*STUDIES ON THE PARASITISM AND CONTROL OF TEA ROOT DISEASE FUNGI IN CEYLON

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Since the classical experiments of Petch in the 1920s, the root diseases of tea in Ceylon have received little attention until interest in them was revived in 1962. Neglect of the problem for nearly 40 years resulted in a surprisingly large area of tea plantings becoming infested with root pathogens. A survey by Mulder and Redlich in 1962 revealed that one root disease alone had destroyed more than a thousand acres of tea in the high-country plantations, while the damage caused by other less serious diseases was also appreciable. These observations prompted a revival of interest in root disease investigations at the Tea Research Institute of Ceylon. This review, which does not claim to be comprehensive, summarizes the results of our recent studies.

There are four root diseases of tea that are economically important in Ceylon, but only Red Root Disease, caused by *Poria hypolateritia* occurs widely. It is also the most difficult one to control. For a long time the root diseases were controlled by the laborious and expensive method of digging and removing infected roots and replanting the cleaned area in tea. Thc efficacy of this practice was generally poor and this accounts partly for the present widespread occurrence of *Poria* Root Disease on many plantations. This method of control failed because of incomplete root extraction. Also, the high cost of the operation caused many estates to abandon it altogether. Recent studies were, therefore, directed towards devising a cheaper and more effective method of control using soil fungicides.

CONTROL BY SOIL FUMIGATION WITH DD

The first material tested was DD as it was then used widely in tea nurseries as a nematocide. In view of its fungicidal properties, its efficacy in controlling *P. hypolateritia* was investigated in a series of field experiments. Results showed that the best control was obtained when DD was applied at the rate of 2,000 lb or 170 gallons per acre at a depth of six inches, but this treatment killed the fungus effectively down to a depth of only 18 inches. As the depth of infested soil is usually about 30 inches, DD was provisionally recommended with the reservation that Guatemala Grass, a non-host for *P. hypolateritia,* be grown on treated land for two years before replanting tea. This would enable the inoculum in the 18 to 30-inch-layer which was not affected by the fumigant, to perish on its own, after the root reserves had been exhausted. In instances where replanting could not be delayed unduly, however, it was suggested that after fumigation, *Tephrosia vogelii* be planted for one year as an indicator of remaining infection before replanting (Shanmuganathan 1964). Meanwhile, the search for a more effective and cheaper material was under way.

CONTROL BY SOIL FUMIGATION WITH METHYL BROMIDE

The success of American workers in controlling *Armillaria mellea* in citrus orchards by soil fumigation with methyl bromide, prompted experiments with this material in 1964. It was found that fumigation with methyl bromide under a polythene cover at the rate of half lb per 100 sq. ft of soil controlled *P. hypolateritia*

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effectively down to three ft. This treatment appeared more effective and economical, and less laborious than fumigating with DD and was, therefore, recommended to plantations in 1965 (Shanmuganathan & Redlich 1965). Methyl bromide is effective at a relatively low dose presumably because tea soils are generally well drained and mean soil temperatures seldom fall below 60°F. Good control has also been obtained in soils with a moisture content as high as 40%. As methyl bromide is highly volatile, the fumigation is carried out under a polythene cover, but this has the added advantage of more effective and uniform fumigation, and the dose can be reduced significantly. For optimum results, the soil should be kept covered after treatment for 48 hr. At present the only snag with this method of control is that the polythene cover degenerates rather rapidly under tropical conditions. Certain brands of reinforced PVC have recently been tested and found satisfactory but their costs at present are prohibitive.

While good penetration of methyl bromide occurs in the soil directly under the cover, the fumigant does not seem to diffuse laterally outside this area even at twice the standard dose. When large infested patches are treated, no unfumigated alleys or strips should, therefore, be left behind. There is good evidence that control is superior, if the patch is divided into units of 200 sq. ft, and each unit fumigated separately (Fig. 1). Fumigation is usually carried out under polythene tarps 24 ft by 14 ft, the edges of which are dug into the soil to obtain a gas-tight seal. The methyl bromide is applied from one pound cans containing 2% chloropicrin as a warning agent. The results of experiments also indicate that control decreases if the area under cover is increased and the fumigant applied at one location. It seems desirable to apply the fumigant at spaced intervals when areas larger than 200 sq. ft are treated under a single tarp (Shanmuganathan & Fernando 1967).

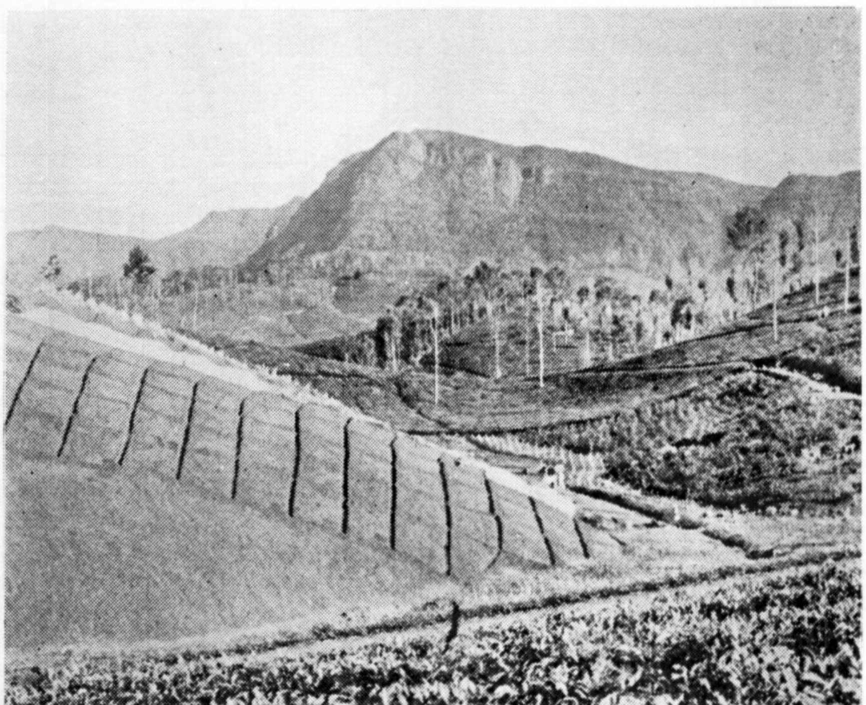

FIGURE 1—*Fumigation of land infected with* P. hypolateritia, *by dividing the area into plots of 200 sq. ft and fumigating each plot separately with methyl bromide*

The mode of action of methyl bromide on *P. hypolateritia* appears to be direct as well as indirect. *Trichoderma viride* was consistently found on test inocula recovered after fumigation, while a *Penicillium* sp. appeared frequently. On many occasions, the build-up of *T. viride* could be seen with the naked eye. Both these fungi are antagonistic to *P. hypolateritia*, and some of the isolates of *T. viride* examined, showed all possible types of antagonism. We have observed in some of our experiments that nearly a week is required to kill the bulk of the deep-seated inoculum, whereas the surface inoculum is killed within 48 hr. It is not clear whether this is because of the slow penetration of the fumigant into the lower layers of the soil, or whether the action of the fumigant in this zone is indirect requiring a longer time to kill the pathogen. It is possible that the action of the fumigant in the upper layers is direct, while in the lower layers, where the fumigant may not reach sufficient concentration for direct killing, the action is largely indirect.

SOME SIDE EFFECTS OF FUMIGATION WITH METHYL BROMIDE

Apart from its effect on the pathogen, and its stimulation of antagonistic fungi, several other benefits also accrue from soil fumigation with methyl bromide. There is a striking increase in the growth of tea planted on treated land and this has been shown to be a direct result of fumigation and not due to the destruction of other root pathogens. A similar effect has also been observed in tea nurseries when nursery soil was fumigated with methyl bromide, but not with DD (Kerr & Vythilingam 1966). Soil nitrogen determinations indicate clearly that this increased growth is related to a change in nitrogen nutrition following the accumulation of ammonia nitrogen after fumigation. We have observed that for several weeks the fumigated soils contained a greater quantity of ammonia nitrogen than the untreated controls, probably because of the inhibition of nitrification. Further, when three different dosages of methyl bromide were used for fumigation, the increase in ammonia nitrogen was linearly related to the dosage and this relationship was significant. Ten weeks after fumigation, the level of ammonia nitrogen was still high, but there was evidence that by this time the level of nitrate nitrogen was increasing, indicating that nitrification had already begun (Fig. 2). These observations provide some indirect evidence that tea can utilize ammonia nitrogen more effectively than nitrate nitrogen like pineapple, potato and rice (Street & Sheat 1958).

Methyl bromide has so far shown no adverse effects such as the stimulation of other root pathogens. It effectively controls the other root fungi *Rosellinia arcuata* and *Ustulina deusta*, and is also an excellent nematocide. It also suppresses weed growth on treated land for over two months.

EPIDEMIOLOGY AND SAPROPHYTIC SURVIVAL

The second part of this paper concerns certain fundamental investigations on inoculum distribution, inoculum potential and saprophytic behaviour of *P. hypolateritia*, and the relationship between shade-free felling and the incidence of charcoal stump rot caused by *U. deusta*.

Excavation and examination of the root system of a large number of infected plants show that *P. hypolateritia* colonizes only the top 30 inches of the root system as no mycelium could be seen below this depth. The fungus invades almost all the lateral roots and the main stump and causes a soft rot. Fructifications are frequently formed on the collar of dead bushes but they do not produce spores. Infection occurs both by contact between healthy and infected roots and by growth of mycelium through the soil, though the former is probably the more common method. The majority of infections appear to arise *via* lateral roots and only a small percentage of plants show infection originating from the main stump.

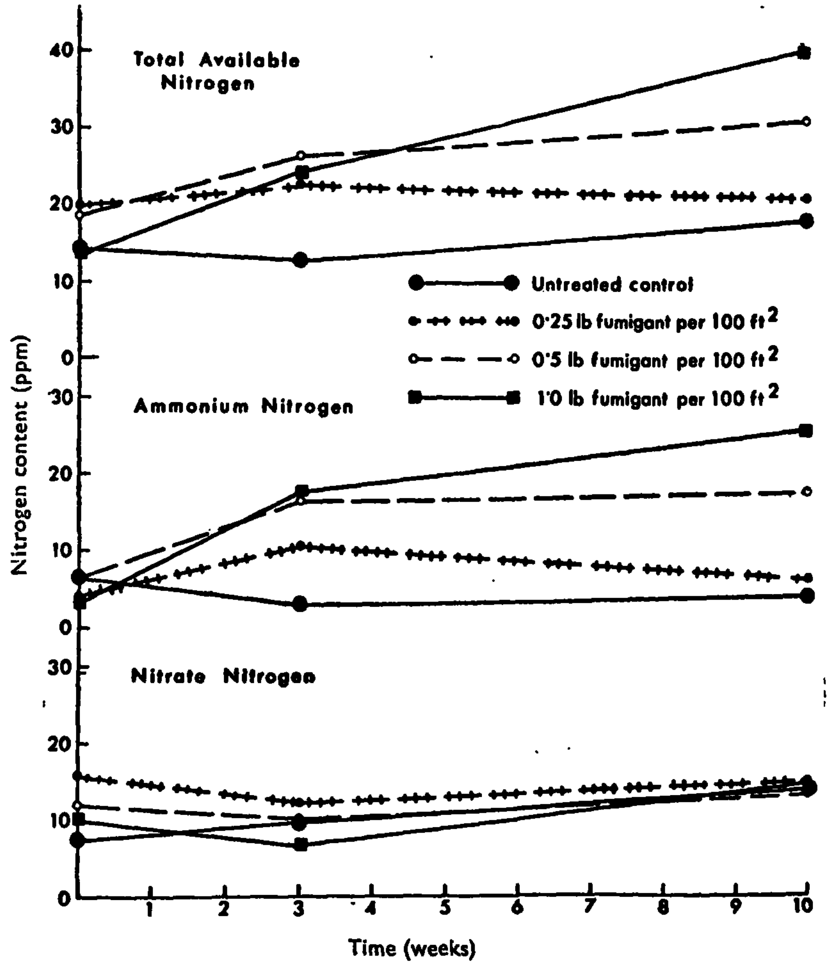

FIGURE 2—*Effect of soil fumigation with methyl bromide on soil nitrogen*

In the absence of air-borne spores, the only known source of inoculum for new outbreaks is infected root material of either tea or shade trees. As the planting of shade trees susceptible to *P. hypolateritia* has long been abandoned, it appears unlikely that shade tree roots can still serve as sources of inoculum. New infections can, therefore, arise only in two ways : in young plantations *via* infected tea roots left over after the uprooting of the old tea, and in both young and old plantings by accidental spread of infected material by man. While the former can be prevented easily by fumigating all infected patches in the old tea before uprooting, the dispersal of infected roots within plantations is more difficult to avoid even with good supervision.

Although it is not known with certainty whether pieces of infected roots scattered amongst standing tea can start fresh outbreaks, recent experiments show that only a small quantity of inoculum is necessary to infect young plants. Using inocula of different volumes, we have determined the smallest inoculum required to kill a young tea plant—it has proved to be surprisingly small, a piece of infected root eight cm long and one cm in diameter being sufficient. With thicker roots even smaller lengths are infective. The inoculum requirements of older plants are now under investigation.

We now recommend that all dead and diseased plants be grubbed out by winching before the affected land is fumigated so that the fumigant has to deal with only the residual inoculum which is not easily recoverable. It is during this initial digging-up operation that the bulk of the inoculum is dispersed, and it has been suggested, mainly by estate managers, that such dispersal can be greatly minimized if the uprooting of infected plants is carried out after fumigation, as the pathogen will be dead in roots taken out after treatment. There are indications from experiments now in progress that this is feasible if the dose of methyl bromide applied is increased to one to two lb per 100 sq. ft of infected soil, as more chemical is required to kill *P. hypolateritia* within large tea stumps.

The duration of survival of *P. hypolateritia* in infected tea roots is under investigation in one long-term experiment. Infected tea roots of different lengths and diameters are buried in fallow soil at depths of one, two and three ft, and at intervals, samples are recovered and their viability and infectivity determined by inoculation of potted tea plants. After three years' burial, nearly all the smaller segments recovered (four inches long and one cm in diameter) were either completely rotten or in very advanced stages of decay and only about 50% contained the pathogen in a viable state. Inoculations showed that these segments were non-infective. Of the larger segments (four inches long and two, three or four cm in diameter), over 80% contained viable mycelium and about 50% were infective. About 75% of these segments, however, were showing definite signs of decay, especially at their ends. Secondary invaders were few, or absent altogether except *T. viride* which was present on all highly decomposed roots. It was noticed that shortly after burial most segments had formed a black mycelial sheath or pellicle around them. This sheath probably served as a barrier preventing the entry of secondary invaders. After the food base was exhausted, however, this barrier seemed to break down and allow the entry of fungi like *T. viride*.

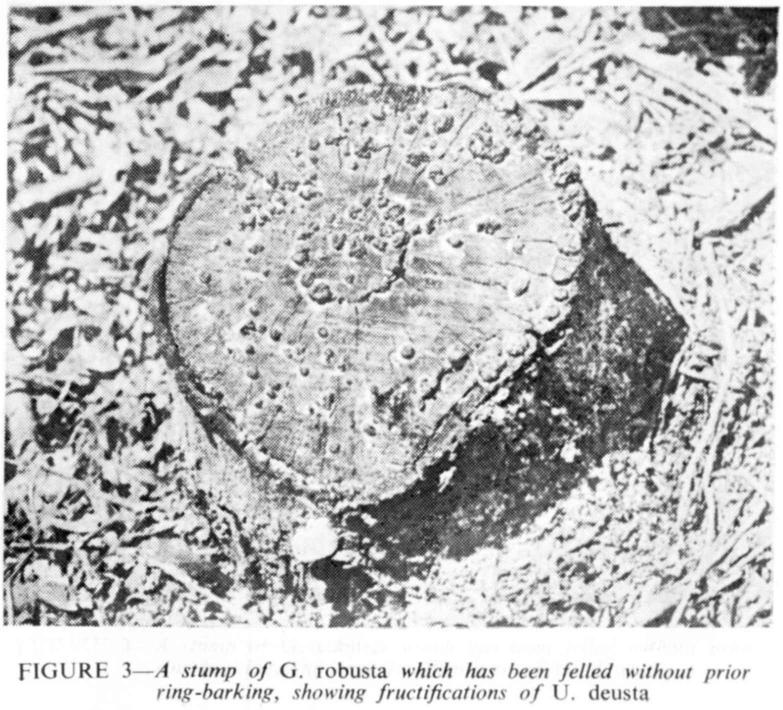

FIGURE 3—*A stump of* G. robusta *which has been felled without prior ring-barking, showing fructifications of* U. deusta

Unlike *P. hypolateritia*, *U. deusta* appears to spread mainly by air-borne spores discharged from fructifications formed on infected shade tree or tea stumps (Fig. 3). Field observations have established beyond doubt that if shade trees are ring-barked about a year before felling, the incidence of Charcoal Stump Rot is greatly reduced. Leach's simple but hightly effective control method has, therefore, proved very useful in minimizing out-breaks of Charcoal Stump Rot on Ceylon tea plantations. *U. deusta* invades exposed stump surfaces of *Grevillea robusta* trees felled without prior ring-barking quite rapidly and then spreads to the adjacent tea. Ring-barking is effective only if trees are felled after complete defoliation and this may take anything from 18 to 24 months for fully grown trees, because the depletion of reserves in the roots is a slow process. This is a serious draw-back as the estate superintendent is often not patient enough and trees are felled long before they are dead, defeating the purpose of ring-barking.

In one experiment, the efficacy of 2-4-D and 2-4-5-T were compared with ring barking to find out whether trees can be killed quicker by treatment with arboricides. The two materials were applied to the trunks at two concentrations, *viz* five and ten % in dieseline. It was found that while 2-4-D was ineffective, 2-4-5-T was highly effective, and killed 35 of the 40 treated trees within seven months. At complete defoliation, however, the roots of these trees were alive and carbohydrate estimations indicated the presence of about 50% reserves, compared with untreated controls (Fig. 4). Further, when inoculated with *U. deusta,* over 75% of the trees were infected, showing that they were still susceptible. On the other hand, the death of ring-barked trees occurred only 18 months after ring-barking when root reserves had declined to about 20% of that in unring-barked trees. Moreover, as the roots apparently died before complete defoliation, on inoculation only a small percentage of the trees were infected (Table 1). It appears, therefore, that treatment with arboricides is not a satisfactory alternative to ring barking.

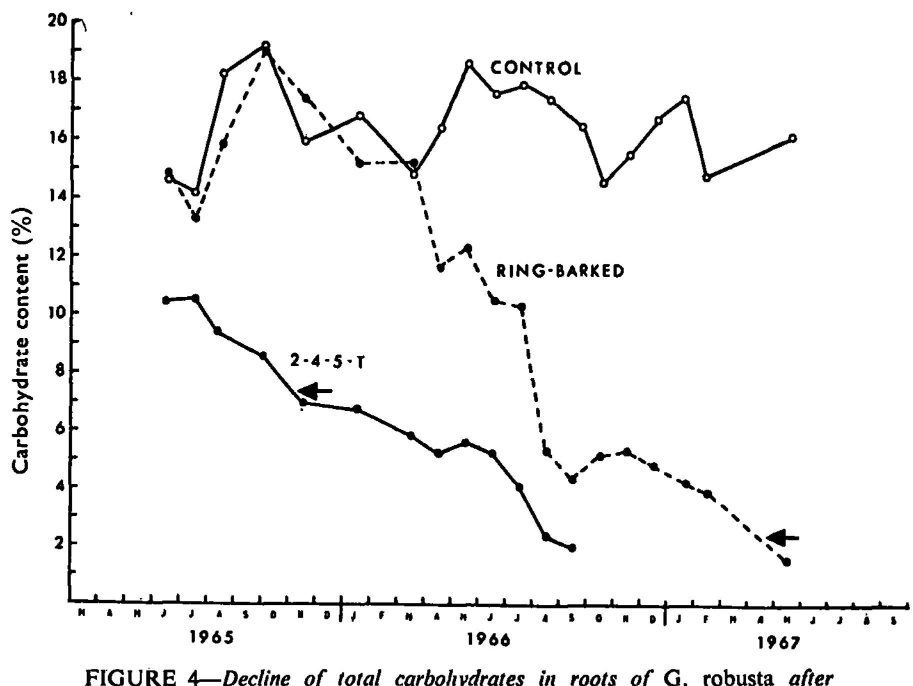

FIGURE 4—*Decline of total carbohydrates in roots of* G. robusta *after treatment—the arrows indicate the time of complete defoliation*

TABLE 1—*Results of inoculation with* Ustulina deusta *of* Grevillea robusta *trees treated variously*

Treatment	Root reserves (%)	No. of trees inoculated	No. of trees infected
2-4-5-T	7.37	34	26
Ring-barked	2.42	7	1
Control	17.41	7	2

SUMMARY AND OUTLOOK

A significant advance in the control of tea root diseases is the recent discovery that methyl bromide is very effective in ridding the soil of many root pathogens of tea. Because of its versatility, efficacy at low dosage and desirable side effects, soil fumigation with methyl bromide has now firmly established itself as a routine measure for root disease control on tea plantations in Ceylon. Methyl bromide is easy to apply and the cost is less than that for manual cleaning. Using methyl bromide, large areas of infected land can be cleaned rapidly and with a good measure of success. The complete eradication of the insidious *Poria* Root Disease seems now possible, if the current interest shown by estate superintendents continues for a few years more.

There is no satisfactory alternative at present to ring-barking shade trees in order to eliminate infections by *U. deusta.* The simpler method of painting the stump surfaces with a bituminous paint immediately after felling is not adequate as this will not prevent the extension of any dormant lesions already present to the entire root system and stump. Though standing trees are not known to be killed by *U. deusta,* inoculation experiments indicate such trees can become infected, but their further development is probably restricted by host resistance. Some aspects of fundamental research reported in this paper are only the beginning. It is hoped that by using the numerous techniques and ideas already developed in this field, valuable information concerning the parasitic and saprophytic behaviour of tea root disease fungi will be obtained in the near future.

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