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CHEMICAL CONTROL OF INFECTION BY HONEY FUNGUS, *ARMILLARIA MELLEA*: A REVIEW[1]

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Accounts of the biology and general principles of the control of honey fungus, *Armillaria mellea* (Vahl, ex. Fr.) Kummer occur frequently in scientific and technical literature. Since the time of the last general article on the biology and control of honey fungus in the Journal (Pawsey, 1973) a two-year program of laboratory research and field trials examining the effectiveness of Armillatox, a proprietary phenolic emulsion (manufactured by Armillatox Limited, 44 Town Street, Duffield, Derby) has been completed at the Commonwealth Forestry Institute, Oxford. This present review of the range of chemical control methods recommended for use against honey fungus is based on a literature survey associated with the recent work at Oxford.

The most comprehensive and relatively recent review of literature on the control of honey fungus is that of Sokolov (1964). This has been the subject of translation from the Russian by the Canadian Department of Forestry 1966 (Translation No. 37) and includes a full account of the biology of the fungus and describes a range of the author's own experiments in the control of infection. Unfortunately the value of this lengthy document is adversely affected by anomalies (possibly introduced in the translation) and by the small amount of experimental detail which prevents the reader from assessing the validity of the author's conclusions on the results obtained. Nevertheless, it is an important document and has been drawn on considerably in the preparation of this present document.

Throughout the survey of information in scientific and trade journals, many instances were found where it was difficult to distinguish between (a) loose first-hand accounts of attempts at control, (b) second-hand recommendations for the use of particular chemicals and methods, and (c) folklore. It seems incredible that the chemical control of this almost uniquitously widespread fungal disease, which is the cause of serious economic losses in a wide range of tree and other crops, should have attracted so little and such poor quality experimentation for so long. The only redeeming chapter in this bewildering and rather depressing story is the development and practice of soil fumigation with carbon disulphide which has been centered largely in citrus and other fruit crops in California.

Many studies have been made of the effect of fungicides on the growth of *A. mellea* on synthetic media under laboratory conditions, but it is not relevant to review such work here. The difficulties and cost of fungicide application in the field in circumstances where huge residual sources of infection are often present in stumps and large roots and from which rhizomorphs extend through the soil over large areas, prevent consideration of the use of many fungicides for commercial control purposes, even of those shown to be very effective against the fungus in agar culture.

The Use of Carbon Disulphide in Orchard Crops

Fumigation of soil with carbon disulphide prior to the planting of a replacement tree crop was apparently first employed in Europe (Girard, 1894, in France, and Oberlin, 1894, in Germany)

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but the technique has been developed mostly in North America, notably in California (Horne, 1914; Fawcett, 1925; Thomas and Lawyer, 1939; and Bliss, 1946 and 1951). Bliss (1951) compared the effect of nine chemicals (carbon disulphide, chloropicrin, chlorine, sulphur dioxide, ammonium hydroxide, ethylene oxide, dichlorethyl ether, tetrachlorethane and formalin) on the activity of *A. mellea* in pieces of citrus root buried in the soil. Carbon disulphide, chloropicrin and ethylene oxide were shown to be most effective in depressing the viability of the fungus. Carbon disulphide, although less toxic than the other two chemicals, was best-suited for field use because of its high vapor pressure and ability to penetrate deeply through the soil. Bliss observed that in fumigated *Armillaria*-infected roots which were subsequently incubated in nonsterile soil, the activity of *Trichoderma viride* (an extremely common and widespread soil-inhabiting fungus) appeared inversely proportional to that of *A. mellea.* Following a series of experiments he concluded that when the fumigant was applied to orchard soil, the destruction of *A. mellea* was primarily due to the antibiotic activity of *T. viride.* Later, Garrett (1957) demonstrated that carbon disulphide affected the growth of *A. mellea* directly, and that this contributed to the antagonistic effect of *T. viride.* In commercial practice, injection of the soil with carbon disulphide (to a depth of one foot at staggered 18 inch intervals, at a rate of 302 gals per acre) is preceded by the physical removal of stumps and the main lateral roots of the old crop. Such treatment is expensive and requires the vigorous supervision of skilled staff, but in the highly productive citrus orchards of California, the cost-effectiveness of the treatment has apparently been proved in commercial practice over a long period of years.

The Ministry of Agriculture Advisory Leaflet on Armillaria root rot (1970) suggests that in Britain, with its generally colder and wetter soils (than California!) the effectiveness of carbon disulphide against honey fungus infection is likely to be uncertain. The 1961 edition of Forestry Commission Leaflet No. 6 (Honey Fungus) mentioned the possible use of carbon disulphide against the disease in Britain. However, very little experimental work on its use in this country has been carried out, and in view of the toxicity and other hazards associated with the material, particularly when handled by unskilled staff, its use has since been strongly deprecated.

Other Chemical Treatments

The task of reviewing the nature and effectiveness of the treatments involving the wide range of other chemicals used against honey fungus is complicated by the fact that so many of the original accounts were published in practical rather than professional or scientific journals, and the exact nature of the treatments and the assessment of their effect on infection were often inadequately or ambiguously described. In many cases, recommendations were made without any reference to experimental work. In a proportion of the original accounts referred to below, it is not clear whether the methods were recommended for protective or remedial treatment of trees, or whether the treatment was intended only to minimize the infection reservoir potential of severely infected or already-killed root systems, or stumps.

Iron and Other Sulphates

Ferrous sulphate is the substance most commonly referred to in accounts of attempts to control natural infection by *A. mellea.* Some accounts refer unspecifically to the use of iron sulphate, but it is assumed that in such cases only the ferrous salt was involved. Gard (1925), in France, recommended the application of ferrous sulphate to the soil at the base of trees. According to him this prevented spore germination and inhibited the growth of the fungus. Some authors refer to the effectiveness of exposure of roots to sunlight, followed by application of ferrous sulphate (and some other materials). The use of this technique in Australia was referred to briefly by Quinn (1924), and in more detail by Thomas and Raphael (1935) in Tasmania, who recommended that the major roots of fruit trees should be uncovered and left open to the action of sunlight, and this followed by two or three applications of ferrous sulphate (1 lb in 4 gallons of water) at intervals of 3-4 weeks. They also state that potassium permanganate solution (½ ounce in 4 gallons of water) applied in the same way also proved effective in checking the development of the fungus. In France (Gard, 1925) recommended for serious infection of walnut that following exposure of the roots, rhizomorphs and affected parts of roots should be removed, and then treated with ferrous sulphate, sulphuric acid, and other fungicides, such as copper sulphate. Barss (1923) working in orchards in Western Oregon, recommended exposure and excision of affected roots followed by the application of Bordeaux mixture paste. He also advocated that the collar region be left exposed to light and air throughout the summer.

Carne (1926) reported from Western Australia that the spread of serious Armillaria root rot in citrus could be prevented by up-rooting and burning badly-affected trees and dressing the soil with ferrous sulphate or quicklime. With slightly-affected trees, all rotted areas of roots should be excised and the remaining roots treated with ferrous sulphate or Bordeaux mixture paste.

Bork (1935) and Pittman (1949) refer to the use of ferrous sulphate in Malta and South Australia, respectively, and Chanturiya (1947) noted the favorable effect of 5% ferrous sulphate solution alone, or combined with potassium permanganate, against infection of mulberry seedlings in Georgia, USSR. Cristinzio (1942) stated that good results could be achieved during early stages of infection of walnut simply by placing pieces of iron sulphate (weighing 100-150 gms) in the soil at the base of affected trees. Pittman (1949) also refers to the sprinkling of crystals of ferrous sulphate evenly over an area of undisturbed soil extending well out into the space between adjacent trees, at the rate of 3-4 lbs per tree.

Sokolov (1964) suggested that ferrous sulphate introduced into the soil (normally as a 10% solution in water) had a negligible direct effect on the fungus but increased the tree's resistance to infection.

Muller (1939) described the treatment of soils in citrus plantations in Java with 1.5-3.0 kg of sulphurous volcanic ash per cubic meter of soil, while Fluiter (1939) suggested the introduction of sulphur into the planting holes shortly before planting on sites where infected stumps and roots had been removed a year or so before.

In view of the many references to the use of ferrous sulphate treatment against honey fungus in different parts of the world, it is surprising that no information could be found in the literature of any valid field trials with this material under conditions in Britain. The lack of recent references to ferrous sulphate in the world literature suggests that this treatment is seldom used commercially now. From the literature quoted above, the authors were unable to make a valid assessment from the evidence presented of the actual efficacy of ferrous sulphate treatments.

Lime

Reference has been made commonly to the advantageous effects of lime application to soil on sites infected by honey fungus, but the validity of such recommendations is far from clear. The nature of the relationship between soil pH and the potential of *A. mellea* to cause infection on any particular site is very poorly understood, and observations on this relationship are confounded by (a) qualitative and quantitative characteristics of the tree population on the site, (b) the wide range of factors affecting tree growth and susceptibility to infection, (c) the effect of lime on nutrient uptake by roots, and (d) the infective substrate potential of the site. As far as can be judged the recommendations for the various uses of lime in controlling *A. mellea* have taken little account of the factors listed above, and no satisfactory data have been found which could form the basis for an objective analysis of the effects of such treatments.

Accounts which recommend the disinfecting use of lime against infection by honey fungus include those of Viennot-Bourgin (1949), Verona (1950) in Italy, Marchal and Foex (1931) in France, and Twarowski and Twarowska (1959) in Russia.

Marchal and Foex (1931) investigated the relationship between walnut root rot caused by *A. mellea* and lime deficiency of the soil. They apparently confirmed previous impressions that there was an inverse relationship between the lime content of the soil and the severity of infection on particular sites. Twarowski (1953) recommended treating the soil in Polish spruce woods with 0.1 to 0.3 kg of lime per square meter. Cartwright and Findlay (1946) advocated abundant liming of acidic soils (in association with the removal of stumps in parks and gardens) but this was based on the opinion (largely unconfirmed) of other workers and not on original observations. The whole literature on the chemical control of *A. mellea* is bedevilled by the reiteration of subjective observations of other workers.

Formalin

A number of authors have recommended the use of formalin in the control of infection by honey fungus, e.g., Viennot-Bourgin (1947), Chanturiya (1947) and Sokolov (1964). Sokolov (1964) reported at length on his work in Russia on a wide range of treatments against honey fungus including formalin treatment , but in his complex account the details of the treatments, the circumstances of infection in the treated areas and the nature of the results achieved are all described very imprecisely. The evidence of Sokolov's field experiments with formalin conflicted markedly with the effects of the material that he observed on infected roots under laboratory conditions. He concluded that field treatments of formalin had an insignificant control effect in the northern forest areas in which the work was carried out. With the introduction of any volatile fumigant into the soil, the effectiveness of the treatment is much affected by soil temperature, and this probably accounts for some of the discrepancies in results achieved with such materials in different parts of the world.

For more recent observations on the use of formalin in Britain, see the description given later of the results of field trials with Armillatox.

Mercuric Chloride

Reitsma (1932) suggested from experimental work that mercuric chloride could be used in the treatment of infected root systems. He also referred to the use of "germisan" and "uspulun", which the present authors have not been able to identify. Pettinga (1950) in Holland, reported the effectiveness of the treatment of exposed infected roots with 0.1% mercuric chloride solution, which was also applied to the stem base to a height of one meter above ground level.

Iodine

Guyot (1933) apparently obtained encouraging results in the control of *A. mellea* in pines in France by the treatment of exposed roots with 0.5% iodine solution.

Cyanamides

Voglini (1929) described successful control of the disease on infected mulberries following the incorporation of 3-5 kg of calcium cyanamide into soil in a trench dug at a radius of one meter around the affected trees. Chantiruya (1947) recommended treating the soil with potassium cyanamide at a rate of 1.0-1.5 kg per square meter.

Stump Treatments

Sokolov (1964) strongly recommended the treatment of the surface of infected stumps and the surrounding soil with sodium fluoride. Twarowski and Twarowska (1959) stated that soil treatment with lime (mentioned earlier) should be supplemented by treatment of stumps with sodium fluoride. In rubber and oil palm plantations in Africa, Steyaert (1948) advocated disinfecting stumps and roots with sodium arsenite.

Before describing the results of more recent chemical soil treatments, it is perhaps relevant to make brief mention of the work on therapeutic injection of tree trunks with a range of chemicals described by Sokolov (1964). The substances used were aqueous solutions of rodananilin, tetramethylthiuramdisulphide (TMTD) at a concentration of 0.1%, copper sulphate at 5%, and a coded and unidentified fungicide. The assessment of the effects of these treatments was unsatisfactory, but there was apparently no evidence of any significant control effect on infection of *A. mellea* in the treated trees.

RECENT OBSERVATIONS

Boric acid

Following initial laboratory experiments on a range of chemicals, Hekso (1971) in Czechoslovakia tested the use of boric acid against root infection by *A. mellea* on living trees and in stumps of *Abies alba.* 3% boric acid solution was apparently applied to the soil surface and to the base of the trees at 0.5-1.0 liters per square meter. Over a period of two years following the time of treatment, no sporophores of *A. mellea* were produced in the treatment plots, although abundant fructifications occurred on the untreated control stumps. No detailed information is given on the method of assessing the degree of infection of standing trees, but the account states that the condition of the treated trees improved, as compared with that of the untreated trees. Following this report of the apparent effectiveness of boric acid, Pawsey and Rahman (1976) included treatment with 3% boric acid, in a small comparative field trial (in a program of field research on Armillatox, see later) in a badly infected eleven-year-old plantation of Scots pine at Elveden in West Fuffolk. In April 1974, two gallons of 3% boric acid solution were applied to the undisturbed surface of the soil within 15 inches radius of the base of individual trees (as described for standard Armillatox treatment by Pawsey and Rahman (1974). The boric acid treatment was replicated on five trees and the effect of treatment assessed after six months (in September, 1974). These trials were concerned primarily with the protective effect of treatment in terms of the activity of rhizomorphs in the soil, and the standard method of assessing rhizomorph activity is referred to later (under Armillatox treatments) and is described by Rahman (1974) and by Pawsey and Rahman (1974). Assessment indicated that the regenerative capacity of the rhizomorphs sampled from the plots treated with boric acid was less than 5% of that of those sampled from the untreated control plots, and there was no evidence of significant phytotoxic effect of boric acid on the Scots pine roots in the treated soil. Further details of this trial are given by Pawsey and Rahman (1976), and the results suggest that further examination of the use of boric acid and other borax compounds against *A. mellea* could be profitable.

Maneb

Denizet (1971) stated that infection by *A. mellea* had been controlled in an area of 2,500 hectares of *Pinus pinaster* in the Landes area of France over a period of twenty years, as a result of treatment involving the application of iron chelate and maneb (manganous ethylene-bis-dithiocarbamate) to the soil at the base of diseased trees, combined with insecticide treatment against unspecified insect infestation. No details were given of the treatments concerned, or of the methods by which the results were assessed. According to Denizet, of the 150-170 patches of infected trees which were treated, only two did not respond to treatment. In view of the success claimed against active infection over a period of years, the lack of detail in this account is most regrettable.

In the Elveden trial in 1974, referred to above, Pawsey and Rahman (1976) included standard treatment of three trees (i.e., two gallons to the undisturbed soil within 15 inches radius of the stem base) with 1% maneb in water prepared from an 80% wettable powder formulation. At assessment in September 1974, the regenerative ability of the rhizomorphs sampled from the plots treated with maneb as 50% that of those taken from the untreated control plots (as compared with 34% following treatment with 1:12 Armillatox, see later, and less than 5% with 3% boric acid in the same trial). No evidence of phytotoxicity was seen on the roots in the maneb-treated plots.

Sodium Pentachlorophenate

Rykowski (1974) reported the successful use of sodium pentachlorophenate in the control of infection by *A. mellea* in Scots pine plantations in Poland. In the field trials described, the material applied was a solution in water containing 50,000 ppm sodium pentachlorophenate (50g active ingredient—in a 20% proprietary formulation—in 1 liter of water). Treatment of the soil around infected trees was carried out in the spring of 1969, but the exact method of application and the amount applied per tree is not clear. It appears that the trials were carried out in three localities, and in each locality treatments were applied to trees in an area of about 2.5 hectares, with trees in separate but comparable areas remaining untreated for control purposes. In the different localities, plantations of 6-year, 5-year, and 1-year-old, respectively, were chosen. Treatments were repeated in the spring of 1971, and an assessment of the condition of the trees made each year up until 1972. Assessment was based on the external appearance of the trees, and Rykowski describes a decrease in the severity of infection damage associated with treatment in the trials in the localities containing the 6-year and 5-year-old trees. Over the four-year observation period, no evidence of phytotoxic effect on the roots of the treated trees was observed.

Armillatox

Bray (1970) reported the use of refined creosote (i.e., creosote from which a proportion of the toxic phenols had been removed) as an apparently effective treatment against active infection by *A. mellea* on a range of living trees in a badly-affected garden site in Surrey. Following this preliminary work with creosote, Bray and her associates were responsible for marketing a proprietary fungicide in Britain, under the name of Armillatox. The material was described as a phenolic emulsion containing 48% of the active ingredient emulsified with a vegetable soap. The material is readily miscible with water and was recommended by the manufacturers to be applied to the soil and to the surface of exposed roots in a mixture containing 1 part of Armillatox to 12 parts of water. Claims were made by the manufacturers of a remedial as well as a protective effect of Armillatox treatment, but until the commencement of research at the Commonwealth Forestry Institute, Oxford, in 1972, no detailed field experimentation had been devoted to it.

Redfern (1971) examined the effectiveness of Armillatox against *A. mellea* in pot culture, and also the extent of phytotoxicity damage associated with the treatment of potted saplings. He described the reduction of growth of rhizomorphs caused by a range of concentrations of Armillatox applied to soil in pots containing infected wood block inocula. The treatment of potted saplings of pine and sycamore with 1:12 dilution Armillatox resulted in some death of small roots of both species. In discussing his results, Redfern emphasized the difference between the conditions in his experiments and those in freely-drained natural soil systems, and observed that a proper evaluation of the effectiveness of Armillatox against *A. mellea* could only be achieved by field experiments under a range of natural soil and site conditions.

Detailed investigations on the biology of *A. mellea* (Redfern 1966) and in other countries where rhizomorphs are the main means by which root infection is initiated, have indicated that the highest incidence of rhizomorph infection occurs in the upper part of the root system close to the base of the stem. If chemical treatments applied periodically to the soil in this area can significantly depress the activity and infection potential of rhizomorphs, without adverse effects on root growth, a considerable degree of protection of the trees against infection by honey fungus could be achieved.

Pawsey and Rahman (1974) described the results of field trials in a large area of young Scots pine seriously infected by *A. mellea,* at Elveden (Warren Wood) in West Suffolk. The area had been planted in stages after the clear-felling of mature oak woodland in 1956. The soil, typical of the Breckland area, was of deep, freedraining sandy type, with pH varying from 5.0 to 7.0 in different parts of the experimental area. They described the results of three experiments involving the treatment of Scots pine, ranging from 9- to 14-year-olds, which commenced in late April 1973. Before treatment, trees were graded into three classes according to the severity of crown symptoms associated with root infection by honey fungus. Preliminary examination of many trees on the site established that the roots of all trees were closely associated with considerable populations of rhizomorphs present in the soil. In one experiment (A), 14-year-old trees were treated in the manner then recommended by the manufacturers, i.e., with exposure of the main lateral roots within a 15 inch radius of the stem base, and application of 1:12 Armillatox (at 2 gallons per tree) to the exposed roots and to the soil as it was replaced in layers. In experiment

(B), 10-year-old trees were treated once with different concentrations of Armillatox (1:4, 1:8, and 1:12), the material being applied to the unbroken soil surface within 15 inches radius of the stem base. In experiment (C), the undisturbed soil at the base of 14-year-old trees was treated on three occasions at two-month intervals with 1:4, 1:8, and 1:12 Armillatox. The experiments were finally assessed in October 1973, but two-month observations were made during the course of the experiments on the general appearance of the crowns of the trees. The effect of treatment on rhizomorphs was assessed by a cultural technique involving the incubation in moist sand of a proportion of the rhizomorph population harvested from the treated area of soil, and from comparable untreated plots. The regenerative capacity of these rhizomorph samples was measured after one month's incubation in sand. Further detail on this assessment method is given by Rahman (1974) as well as by Pawsey and Rahman (1974). In each of the above experiments the percentage of rhizomorphs which showed ability to regenerate was markedly affected by Armillatox treatment, varying from 11% (as compared with rhizomorphs harvested from the soil around untreated control trees) to zero percent (i.e., complete supression of rhizomorph growth). The mean extent of new rhizomorph growth in sand per unit length of the original sand-incubated rhizomorph samples was similarly affected by Armillatox treatment. The difference between rhizomorph regenerative ability in treated and untreated plots in all three experiments was highly significant statistically.

On exposure of the Scots pine roots at the time of rhizomorph sampling, there was no evidence of phytotoxic damage to roots (other than to the smallest roots) in the treated area of soil caused by any of the treatments, even by repeated application of 1:4 Armillatox. Visual assessment of the condition of the crowns of trees in the experiment, and also the results of cultural assessment of the condition of mycelium beneath the bark of roots in treatment plots, gave no indication of any remedial effects of any of the treatments on established infection.

During the period of the above experiments at Elveden in 1973, the effects of various concentrations of Armillatox on the roots of other tree species on the same site were examined (Pawsey and Rahman, 1976). Two gallons of the material were applied once, in June, in the standard fashion at concentrations of 1:4, 1:8, and 1:12 around the base of small trees (6-12 ft in height) of the following species: — Norway spruce, European larch, sycamore, oak, and sweet chestnut. With the hardwood species, the effects of the treatment were judged by the superficial appearance of the foliage of treated and untreated trees in 1973 and 1974, but in the larch and spruce, assessment also involved examination of the root system in the treated area of soil six months after treatment. Evidence of phytotoxicity was confined to the death of a proportion of very small roots in the treated area of soil, and even with 1:8 and 1:4 Armillatox treatment there was no evidence of significant damage to roots over 0.5 cm in diameter.

In 1974, a further trial was carried out in Warren Wood, Elveden, in a compartment of 11-year-old Scots pine immediately adjacent to that used in 1973 for experiment (B) (above). Standard treatments with 1:12 and 1:16 Armillatox (as described above) were compared with treatments with 3% boric acid, 1% maneb, and 2% copper sulphate. All treatments were applied at 2 gallons per tree in April 1974, and rhizomorphs were sampled for laboratory assessment in September 1974. The results of this trial are described in detail by Pawsey and Rahman (1976). Although the regenerative ability of the rhizomorphs in the 1:12 Armillatox treatment plots was reduced as compared with the untreated controls, the effect of treatment with this material was far less marked than that recorded in the trials on the same site in 1973. As compared with the rhizomorphs from untreated control plots, the regenerative ability of incubated rhizomorphs subjected to the different treatments was as follows: — 1:12 Armillatox, 34%; 1:16 Armillatox, 84%; 3% boric acid, 4.2%; 1% maneb, 59%; and 2% copper sulphate, 49%.

Also in 1974, a series of experiments with Armillatox under entirely different site conditions was commenced in Alice Holt Forest, Surrey. The detailed results of these experiments and others in the Forest of Dean and else where are described by Rahman (1974), and Pawsey and Rahman (1967). In the main experiment in Alice Holt Forest, replicated treatments with 1:12 Armillatox were applied to 12-year-old trees of Lawson cypress, Western red cedar, Serbian spruce, grand fir, Japanese larch, and Western hemlock. The trees were in plots in a species trial established after clear-felling of oak woodland. Numerous hardwood stumps infected by honey fungus were present on the site, and large populations of rhizomorphs were found in the upper soil layers. The soil was of moderately heavy clay type. All treatments were applied at 2 gallons per tree on 19th and 20th March 1974, and harvesting of rhizomorphs from the treatment plots was carried out on 22nd and 23rd May 1974. Samples of the rhizomorph population from each treatment plot were assessed by the sand incubation method referred to above. There was much variation in the effect of Armillatox treatment on rhizomorphs in the replicated treatment plots, but the overall effect of treatment was much less pronounced than in the Warren Wood experiments in 1973 and 1974, with approximately 62% of the rhizomorph samples regenerating in sand culture (as compared with the untreated controls). Although most of the trees of the different species in the trial were not significantly damaged by the application of 1:12 Armillatox, bark necrosis attributable to treatment was observed on roots larger than 1 cm in diameter of western hemlock and grand fir. Similar results on the effect of Armillatox treatment on rhizomorphs were obtained on another site in Alice Holt Forest in 1974, and in other experiments in the Forest of Dean in 1973 (Pawsey and Rahman, 1976). In the Forest of Dean, serious damage was caused to the roots of birch trees (6-10 ft. high) by single applications of 1:12 Armillatox.

In general, these field trials with Armillatox indicated that site and possibly climatic conditions exerted considerable influence on the effect of Armillatox treatment on rhizomorphs and on tree roots. On the free-draining sandy site at Elveden, the effect of treatment on rhizomorph activity was dramatic, with only slight phytotoxic damage to the smallest roots in the treated soil. On heavier soil types, the effect of treatment on rhizomorph activity tended to be much reduced, with evidence of higher incidence and severity of phytotoxic damage to the roots of some tree species.

In the trials in Alice Holt Forest in 1974, treatments with 2.0% and 0.5% formalin (applied in the same way as Armillatox) were also tested. There was a significant difference between the effects of the two concentrations of formalin. 2.0% formalin had a more marked effect on rhizomorph activity than 1:12 Armillatox (12% and 62% regenerative ability respectively, compared with the untreated controls), while that of 0.5% formalin was very similar in effect to the standard 1:12 Armillatox treatment. The phytotoxic effect of 2% formalin appeared to be comparable with that of 1:12 Armillatox. Formalin treatment was not incorporated into other trials on other sites. There was no evidence in any of the trials carried out from the Commonwealth Forestry Institute in 1974 of any significant effect of treatment (with any of the materials used) on infection by *A. mellea* already established in the roots before treatment.

The recent work at Oxford has demonstrated that a number of materials applied to the soil around the base of trees can cause the death or suppress the growth potential of a substantial proportion of the population of rhizomorphs in the treated soil. The effect of treatment may vary considerably from site to site, and from year to year, both with respect to the mortality of rhizomorphs and the phytotoxic damage to roots caused by the treatment. However, the results of this limited program of field trials, and the results of other published work, given above, suggest that materials with consistent toxicity to rhizomorphs but with insignificant effect on root growth could be shown to be available for large-scale commercial protective use against infection by *A. mellea*. A considerable and coordinated program of field and laboratory work on this subject needs little justification, particularly in view of the small amount of poor quality, and fragmented investigation that has been devoted to it over a long period of years.

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