SOME OBSERVATIONS ON *PORIA* CONTROL BY SOIL FUMIGATION WITH METHYL BROMIDE

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Field experiments indicated that for effective control of *Poria* Root Disease (*Poria hypolateritia*), the lowest dose of methyl bromide that can be applied is half pound per 100 sq. ft. When applied at this rate, little or no penetration of the fumigant occurs outside the treated area, and it is, therefore, suggested that when large infested patches are taken for treatment, the entire area should be fumigated. Control is likely to be better if the patch is divided into units of 200 sq. ft and each unit fumigated separately. A covering period of 48 hr seemed adequate, and tea can be planted if necessary soon after the covers are removed.

Some of the side effects of methyl bromide fumigation observed were a significant increase in the growth of tea planted on treated land, an increase in the total available nitrogen and ammonium nitrogen in the soil, stimulation of fungi antagonistic to *P.hypolateritia* like *Trichoderma viride* and *Penicillium* spp. and the suppression of weed growth for over two months. No adverse effects have been observed so far on tea planted in fumigated soil.

Methyl bromide also controlled effectively Black Root Disease of tea (*Rosellinia arcuata*) at the same dose.

Introduction

Methyl bromide was recently shown to be an extremely effective fumigant for the control of *Poria* Root Disease of tea (Shanmuganathan & Redlich 1965). This chemical was, therefore, recommended to estates for the eradication of the fungus *Poria hypolateritia* and is now used on many estates for this purpose. Early work with this material was designed mainly to decide recommendations for practical use and was concerned with determining the effective dose. The present work concerns investigations relating to the minimum effective dose, duration of treatment, planting time, extent of diffusion of the fumigant outside the treated area, and the effects of the fumigant on soil microflora and soil nitrogen. This paper describes these investigations and discusses the results obtained.

Materials and methods

The soil fumigation was carried out under polythene sheet (gauge 700) measuring up to 24 ft × 12 ft, the edges of which were dug into the soil to obtain a gas-tight seal. Each sheet was raised from the ground using sacks filled with straw to create space for the even distribution of gas. The methyl bromide was applied from one pound cans and contained 2% chloropicrin (tear gas). The fumigant was vapourized by immersing the cans in hot water, and it entered beneath the tarp as a gas. The sheets were removed two to seven days after the application of the fumigant.

Plots were 200 sq. ft in area, unless otherwise stated, and in all plots test inocula consisting of fungus-infected segments of tea roots, four in. long and one in. in diameter, were buried at different depths before fumigation. These were recovered two to four weeks after treatment and tested in the laboratory for viability. Test inocula were prepared as described previously (Shanmuganathan 1964). Soil moisture was between 25-40% (oven-dry basis) and soil temperature between 63-72°F, six in. below ground level at the time of fumigation.

Experiments and results

Post-treatment planting

To determine how soon tea can be planted on treated land without any obvious ill-effects, three plots were fumigated at the rate of half pound per 100 sq. ft (hereafter referred to as the standard treatment). Two days after fumigation, the cover was removed from one of the plots, and ten one-year-old tea plants (clone TRI 2023) were planted on this plot. On the same day, an untreated plot was also planted similarly. The second treated plot was planted likewise four days after fumigation, and the third eight days afterwards.

The plants grew satisfactorily on all four plots without showing any visible signs of phytotoxicity, and after eight months they were uprooted carefully with their roots, washed to remove soil adhering to the roots, and weighed. The results are shown in Table 1 from which it can be seen that fumigation with methyl bromide has no adverse effect on tea even if planting is carried out two days after fumigation. On the contrary, fumigation seems to have a beneficial effect by promoting greater growth. The implications of this observation will be discussed later.

TABLE 1—*Effect of methyl bromide fumigation on subsequent plant growth — Mean weight of 10 plants (clone TRI 2023) grown on treated plots 2, 4 and 8 days after treatment*

Planting time (No. of days after treatment)	Mean weight (g)
2	500.4
4	577.5
8	528.8
LSD (P = 0.05) —	149.4
Mean	535.5
Untreated control	412.0
LSD (P = 0.05) —	121.4

Duration of covering period

A covering period of seven days was recommended earlier although this was considered to be long (Shanmuganathan & Redlich 1965). To find out whether this period could be shortened without any loss in control, a series of experiments was conducted in which covering periods of two, four, seven or eight days were tested. The efficacy of the treatments was determined by the number of units of test inocula rendered non-viable.

Four experiments were carried out ; in two, inocula were removed immediately after the cover was taken off, and in the other two, this was done eight days later.

TABLE 2—*Control of* P.hypolateritia *by methyl bromide fumigation — Effect of different covering periods on control — Polythene cover and roots removed 2, 4 and 8 days after treatment*

	Covering period (days)	No of root segments out of 5 showing viable *P.hypolateritia* 1 ft depth	2 ft depth
Experiment 1	2	0	2
	4	0	2
	8	0	1
	Untreated	5	5
Experiment 2	2	0	3
	4	0	1
	8	0	0
	Untreated	5	5

FIGURE 1 — *The growth antagonistic fungi on tea roots infected with* P. hypolateritia *after fumigation with methyl bromide under field conditions-* Top to bottom a) T. viride *growing on a root after fumigation*; b) Penicillium *spp. growing on a root after fumigation*; c) *an unfumigated root showing the presence of* P. hypolateritia

Polythene cover removed after 2, 4 and 8 days ; roots removed after 8 days

	Covering period (days)	No of root segments out of 5 showing viable *P.hypolateritia* 1 ft depth	2 ft depth	3 ft depth
Experiment 3	2	0	1	0
	4	0	0	0
	8	0	0	0
	Untreated	5	5	5
Experiment 4	2	0	0	0
	Untreated	5	5	5

The results (see Table 2) indicated that a covering period of two days' duration was sufficient to obtain good control of *P.hypolateritia.* The poor control in Experiments 1 and 2, especially at the lower depth, is probably because of the early removal of inocula from the plots. It appears, therefore, that at least a week is necessary to kill the inocula in the lower layers of the soil following fumigation.

Minimum effective dosage

In the experiments described earlier (Shanmuganathan & Redlich 1965) doses of half, one, two and four lb per 100 sq ft were tested and all doses gave excellent control of *P.hypolateritia.* The lowest dose, *viz* half lb per 100 sq ft was, therefore, recommended for practical use by estates. The question then arose as to whether doses lower than half lb could also give good control. To test this, an experiment was conducted in which doses of one fourth and half lb were compared using plots of 400 sq. ft. This experiment also included the standard treatment, *viz* one lb applied to plots of 200 sq. ft. The results are shown in Table 3 from which it appears that a dose of one fourth lb is unlikely to give satisfactory control of *P.hypolateritia.* The same seems to be true if the half lb dose was applied to plots of 400 sq. ft. A second experiment gave almost similar results.

TABLE 3—*Efficacy of two doses of methyl bromide in controlling* P.hypolateritia

Dose (lb/100 sq. ft)	Plot size (sq. ft)	No. of infected roots out of 5 showing viable *P.hypolateritia* Depth of burial (ft) 1	2	3
¼	400	1	3	4
½	400	1	2	3
½ (standard treatment)	200	0	0	2
Untreated	400	5	5	5

Diffusion of fumigant outside treated area

To study the distribution if any, of the fumigant, outside the treated area, an experiment was conducted using three plots of 200 sq ft. Test inocula were buried outside the plots at distances of one, two and three ft from the edges and at depths of one and two ft. The standard dose of half lb of methyl bromide per 100 sq. ft was applied to all three plots ; a fourth plot served as a check. Inocula were retrieved after a month and tested for viability in the usual manner. The results are shown in Table 4 from which it is clear that the distribution of fumigant outside the treated area is almost negligible and totally inadequate to kill the fungus in infected roots.

TABLE 4—*Lateral distribution of methyl bromide outside treated area — No. of root segments out of 4 in which* P.hypolateritia *had been killed*

	Distance from edge of plot (ft) 1	2	3
A — Depth 1 ft			
Plot 1	0	0	0
Plot 2	0	0	0
Plot 3	0	0	0
Control	0	0	0
B — Depth 2 ft			
Plot 1	0	0	0
Plot 2	0	1	0
Plot 3	0	0	1
Control	0	0	0

In another experiment, the extent of lateral distribution was studied using three doses of methyl bromide, *viz* half, one and two lb per 100 sq. ft. The results are given in Table 5, and confirmed that lateral diffusion was practically nil except at the highest dose (two lb per 100 sq. ft), but even this was not significant.

TABLE 5—*Lateral distribution of methyl bromide outside treated area — No. of root segments out of 8 in which* P.hypolateritia *had been killed*

Dose (lb per 100 sq. ft)	Distance from edge of plot (ft) 1		2	
	Depth 1 ft	2 ft	1 ft	2 ft
½	0	0	1	0
1	0	0	0	0
2	1	2	0	1
0	0	0	0	0

Some side effects of methyl bromide fumigation

1—*Effect on soil fungi*

The fungus *Trichoderma viride* was consistently found on test inocula recovered after fumigation. It sporulated profusely on the root segments, when incubated in the laboratory for a few days (Figure 1). *T.viride* was also found to sporulate copiously in the soil and thus appeared to be the dominant fungal recolonizer of fumigated soil. Another fungus which frequently appeared on dead roots following fumigation was a *Penicillium* spp., also antagonistic to *P.hypolateritia* in culture plates.

2—*Effect on soil pH*

The pH values for treated and untreated plots in three experiments showed no significant differences.

3—*Effect on soil nitrogen*

Soil fumigants may sometimes inhibit temporarily the action of nitrifying bacteria and retard the conversion of ammonia nitrogen to nitrate nitrogen, a phenomenon referred to as ' nitrification lag ' (Tam & Clark 1943 ; Good & Carter 1965). The resulting accumulation of ammonia nitrogen may be toxic to certain plants which are ammonia sensitive, but beneficial to those which can take up ammonia nitrogen.

In one experiment, soil nitrogen was determined before treatment and again three and ten weeks after treatment with three doses of methyl bromide. Results showed that there was a highly significant increase ($P < 0.001$) in the ammonia nitrogen in the soil three weeks after fumigation. There was also a reduction in the nitrate nitrogen but this was not significant. Further, the increase in ammonia nitrogen was linearly related to the dose of methyl bromide within the concentrations tested (one fourth, half and one lb per 100 sq. ft), and this relationship was significant ($P < 0.05$). The total available nitrogen also showed a significant increase ($P < 0.01$), an effect probably resulting from the highly significant increase in the ammonia nitrogen. The same trend was evident ten weeks after fumigation, the level of ammonia nitrogen still remaining high, but nitrate nitrogen had also increased to the original pre-treatment level indicating that nitrification had already begun. No further nitrogen determinations were made.

4—*Efficacy against other root parasites*

There is evidence in the literature that soil fumigation with methyl bromide for the control of certain soil fungi and parasitic nematodes may sometimes induce the development of other root-rotting fungi (Hagne, Lubatti & Page 1964). We have, however, not seen this in any of our experiments. As ***Rosellinia arcuata*** is generally more resistant to chemicals than the other root disease fungi of tea (unpublished data) the efficacy of methyl bromide against *R.arcuata* was determined in a field experiment. Two doses were tested, *viz* half and one lb per 100 sq. ft ; both gave excellent control down to a depth of two feet. It appears, therefore, that *R.arcuata* can also be controlled with the standard dose used for controlling *P.hypolateritia.*

5—*Effect on weeds*

Methyl bromide completely controlled weeds including grasses for a period of over two months following treatment with the standard dose.

Different types of covering materials

Black polythene (gauge 700), unsupported plastic sheeting, and water-proofed canvas were tested for possible use as substitutes for clear polythene and were found to be sufficiently gas tight. They have, however, certain disadvantages which are discussed below.

Discussion

Experiments indicate that areas harbouring *P.hypolateritia* can be planted successfully with tea even as early as two days after treatment with methyl bromide, showing that an aeration period is not necessary if the area is to be replanted with tea. This is probably because the dose of methyl bromide used is relatively low compared with rates normally recommended (one to two lb per 100 sq. ft) for fumigation of seed-beds, nurseries *etc.* Further, rooted tea plants, usually about a year old, at planting time, may be less sensitive to methyl bromide than seeds and seedlings.

The vegetative response of the tea plant to soil fumigation by methyl bromide seems to be a favourable one. The greater growth of tea on treated land cannot be attributed, at least in this case, to the destruction of other root pathogens of tea as the experiment was conducted on land apparently free from such pathogens. Moreover, Kerr & Vythilingam (1966) have found that growth of young tea plants was significantly better if nursery soil was fumigated with methyl bromide but not with DD. This striking increase in growth is probably related to a shift in nitrogen nutrition following the accumulation of ammonia nitrogen after fumigation. There is thus some indirect evidence that the tea plant can use ammonia nitrogen more effectively than nitrate nitrogen like pineapple, potato and rice (Street & Sheat 1958).

Soil nitrogen determinations clearly indicate that for many weeks the fumigated soils contain a greater amount of ammonia nitrogen than the untreated control, as a result of inhibition of nitrification by the fumigant. It is interesting to note that within the treatments, there were differences in the levels of ammonia nitrogen, which were related to the concentrations of the fumigant applied. Total available nitrogen also showed a significant increase following fumigation, and it is not clear whether this is due to the stimulation of the ammoniacal bacteria and fungi/and/or certain nitrogen-fixing organisms. Further investigations are, of course, necessary to ascertain whether the observed changes in soil nitrogen can be correlated with corresponding changes in the soil microflora, especially the nitrifying bacteria.

The experiment on the duration of the covering period showed that a covering period of 48 hr is sufficient to obtain good control of *P.hypolateritia*. This is in accordance with the observations of several other workers who found that if the soil temperature was above 60°F, a covering period of 24-48 hr was generally adequate to control most fungi and nematodes. As temperatures seldom fall below 60°F in most tea soils, a covering period of even 24 hr may be sufficient for the control of *P.hypolateritia*. These experiments also indicate that the diffusion of methyl bromide into the lower layers of the soil proceeds even after the cover is removed after 48 hr. This is perhaps why more than 48 hr are necessary to kill the bulk of the deep-seated inoculum.

It is evident from the experiments on application rates, that it would not be possible to reduce the currently recommended dose (Shanmuganathan 1967) any further as this would result in decreased control. Further, there are also indications that control will decrease if the size of the treated area is increased and fumigant applied at any one location. It seems desirable, therefore, to introduce the fumigant at spaced intervals if plots larger than 200 sq. ft are treated. In the alternative, a distribution tube consisting of a long gas pipe perforated at three ft intervals may be used to distribute the gas evenly in the space below the sheet.

Hardly any fumigant seems to diffuse outside the area under cover even at twice the standard dosage. This is indeed surprising, and it suggests that when treating large infected areas, **every effort should be made to fumigate the entire area without leaving behind any unfumigated alleys between plots.** Where this is not practicable any unfumigated areas should be treated with DD (Shanmuganathan 1967). Patches can be fumigated safely up to about 18 in. from the nearest healthy tea.

There are indications (Middleton 1967 ; Shanmuganathan & Fernando 1966) that on steep areas, when the long edge of the 20 ft × 10 ft polythene tarp is placed at right angles to the contour, soil fumigation nearer the upper edge of the tarp may be less effective than that nearer the bottom edge. This is possibly because the fumigant tends to move down the hill before it penetrates the soil. In order to avoid this, it would probably be better if on steep slopes, the tarp is placed along the contour, instead of at right angles to it.

The efficacy of methyl bromide against *R.arcuata* at the standard dose implies that there is no danger of *R.arcuata* being stimulated in soil treated for *P.hypolateritia*. Methyl bromide appears, therefore, to be a versatile fumigant, highly effective against a wide range of plant parasites including fungi, nematodes, and possibly insects, as well as weeds. The parasitic nematodes of tea can be controlled in the field with a dose as low as half lb per 100 sq. ft (unpublished data). Methyl bromide probably owes its success to rapid dispersion at ambient temperatures under a gas-tight seal.

The stimulation of *T.viride* and some *Penicillium* spp. by methyl bromide seems to be a general feature of a number of soil fumigants such as DD, chloropicrin, carbon disulphide and formalin, and should be considered a beneficial side effect, as these fungi are antagonistic to *P.hypolateritia*. The rapidity with which *T.viride* recolonizes fumigated soils is attributed as much to its high growth rate as to its tolerance to fumigants (Saksena 1960).

Methyl bromide does not seem to have any significant effect on soil pH, and this is a great advantage because young tea cannot be established satisfactorily if pH is above 5.5.

All the covering materials tested were satisfactory. Water-proofed canvas, however, is far too expensive, and black polythene and ordinary household plastic sheeting are both not very durable. Black polythene becomes very soft and is easily torn on exposure to intense heat while plastic sheeting becomes brittle and degenerates. Certain supported vinyl/nylon and some PVC materials that are now being tested seem more durable than polythene, although they are a little more expensive. These are not available yet on the market, and for the time being, clear polythene seems to be the best covering material.

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