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Control of termites and other soil pests of groundnuts with special reference to controlled release formulations of non-persistent insecticides in India and Sudan

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Abstract

Trials for the control of soil pests, particularly of termites (Isoptera: Termitidae), in groundnuts (*Arachis hypogaea*) in India and Sudan used chlorpyrifos and isofenphos granules, chlorpyrifos , phorate, carbosulfan and carbofuran in controlled release formulations, and chlorpyrifos seed dressing. Their effects on foliar pests were also noted. Chlorpyrifos controlled release pellets were as effective as aldrin, used as a standard, in reducing root and pod attack and, like aldrin, doubled yields. Isofenphos and chlorpyrifos granules increased yields and reduced pod damage, but to a lesser extent. Other treatments were less effective. Carbosulfan and phorate controlled release and isofenphos granules reduced leaf miner attack. These trials establish the efficacy of controlling termites and other soil pests with controlled release formulations of otherwise non-persistent insecticides. However, the expensive formulation is unlikely to be cost-effective for rural farmers in developing countries and, in the case of chlorpyrifos , residue levels in kernels may be unacceptable. Future work should investigate other insecticides in the formulation and development of cheaper controlled release matrices.

Introduction

Groundnuts (*Arachis hypogaea*), like many crops, are subject to serious and widespread attack by termites and other soil insects in the semi-arid regions of Africa and Asia (Amin, 1981; Clinton, 1962; El Amin *et al.*, 1983; Feakin, 1973; Johnson *et al.*, 1981; Reddy & Ghewande, 1986; Wightman & Amin, 1988). Damage to pods is often associated with fungal contamination due to *Aspergillus flavus*, leading to production of aflatoxins (Johnson & Gumel, 1981; McDonald & Harkness, 1963; Sellschop, 1965).

Control has relied almost exclusively on the use of insecticides, applied to the soil or used as a seed dressing, to form a barrier which repels or kills foraging insects. The insecticides must be sufficiently persistent to

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provide protection for the life of the crop (three to four months for groundnuts). Other crops may require longer persistence and forestry trees require two to three years. The only insecticides able to provide this reliably are persistent organochlorines (cyclodienes) (Cowie *et al.*, 1989; Feakin, 1973; Melamed-Madjar, 1967; Rao *et al.*, 1978; Sands, 1977).

However, concern over the health and environmental hazards of cyclodienes has led to an almost total ban on their use in the developed world. Their use in developing countries is decreasing because some governments have banned them on similar grounds, many aid donors no longer sanction their use except in special circumstances, and many developed countries prohibit the import of food-stuffs which contain residue levels greater than 100 μg/g.

There is a clear need for acceptable alternatives. Conventional formulations of most insecticides are broken down rapidly in the soil and cannot protect crops for a sufficient period. However, some may persist long enough to give some control. Chlorpyrifos is now widely used as an alternative to cyclodienes for termite control in buildings in the USA where, under some conditions, it persists for up to 19 years (Mauldin *et al.*, 1987). Persistence was much less in cultivated soil in the tropics, giving only limited control (Wood *et al.*, 1987). Isofenphos soil treatment in cotton in the Yemen Arab Republic gave some increase in yield (Wood *et al.*, 1987). Neither insecticide, in conventional formulation, compares well with cyclodienes but both may have some potential.

Pesticides which break down rapidly in the soil can have their active life increased by incorporation into an inert matrix from which they are slowly released. Once released they break down as usual. Such controlled release (CR) formulations have the advantages of the cyclodienes without the problems associated with their long term persistence (DeGroot & Valvasori, 1989).

The trials reported here were carried out on groundnuts in India using aldrin, as a soil treatment or seed dressing (the standard practices), comparing it with various formulations of less persistent insecticides, including conventional granular (G) formulations of chlorpyrifos and isofenphos, chlorpyrifos seed dressing (SD), and chlorpyrifos, phorate, carbosulfan and carbofuran in CR formulations. The CR chlorpyrifos, phorate and carbosulfan were formulated in plastic pellets giving active lives of about four months; the CR carbofuran was in lignin pellets, also with an active life of about four months.

Termites, especially, are major pests of crops and trees in many semi-arid regions of Africa and Asia (Harris, 1971; Sands, 1977). 10-30% losses are common but total destruction has been recorded (Cowie *et al.*, 1989; Johnson *et al.*, 1981; Kaushal & Deshpande, 1967; Sands, 1977; Sen-Sarma, 1986). The most important crop-damaging termites in Africa and Asia belong to the genera *Microtermes*, *Odontotermes* and *Macrotermes* (Termitidae: Macrotermitinae) (Sands, 1977). *Macrotermes* spp. and some *Odontotermes* spp. build conspicuous mounds and some control may be achieved by killing or removing the queen. However, the need for an alternative to the cyclodienes as a generally effective protective measure has become acute. The results of the present trials on groundnuts are relevant to other crops attacked by both termites and other soil pests.

Materials and methods

Establishment and layout of trials

Trials 1 and 2 were carried out on the research station of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) near Hyderabad, India, in the 1986 rainy season. Trials 3 and 4 were conducted in the 1986 and 1987 rainy seasons, respectively, in collaboration with the Department of Entomology, University of Agricultural Sciences, Bangalore, at the University's Dryland Research Station at Chintamani near Bangalore. Trial 5 took place in Nyala, Western Sudan in collaboration with the Western Savanna Development Corporation in the 1987 rainy season.

In trials 1-4, seeds (cv Robut 33-1) dressed with tetramethylthiuram fungicide were sown in rows 60 cm apart with 25 cm spacing. The wide spacing was to increase risk of termite attack on a particular plant (Crowther & Barlow, 1943). The trials received a single application of chlorothalonil three weeks after sowing, to control foliar fungal diseases. In Sudan, local seed was used with no fungicide treatment.

The trials were laid out in randomized block designs with four replicates. Treatments are indicated in table 1. Application rates were based on the results of Wood *et al.* (1987) (chlorpyrifos and isofenphos granules) or on the manufacturer's recommended rate (control release granules and aldrin). In trials 1, 2, 3 and 5 plots were 11 × 11 m with a 2 m untreated discard on each side. Observations were made in the central 7 × 7 m area. In trial 4, plots were 15 × 11 m with a 2 m discard and a central 11 × 7 m monitoring area. Aldrin and chlorpyrifos seed dressings were applied just before sowing. The soil insecticides were applied by hand to the sowing furrow and mixed with the soil before sowing.

Germination, mortality, pest attack and yield

Except in the Sudanese trials, all plots were examined at three week intervals. Live plants were counted and dead plants examined to determine cause of death. Twenty-five plants per plot were checked for foliar pests. If attack was heavy, dimethoate was applied at 200 g /ha.

At harvest, plants in six randomly-selected rows were dug up and the pods and roots examined for soil insect attack. The plants were sun-dried and the pods and haulms weighed. Damaged pods were separated from healthy pods and the type of damage identified. Both sets of pods were shelled and the kernels weighed. In trial 1, yields of entire plots were compared with those of sample rows to check the validity of the sampling procedure. In trials 2 and 3 the kernels were shaken on a 5 mm mesh sieve, to remove small ones; those retained by the sieve were re-weighed.

Results were analysed using the 'GENSTAT' and 'INSTAT' programmes for analysis of variance and differences among treatments determined by least significant difference. Analysis was performed on square root transformed data if necessary.

Table 1. Treatments used in the soil insecticide trials.

Formulations: D - dust, G - granules, SD - seed dressing, CR - controlled release.
Application: FST - furrow soil treatment, SD - seed dressing, NI - no insecticide.

Insecticide	Rate	Application
Trial 1 (ICRISAT)		
Aldrin D	1 kg a.i./ha	FST
Aldrin SD	5 g a.i./kg seed	SD
Chlorpyrifos G	5 kg a.i./ha	FST
Chlorpyrifos CR	4 kg a.i./ha	FST
Chlorpyrifos SD	5 g a.i./kg seed	SD
Isofenphos G	5 kg a.i./ha	FST
Control	-	NI
Trial 2 (ICRISAT)		
Chlorpyrifos CR	4 kg a.i./ha	FST
Phorate CR	4 kg a.i./ha	FST
Carbosulfan CR	4 kg a.i./ha	FST
Aldrin D	1 kg a.i./ha	FST
Control	-	NI
Trial 3 (Bangalore)		
Aldrin D	1 kg a.i./ha	FST
Chlorpyrifos G	5 kg a.i./ha	FST
Isofenphos G	5 kg a.i./ha	FST
Carbofuran CR	0.75 kg a.i./ha	FST
Chlorpyrifos SD	5 g a.i./kg seed	SD
Control	-	NI
Trial 4 (Bangalore)		
Aldrin D	1 kg a.i./ha	FST
Chlorpyrifos G	4 kg a.i./ha	FST
Chlorpyrifos CR	4 kg a.i./ha	FST
Chlorpyrifos CR	2 kg a.i./ha	FST
Chlorpyrifos CR	1 kg a.i./ha	FST
Carbosulfan CR	4 kg a.i./ha	FST
Phorate CR	4 kg a.i./ha	FST
Isofenphos G	5 kg a.i./ha	FST
Isofenphos G	2 kg a.i./ha	FST
Control	-	NI
Trial 5 (Sudan)		
Aldrin D	1 kg a.i./ha	FST
Chlorpyrifos CR	4 kg a.i./ha	FST
Carbosulfan CR	4 kg a.i./ha	FST
Phorate CR	4 kg a.i./ha	FST
Control	-	NI

Analysis of soil and plant material

Soil samples from the aldrin D, chlorpyrifos G and isofenphos G plots were collected at intervals during trial 1, and stored in aluminium foil at -20°C. No soil samples were collected from the CR treatments as it was not possible to remove the insecticide pellets from the soil. Analysis would then have measured the insecticide remaining in the granules, as well as that available in the soil for controlling pests. Samples (100 g) of kernels and haulms were collected from each plot in trials 2 and 5 and of kernels only from each plot in trials 1 and 3. These and the soil samples were analysed for insecticide residues. Paired replicates from each treatment were bulked. Groundnut samples were ground in a laboratory blender; foliage was chopped up in a food processor; stones and plant matter were removed from the soil samples. The plant material was soxhlet extracted using hexane. Each sample of soil (25 g) was mixed with 6 ml water and, after 15 minutes, sufficient sodium sulphate was added to make the mixture free flowing. The sample was then soxhlet extracted using 3:1 hexane/acetone mixture. The cleaned extracts were analysed on a Perkin Elmer 8400 series GLC using electron capture and flame photometric detection.

Samples (50 g) of kernels from each plot in trials 1, 2 and 3 were analysed for oil using soxhlet extraction and moisture content by weighing before and after drying.

Termite damage and fungal attack

Termite damage on pods from the discard rows of trial 1 was categorized as: 1. No damage to pods or kernels. 2. Damaged pods, undamaged kernels. 3. Damaged pods, damaged kernels. Samples of kernels from these groups were then plated out on agar to check for presence of *Aspergillus flavus* and other fungi.

Results

Soil pests present on experimental plots

Groundnuts on the trials in India were attacked by a number of soil pests, listed below, which damaged the roots and the pods. In western Sudan *Microtermes* spp. were the only significant soil pests.

Microtermes obesi Holmgren was the most important pest. Root attack by these termites (first observed six weeks after sowing) was initiated just below the soil surface and followed by tunnelling up into the stem leading to wilting and death of the plant. They occasionally entered the roots through damage caused by white grubs early in the season but generally attacked healthy, undamaged plants. *M. obesi* attacked pods by making a small hole in the pod and eating the soft lining and/or kernels, or by removing soft tissue from the outside of the pods (scarification). In some cases, heavy scarification of the pod caused large irregular holes in the shell.

Odontotermes obesus (Rambur) readily attacked dead groundnut foliage, which it consumed completely under soil sheeting, but attack on live plants was insignificant. Other termites, *Odontotermes bellahuniensis* Holmgren & Holmgren, and *O. redemanni* (Wasmann) were found in the ICRISAT trials and *O. wallonensis* (Wasmann) and *O. ceylonicus* (Wasmann) were found at Chintamani but did not attack either live or dead groundnut plants.

White grubs (Coleoptera: Scarabaeidae) attacked roots and young pods early in the season. They removed lateral roots or cut through the tap root. The majority of affected plants compensated for the damage by sending out additional lateral roots and survived, but if the wound was damaged further by *M. obesi* the plants died. White grubs attacked the distal end of young pods causing distortion of the pod and loss of one or more kernels. Earwigs (Dermaptera) made large (5 mm diameter) holes in the pods and attacked the kernels.

False wireworms (Coleoptera: Tenebrionidae) made smaller (1-2 mm diameter) holes in the pods and burrowed into the kernels.

Table 2. Incidence of foliar insect pests in the ICRISAT trials.

Trial and treatment	Percentage of plants attacked					
	Spodoptera	*Heliothis*	*Myllocerus*	*Aproaerma modicella*	*Empoasca*	thrips
Trial 1						
Aldrin D	0	10	69	100	99	100
Aldrin SD	0	31	79	100	99	100
Chlorpyrifos G	0	20	71	100	100	100
Chlorpyrifos CR	7	24	61	100	99	100
Chlorpyrifos SD	0	20	76	100	96	100
Isofenphos G	1	42	85	55	100	100
Control	0	26	78	100	96	100
Trial 2						
Chlorpyrifos CR	3	33	73	100	98	100
Phorate CR	6	28	63	50	97	100
Carbosulfan CR	9	35	60	100	99	100
Aldrin D	0	19	63	97	100	100
Control	0	31	72	100	100	100

Table 3. Effect of soil insecticides on attack by leaf miners (*Aproaerma modicella*)

Treatment	Rate kg/ha	Percentage plants attacked				
		Trial 1	Trial 2	Trial 3	Trial 4	
					1	2
Aldrin D	1	100	97	90	76	59
Aldrin SD		100	-	-	-	-
Chlorpyrifos SD		100	-	77	-	-
Chlorpyrifos G	4	100	-	91	65	52
Chlorpyrifos CR	4	100	100	-	63	59
Chlorpyrifos CR	2	-	-	-	43	47
Chlorpyrifos CR	1	-	-	-	44	47
Carbosulfan CR	4	-	100	-	3a	7a
Phorate CR	4	-	50a	-	29a	23a
Isofenphos G	5	55a	-	29b	2a	3a
Isofenphos G	2	-	-	-	7a	11a
Control		100	100	87	73	67
CV%				21.2	19.7*	22.1*
SED				11.1	0.7*	0.8*

* from square root (x+0.5) transformation
\- treatment not applied
a significantly lower ($P< 0.01$) than control
b significantly lower ($P< 0.05$) than control

Dorylus orientalis Westwood (Hymenoptera: Formicidae) were found attacking groundnut kernels on one occasion but other pod damage may have been caused by them (see below).

Sphenoptera perroteti Guérin-Ménéville (Coleoptera: Buprestidae), the groundnut root-borer, tunnelled into the base of the stem and ate the root until, at pupation, only the outer cortex remained and the plant died. Some plants survived attack because of compensatory thickening of the root following rain. On two occasions first instar larvae were found in pods.

After harvest it was not always possible to distinguish between small holes in pods due to termites, false wireworms or ants and between large holes made by termites or earwigs. The distinctions were further complicated if attack was by more than one pest at a time. Consequently, pod damage has been classified as 'po borer damage' (mainly pods penetrated by termites bu including penetration by false wireworms, earwigs o ants) or 'termite scarification'. In newly-harvested plant termite pod-boring could be distinguished by the pres ence of soil runways and/or termites, and was recorded

Effect of insecticide on attack by soil pests

Trial 1. Pod yields from the six row samples and fron complete plots for each treatment were strongly correlat ed (r = 0.965) showing that the samples were representa tive. The number of plants attacked by one or more soi pests was significantly lower ($P< 0.01$) in the aldrin D chlorpyrifos CR and chlorpyrifos G treatments than i other treatments. *Sphenoptera perroteti* larva attack on th

Table 4. Effect of treatment on soil insect damage to plants in trial 1.

Treatment	Percentage plants attacked					
	Termite damage		White grub	Root borers	Pod borers	Total
	roots	pods				
Aldrin D	0.0	3.5	8.6b	9.8	7.6a	39.7a
Aldrin SD	8.0	7.1	36.0c	15.7	22.6a	83.8
Chlor. G	1.0	3.8	4.1b	2.9b	8.9a	35.9a
Chlorpyrifos CR	0.0	2.0	11.4	2.6b	2.4a	39.7a
Chlorpyrifos SD	0.0	7.3	22.4	10.1	22.8a	64.1
Isofenphos G	1.6	7.8	6.2	31.1	12.1a	49.4
Control	5.4	13.2	20.0	22.0	52.7	79.1
CV%	76.6*	32.1*	37.0*	30.7*	24.2*	27.0
SED	0.69*	0.55*	0.94*	0.73*	0.67*	8.2

* square root (x+0.5) transformation
a significantly lower ($P < 0.01$) than control
b significantly lower ($P < 0.05$) than control
c significantly higher ($P < 0.01$) than control

Table 5. Effect of treatment on yield in trial 1.

Treatment	Yield (g per sample)			Pod damage percentage	Shelling percentage
	Haulms	Pods	Kernels		
Aldrin D	665	410a	290a	3.9b	70.7
Aldrin SD	678	251	166	11.0	65.7b
Chlorpyrifos G	664	236	170	9.7	70.8
Chlorpyrifos CR	730	387a	285a	3.1b	73.5
Chlorpyrifos SD	614	273	185	10.8	68.2
Isofenphos G	640	307	222	5.3b	72.3
Control	544	197	139	20.9	70.5
CV%	12.6	28.3	28.4	34.1*	3.4*
SED	81.3	83.4	59.1	0.7*	1.7*

* square root (x-0.5) transformation
a significantly higher ($P < 0.05$) than control
b significantly lower ($P < 0.05$) than control

roots was reduced significantly ($P < 0.05$) by chlorpyrifos G and chlorpyrifos CR but was significantly greater ($P < 0.05$) in the isofenphos G than in all treatments except the control. No fresh white grub damage to roots was observed at harvest. Healed white grub damage on the tap roots was significantly less frequent ($P < 0.01$) in the aldrin D and chlorpyrifos CR plots but greater ($P < 0.01$) in the aldrin SD treatment than the controls; there was no difference between isofenphos, chlorpyrifos G and control treatments. The number of plants with pods scarified by termites was significantly lower ($P < 0.05$) than in the control only in the chlorpyrifos CR treatment. In this treatment, pod borer attack was significantly less ($P < 0.01$) than in the other treatments which, in turn, had a significantly lower level of attack ($P < 0.01$) than the controls (table 4).

Yield of undamaged pods and kernels was significantly greater ($P < 0.05$) than in controls only in the aldrin D and chlorpyrifos CR treatments which both gave approximately double the control yield. Yield from the isofenphos G treatment was 1.6 times the control but the difference was not significant (table 5). The percentage of damaged pods was significantly lower in the aldrin D, chlorpyrifos CR and isofenphos G treatments than in the control. This difference was significant for pod borer damage ($P < 0.05$) but not for termite scarification (table 6). The weight of haulms did not vary significantly among treatments. The shelling percentage (weight of kernels/weight of full pods × 100) for aldrin SD treatments was significantly less than all others ($P < 0.01$) (table 5).

Trial 2. There was very little damage from soil insects (<8% in all treatments) in this trial. There was no significant difference among treatments in overall soil insect damage, pod damage (scarification or pod borer) or haulm, pod or kernel weight.

Trial 3. The number of plants with no root or pod damage was significantly higher ($P < 0.01$) in the aldrin D, chlorpyrifos G and isofenphos G treatments and

Table 6. Effect of treatment on pod damage in trial 1.

Treatment	% pod damage	% termite scarification	% pod borer damage
Aldrin D	3.9a	1.3	1.8a
Aldrin SD	11.0	2.8	6.2
Chlorpyrifos G	9.7	1.7	6.8
Chlorpyrifos CR	3.1a	0.9	1.5a
Chlorpyrifos SD	10.8	2.3	7.7
Isofenphos G	5.3a	2.6	2.7a
Control	20.9	5.5	13.3
CV%	34.1*	33.1*	41.6*
SED	0.70*	0.38*	0.66*

* square root (x+0.5) transformation
a significantly lower ($P< 0.05$) than control

Table 7. Effect of treatment on soil pest attack in trial 3.

Treatment	% plants not attacked	% plants attacked	
		Termite damage	Earwig damage
Aldrin D	79.6a	19.6b	4.0
Chlorpyrifos G	87.9a	7.2a	1.8
Isofenphos G	75.8a	22.3b	1.8
Carbofuran CR	62.7b	31.5	5.8
Chlorpyrifos SD	63.8b	31.2	3.5
Control	46.1	48.5	4.0
CV %	9.4	13.4*	25.3*
SED.	4.60	0.47*	2.4*

* square root (x+0.5) transformation
a significantly higher ($P< 0.01$) than control
b significantly higher ($P< 0.05$) than control

significantly higher ($P< 0.05$) in the carbofuran CR or chlorpyrifos SD treatments than the controls. There was no significant difference in earwig attack (table 7). The number of plants with termite damage to pods was significantly less than in controls in the chlorpyrifos G ($P< 0.01$), aldrin D and isofenphos G ($P< 0.05$) treatments. Pod damage was significantly less ($P< 0.05$) in these treatments than in controls but there was no significant difference among treatments in the yields of pods, kernels or haulms (table 8).

Trial 4. There were no significant differences in non-lethal termite damage to plant roots at harvest, which varied from 1.2% in the phorate CR treatments to 7.7% in the control. Pod damage by termites (scarification and boring) and false wireworm (boring) was low (2.3-4.4% in treated plots, 5.7% in controls) and differences were not significant. Yield of pods in the isofenphos G (5 kg/ha), phorate CR and carbosulfan CR treatments was significantly greater ($P< 0.05$) than in the control, with yields of 2.3, 2.3 and 2.7 times the control, respectively. Yields of kernels were significantly greater ($P< 0.05$) in the aldrin D, isofenphos G (5 kg/ha), phorate CR and carbosulfan CR treatments than in the control. Mean shelling percentage of nuts (range 50-57%) did not differ significantly. There were no significant differences in mean haulm weight.

Trial 5. Yield assessments were not made in this trial. There was significantly less root damage in aldrin, chlorpyrifos and carbosulfan treatments than in controls ($P<$ 0.01 in all cases). Significantly fewer pods were penetrated in these treatments ($P< 0.01$ in all cases) and the phorate treatment ($P< 0.05$) than in controls. Only the aldrin and chlorpyrifos treatments had significantly ($P<$ 0.01) less pod scarification than the controls. Plant mortality was significantly less in the aldrin and chlorpyrifos treatments ($P< 0.01$) and the carbosulfan and phorate treatments ($P< 0.05$) than in controls.

Germination and pre-harvest plant mortality

There was no significant difference in germination among treatments in any trial. No mortality was observed in any treatment until 45 days after sowing. In trial 1, pre-harvest mortality due to termites at 90 days was significantly greater ($P< 0.05$) in control (5.5%) than in treated plots (0.2-1.5%). Groundnut rootborers killed significantly more plants in the control (6%) and isofenphos G plots (6.5%) than in other treatments ($P< 0.05$). In trial 2, pre-harvest mortality was low (<4%) in all treatments and there was no significant difference among them in mortality due to termites or groundnut root borer. In trial 3, pre-harvest mortality caused by *M. obes* was significantly less ($P< 0.05$) in the aldrin D (0.6%) and chlorpyrifos G (0.9%) treatments than in control (4% and carbofuran CR plots (6%). There was considerabl variation in germination success in trial 4 (20-100% partly due to birds eating the seed, but no significant difference among treatments.

Effect of insecticides on attack by foliar insect pests

Incidence of foliar insect attack in the ICRISAT trials is shown in table 2. Cicadellidae (Homoptera) (*Empoasca* spp.) and thrips attacked most plants but caused little damage A few plants showed *Spodoptera* damage. Grey weevil (*Myllocerus* sp.) and *Heliothis* larvae damage was seen on many plants but usually confined to one or two leaves per plant. There was heavy leaf miner *Aproaerma modicella* (Deventer) infestation in most plots (but see below). The Bangalore trials had few foliar pests, only *A. modicella* occurred in any number. Phorate CR, and isofenphos G significantly reduced leaf miner attack compared to controls in all trials in which they were included ($P< 0.01$ trials 1, 2 and 4; P, 0.05 trial 3) (table 3). Carbosulfan was more effective than phorate in trial 4 but had no effect in trial 2 (table 3). The dimethoate spray applied after these assessments controlled all the foliar pests.

Residues

Plant material. Residues of chlorpyrifos were detected in all haulm and kernel samples from the chlorpyrifos plots (table 9). No other residues were found in the haulms. Concentrations in the kernels varied from trace levels (chlorpyrifos SD, trial 3) to 0.79 mg/kg (chlorpyrifos CR, trial 1), with the three chlorpyrifos CR trials differing markedly. Kernels from the aldrin D and aldrin SD plots contained residues of dieldrin, a breakdown product of aldrin, but no detectable traces of aldrin. No

Table 8. Effect of treatment on yield and pod damage from six rows in trial 3.

Treatment	Haulm weight g	Pod weight g	Pod no.	Kernel weight g	Shell %	Kernel (<5 mm) weight	Damaged pods %
Aldrin D	788.7	252.0	440.5	156.8	61.6	137.8	6.5a
Chlorpyrifos G	763.7	276.1	398.5	173.9	61.6	147.5	5.6a
Isofenphos	852.5	319.5	517.5	204.9	64.5	187.9	7.2a
Carbofuran	707.5	208.9	381.7	129.4	62.1	111.0	16.1
Chlorpyrifos SD	735.0	212.7	387.2	133.0	62.1	116.1	12.2
Control	727.5	194.6	346.2	121.2	62.7	105.9	17.9
CV %	26.1	44.3	36.7	45.3	3.7	44.7	13.8*
SED.	140.5	76.4	107.2	49.0	1.6	42.5	0.3

* square root (x+0.5) transformation
a significantly lower ($P < 0.01$) than control

isofenphos or phorate was found in kernels from these treatments. Only dieldrin residues were found in kernels from the control treatments in trials 1 and 2, presumably from residues in the soil from previous use of aldrin or dieldrin. No insecticide residues were found in the control treatments in trial 3 (table 9). Residues of aldrin, chlorpyrifos and isofenphos were still detectable in the soil 92 days after application (table 10).

Oil and moisture content of the kernels varied among trials (trials 4 and 5 not analysed) but there was no significant difference among treatments. Mean oil contents for trials 1, 2 and 3 were 46.5%, 47.6% and 45.4%, respectively.

Fungal attack

Significantly more kernels were infected with *A. flavus* when the pods had been damaged by termites than in the absence of damage ($P < 0.01$) and significantly more again ($P < 0.001$) when the kernels had also been damaged (table 11). Of the kernels from the last group 5.6% carried spores of other pathogenic fungi (2.2% *Aspergillus niger*, 1.2% *Aspergillus terreus* 0.4% *Rhizophus arrhizus*, 1.8% *Macrophomina phaseolina*, 1.1% *Rhizoctonia solani*.

Discussion

Damage by soil pests

The initial aim of this work was to investigate alternative insecticides and formulations to the use of cyclodienes for control of termites as groundnut pests. However, the trials were complicated by the presence of other pests attacking roots or pods. Of these, only white grubs are usually considered as a major groundnut pest (Atwal, 1976; Rao *et al.*, 1978). White grub attack on roots in the trials seldom killed the plants unless followed by secondary attack by *M. obesi*. False wireworms, earwigs and ants are minor pests, seldom referred to in the literature. False wireworms caused some pod damage in all trials but, because of the similarity to termite damage, this was not recorded separately. Earwig damage, both scarifying and making holes in the pods, was observed at both locations but ants were observed attacking pods on only one occasion in the trials at ICRISAT and were not common at Chintamani. Groundnut root-borer are generally minor pests in India but occasionally cause serious damage to groundnuts in the south (Atwal, 1976). At ICRISAT in 1986, there was an unusually high infestation. Up to 70% of the groundnut plants were attacked in the discard area on the southern edge of the trial field. They generally attacked the tap root and most of the affected plants died. Termites were the most important pests in these trials, however, of necessity, the yield and pod damage data indicate the success, or otherwise, of the various treatments in controlling soil pests in general rather than termites alone.

Termite attack on groundnuts is inversely related to rainfall in some regions (Johnson *et al.*, 1981), although this is only a broad generalization (Logan *et al.*, 1990). In trial 1, dry conditions in the six weeks before harvest were conducive to termite attack. Trial 3 had similar conditions but the pre-harvest drought was not so pronounced. Conditions in the other trials were less conducive to damage. In trial 2, after initial good rains, all plots were affected by drought, which made the ground hard and prevented peg penetration. Heavy rain at 14 weeks rotted the pods already in the ground but revived the plants which then produced a second, larger crop which suffered very little soil insect damage. At Chintamani in 1987 (trial 4), there were reasonable rains in the middle of the season and some rain most weeks up to harvest, which seems to have been sufficient to reduce termite damage.

Insecticides

The most successful treatments were aldrin D, chlorpyrifos CR, isofenphos G and chlorpyrifos G, in that order. Aldrin D performed well in all of the trials and confirmed its effectiveness against soil pests. However, aldrin SD had little effect on yield or pod damage. It was associated with reduced termite and groundnut root-borer attack but a significant increase in white grub attack on roots.

The CR pellet was the most effective formulation of chlorpyrifos with yields in trial 1 equivalent to those produced by aldrin and significant reductions in pod and root damage and plant mortality. The results of trial 1 suggest that the CR pellets continued to release significant amounts of insecticide throughout the trial

Table 9. Insecticide residues in groundnut kernels and haulms.

Treatment	Residues (mg/kg)					
	Kernels Trial 1	Kernels Trial 2	Kernels Trial 3	Haulms Trial 2	Kernels Trial 5	Haulms Trial 5
Aldrin D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dieldrin	0.48-0.62	0.42	0.41	N/A	0.2-0.37	<0.01
Aldrin SD	<0.01	-	-	-	0.17-0.25	0.01
Dieldrin	0.02-0.04	-	-	-	-	-
Chlorpyrifos SD	0.03-0.04	-	trace	-	-	-
Chlorpyrifos G	0.51-0.58	-	0.22	-	-	-
Chlorpyrifos CR	0.88-0.071	0.05	-	0.04-0.45	0.17-0.25	0.01
Carbosulfan CR	-	-	-	-	<0.05	<0.05
Phorate CR	-	<0.01	-	<0.01	<0.01	<0.01
Isofenphos G	<0.02	-	<0.01	-	-	-
Control						
Aldrin	<0.01	<0.01	<0.01	<0.01	N/A	N/A
Dieldrin	0.01-0.33	0.03-0.04	<0.01	N/A	N/A	N/A
Chlorpyrifos	<0.02	<0.02	<0.02	<0.02	N/A	N/A
Phorate	-	<0.01	-	<0.01	N/A	N/A
Isofenphos	<0.02	-	<0.01	_	N/A	N/A

N/A not analysed
- treatment did not occur in this trial

despite very dry conditions. Chlorpyrifos G also reduced pod and root damage but had no significant effect on yields. The seed dressing performed similarly but was less effective.

Isofenphos G, like chlorpyrifos G, persisted in the soil to the end of the trial, albeit at low levels, and provided protection against soil pests. Yield was increased in trials 1 and 4 to 1.6 and 2.3 times that of the control, respectively, and pod damage was significantly reduced in trials 1 and 3.

Carbosulfan CR and phorate CR gave significantly greater yields than the control (2.3 and 2.6 times, respectively) in trial 4. The three systemic insecticides, isofenphos, carbosulfan and phorate, greatly reduced leaf miner attack in all trials. It is possible that this protection was responsible for the increased yield in each of these treatments in trial 4 where foliar spraying to control leafminers was ineffective. In all other trials the plants were sprayed when leaf miners became apparent and before yield could have been affected, i.e. pre-flowering (Gibbons, 1985).

Insecticide residues in plants and soil

Although chlorpyrifos is generally considered non-systemic (Worthing & Walker, 1987) it is absorbed by roots and leaves and there is some translocation (Hartley & Kidd, 1983). Groundnuts are particularly liable to accumulate pesticide because of their high lipophilic content (Matsumura & Madhukar, 1984). There was considerable variation in the chlorpyrifos residue levels in different trials (0.3 to 0.79 mg/kg in kernels; 0.04 to 0.45 mg/kg in haulms), perhaps due to variations in soil type or moisture levels which influenced either the rate of release of the CR insecticide or the rate of uptake by the plant. The dried foliage from groundnuts grown in soil treated with 2 kg a.i./ha chlorpyrifos CR in Malawi was not attacked by termites, possibly because it contained residues (Wightman, personal observation).

The FAO/WHO recommended acceptable daily intake (ADI) is 0.01 mg/kg body weight. There is no published FAO/WHO recommended maximum residue level (MRL) for chlorpyrifos in groundnuts. MRLs of up to 2 mg/kg are given for various vegetables but the most relevant is probably that for cottonseed/cottonseed oil i.e. 0.05 mg/kg (FAO/WHO, 1986). On this basis chlorpyrifos would not be considered a suitable insecticide for use with groundnuts but could probably be used for other crops which accumulate lower residue levels. The systemic insecticides, phorate, carbosulfan and isofenphos were not detected in the kernels or haulms. Possibly these insecticides are broken down in the plant more rapidly than chlorpyrifos.

The CR formulations provide the long-term action of the cyclodienes but, as they do not persist in the soil once released, should not give rise to the same environmental problems. In addition, as the active ingredient is enclosed in a plastic pellet, they are safer to handle. The mammalian dermal toxicity of phorate CR, for example, is almost 12 times lower than that of the granular formulation and oral toxicity should be similarly reduced (O'Hanlon, 1986).

Economics of insecticidal control of termites

Control of termites requires prophylactic treatment as it is impossible to predict the intensity of attack at the start of the season in areas where termites are common. For treatment to be worthwhile, the value of the crop saved in years of high termite attack must pay for the cost of treatment, not only in that year, but also in the years when there is little termite damage. No prices are available for the CR formulations used in these trials but similar formulations used to protect forestry trees cost

Table 10. Residues of insecticide in soil samples in trial 1.

Days	Concentration in soil (mg/kg)		
	Aldrin dust	Chlorpyrifos granules	Isofenphos granules
3	1.26	33.2	19.2
17	1.13	17.7	5.24
47	0.05	0.83	0.18
92	0.01	0.02	0.06

Table 11. Infection of groundnuts by *Aspergillus flavus*.

Damage category	% pods infected
no damage	3.0
damaged pods, undamaged kernels	9.5
damaged pods, damaged kernels	31.0

about US$6/kg at the port of entry, equivalent to approximately $9 to the user (P. May (Incitec International), pers. comm. 1988). If the application rate is 4 kg a.i./ha then 40 kg product would be required. However as only the furrows are treated, assuming 20 cm furrows spaced 60 cm apart, only one quarter of the area is treated so only 10 kg product are required. The cost per hectare would be about $90. If and when they become more widely used the price may fall but is unlikely to become economic for control of groundnut pests in the semi-arid tropics even in areas of consistent high attack. However, CR formulations using cheaper matrices may be cost-effective. The lignin based CR granules were not effective (trial 3) but are effective against brown planthopper (*Nilaparvata lugens* (Stål) (Homoptera: Delphacidae) in rice (R.M. Wilkins, pers. comm.). Impregnated with different insecticides or used at higher application rates, they may provide a cheaper CR method for control of termites. Other materials are under consideration by pesticide manufacturers, but any alternative to the cyclodienes, whether in controlled release or conventional formulation will inevitably be more expensive. A combination of minimal use of modern pesticides and non-chemical control methods (Logan *et al.*, 1990) in an integrated approach probably offers the greatest potential for a long-term solution. There is now an urgent need to develop such techniques.

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