BIOLOGY AND CONTROL OF THE LIVE-WOOD TERMITES OF TEA

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A fumigation technique using aluminium phosphide (Phostoxin) was developed for controlling the live-wood inhabiting termites of tea. This method is likely to have wide applicability in controlling termites infesting other perennial crops, timber and forest trees. Good results were also obtained with ethylene dibromide, trichlorobenzene and paradichlorobenzene. Ethylene dibromide and trichlorobenzene were found to be phytotoxic and are not suitable for use. Para-dichlorobenzene needs further investigation in this respect as well as for termite control. Phostoxin gave consistently good results and in almost all instances absolute control of each colony was obtained with low dosage rates. Since applications of both persistent non-systemics and systemic insecticides were of no value in controlling the live-wood termites, the fumigation technique using Phostoxin is recommended.

Observations made on the biology of the three species of termites during these studies are also recorded and discussed. The low-country species *Glyptotermes dilatatus* which has spread to new VP tea fields in some areas is a potential danger to young plantations; the ways and means of avoiding its further spread are discussed in the light of the recent findings.

Three species of termites of the family Kalotermitidae attack the live-wood of the tea plant in Ceylon. These are *Postelectrotermes militaris* (Desneux) (= *Neotermes militaris* Desneux), *Neotermes greeni* (Desneux) and *Glyptotermes dilatatus* (Bugnion).

Postelectrotermes has been a serious, but localized pest since the early 1920s. It is commonly called the 'Up-Country Live-Wood Termite' and occurs mostly at elevations between 3500 and 4500 ft, particularly in the Maskeliya district, and to a lesser extent in the Dimbula district. *Glyptotermes,* though not considered important earlier, has now become a very serious pest at lower elevations (below 3000 ft) attacking seedling as well as newly planted VP tea, mostly in Galle, Kelani Valley, Kalutara and Ratnapura Districts. *Neotermes* found at elevations up to 3500 ft is not as common as *Glyptotermes,* but attacks by these two species can occur concurrently. *Glyptotermes* and *Neotermes* are commonly called "Low-Country Live-Wood Termites".

Postelectrotermes feeds on the live heartwood of roots, stems and branches of the tea plant, and has a gallery system which is continuous and confined to a part or the whole bush (Figure 1). Feeding of *Neotermes* and *Glyptotermes* is restricted to the heartwood of stems and branches above the collar region, and the gallery system is not continuous and is confined to above ground parts (Figures 2 and 3). The control of the three species of live-wood termites named above is difficult, since the colonies are well protected within the host plant. During recent investigations (Danthanarayana 1968a, 1969) on the control of *Postelectrotermes* and *Glyptotermes,* a method was developed which gave absolute control of each colony in most instances. As this method is new, the purpose of this paper is to describe these experiments in some detail and to make recommendations based on the findings. General observations made on the biology of the two species during these investigations are also reported and discussed as these findings are new. A preliminary report on this work, in which the chemical control investigations were discussed briefly, has already been published (Danthanarayana & Fernando 1970).

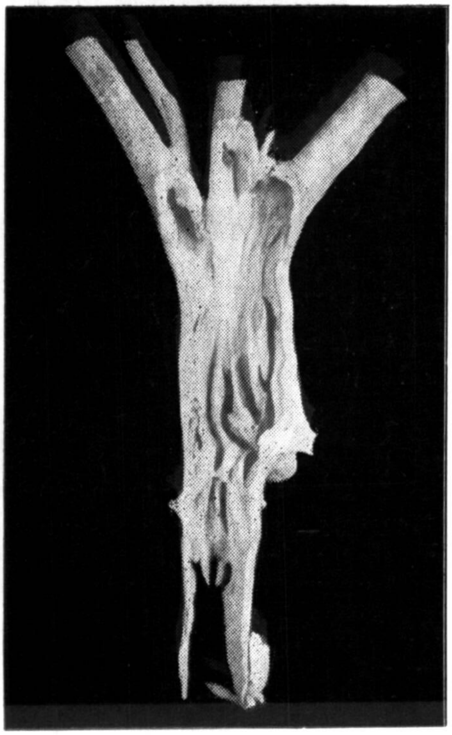

FIGURE 1—*The gallery system of* Postelectrotermes militaris (*Up-country Live-wood Termite*)

FIGURE 3'— *The gallery system of* Glyptotermes dilatatus (*the common Low-Country Live-Wood Termite*)

FIGURE 2 — *The gallery system* of Neotermes greeni (*the less common Low-Country Live-Wood Termite*)

FIGURE 4—*Drilling tea branch for controlling* Glyptotermes dilatatus

FIGURE 5—*The method of introducing aluminium phosphide (Phostoxin) pellet to control* Glyptotermes dilatatus

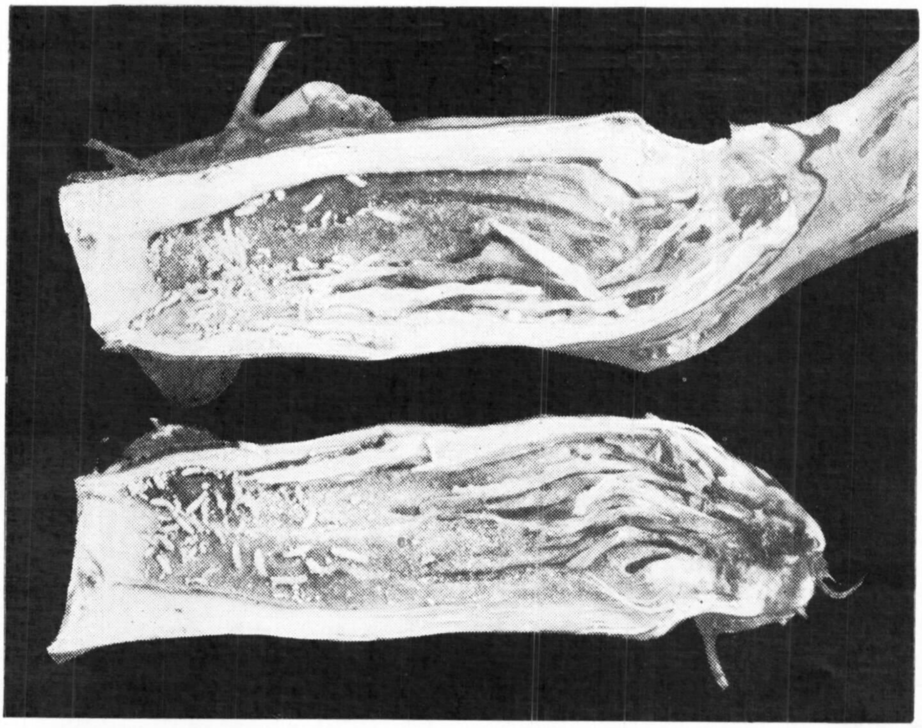

FIGURE 6 — *The results of aluminium phosphide* phostoxin *treatment agains:* Postelectrotermes militaris—*Note the dead termites in the lower parts of the gallery and the powdery residue of Phostoxin*

MATERIALS AND METHODS

The experiments carried out and their locations are given below :-

E53, E79, E80 and E81—Talangaha Estate, Nakiadeniya

E54—Moray Estate, Maskeliya

E55 to E71—Galboda Estate, Ratnapura

E77 and E78—Alton Group, Upcot.

Experiments E53, E54, E55 and E71 were of the randomized block design with four replicates. These experiments were carried out in pruned seedling tea from 1966 to 1969, and had a standard plot size of 1/20 acre. In Experiments E77 to E81, because of the nature of the treatments (see later), no plots were demarcated, but large numbers of termite-infested bushes were treated and four bushes were sampled after treatment to represent four replicates. Experiments E77 to E81 were carried out during 1969. In the experiments reported here, the following insecticides and fumigants were evaluated :—

Aldrin (Aldrex 20% EC; *ex* Shell, England—Lankem)
Aluminium phosphide (Phostoxin; *ex* Degesh, Germany—Hayleys)
BHC (Lin-Dol 6% granular; *ex* Mackwoods)
BHC (BHC smoke generator; *ex* ICI, UK—CIC)
Bidrin (Bidrin 85% technical; *ex* Shell, England—Lankem)
Chlordane (Intox-8; *ex* Sandoz, Switzerland—Baurs)
DDT (Deenol 25% EC; *ex* Baurs)
Demeton-methyl (Metasystox R 20% EC; *ex* Bayer, Germany—Hayleys)
Dibromochloropropane (Nemagon 20% granular; *ex* Shell, England—Lankem)
Dibromochloropropane (Fumazone 75% EC; *ex* Dow, USA—Harrison & Crosfield)
Dichlorvos (Vapona 48% EC; *ex* Shell, England—Lankem)
Dieldrin (Dieldrex 20% EC; *ex* Shell, England—Lankem)
Dimethoate (Roxin 40% EC; CELA, Italy—Ceypag)
Dimethoate (Rogor 40% EC; *ex* Fisons, England—Harrison & Crosfield)
Dowco-179 (Dursban 4E; *ex* Dow, USA — Harrison & Crosfield)
Endrin (Endrex 20% EC; Shell, England—Lankem)
Ethylene dibromide (Dowfume W-85; *ex* Dow, USA—Harrison & Crosfield)
Heptachlor (Heptachlor 2E; *ex* Velsicol, USA—Baurs)
Methyl bromide (Methyl bromide 98% + chloropicrin 2%; *ex* Lankem)
Ortho-dichlorobenzene (Ortho-dichlorobenzene; *ex* BDH, England)
Para-dichlorobenzene (Mascador pellets; *ex* ICI, England—CIC)
Phenthoate (Cidial 50% EC; *ex* Montecatini, Italy—C.E. Peiris & Co.)
Phosphamidon (Dimecron 50% EC; *ex* Ciba, Switzerland—Baurs)
Prothoate (Fac 40% EC; *ex* Montecatini, Italy—C.E. Pieris & Co.)
Sodium cyanide (Cymag dust; *ex* Plant Protection, UK—CIC)
Trichlorobenzene (Trichlorobenzene; *ex* BDH, England)
UC-21149 (Temik 10-G; *ex* Union Carbide, USA—Mackwoods)
Zinc phosphide (Zine phosphide powder; *ex* Plant Protection, UK—CIC)

The trade name, the name of the manufacturers and their agents in Ceylon are given in parentheses.

The persistent organochlorine insecticides (aldrin, dieldrin, chlordane, DDT endrin and heptachlor) and the two organophosphate insecticides, phenthoate and Dursban were given as sprays to wet the whole bush frames and the soil surrounding the bushes, using 1.5-2.0 lb active ingredient per acre (Experiments E54, E55 and E71). These insecticides were also applied using the method developed by Austin (1957) for *Postelectrotermes,* where jets of dieldrin or chlordane, as 0.1% and 0.25% solutions respectively, were forced into each colony through an opening, using a pressurized knapsack sprayer (with the swirl plate of the nozzle removed) at about 70 lb pressure (Experiment E54).

The systemic organophosphate-type insecticides (dimethoate, phosphamidon, demeton-methyl, prothoate and Bidrin) were given as (i) drenches of whole plants, (ii) soil drenches around each plant, and (iii) by injection of each plant through holes drilled in the trunk, a method similar to that used in controlling tree pests by trunk injection (Leatherdal 1966; Wallace, 1966). These methods were used in Experiments E53-E55. The carbamate-type systemic insecticide (Temik) was applied in the granular form around each plant (Experiment E71).

The fumigants (aluminium phosphide, zinc phosphide, dibromochloro-propane, dichlorvos, ethylene dibromide, ortho-dichlorobenzene, para-dichlorobenzene, trichlorobenzene, BHC granules and sodium cyanide) were evaluated by drilling a hole into each gallery system and introducing the solid or liquid fumigant into the hole; after introducing the chemical, the hole and other cavities present in the trunk were sealed with putty or clay to make it air tight (Figures 4 and 5). For drilling holes, a hand drill or a small electric drill operated by a portable generator (Honda 300 watt generator) was used. This method was used in experiments on *Glyptotermes* (E79-E81). In the case of *Postelectrotemes* drilling of a hole was not necessary because the cavities were large and easily exposed by pruning (Experiment E77, E78). Application of some fumigants (methyl bromide, BHC smoke generator, aluminium phosphide, dichlorvos, ethylene dibromide and trichlorobenzene) was done under polythene cover, soon after pruning; but it was found that covering with polythene sheets with or without chemicals even for a few hours is detrimental to tea bushes (Experiment E79). Results of fumigation under polythene cover are not presented because all bushes in both treated and untreated plots were killed with the termites within.

In addition to the chemical treatments, an untreated control was included in each experiment. The experiments, the rates of application and other details are listed in Tables 4-12.

The effect of each treatment was evaluated by uprooting and dissecting the bushes, and counting all dead and live individuals found within. Four bushes (colonies) selected at random were sampled from each treatment. It must be noted that because of the nature of the problem, particularly the variations in colony size (see Tables 1 and 2), it was not possible to sample portions of tea bushes. It was our view that examining each colony, and taking four such colonies (bushes) to represent four replicates was a satisfactory method of sampling and caused only little damage to the tea fields. In Tables 4-12, the mean number of individuals (other than eggs) per colony and the precentage kill are given.

RESULTS

Observations on the biology

All three species of live-wood termites of the tea plant belong to the family Kalotermitidae. Kalotermitidae, commonly called dry-wood termites, live inside their food supply eating the wood as they go along, with little or no connection with the ground at any stage of their development (Harris 1969). It was observed that the caste system in all three species is represented by worker (nymph functioning as worker) soldier and reproductive; reproductives are present as the royal pair, supplementary reproductives, and as alate nymphs (winged young) and alate imagos, (winged adults). The alate imagos are also often referred to as alatae. The proportion of the different castes in *Postelectrotermes, Glyptotermes* and *Neotermes* encountered during these investigations are presented in Tables 1–3.

TABLE 1 — *Summary of field observations on* Postelectrotermes militaris *castes*

Caste	Minimum No. per Colony	Maximum No. per colony	Mean No. per colony	Standard error
Larvae	0	638	73.73	40.81
Nymphs	60	2158	440.00	147.07
Soldiers	2	76	16.40	5.09
Alate nymphs	0	46	3.06	3.06
Alate (alate imagos)	0	137	9.13	9.13
Functional reproductives (primary and secondary reproductives)	0	240	20.26	15.90

TABLE 2 — *Summary of field observations on* Neotermes greeni *castes*

Caste	Minimum No. per colony	Maximum No. per colony	Mean No. per colony	Standard error
Larvae	0	586	195.6	10.85
Nymphs	65	871	420.4	147.09
Soldiers	2	24	10.6	4.10
Alate nymphs	0	13	2.6	2.59
Alate (alate imagos)	0	3	0.6	0.59
Functional reproductives (primary and secondary reproductives)	2	15	6.4	2.61

TABLE 3 — *Summary of field observations on* Glyptotermes dilatatus *castes*

Caste	Minimum No. per colony	Maximum No. per colony	Mean No. per colony	Standard error
Larvae	0	1057	76.56	7.91
Nymphs	5	2487	283.21	58.10
Soldiers	0	141	15.91	0.99
Alate nymphs	0	815	29.77	5.04
Alate (alate imagos)	0	88	0.99	0.44
Functional reproductives (primary and secondary reproductives)	0	63	3.21	0.36

In *Postelectrotermes* militaris, 104 colonies were examined of which nine were vacant. In *Glyptotermes* dilatatus, altogether 305 colonies were examined of which 21 were vacant. Only five colonies of *Neotermes greeni* were available and none was vacant. As the last two species are almost always found occurring concurrently, it is clear that *Glyptotermes* is the predominant species and therefore the most important low-country termite.

Chemical control

Results of the chemical control experiments are presented in Tables 4–12. It was found that application of persistent organochlorine insecticides (dieldrin, aldrin, heptachlor, chlordane, endrin and DDT) had no effect probably because of the secretive habits of the termites; they do not come in contact with the outer surface of the tea bush (Tables 5–7). Treatments with systemic insecticides (dimethoate, phosphamidon, demeton-methyl, prothoate, Bidrin and Temik) too were ineffective although several techniques of applications were tried out (Tables 4–7).

TABLE 4 — *Evaluation of insecticides against* Glyptotermes dilatatus *at Talangaha Estate, two weeks after treatment (Experiment* **E53***)*

Treatment	Rate (lb ai/acre)	No. of termites/colony (No. of reproductives* given in parentheses)	Percentage kill
1. Demeton-methyl	0.3	297 (4)a	0
2. Dimethoate	0.6	294 (2)a	4.76
3. Bidrin	0.7	342 (1)	0
4. Demeton-methyl	0.3	570 (1)a	0
5. Dimethoate	0.6	396 (5)	0
6. Bidrin	0.7	155 (4)	3.2
7. Demeton-methyl	0.8	215 (4)a	0.2
8. Dimethoate	1.6	62 (2)	0
9. Bidrin	3.4	303 (2)	0
10. Untreated control	—	564 (3)	0

NB — Treatments 1–3 : Drench of the entire bush using 80 gallons of water per acre.

Treatments 4–6 : Soil drench around the plants using 200 gallons of water per acre (The number of bushes per acre was approximately 3600).

Treatments 7–9 : Injection into each plant through a hole drilled on the trunk at the rate of 0.5 ml of formulation per bush.

*Other than alate nymphs and alate imagos (alatae)

a — Mean of three colonies as one was vacant

TABLE 5 — *Evaluation of insecticides against* Postelectrotermes militaris *at Moray Estate, one month after treatment* (*Experiment* E54)

Treatment	Rate (lb ai/acre)	No. of termites/colony (No. of reproductives* given in parentheses	Percentage kill
1. Dieldrin	1.5	1255 (29)	0
2. Aldrin	1.5	2114 (39)	0
3. Heptachlor	1.7	1502 (15)	0
4. Chlordane	1.8	1409 (29)	0
5. Dimethoate	0.8	1129 (60)	0
6. Phosphamidon	0.6	1564 (9)	0
7. Dichlorvos	1.2	540 (30)	0
8. Dimethoate	0.8	613 (28)	0
9. Demeton-methyl	0.5	593 (11)	0
10. Dieldrin	1.5	501 (12)	9.6
11. Chlordane	1.7	215 (5)	13.0
12. Untreated	—	915 (12)	0

NB — Treatments 1– 7 : Drench of the entire bush using 80 gallons of water per acre, using knapsack sprayers.

Treatments 8– 9 : Soil drench around the plants using 200 gallons of water per acre (The number of bushes per acre was approximately 3600).

Treatments 10–11 : Gallery exposed and a jet of insecticide forced in using 200 gallons of water per acre (Austin's method).

*Other than alate nymphs and alate imagos (alatae)

TABLE 6 — *Evaluation of insecticides against* Glyptotermes dilatatus *at Galaboda Estate, one month after treatment* (*Experiment* E55)

Treatment	Rate (lb ai/acre)	No. of termites/colony (No. of reproductives* given in parentheses)	Percentage kill
Dieldrin	1.5	693 (5)	0.7
Aldrin	1.5	242 (7)	0
Heptachlor	1.7	689 (5)	0
Chlordane	1.8	855 (14)	0
Dimethoate	0.8	1147 (9)	0
Phosphamidon	0.6	892 (11)	0
Dichlorvos	0.9	917 (8)	0
Untreated control	—	1208 (6)	0

NB — Insecticides were applied as sprays on entire tea bushes using 80 gallons of water per acre, using knapsack sprayers.

*Other than alate nymphs and alate imagos (alatae)

TABLE 7 — *Evaluation of insecticides against* Glyptotermes dilatatus *at Galaboda Estate, one month after treatment (Experiment* E71)

Treatment	Rate (lb ai/acre)	No. of termites/colony (No. of reproductives* given in parentheses	Percentage kill
Dieldrin	1.5	324 (4)	0.61
Aldrin	1.5	—	—
Heptachlor	2.0	654 (0)	0.15
Chlordane	1.9	6 (0)a	0
Temik 10-G	4.0	666 (4)a	0
Dimethoate	1.0	599 (2)	0
Dursban	1.0	531 (5)	0
Phenthoate	2.5	413 (11)	0
Prothoate	1.0	1689 (66)a	0
Endrin	1.5	69 (1)	0
DDT+Endrin	1.5+0.75	3 (3)a	0
Untreated control	—	664 (2)a	0

NB — All insecticides except Temik 10% granules were applied as sprays on entire tea bushes using 80 gallons of water per acre.

*Other than alates nymphs and alate imagos (alatae)

a — One colony vacant

The most effective method of getting the poison to reach the termite nests was by introducing the chemical into the gallery system and then allowing it to diffuse within the galleries in the gaseous form. The fact that fumigants cannot be applied under polythene cover has been explained earlier.

Of the fumigants evaluated, good results were obtained with aluminium phosphide (Phostoxin), dichlorvos (Vapona), trichlorobenzene, ethylene dibromide, sodium cyanide (Cymag) and para-dichlorobenzene. Aluminium phosphide, (Phostoxin) gave the best and most consistent results (Figure 6); in most instances absolute control of each termite colony was obtained, even at the low dosage rates of 0.15 g for *Glyptotermes* (Experiment E79, Table 10) and 0.6 g for *Postelectrotermes* (Experiment E78, Table 9). Phostoxin was non-phytotoxic. Results with the other effective fumigants were variable. Dichlorvos gave partial control (Tables 8, 11 and 12). Ethylene dibromide and trichlorobenzene, though very effective at high rates of application (Tables 8, 11 and 12) were found to be phytotoxic. Sodium cyanide (Cymag), which liberates hydrogen cyanide gas, gave partial control, and for this reason and also because of the dangers involved in handling this compound, was not examined further (Table 11). Para-dichlorobenzene gave good results at higher rates of application, though the results were not very consistent (Tables 11 and 12). Results of all other fumigants were inferior to that obtained with ethylene dibromide, dichlorvos, trichlorobenzene, para-dichlorobenzene, sodium cyanide and aluminium phosphide. Aluminium phosphide (Phostoxin) gave the best and most consistent control of the termites, at all dosage rates evaluated, and was non-phytotoxic (Tables 8–11).

TABLE 8 — *Evaluation of fumigants against* Postelectrotermes militaris *at Alton Estate, one week after treatment* (*Experiment* E77)

Treatment per colony (bush)	No. of termites/colony (No. of reproductives* given in parentheses)	Percentage kill
"Phostoxin" 3 g	892 (48)a	99.8
"Phostoxin" 3 g	2313 (15)	99.9
Ethylene dibromide 20 ml	1011 (8)a	85.4
Trichlorobenzene 10 g	571 (51)	93.3
Dichlorvos 2 ml	1157 (50)	64.6
Dichlorvos 4 ml	1330 (49)	40.3
Ortho-dichlorobenzene 10 ml	1031 (37)	10.6
"Fumazone"	836 (14)a	10.3
"Nemagon"	1806 (150)	1.4
Untreated control	2329 (20)	0

*Other than alate nymphs and alate imagos (alatae)

a — Mean of three colonies as one was vacant

TABLE 9 — *Evaluation of aluminium phosphide (Phostoxin) against* Postelectotermes militaris *at Alton Estate, three days after treatment* (*Experiment* E78)

Treatment per colony (bush)	No. of termites per colony (No. of reproductives* given in parantheses)	Percentage kill
"Phostoxin" 0.6 g	473 (1)	84.5
"Phostoxin" 1.2 g	391 (61)	98.9
"Phostoxin" 2.4 g	946 (19)a	100
Untreated control	308 (2)	0

*Other than alate nymphs and alate imagos (alatae)

a — Mean of three colonies as one was vacant

TABLE 10 — *Evaluation of aluminium phosphide (Phostoxin) against* Glyptotermes dilatatus *at Talangaha Estate, three days after treatment* (*Experiment E79*)

Treatment per colony (bush)	No. of termites per colony (No. of reproductives* given in parentheses)	Percentage kill
"Phostoxin" 1.2 g	374 (6)	60.
"Phostoxin" 0.6 g	1080 (0)	96.9
"Phostoxin ' 0.3 g	246 (3)	93.9
"Phostoxin" 0.15 g	60 (2)a	100
Untreated control	1326 (10)	0

*Other than alate nymphs and alate imagos (alatae)

a — Mean of three colonies as one was vacant

TABLE 11 — *Evaluation of fumigants against* Glyptotermes dilatatus *at Talangaha Estate, one week after treatment* (*Experiment* **E80**)

Treatment per colony (bush)	No. of termites per colony (No. of reproductives* given in parentheses)	Percentage kill
"Phostoxin"	26 (0)	100
Ethylene dibromide 0.5 ml	553 (3)	10.1
Ethylene dibromide 1 ml	363 (1)	53.1
Ethylene dibromide 2 ml	362 (9)	68.2
Ethylene dibromide 5 ml	315 (2)	91.7
Dichlorvos 10 ml	740 (1)	36.8
Dichlorvos 5 ml	965 (5)	27.4
Dichlorvos 2.5 ml	115 (1)	24.3
Dichlorvos 1 ml	609 (3)	20.6
Zinc phosphide 2 g	621 (2)	7.5
Zinc phosphide 1 g	139 (3)	0
Zinc phosphide 0.5 g	287 (2)	0
"Cymag" 2 g	915 (7)	26.3
"Cymag" 1 g	229 (1)	14.4
"Cymag" 0.5 g	712 (1)	1.8
Para-dichlorobenzene 1 g	417 (7)	2.8
Para-dichlorobenzene 2 g	375 (2)	55.2
Para-dichlorobenzene 3 g	696 (2)	8.9
Para-dichlorobenzene 4 g	547 (1)	84.6
Trichlorobenzene 2 g	708 (2)	1.1
Trichlorobenzene 1 g	278 (4)	4.6
Trichlorobenzene 0.5 g	336 (1)	0
Trichlorobenzene 0.25 g	1137 (7)	30.0
BHC granular 10 g	918 (5)	24.8
BHC granular 5 g	768 (2)	0
BHC granular 3 g	438 (2)	6.1
BHC granular 1 g	616 (5)	17.5
Untreated control	840 (4)	0

*Other than alate nymphs and alate imagos (alatae)

TABLE 12 — *Evaluation of fumigants against* Glyptotermes dilatatus *at Talangaha Estate, two weeks after treatment* (*Experiment* **E81**)

Treatment per colony (bush)	Mean No. of termites/colony (No. of reproductives* given in parentheses)	Percentage kill
Dichlorvos 10 ml	570 (4)	42.9
Dichlorvos 5 ml	379 (3)	13.7
Ethylene dibromide 2 ml	156 (2)	42.3
Ethylene dibromide 5 ml	288 (13)	84.7
Para-dichlorobenzene 2 g	250 (2)	50.8
Para-dichlorobenzene 4 g	698 (4)	45.5
BHC granular 5 g	293 (3)	18.4
BHC granular 10 g	255 (1)	19.2
Trichlorobenzene 1 g	176 (1)	91.4
Trichlorobenzene 2 g	211 (1)	43.6
Untreated control	775	0

*Other than alate nymphs and alate imagos (alatae)

DISCUSSION AND CONCLUSIONS

Termite biology

Termites (Isoptera) form a small, homogeneous order of insects, all the known species of which are found living in discrete, highly organized communities. They are commonly known as 'white ants', but are distinctly different from ants. There are no sub-social termites, and the social behaviour (social organization that includes community living, nest building, division of labour and brood care) involving polymorphism has led to caste differentiation. The most advanced species of termites have achieved a complexity of social organization and nest structure unsurpassed by any other social insect. A termite community consists basically of one or more pairs of functional reproductives and a comparatively large number of immature individuals in various stages of development. The immature individuals may either be in the process of developing towards the fully mature insect, or be in a state of arrested development (Harris & Sands 1965).

In Kalotermitidiae, to which the live-wood termites of tea belong, the functional reproductives are of two classes, primary and secondary (Tables 1–3). The latter are also known as supplementary reproductives. Primary reproductives are the founders of a community and the two sexes are customarily called the king and queen and form the royal pair. The secondary reproductives are produced within a community, in response to the loss of the primary pair, from nymphs whose internal development has been accelerated without change in outward form after a single moult or from alatae (winged adults) awaiting the swarming season; although sexually mature, their wings are forcibly removed and are thus deprived of flight. Male and female reproductives are present in equal numbers and copulation takes place intermittently throughout their lives.

The castes which are non-reproductives exhibit varying degree of polymorphism in the different families of termites. Broadly speaking they fall into four categories: larvae, nymphs, soldiers and workers. The first two or three instars (stages of development) are undifferentiated, apart from indications of sex, and are referred, to as larvae. Later stages which show wing pads of increasing length and progression towards the adult (alatae) are referred to as nymphs. Observations made on the three species of live-wood termites of tea showed that all five types of castes are represented in these species namely, reproductive (primary, secondary and alatae) larvae, nymphs, workers and soldiers (Tables 1 – 3). It is, however, known that a distinct worker caste is absent in Kalotermitidae (Harris 1957), but the work of the community is done by nymphs whose development to the winged adult (alatae) may be arrested, temporarily or permanently at any stage to meet the needs of the community. The name pseudergate has been suggested to the working nymph of Kalotermitidae by Weesner (1960).

Soldiers develop from larvae and are present in almost all termite groups including Kalotermitidae. As a rule both sexes contribute to the soldier caste, but become sterile during development. Soldiers are distinguished by a very large head and a pair of powerful jaws; the shape and form of the head and the jaws are characteristic for each termite species and are used in the identification of the species. The method of indentification of tea termites using the soldier head as a key is given in the articles by Ranaweera (1962) and Cranham (1966). The main function of the soldier is to defend the colony against invasion by enemies.

The food of the live-wood termites of tea is almost exclusively heart-wood; in advanced stages of attack by *Glyptotermes*, sapwood and bark are also eaten causing the death of branches or bushes. As pointed out earlier food gathering and nest expansion, or in other words gallery construction, are carried out by the nymphs that function as workers. Those which take no part in the collection and preparation of food are the reproductives, soldiers, larvae and nymphs about to become alatae. The digestion of the wood is done with the aid of symbiotic intestinal protozoa. Food circulates within the colony by a process of soical rumination and is passed from one individual to another by regurgitation or as faeces. The larvae, soldiers and reproductives are unable to feed by themselves and are fed by the nymphs. The regulation of castes within a community is dependent on the influence exerted by the size of the community, by seasonal factors, and to a great extent on inhibitory substances which are variously referred to as socio-hormones, ectohormones and more recently as pheromones. Feeding activities with its associated acts of grooming and soliciting is considered to be the basis of social organization in termites (Harris & Sands 1965).

As live-wood termites are serious pests of tea, information on how new colonies are founded is valuable when control techniques are evolved (although termite control was the prime object of this investigation). We were able to establish that winged sexual forms are present in all three species. It was observed that the caste system and the function of the castes of the three tea termites conformed to that found in other members of Kalotermitidae as described earlier. The colonies are established within the food source (the tea bush) and the individuals are accustomed to the microclimate—humidity and temperature—prevailing inside the galleries. So that they are well insulated from external climatic conditions. They have only restricted access to the outside, since accidental holes, and those made for swarming of the alatae and the disposal of frass, are quickly plugged with faecal matter. Clearly it is for this reason, that powerful and persistent insecticide applications on the tea bush frames and soil drenches with these insecticides were ineffective against these termites.

Our observations indicate that colony foundation in the three live-wood termites of tea occurs by the dispersion of winged reproductives (alatae) from the parent colony. In *Postelectrotermes*, which also attacks the root system of the tea bush, colony foundation can also occur from bush to bush by root contact (Green 1907; King 1937). Termites are usually not regarded as migrants. The flight of the primary reproductive (alatae) has been shown to be a ecological adaptation for dissemination of the species, but is not continued for long by each individual (Johnson 1969). Dispersal of termites by flights (swarming) has been shown to be essentially seasonal, being associated with increased atmospheric humidity immediately prior to, during or after rain (Harris & Sands 1965). In the three species we studied, no detailed observations were made on flight.

Survival of alatae after swarming is extremely small as many are destroyed by predators (predatory insects, amphibia, reptiles and mammals) and others are lost during competition for nest sites. It has been suggested by Harris and Sands (1965) that generally in termites, those pairs most likely to found new colonies successfully will be composed of individuals which have flown furthest from their parent colony, and reached a site such as would be left by the recent extinction of another colony in the area. Our observations indicate that, although this could happen to some extent in the three species studied, new colonies are mostly initiated in new tea plants. It was observed that large numbers of vacated nests (tea bushes) were found in older fields. Also in the case of *Glyptotermes* and *Neotermes* many tea bushes are completely destroyed within 5–15 years after invasion.

As swarming (also referred to as the 'nuptial flight') is dependent on weather factors, and as it occurs simultaneously in most colonies, there is ample opportunity for the mixing of alatae from different nests. In the termite species *Paraneotermes simplicicornis*, the alatae accumulate in the termitarium for about three weeks before the first flight. They remain quiescent for about three weeks before the nuptial flight until the temperature rises above a certain value; then they become active and emerge from the nest and take off (Nutting 1966). According to Johnson (1969), a similar process occurs in other termite species as well. Primary reproductives (alatae) who are the founders of new colonies have a basal suture in the wings and the wings are shed along this suture in response to the stimulus of meeting one of the opposite sex. Behaviour after the sexes have met involves wing shedding and searching for a nest site. In the tea termites, dead wood resulting from shot-hole borer (*Xyleborus fornicatus* Eichh.) damage, fungus damage, cankers, pruning cuts, dead snags and areas of sun scorch damage are usually used to obtain a foothold in the bushes. As *Glyptotermes* and *Neotermes* were found almost exclusively in tea bushes with shot-hole borer damage, it would seem that wood rot and die-back of branches resulting from shot-hole borer attack pre-dispose tea bushes to live-wood termite invasion. Shot-hole borer control, according to the methods recommended (Danthanarayana 1968b) and bush sanitation (removal of dead wood of tea and shade trees at pruning time) therefore appear to be a preventive method of controlling live-wood termites, particularly in young fields, both seedling and VP.

As termites are known to be weak flyers, incapable of flying long distances (Johnson 1969) and because the numbers of alatae in *Postelectrotermes, Neotermes* and *Glyptotermes* were found to be rather low in the colonies examined during our studies (Table 1 – 3), it is unlikely that these three termite species are able to spread very rapidly from one tea planting district to another; this may be one of the reasons why *Postelectrotermes* is mostly confined to the Maskeliya district. In the case of *Glyptotermes* and *Neotermes,* the observations we have made during survey trips and advisory visits suggest that new attacks by these termites, particularly in VP tea planted in early 1960s are associated with the existence of termites in neighbouring old seedling fields, within the same estate or in estates nearby.

Termite control

The earliest method of controlling *Postelectrotermes* was by blowing in of Paris Green through small holes bored into the stems of infested tea bushes (Jepson 1929). As this method did not work well in practice, and the use of arsenicals was hazardous, it was not recommended (see Ranaweera 1962). Later, Austin (1957) developed a method for controlling *Postelectrotermes* by forcing jets of dieldrin or chlordane into a colony through an opening using a pressurized knapsack sprayer. Although Austin reported good results with this method, in practice it was not very successful and was, therefore, not adopted by tea planters. The experiments described in this work showed that this method gave only partial control of each colony (Table 5). In the case of *Neotermes greeni* and *Glyptotermes dilatatus* which construct net works of small galleries (Figures 2 and 3) in contrast to the hollowing out of stems and roots by *Postelectrotermes* (Figure 1), the above methods were not applicable because the nature of gallery systems did not permit forcing in of chemicals. Thus, control methods for these two species have not been available hitherto.

Results of our experiments showed that conventional methods of termite control with persistent organochlorine insecticides are of no value in controlling live-wood inhabiting termites of tea. It must be noted, however, that these insecticides are effective against scavenging termites of tea (see Ranaweera 1962, Cranham 1966). It was also found during our studies that several well-known systemic insecticides with a broad spectrum of activity were also ineffective in controlling the live-wood termites, probably because the chemicals are not translocated to the walls of the termite tunnels, where feeding occurs. When fumigation techniques were resorted to, the application of fumigants to pruned tea under polythene cover was not practicable as this was detrimental to the plants, probably due to the high temperatures that developed within the sealed tents. *This observation is significant, because it may be possible in future investigations to determine an optimum covering period which will kill the termites but leave the plants unharmed.*

It was found that the best method of fumigation was to introduce the fumigant into the gallery system and then seal the openings. The fumigant then diffuses within the tunnels eliminating most or all individuals; the degree of kill which is partly dependent on the diffusing properties of the chemical, varied among the effective fumigants. Aluminium phosphide, ethylene dibromide, trichlorobenzene and para-dichlorobenzene were the most effective in controlling the termites. Of these ethylene dibromide and trichlorobenzene showed phytotoxic effects. It was not possible to obtain a thorough evaluation of para-dichlorobenzene in these experiments, particularly from a phytotoxic point of view, and this compound, therefore, needs further investigation before it can be recommended. Since aluminium phosphide gave more consistent results in the first experiment (Table 8) and also because of its safe and easy handling properties, this compound was tested repeatedly in later experiments. The results showed that it is possible to obtain absolute control of each termite colony with aluminium phosphide (Tables 8–11).

Phostoxin is a solid fumigant which has been developed for fumigation of grain, flour and stored products against insect pests (Lindgren, Vincent & Strong 1958). It is composed of a mixture of pure aluminium phosphide and ammonium carbamate in tablet or pellet form. On exposure to moisture in the atmosphere or in the commodity to be fumigated, aluminium phosphide generates phosphine gas which is highly toxic to all stages of insects (Lindgren *et al* 1958). Ammonium carbamate releases carbon dioxide and ammonia, and prevents spontaneous ignition of phosphine gas. After decomposition is complete, aluminium hydroxide is left behind as a harmless residue. Aluminium hydroxide is a constituent of clay and is not phytotoxic. Tea bushes treated with Phostoxin showed no signs of adverse effects.

A Phostoxin tablet measures 20 mm in diameter and 5 mm in thickness, weighs 3 g and yields 1 g of phosphine gas. The pellets weigh 0.6 g each. For controlling *Postelectrotermes* which has a large gallery system, 1.2 g of Phostoxin (two pellets or one half of a tablet) were found to be sufficient. It is likely that the dose can be further reduced to 0.6 g (one pellet or one quarter of a tablet). For controlling *Glyptotermes* which has a smaller gallery system, very low doses such as 0.15 or 0.3 g ($\frac{1}{4}$ or $\frac{1}{2}$ of a pellet) were found to be effective. Results clearly showed that in all experiments absolute control of each termite colony was obtained in most instances. The few instances of failure are attributable to possible misplacement of the chemical or to improper sealing of all openings; for the fumigant to be effective the colony must be made fairly air-tight. Another possible cause for occasional failure is that, in *Glyptotermes* and *Neotermes,* because the colonies are small, two or more independent colonies may exist in the same bush, particularly if the bush happens to be large. If such instances are detected it will be necessary to make more than one insertion of Phostoxin for controlling the termites. It must be mentioned, that the method (the use of Phostoxin against live-wood termites) developed by us has already proved useful in tea termite control as well as control of live-wood termites of several other tree crops overseas (Davies 1969; Simmonds 1969; Scarborough 1969; personal communication). Colonies of *Postelectrotermes, Glyptotermes* and *Neotermes* are generally discovered during the time of pruning of the tea plant. In the latter two species, termite damage can also be detected during periods of drought when infested bushes may show prominent dead branches. Whether the bush is pruned or not, once a termite gallery system is located, it is advisable to treat the bush immediately on the lines suggested below (see section on recommendations). Control methods must be strictly enforced if live-wood termites are detected in new VP clearings in the low-country, in order to prevent the spread of the pest to surrounding bushes. It will be of interest to note that our observations over the last five years suggest that in new VP fields, the live-wood termites first begin to colonize isolated bushes, and then gradually invade other plants closeby.

The method of control described here using Phostoxin is comparatively expensive and will not be economical in old seedling tea where large numbers of bushes may have to be treated. It is suggested that the method be adopted when termites are detected in VP tea and in young seedling tea. It is rather unfortunate that, because of the secretive habits of these termites, early attack cannot be detected. In this connection, it is of interest to mention that methods are available to locate colonies of certain termite species that live within timber trees (Greaves, Armstrong, McInnes & Dowse 1967; Ardley, Clifford & Gay 1965). So far, it has not been possible to evolve a method to detect termite colonies within tea plants during initial stages of attack.

RECOMMENDATIONS

Up-Country Live-Wood Termites (Postelectrotermes militaris)

At pruning time, when the gallery system becomes exposed, insert 1 or 2 pellets of Phostoxin and seal the opening with clay. It is also necessary to seal all other openings of the gallery system, in the same way. As the galleries of this termite are large tunnels hollowed out in branches, stems and roots, it is not necessary to drill a hole for access to insert Phostoxin, as done in the case of the low-country species (see below).

The lower dose of 1 pellet may be used for small bushes and the large dose of 2 pellets for the large bushes. If Phostoxin is not available in the pellet form, use $\frac{1}{4}$ or $\frac{1}{2}$ of a tablet. If properly carried out it is possible to eradicate all termites within each treated bush, in 2–3 days.

Low-Country Live-Wood Termites (Glyptotermes dilatus *and* Neotermes greeni)

At pruning time, when the galleries become exposed, drill a hole $\frac{1}{4}$–$\frac{1}{2}$ inch in diameter into the gallery system. Drilling of holes can be carried out with a hand drill, but in large scale operations, it is recommended to use an electric drill operated by a portable generator; the latter method will considerably reduce labour costs.

After drilling the hole, introduce 1/8 or 1/10 of a tablet of Phostoxin into the cavity and seal the opening with clay. It is also necessary to seal all other openings of the gallery system. When inserting the chemical, it must be ensured that a portion of the tablet is in contact with the termite tunnels so as to enable maximum diffusion of gases; if the chemical is not placed in contact with any of the galleries, no control will be obtained. Division of the Phostoxin tablet into smaller portions can be conveniently carried out manually with the aid of a file, but protective gloves (rubber or polythene) must be worn when handling the tablets and pellets.

It is in order to carry out the Phostoxin treatment during any time of the pruning cycle, if infestations can be detected. The usual signs of detection of termite attack are branch and stem breakage with live termites and galleries at the point of break, or death of one or more branches, particularly during a period of drought; the dead or dying branches can be pruned to reveal the galleries.

As pointed out previously, this method of termite control is expensive, and is, therefore, more valuable as a method of preventing further spread of the pest in newly attacked fields. In heavily infested old seedling tea, the method is uneconomical and is not recommended, unless estates are prepared to invest 10–12 cents per bush. As old tea, widely attacked by the low-country live-wood termites are a source of infection to new VP tea, it is advisable to uproot and replant such uneconomical tea fields. Also, because shot-hole borer damage is considered to be one of the factors that predispose tea bushes to termite infestation, it is important to take vigilant shot-hole borer control measures, particularly in the new clearings. The present recommendation for shot-hole borer control is the application of the insecticide heptachlor. Heptachlor application itself will have some effect in eliminating termites at the time of founding of new colonies, because this insecticide will kill the primary reproductives which begin new colonies, when they come into contact with it. Details of shot-hole borer control with heptachlor in both new and old tea have been published (Danthanarayana 1968).

Finally, it must be emphasized that the low-country live-wood termite problem is becoming increasingly important, as *Glyptotermes* is now found in high yielding VP clearings planted in the early 1960s, particularly in Galle district.

Prompt action, on the lines suggested above is needed to prevent it from devastating some of our best tea areas.

PRECAUTIONS

1 — Application of Phostoxin should be done under the supervision of a responsible officer.

2 — Phostoxin should be handled carefully as it is highly toxic to all forms of animal and human life. Swallowing a tablet is fatal.

3 — Phostoxin tubes and tins should be opened in open air only; all contents should be used in one operation. Storage of opened tubes and tins will render the tablets and pellets that are left over less effective.

4 — Tubes and tins containing Phostoxin should be kept under lock and key and no person should be allowed to sleep in a room where they are stored.

5 — After fumigation, hands and exposed parts should be washed with soap. Contaminated clothing should be removed.

6 — Empty tins should be destroyed under personal supervision.

7 — Whenever pesticides are used, *read and follow carefully the instructions on the label.*

SUMMARY

1 — An account is given of the biology of the three species of live-wood termites of tea and methods of controlling them.

2 — Observations made during these investigations provided new information on polymorphism, dispersal and founding of new colonies.

3 — Application of persistent organochlorine insecticides such as aldrin, dieldrin, heptachlor, chlordane, DDT and endrin and several organophosphate-type insecticides had no effect because of the secretive habits of the termites; they do not come in contact with the outer surface of the tea bush where the insecticide deposit is found.

4 — Application of systemic insecticides (dimethoate, phosphamidon, demeton-methyl, prothoate, Bidrin and Temik) by various techniques was also ineffective in controlling the termites.

5 — Only fumigation of each individual colony (tea bush) with a solid or liquid fumigant introduced into the gallery system, controlled the termites.

6 — The above technique developed during these studies is a new approach in controlling termite colonies that live within plants. The method is likely to have wide application in other crops infested in a similar manner.

7 — Of eleven fumigants evaluated, the best results were given by aluminium phosphide (Phostoxin) in tablet or pellet form. Ethylene dibromide, trichlorobenzene and para-dichlorobenzene too gave good results. The first two compounds were toxic to the tea plant and the last compound needs further investigation.

8 — It is concluded that fumigation with Phostoxin is the best method of controlling live-wood termites of tea. With Phostoxin it is possible to obtain absolute control of each termite colony with no phytotoxic effects.

9 — Based on the results of experiments described, recommendations are made for controlling the three species of live-wood termites.

10 — It is suggested that, specially in the case of the low-country species *Glyptotermes dilatatus,* prompt action needs to be taken to prevent its spread in new VP fields. The fumigation technique using Phostoxin described in this paper and shot-hole borer control measures recommended earlier should help to achieve this objective.

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