and that most mortality occurred between December 20 and January 23.

Genetics

Although elm species vary greatly in their susceptibility to Dutch elm disease, none are immune. Localization of infections within small branches and subsequent remission of foliar symptoms of the disease has been noted in resistant trees (Sinclair et al. 1973; Sinclair and Brener 1974; Sinclair et al. 1974; Sinclair et al. 1975a). Factors associated with resistance in elms include rapid formation of tyloses after infection (Elgersma 1973), slow suscept growth (Sinclair et al. 1974; Sinclair et al. 1975a), and subnormal development of xylem vessel elements (Sinclair et al. 1975b). Tree age also apparently affects resistance. Small seedlings have a resistance mechanism that affords some degree of protection from the disease. Schreiber (1970) has shown spore germination of *C. ulmi* to be strongly inhibited by leaf extracts from 1 to 7 month-old seedlings, but this effect disappeared in 10 to 12 month-old seedlings. The inhibitory extract was identified as dialysable. Stem extracts were less inhibitory, and extracts from seedlings over 6 months old, and from roots, increased or stimulated fungus spore germination.

Tri-specific aneuploid seedlings, resulting from crosses between *U. parvifolia* Jacq. (Chinese elm) and 2 triploid hybrids, were found highly susceptible to the disease as were crosses between *U. serotina* Sarg. (Red elm) and *U. pumila* L. (Siberian elm) (Santamour 1974). The Sapporo Autumn Gold elm, a hybrid between Siberian and Japanese elm, has been released for public trial following studies establishing its resistance to Dutch elm disease over a 15-year period (Smalley and Lester 1975). The Urban elm, a cross between a hybrid elm from the Netherlands [*U. hollandica* var. *vegeta* (Loud.) Rehd. (Huntington elm) x *U. carpinifolia* Gleditsch. (Smooth-leaved elm)] and Siberian elm exhibits resistance to Dutch elm disease and will be available in about 3 years for public trial (Anonymous 1975). Although several experiment stations have found numbers of resistant American elms, transmission of parental resistance to either seedlings or clonal progeny has been poor. However, from preliminary genetic results it appears that resistance in the Asian elms can be transmitted to seedlings and clonal progeny (Sinclair et al. 1974; Smalley 1974; Tashirc 1975; Lester and Smalley 1975).

Genetic Variation in C. ulmi

Gibbs and Brasier (1973) found that in Great Britian isolates of C. ulmi could be classified into two groups; an aggressive strain and a nonaggressive strain. Inoculation experiments on U. procera Salisb. (English elm), U. glabra (Wych elm), and U. pumila with isolates of C. ulmi from Canada, the United States, England, France, the Netherlands, and Iran confirmed earlier work on the correlation between cultural characters and pathogenicity. Inoculation of a wide range of elm clones with aggressive and nonaggressive isolates of C. ulmi provided evidence for the nonspecific resistance of elms to the disease. The highest level of resistance was found in U. pumila or in some clones containing U. pumila. One clone of U. japonica (Rehd.) Sarg. (Japanese elm) also seemed to be resistant (Gibbs et al. 1975). The cultural differences observed by Gibbs and Brasier between aggressive and nonaggressive strains of C. ulmi are due to virus infection, the aggressive strain being virus-free and the nonaggressive strain infected (Atanasoff 1973).

In Britian a strain of C. ulmi has been reported with some affinity to the "fluffy" aggressive strain, but which produces small black-brown sclerotium-like bodies in culture. A study of mating reactions showed that these isolates, known as the "proto" type, are a very fertile form of the aggressive strain, with the ability to form protoperithecia in culture and a marked tendence to "self" (Brasier and Gibbs 1975).

Extracts from Colorado isolates of C. ulmi mycelium were recently sampled for genetic variability and compared with those obtained from isolates in Wyoming, Iowa, and Massachusetts. The Colorado isolates showed no protein or isozyme variation. This indicates that the Colorado population is of recent origin and derived from a single virulent, aggressive strain. An Iowa isolate was most similar to that of the pathogenic Colorado strain suggesting that the Colorado strain was recently derived from the Iowa strain (Reeves 1974).

Toxins

The toxins produced by *C. ulmi* which produce the symptoms of Dutch elm disease have been isolated in an attempt to inactivate them through chemotherapeutic treatments. A clear non-viscous solution toxic to American elm seedlings has been isolated from *C. ulmi* culture fluid (VanAlfen and Turner 1973). Recently Takai (1973, 1974) produced a high molecular weight carbohydrate, cerato-ulmin, which when injected into elm cuttings produced typical Dutch elm disease symptoms. Takai related the pathogenicity of *C. ulmi* to the production of cerato-ulmin. Strains with high cerato-ulmin production were found to be highly pathogenic.

VanAlfen and Turner (1975) reported water-soluble glycopeptides isolated from cultures of *C. ulmi* to be the toxins involved in Dutch elm disease. These toxins act by reducing stem conductance. Dextrans of high molecular weight were found to mimic the action of the toxin in stem and petiole conductance. Disruption of the water-conducting system of elms by small quantities of compounds of high molecular weight is suggested as a possible factor in this wilt disease.

Sanitation and Dutch Elm Disease Control

A major approach to controlling the spread of Dutch elm disease is to control the population of elm bark beetles. Sanitation involves the prompt removal of dead or dying elms which are required for beetle breeding. To be successful, sanitation must be a community effort and should be combined with other control measures. Communities with good sanitation programs are holding their annual losses to 3-5 percent (Hart 1974). Cannon and Worley (1976) have reported that only municipalities that conduct an intensive disease control program which includes sanitation could expect to retain 75 percent of their elms for more than 20 to 25 years. A present study by Barger (1975) is attempting to demonstrate that annual losses can be reduced from over 6 percent to 3 percent or less with a well-managed sanitation program.

Pruning

Pruning healthy elms as a preventative or diseased elms as a cure for Dutch elm disease offers little hope individually as a control measure (Hart 1970; Hart et al. 1967). Pruning infected parts of elms showing early symptom development has recently been investigated using 62 elms pruned and traced in 1972 (Campana 1975). He found that 31 survived without disease in 1973. Survival was correlated with linear distance of disease-free wood distal to pruning cuts. The greater the length of clear wood between the pruning cut and the area of infection, the better the chances for arresting the disease. Combination treatments of solubilized benomyl and pruning showed less disease incidence than with benomyl alone or benomyl applied before pruning than with pruning alone or with benomyl following pruning.

Conclusions

Many recent approaches to the control of Dutch elm disease have been developed and each has potential for controlling this disease in the future. No single preventative or cure is likely to succeed individually but rather a combination of approaches will likely give best results.

Sanitation is still the basis for any control program and should focus on the reduction in the population of bark beetle vectors by direct control and the destruction of infected dead and dying elms which are essential for beetle breeding.

Benomyl and its derivatives appear to offer the best chemical management hope for protection of American elm and control of Dutch elm disease. New chemical formulations and solubilization has further increased this hope. Of particular note is the granting of a full commercial label to Lignasan BLP by the Environmental Protection Agency on May 12, 1976. This compound has proven highly effective in disease control during recent field testing of mature elms.

Refinements in the development of pheromones and other attractants as well as antagonists offer potential for controlling bark beetles. The most practical application of such techniques would be their use in an integrated control program.

The recognition of identifyable aggressive and non-aggressive strains of C. ulmi is a major breakthrough. The significance of this discovery lies both in its importance in long term programs for breeding resistant elms and in protecting existing elms. Control approaches and spread of C. ulmi will depend on the fungus strain and its relative pathogenicity.

New scientific information is rapidly appearing which may alter current control approaches making close cooperation between scientists essential. Only through a collaborative and interdisciplinary effort will this disease be controlled.

Literature Cited

Anonymous. 1975. The Urban elm. Mich. For. and Park Assoc. Newsletter 14(5).

Atanasoff, D. 1973. The effect of superparasites on the pathogenicity of their hosts. Phytopathology Z., 78:182-186.

Barger, J.H. 1975. Efficacy investigations of sanitation against the Dutch elm disease. USDA For. Serv. Northeastern For. Exp. Sta. No. 2251-12, 23 pp.

Biddle, P.G. 1973. Continuing the Dutch elm disease fight. Two reports on benomyl. Gardeners Cron. 173:25-31.

Brasier, C.M., and J.N. Gibbs. 1975. Highly fertile form of the aggressive strain of _Ceratocystis ulmi_. Nature 257:128-131.

Brewer, J.S., and N. Oshima. 1975. Dutch elm disease. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-63394-1.

Burdekin, D.A., and H.M. Heybroek (Eds.). 1975. Dutch elm disease. Proc. of IUFRO Conf. USDA For. Serv. Publ., 94 pp.

Cannon, W.N. Jr., and D.P. Worley. 1976. Dutch elm disease control: Performance and costs. USDA For. Serv. Res. Pap. NE-345, 7 pp.

Campana, R.J. 1975. Pathology of wilt diseases of trees. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-11948-6.

Campana, R.J., Gregory, G., and T. Jones. 1973. Arrest of symptom development in Dutch elm disease with pressure injection of solubilized benomyl. In: Abstr. Pap., 2nd Int. Congr. Plant Pathol., Minneapolis.

Costonis, A.C., and H.F. Davis. 1973. Possibility of controlling Dutch elm disease with an antibiotic. In: Abstr. Pap., 2nd Int. Congr. Plant Pathol., Minneapolis.

Doskotch, R.W., Keely Jr., S.L., and L.R. Schreiber. 1975. Isolation and identification of an antifungal agent from seeds of American elm. Phytopathology 65:634-635.

Elgersma, D.M. 1973. Tylose formation in elms after inoculation with _Ceratocystis ulmi_, a possible resistance mechanism. Neth. J. Plant Pathol. 77: 218-220.

Gibbs, J.N., and C.M. Brasier. 1973. Correlation between cultural characters and pathogenicity in _Ceratocystis ulmi_ from Britain, Europe and America. Nature 241:381-383.

Gibbs, J.N., and D.R. Clifford. 1974. Experiments with MBC derivatives for the control of Dutch elm disease. Ann. Appl. Biol. 78:309-318.

Gibbs, J.N., Brasier, C.M., McNabb Jr., H.S., and H.M. Heybroek. 1975. Further studies on pathogenicity in Ceratocystis ulmi. Eur. J. For. Pathol. 5: 161-174.

Hart, J.H. 1970. Attempts to control Dutch elm disease by pruning. Plant Dis. Rep. 54:985-986.

Hart, J.H. 1974. Dutch elm disease control. Copy of talk given at 44th Annual Michigan Turf grass Conf., Jan. 15, 1974.

Hart, J.H., Wallner, W.E., Caris, M.R., and G.K. Dennis. 1967. Increase in Dutch elm disease associated with summer trimming. Plant Dis. Rep. 51: 476-479.

Holmes, F.W., and M.A. McKenzie. 1975. Pathology of wilt diseases of trees. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-14795-5.

Hostetler, B.B. 1975. Studies on the smaller European elm bark beetle. Masters Thesis, Colorado State Univ., Fort Collins, 21 pp.

Janutolo, D.B., Salyer, T.D., and R.J. Stipes. 1975. Effect of fungitoxicants on the viability of Ceratocystis ulmi conidia. Ann. Proc. Amer. Phytopathol. Soc. 1974, 1:151-152.

Kind, E.J., and R.J. Campana. 1975. Prophylactic and therapeutic effect of methyl-2-benzimidazolecarbamate hydrochloride (MBC-HCL) against Dutch elm disease in nursery elms. Ann. Proc. Amer. Phytopathol. Soc. 1974, 1:31.

Kondo, E.S., and G.D. Huntley. 1974. A large capacity injection system for chemical solutions in Dutch elm disease control. Can. For. Serv. No. 0-X-192.

Lester, D.T., and E.B. Smalley. 1975. Breeding for disease resistance in Ulmus. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-59809-3.

Lincoln, A.C. 1975. Biology and control of insect pests of shade trees in Northeastern U.S. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-213-4.

Munro, G. 1976. Recent work with soluble benlate in Canada. J. Arboricult., 4:74-76.

Neely, D. 1974. Efficacy of soil injections and foliar sprays of benomyl for the control of Dutch elm disease in large nursery elms. Plant Dis. Rep. 58:261-264.

Peacock, J.W., Silverstein, R.M., Lincoln, A.C., and J.B. Simeone. 1973. Laboratory investigations of the frass of Scolytus multistriatus (Coleoptera: Scolytidae) as a source of pheromone. Envir. Entomol. 2:355-359.

Peacock, J.W., Cuthbert, R.A., Gore, W.E., Lanier, G.N., Pearce, G.T., and R.M. Silverstein. 1975. Collection on porapak Q of the aggregation pheromone of Scolytus multistriatus (Coleoptera: Scolytidae) J. Chem. Ecol. 1:149-160.

Prasad, R. 1972. Translocation of benomyl in elm (Ulmus americana L.). II. Some environmental factors affecting uptake and distribution by roots. III. Retention on and penetration through bark. Infor. Rep., Chem. Control Res. Inst., Canada.

Prasad, R. 1974a. Translocation of benomyl in elm (Ulmus americana L.) VIII. Prevention of the Dutch elm disease, Ceratocystis ulmi (Buism.) Moreau, in mature trees following pressurized trunk injections. Infor. Rep., Chem. Control Res. Inst., Canada. No. CC-X-73, 14 pp.

Prasad, R. 1974b. Translocation of benomyl in elm (Ulmus americana L.). VII. Application of the trunk injection method for suppression of the Dutch elm disease, Ceratocystis ulmi (Buism.) Moreau, in land mark and historical trees. Infor. Rep., Chem. Control Res. Inst., Canada. No. CC-X-72, 16 pp.

Prasad, R., and D. Travnich. 1973. Translocation of benomyl in elm (Ulmus americana L.). IV. Uptake and movement through the foliage under laboratory and field conditions. Infor. Rep., Chem. Control Res. Inst., Canada.

Prasad, R., and D. Travnich. 1974. Evaluation of fungicides for control of tree diseases. II. Screening against the Dutch elm disease, Ceratocystis ulmi (Buism) Moreau under laboratory conditions. Infor. Rep., Chem. Control Res. Inst., Canada. No. CC-X-75, 15 pp.

Reeves Jr., F.B. 1974. Genetic variation in Ceratocystis ulmi. Amer. J. Bot. (Abstr.). 61:24, (5, Suppl.).

Rexrode, C.O. 1974. Effect of pressure-injected oxydemetenmethyl, cacodylic acid, and 2, 4-D amine on elm bark beetle population in elms infected with Dutch elm disease. Plant Dis. Rep. 58:382-384.

Rexrode, C.O., and J.W. Lockyer. 1974. Laboratory assay of cacodylic acid and meta-systox-R on Scolytus multistriatus and Pseudopityophthorus sp. USDA For. Serv. Res. Note NE-190, 4 pp.

Roberts, B.R., Hock, W.K., and L.R. Schreiber. 1973. The effect of benomyl on the growth of American elm seedings. Phytopathology 63:85-87.

Santamour Jr., F.S. 1974. Resistance of new elm hybrids to Dutch elm disease. Plant Dis. Rep. 58:727-730.

Schreiber, L.R. 1970. Viability of Ceratocystis ulmi in young seedlings of American elm and the effects of extracts from their tissues on conidial germination. Phytopathology 60:31-35.

Silverstein, R.M., Pearce, G., Gore, W., Peacock, J., Cuthbert, R., Simeone, J., Lamier, G., and W. Jones. 1974. Research team finds Dutch elm disease control. Newsletter of the State Univ. New York, Coll. Envir. Sci. and For., Sept., 4 pp.

Simeone, J., Lanier, G., and R.M. Silverstein. 1975. Elm Res. Inst. Progress Rep., Spring, 3 pp.

Sinclair, W.A., Zahand, J.P., and J.B. Melching. 1973. Localization of infection in American elms resistant to Ceratocystis ulmi. Phytopathology 63:207 (Abstr.).

Sinclair, W.A., and W.D. Brener. 1974. Dutch elm disease in clones from white elms resistant and susceptible to Ceratocystis ulmi. Phytopathology 64:675-679.

Sinclair, W.A., Welch, D.S., Parker, K.G., and L.J. Tyler. 1974. Selection of American elms for resistance to Ceratocystis ulmi. Plant Dis. Rep. 58: 784-788.

Sinclair, W.A., Zahand, J.P., and J.B. Melching. 1975a. Localization of infection in American elms resistant to Ceratocystis ulmi. Phytopathology 65:129-133.

Sinclair, W.A., Zahand, J.P., and J.B. Melching. 1975b. Anatomical marker for resistance of Ulmus americana to Ceratocystis ulmi. Phytopathology 65:349-352.

Smalley, E.B. 1974. Elm. McGraw-Hill Yearbook Sci. and Technol. McGraw-Hill,New York, 3 pp.

Smalley, E.B., and D.T. Lester. 1975. The nature of Dutch elm disease resistance in Ulmus. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-59809-3.

Sterner, T.E. 1975. Evaluation of new compounds in arresting growth of Ceratocystis ulmi in elm branch sections. Plant Dis. Rep. 59:638-640.

Takai, S. 1973. Cerato-ulmin, a wilting agent of the Dutch elm disease fungus. In: Abstr. Pap., 2nd Int. Congr. Plant Pathol., Minneapolis.

Takai, S. 1974. Pathogenicity and cerato-ulmin production in Ceratocystis ulmi. Nature 252:124-126.

Tashirc, H. 1975. Biology and control of insect and mite pests of elm. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-7725-4.

VanAlfen, N.K., and N.C. Turner. 1973. The plugging of elm seedlings stems by Ceratocystis ulmi toxin. In: Abstr. Pap., 2nd Int. Congr. Plant Pathol., Minneapolis.

VanAlfen, N.K., and G.S. Walton. 1974a. Pressure injection of benomyl and methyl-2-benzimidazolecarbamate hydrochloride (MBC·HCL) for the control of Dutch elm disease. Phytopathology 64:1231-1234.

VanAlfen, N.K., and G.S. Walton. 1974b. An evaluation of the Lowden formulation containing nystatin for Dutch elm disease control. Plant Dis. Rep. 58:924-926.

VanAlfen, N.K., and N.C. Turner. 1975. Influence of a Ceratocystis ulmi toxin on water relations of elm (Ulmus americana). Plant Physiol. 55:312-316.

Wilson, C.L., Schreiber, L.R., and W.K. Hock. 1975. Nature and control of Dutch elm disease and other diseases of shade trees. Notice of Res. Proj. Smithsonian Sci. Infor. Exch., No. GY-18209-5.