SOIL PERSISTENCE, PLANT AND NON-TARGET INSECT UPTAKE OF ENDOSULFAN AND LINDANE APPLIED TO SOYA BEAN AND MAIZE IN FIELD TRIALS IN ZIMBABWE

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Abstract

The persistence of lindane and endosulfan in the soil, uptake by, and distribution in plants, and effects on and absorption by non-target insects, following application of the insecticides for the control of maize pests and soya bean respectively were determined under Zimbabwean weather conditions. No large scale effects on the non-target insects were observed though some small effects on the populations of semiloopers and orthoptera in the endosulfan treated soya bean plot were noted. Concentrations of the insecticides in spiders declined during the trial though those in grasshoppers and crickets appeared to increase.Concentrations of both insecticides in soil fell rapidly during the first 7 weeks after application but, after that, the rates of loss were much slower possibly owing to the drier conditions prevailing during this later period, reducing both physicochemical and microbial loss processes. Initial concentrations of both insecticides in all the vegetative parts of plants examined after spray application declined systematically to low levels during the 10 weeks of observation, probably owing to both metabolism within the plants and to crop volume dilution effects and will have declined to even lower levels by harvest time. Surprisingly, low concentrations of lindane and endosulfan were found in the harvested maize and soya bean seeds. At early stages after application, there were also traces of both insecticides in the vegetative parts of the plants from the untreated, control plots probably arising from uptake of soil residues from the previous year and/or spray drift but these became undetectable at later stages of growth.

1. INTRODUCTION

1.1. Background

By 1989 it was estimated that Africa accounted for 5% of the world pesticide use [1]. Most of these pesticides are used for pest control in agriculture. Although the use of pesticides in agriculture has been reported to have adverse effects on both man and other non-target organisms in the environment, agricultural development and the need to increase food production demands the use of pesticides. It is however necessary to assess the impact of the use of pesticides on the environment.

This impact will depend on several factors including temperature, rainfall, soil type, biotic activity, light intensity, land cultivation and other agricultural practices. These factors determine the persistence of the pesticide in a specific environment, and in this respect organochlorine pesticides have been found to be the most persistent as a group. Thus although the impact of pesticides on the environment has been studied extensively in the developed countries, there is still need to assess their impact in developing countries as agricultural practices in these countries may differ from those used in the developed countries.

Of major concern in Zimbabwe has been the use of organochlorine pesticides to control tsetse fly and malaria vectors. Pesticide sprays for tsetse fly control began in the early 1960s. Pesticides which have been used include dieldrin (1962-1967) and DDT (1968 to present) [2, 3]. Endosulfan and deltamethrin are also used, especially in aerial sprays [4]. In addition to its use in the control of tsetse fly and malaria vectors, DDT was used extensively in agriculture prior to 1983 when the use of DDT in agriculture was banned. Dieldrin,

endosulfan and deltamethrin are used extensively in agriculture. Table 1 shows the list of organochlorine pesticides registered for use in agriculture in Zimbabwe [5]. Contamination of non-target invertebrates and vertebrates like birds, reptiles, amphibia, fish, mice and sometimes large mammals as a result of aerial spraying of riverine and lake shore vegetation with DDT and endosulfan to kill tsetseflies in the Zambezi Valley area has been reported [6], but direct study of the effects of organochlorine pesticides on the agrosystem have yet to be undertaken in this country.

The aims of this study were: (a) To determine the persistence of organochlorine pesticides in the agrosystem, and (b) to monitor pesticide residues in the different compartments of the agrosystem. The pesticides selected for the study are endosulfan and Lindane. Endosulfan is used extensively for the control of the heliothis boll-worm, the semi-looper caterpillar and aphids in soya bean and groundnut crops, aphids in potatoes and the cutworm and red mite in maize [1] while lindane is used as for seed dressing [5]. A number of organochlorine formulations registered for use in Zimbabwe is listed in Table 1.

1.2. Persistence of lindane and endosulfan in soil

The soil is the major sink for chemicals applied to crops. Persistence patterns will vary from one climate to another and also depending on the chemical nature of the pesticide and the type of soil [7]. In cold climates degradation was generally found to be slower than in tropical climates [7, 8]. Lindane undergoes microbial degradation by dechlorination to pentachlorocyclohexane [9]. The bacteria, *Clostridium sporogenies* and *Bacillus coli*, produce benzene and monochlorobenzene from lindane [10]. Other possible transformations of lindane which occur especially in wet and submerged conditions include isomerization into the α- and β-HCH isomers of lindane [11]. The isomers were shown to be rapidly degraded

Table 1. Some organochlorine pesticides registered for use in agriculture in Zimbabwe

Trade Name	Active Ingredient	Toxicity Class*
Aldrin 40% w.p.	aldrin 40%	P
Anti-Kil	chlordane 30%	A
Razor	chlorthal-dimethyl 36%	G
Dicofol 40 E.D.	dicofol 40%	A
Kelthane	dicofol 18,5%	G
Dieldrex 50 w.p.	dieldrin 50%	P
Thionex 1% granules	endosulfan 1%	G
Thiodan 1% granules	endosulfan 1%	G
Thiodan 20 e.c.	endosulfan 20%	P
Multi Benhex	γ-BHC 12% +total BHC 75%	A
Gamatox House spray	γ-BHC 5,0%	A
Bexadust (L)	γ-B.H.C. 0,6%	G
Agri seed Dress 75%	lindane 1%	G

*P = extremely toxic; A = toxic; G= non-toxic.

in soil [12]. Endosulfan was found to undergo epoxidation which is enzyme catalyzed [13] and other transformations which include hydrolysis, reduction and hydroxylation [14]. Mechanical processes such as volatilization and run off also deplete the levels of these chemicals in soil.

The persistence of endosulfan in the soil has attracted attention from several workers. Burns studied the degradation of the insecticide in soils[15]. Kathpal et al. [16] and Martens [17] studied the kinetics of its degradation in soils and reported rates of 63% loss in 2-3 months and 5.4% in 15 weeks, respectively. Martens also studied the non-microbial degradation of the insecticide in soils under varying conditions of pH, sample wetness and temperature, and found that degradation was faster in wet samples with a higher pH. El Beit studied the kinetics of leaching of endosulfan in sediments and found that the rate of leaching was slow compared to the rate of degradation by micro-organisms [18].

1.3. Uptake of the pesticides by non-target fauna

Insects were selected for study as examples of non-target lower fauna. The uptake of organochlorine pesticides by insects following application for the control of agricultural pests in Europe and the American continents has been reported by several workers [19]. Gish found organochlorine pesticide residues of up to 0.60-0.65 $\mu g\ g^{-1}$ in beetle larvae from two agricultural fields in the USA [20]. Korschgen reported values as high as 8 ppm for aldrin and dieldrin residues in ground beetles from aldrin treated fields [21]. In Africa, DDE, DDT and dieldrin were detected in *Chiron.* L, *Corixidae*, and *Chironomidae* from Kenya by Lincer [22] and Greichus [23], while Muller reported on the uptake of dieldrin by ants, lepidoptera and isoptera following dieldrin application for the control of tsetse fly in Cameroon [24] Dieldrin, DDT and DDE were also detected in various insects by Greichus et al. in Zimbabwe [23].

1.4. Pesticide residues in crops

Several workers have studied the occurrence of pesticide residues in crops. Beestman et al. studied the translocation of dieldrin into corn from the soil and found that although 70-90% of the residues were found in the stems, appreciable quantities, up to 2%, eventually reached the seed [25]. These workers concluded further that residues measured at harvest time do not represent the total uptake by the plant during its life time because some of the absorbed insecticides are metabolized. Dormal et al. [26] and Brett and Bowery [27] found 0.3-1.5 $\mu g\ g^{-1}$ DDT residues and 0.4 $\mu g\ g^{-1}$ lindane residues respectively in beans and McCaskill et al. found 6 $ng\ g^{-1}$ lindane residues in soybean [28], while Bruce et al. reported levels as high as 0.11 $\mu g\ g^{-1}$ heptachlor in soybean [29].

1.5. Aims of the present study

The work reported in this paper was carried out between 1991 and 1995, and was conducted as part of the FAO/IAEA Co-ordinated Research Program on "Adverse Side Effects on Flora and Fauna from the Use of Organochlorine Pesticides on the African Continent". The trials conducted during the 1991/92, 1993/94 and 1994/95 growing seasons, November to March in Zimbabwe, were adversely affected by severe droughts during these periods. As a result, meaningful data were only collected during the 1992/93 growing season.

2. MATERIALS AND METHODS

2.1. Experimental field site preparation

The 1992/93 field experiments were conducted on specially designated land in the experimental section of the University of Zimbabwe Farm approximately 10 km from the University. After mechanical land preparation, the trial field of ~2 hectare was divided into 4 plots of approximately 0.25 ha each and alternate plots planted with commercially dressed soya and maize seed on 23 December 1992. The experimental plot was bordered by cattle fodder to the north and east, while plot A was bordered by a maize crop, and plot B was bordered by a roadway. The crops were separated by a 1.5 m buffer zone. This was done to simulate actual agricultural practice as closely as possible.

2.2. Pesticide application

The spraying of both soya and maize was carried out on 20 February, 1993. Thiodan (endosulfan) 50 WP (300 g) and Multi-Benhex (lindane) 75 WP (270g) were diluted in water (120 L) and applied using 15 L knapsack sprayers (Taurus Spraying Systems, Zimbabwe) to the respective plots, equivalent to application rates of 600 and 810 g AI ha^{-1}, respectively. To ensure the pesticide was applied evenly, preliminary spraying tests were carried out using water.

2.3. Sample collection

2.3.1. Soil samples

In each plot 4 subplots, each 5 m x 5 m and 10 m from the edge of the plot, were marked out. Four soil samples were collected from each of the four subplots in each plot. Each plot was divided into 4 quadrants and one soil core was collected from each quadrant. Sampling was done by means of a cylindrical soil corer 50 mm x 150 mm. Each soil core was placed into a clean polyethylene bag which was then sealed and labelled with the subplot number and the sampling point number. The samples from each plot were then placed into a single bag which was sealed and labelled with the plot letter, for transportation to the laboratory where they were stored in a deep freezer until they were taken for analysis.

2.3.2. Insect samples

Insect samples were collected using 4 pitfall traps per subplot after Critchley et. al. [30]. The traps were set 2, 4 and 10 weeks after the experimental plots were sprayed with the pesticides. Pretreatment traps were set 2 weeks before spraying. On each occasion the traps were left overnight for collection the next day. The inner cups of the traps containing the trapped insects were transported to the laboratory where the insects were classified. Each order of insects was transferred to a separate plastic vial and stored in a deep freezer without a preservative. Because of the low numbers of insects trapped, all insects of the same order from each plot were pooled together to form a single composite sample as shown in Table 4.

2.3.3. Plant samples

For residue analysis, 12 plants per plot were randomly taken. For each plot the plants were divided into stems and leaves, and roots at the field. Each of the two samples per plot

Table 2. Recovery of lindane and α- and β- endosulfan from soil samples spiked at three levels

lindane			α- endosulfan			β- endosulfan		
amount added ngg^{-1}	amount found ngg^{-1}	% recovery	amount added ngg^{-1}	amount found ngg^{-1}	% recovery	amount added ngg^{-1}	amount found ngg^{-1}	% recovery
3.01	2.50	83	2.48	2.10	85	2.53	2.20	87
6.32	5.00	80	5.00	4.20	84	5.04	4.40	87
9.32	9.04	97	9.00	8.93	99	9.83	9.77	99

Table 3. Mean residues of lindane and α- and β- endosulfan found in soil cores from the treated and untreated plots in the 1992/93 field trial

Interval after application, weeks	Mean residue concentration, ngg-1 (± SE)					
	treated plots			untreated plots		
	lindane	α-endosulfan	β-endosulfan	lindane	α-endosulfan	β-endosulfan
maize plots						
pretreatment	nd[a)]	20 ± 7	6 ± 2	nd	nd	nd
2	227 ± 71	29 ± 13	17 ± 10	1 ± 2	1 ± 2	nd
5	137 ± 33	4 ± 3	7 ± 6	nd	nd	nd
7	53 ± 13	8 ± 6	3 ± 5	-[b)]	-	-
10	37 ± 8	5 ± 4	0.4 ± 0.8	nd	nd	nd
25	24 ± 4	3 ± 2	1 ± 2	-	-	-
soya plots						
pretreatment	16 ± 7	nd	nd	-	-	-
2	3 ± 2	185 ± 5	119 ± 121	3 ± 3	1 ± 1	nd
5	6 ± 5	83 ± 10	40 ± 7	4 ± 4	2 ± 1	nd
7	7 ± 8	71 ± 1	23 ± 2	2 ± 3	4 ± 4	nd
10	-	-	-	1 ± 1	1 ± 2	nd
25	1 ± 2	40 ± 3	13 ± 2	-	-	-

a) nd = not detected b) - = analysis not conducted

was then placed in a polyethylene bag which was then sealed, labelled with the plot number and sampling date. The seed samples were randomly taken from each of the four plots at harvest and placed into polyethylene bags which were labelled as described above. The samples were then transported to the laboratory were they were stored in the deep freezer prior to residue analysis.

2.4. Residue analysis

2.4.1. Preparation of Florisil cleanup columns

Florisil (residue grade, Supelco, USA, ~5 g) was packed into a Pyrex glass column (10 mm i.d. x 110 mm) followed by anhydrous sodium sulphate (Merck, Germany, ~5 g).

Table 4. Total insect pitfall catches over 24 hours

Plot	Crop	Pesticide treatment	Insect order	Number of insects caught				
				Week / Date				
				pretreat -ment	0 20Feb	2 6Mar	3 11Mar	11 11May
A	maize	lindane	arachnida	40	43	48	41	62
			coleoptera	45	63	53	59	69
			orthoptera	17	23	15	15	28
B	soya	endosulfan	arachnida	23	24	30	21	26
			coleoptera	4	4	3	3	6
			orthoptera	62	50	58	12	29
C	maize	untreated control	arachnida	30	38	41	49	23
			coleoptera	11	21	31	49	42
			orthoptera	10	13	11	8	7
D	soya	untreated control	arachnida	48	41	38	42	49
			coleoptera	44	62	51	40	44
			orthoptera	19	15	14	18	23

The column was washed with hexane (20 mL) followed by methanol + hexane (0.5 + 9.5 by volume, 20 mL) and then dried at 180°C overnight. The column was cooled and then prewetted with hexane (10 mL).

2.4.2. Extraction and clean up of soil samples

Each soil core was taken for residue analysis. The frozen sample was thawed, ground and passed through a 2.5 mm sieve. A mass (equivalent to 1 g dry weight of the soil) was taken from the core and weighed into a beaker (10 mL). Acetic acid (0.5 mL) was pipetted into the beaker and the mixture was stirred using a glass rod. Nonane (0.5 mL) was added to the slurry and the mixture was again stirred with the glass rod. The resulting slurry was ultrasonicated for 30 minutes. The mixture was then allowed to stand and pesticide grade silica gel (Merk, 5 g) was added and the mixture stirred. The finely divided powder was transferred into a cellulose extraction thimble (Merk) containing silica gel (5 g). The thimble was then placed into a Soxhlet extraction apparatus and extracted with hexane + benzene (2 + 1 by volume) for 4 hours. The crude extract was concentrated in a Kuderna-Danish flask to 1mL. This concentrate was quantitatively transferred to a Florisil clean up column and eluted with hexane (20 mL - first fraction) followed by methanol + hexane (0.5 + 9.5 by volume, 20 mL - second fraction). The fractions were separately concentrated in the Kuderna-Danish flask (to 1 mL) and stored in glass vials (1.8 mL) with Teflon lined screw caps (Supelco, USA) at 4°C until analysed by the GC method described in section 2.4.4.

In preliminary studies soil samples (1 g) were spiked with a solution containing a mixture of lindane, α-endosulfan and β-endosulfan standards. Each spiked sample was stirred to ensure even distribution of the pesticides in the sample and then stored in the dark for 24 hours to equilibrate before extraction, clean-up, concentration and analysis as described above.

Table 5. Mean residues of lindane, α- and β-endosulfan and endosulfan sulfate in insects caught in the pitfall traps within the sprayed plots at intervals after spray application

Interval after application, weeks	Insect species	Residue concentrations, ngg^{-1}			
		lindane	α-endosulfan	β-endosulfan	endosulfan sulfate
maize pretreatment	spiders	nd[a)]	nd	nd	nd
	crickets	nd	nd	nd	nd
	semiloopers	nd	nd	nd	nd
2	spiders	5.1	0.5	nd	nd
	crickets	2.87	0.42	0.002	nd
	semiloopers	nd	0.045	nd	nd
4	spiders	1.75	nd	nd	nd
	crickets	-[b)]	-	-	-
	semiloopers	-	-	-	-
10	spiders	-	-	-	-
	crickets	20.06	6.16	nd	nd
	semiloopers	-	-	-	-
soya pretreatment	spiders	nd	nd	nd	nd
	crickets	nd	nd	nd	nd
	grasshoppers	nd	nd	nd	nd
2	spiders	nd	6.91	nd	nd
	crickets	nd	1.56	2.36	nd
	grasshoppers	0.002	nd	nd	nd
4	spiders	0.53	3.86	nd	nd
	crickets	-	-	-	-
	grasshoppers	nd	4.29	nd	nd
10	spiders	-	-	-	-
	crickets	nd	1.84	nd	nd
	grasshoppers	nd	28.16	nd	nd

a) nd = none detectable b) - = not analysed

Table 6. Recovery of lindane, α- and β-endosulfan and endosulfan sulfate from spiked plant samples

Plant sample	Spiked concentration, ngg^{-1} ; % Recovery							
	lindane		α-endosulfan		β-endosulfan		endosulfan sulfate	
	spike	% rec.	spike	% rec.	spike	% rec.	spike	% rec.
maize stems+roots	5.02	76.1	3.08	93.3	3.88	96.9	4.62	105.2
soya stems+roots	7.32	84.6	14.3	70.3	5.78	70.3	6.00	77.5
maize seed	16.0	90.3	18.0	97.1	13.2	97.8	18.4	95.7
soya seed	10.0	82.0	5.76	81.6	13.2	106.2	14.1	88.7

Table 7. Residues of lindane, α- and β-endosulfan and endosulfan sulfate in plant samples at intervals after spraying

Plant sample	Interval after spraying, weeks	Residue concentration, ngg^{-1}							
		Sprayed plots				Unsprayed control plots			
		lindane	α-endo	β-endo	endo sulfate	lindane	α-endo	β-endo	endo sulfate
maize roots	pretreat	nd[a)]	nd	nd	nd	nd	nd	nd	nd
	2	13.8	0.4	nd	nd	nd	0.2	nd	nd
	5	8.8	0.1	0.5	nd	nd	nd	nd	nd
	10	8.2	1.0	nd	nd	nd	nd	nd	nd
maize stems +leaves	pretreat	nd	nd	nd	nd	nd	nd	nd	nd
	2	19.3	0.3	nd	nd	nd	0.2	nd	nd
	5	9.5	0.2	0.15	nd	nd	nd	nd	nd
	10	1.06	0.07	nd	nd	nd	nd	nd	nd
maize seed		1.32	0.62	nd	nd	nd	nd	nd	nd
soya roots	pretreat	nd	nd	nd	nd	nd	nd	nd	nd
	2	1.72	12.7	3.31	nd	0.8	0.2	nd	nd
	5	0.13	6.55	0.4	nd	0.79	nd	nd	nd
	10	0.14	1.53	0.19	nd	nd	nd	nd	nd
soya stems +leaves	pretreat	nd	nd	nd	nd	nd	nd	nd	nd
	2	0.01	2.22	0.10	nd	0.77	0.40	0.18	nd
	5	0.07	6.57	2.02	nd	0.80	2.91	nd	nd
	10	nd	1.50	0.10	nd	nd	nd	nd	nd
soya seed		0.28	2.21	0.06	nd	0.04	0.02	nd	nd

a) nd = none detectable

2.4.2. Extraction and clean up of insect samples

A composite sample of insect species was crushed and divided into two approximately equal portions. The portions were weighed into a beaker (20 mL) and anhydrous sodium sulphate (~10 g) added. The mixture was ground using a glass rod until it was finely divided. Acetonitrile (15 mL) was added and the mixture stirred for about 10 minutes using a sonicator. The mixture was centrifuged and the supernatant transferred to a Kuderna-Danish flask. The residue after centrifugation was re-extracted with a further portion of acetonitrile and the supernatant combined with the first extract. The combined extract was then concentrated (to 1 mL), quantitatively transferred to a Florisil clean up column and eluted with hexane (20 mL, - fraction 1) followed acetonitrile + hexane (0.5 + 9.5 by volume, 20 mL - fraction 2). The two fractions were concentrated and analyzed separately as described above for soil samples.

In preliminary studies a composite sample of insects from one pitfall trap was crushed and divided into 6 approximately equal portions three of which were spiked with 18.3 ng g^{-1}, 12.1 ng g^{-1}, 1.62 ng g^{-1} and 18.2 ng g^{-1} of lindane, α-endosulfan, β-endosulfan and endosulfan sulphate respectively. The fortified samples were left to stand for 24 hours to allow the

samples to equilibrate before being extracted, concentrated and analysed as described above. The unspiked portions were used as the blanks.

2.4.3. Crop samples

The samples were ground using a Phillips grinder (Phillips, Mexico). Duplicate aliquots (5 g) were accurately weighed into a Phillips homogenizer (Phillips, Mexico) containing acetonitrile (50 mL) and homogenized at high speed until the sample was reduced to a slurry. The slurry was quantitatively transferred into 6 centrifuge tubes and then centrifuged at ~5000 rpm. The supernatants were combined into a Kuderna-Danish concentration tube. The sediment in each centrifuge tube was washed with further acetonitrile (3 mL) and recentrifuged. The rinsings were then transferred to the concentration tube containing the first supernatants. The extracts were then concentrated (to 1mL) and transferred to a prepared Florisil clean up column and allowed to stand for 2 minutes to equilibrate before being eluted first with hexane (15 mL - fraction 1) and then with acetonitrile + hexane (0.5 + 9.5 by volume, 15 mL - fraction 2). The fractions were each concentrated in a Kuderna-Danish flask (to 1 mL) and either analysed immediately or stored in Teflon stoppered glass vials at 4°C until analysed by the GC method described in section 2.4.4.

In preliminary studies the ground root, stem, leaf, and seed samples were spiked with an aliquot (1 mL) of a solution containing a mixture of lindane, endosulfan and endosulfan sulphate as shown in Table 8. Each sample was stirred to ensure even distribution of the spike in the sample and allowed to equilibrate for 24 h before homogenizing, extraction, clean up and analysis as described above.

2.4.4. Details of the gas chromatographic analysis method

Gas chromatograph : Varian Model 3300 GC (Varian AB, Solna, Sweden) fitted with a microprocessor, a split/splitless capillary injector, a Varian Model 4400 integrator and a ^{63}Ni electron capture detector (ECD); column : 30 m x 0.25 mm refined silica capillary column coated with DB-1701 (J and W Scientific, CA, USA); carrier gas: ultra pure nitrogen: flow rate : 5 mL min^{-1}; make-up gas : 25 mL min^{-1} ; temperatures : column, programmed from 100°C held for 2min and then heated to 250°C at 10°C min^{-1} and held for 3min; injector, 150°C and operated in the splitless mode during the first 30 seconds only; detector, 300°C. Quantitation was by the external standard calibration method.

3. RESULTS AND DISCUSSION

3.1. Persistence of lindane and endosulfan in the soil

Recoveries of the insecticides from the spiked soil samples were reasonable for all compounds varying between 80-97% (lindane), 84-99% (α-endosulfan) and 87-99% (β-endosulfan) (Table 2) suggesting that extraction and analysis of the field core samples would be satisfactory.

Lindane, α- and β-endosulfan disappeared rapidly during the first 7 weeks after application but declined to much slower rates in the period up to harvest at 25 weeks after application (Table 3). Losses suggested pseudo first order degradation rates over the initial 7 week stage. Similar results were obtained by Liechtenstein and Schultz following a single

application of 25 lbs of dieldrin per acre of Wisconsin soil, USA [31]. The rapid initial rate of loss may be attributed both to microbial degradation during the weeks of high rainfall when the soil was moist and to physicochemical losses by volatilisation and photodegradation. Loss of insecticide by run-off was probably minimal as shown by the extremely low levels of the insecticides detected in the untreated plots.

Lindane was also detected in plot B, while endosulfan was also detected in plot A, the plots which were not treated with that specific pesticide (Table 3). This was attributed to the fact that these plots had been treated by these insecticides in the previous year and indicates the likely extent of carry-over each year.

3.2. Variation of non-target insect populations

At the intervals examined, there were only a few obvious effects on the populations of the species of insects caught in the pitfall traps (Table 4). Firstly, there was a very low population of coleoptera in the endosulfan-treated soya bean plot (B) throughout the study, including the pretreatment period. Secondly, in this plot, the population of semiloopers declined systematically during the 10 week period of monitoring and, thirdly, the population of orthoptera was also lower at the last two intervals of observation though perhaps not outside statistical confidence limits.

It is possible, of course, that at intervals immediately following spray application there could have been larger reductions in the populations of all the species but at the time of the first assessment (2 weeks) their populations had recovered and remained unchanged during the trial, except for the coleoptera, and orthoptera in plot B.

3.3. Uptake of lindane and endosulfan by non-target insects

No insecticide was detected in any of the insects caught in the pitfall traps before spray application. At an interval of two weeks after application, lindane was detected in the insects caught in the traps from the maize plot treated with lindane but also traces of endosulfan (Table 5), presumably from cross-contamination. Similarly, both endosulfan isomers were detected in the insects trapped in the plot of soya beans treated with the endosulfan but, in this case, cross-contamination with lindane was hardly apparent (Table 5). Initially, spiders absorbed more than the other insects but the levels of both lindane and endosulfan (mainly the α-isomer) seemed to decline at later stages, though the data is limited. Spiders are known to be very susceptible to pesticides and can die from very low insecticide doses. Thus the levels in new generations or invasions of spiders decrease as the levels of the insecticides in the plot decrease with time.

Interestingly, the concentration of lindane in crickets and of endosulfan in grasshoppers appeared to increase with time reaching 20 ng g^{-1} and 28 ng g^{-1}, respectively. The reason for this is unknown but may be related to their diet (Table 5).

In contrast, no detectable residues were found in most of the insects caught in the traps in the untreated, control plots C and D (data not shown). The only exceptions were that traces of lindane were detected in grasshoppers in both plot C (0.09 ng g^{-1}) and plot D (0.003 ng g^{-1}) and α-endosulfan was detected, also in grasshoppers, in plot D (0.004 ng g^{-1}). Grasshoppers are much more mobile and these results may be due to the migration of these insects from the treated plots.

3.3. Distribution of residues in crops

In the preliminary studies, recoveries of all compounds from the spiked samples of the various parts of the crop plants were reasonable with recoveries of 76-90% (lindane), 70-97% (α-endosulfan), 70-106% (β-endosulfan) and 78-105% (endosulfan sulfate) (Table 6), indicating that the overall extraction and analysis procedures were satisfactory for examination of the field crop samples.

Lindane and endosulfan were detected in all components of the maize and soya bean plants from the treated plots. For both maize and soya bean roots, insecticide levels were initially high then declined with time (Table 7). For example, lindane concentration in maize roots was initially found to be 13.8 ng g^{-1} at 2 weeks after spraying but then declined to 8.2 ng g^{-1} at 10 weeks after spraying. In soya bean roots, endosulfan concentration was initially at 12.7 ng g^{-1} at 2 weeks after spraying and declined to 1.53 ng g^{-1} at 10 weeks after spraying. Lindane concentrations in maize stems and leaves was initially higher than in the roots at 2 weeks after spraying but, as the volume of crop foliage increased its concentration declined to low levels and below the level in the roots at 10 weeks after spraying.

The trend for endosulfan in soya bean stems and leaves is different to that of lindane in maize stems and leaves. Endosulfan in soya stems and leaves is initially low at 2.22 ng g^{-1} at 2 weeks after spraying then increased to 6.55 ng g^{-1} at 5 weeks after spraying before dropping to a low concentration of 1.53 ng g^{-1} at 10 weeks after spraying. The decline in pesticide levels with time is a complex combination of absorption, metabolism and crop volume dilution effects. The concentrations obtained for lindane in maize and soya bean grain at harvesting time were 1.32 and 2.21 ng g^{-1} respectively. These concentrations, although low, are still surprising since neither compound is expected to be transported to the storage sinks of plants.

Occasionally, trace levels of insecticide were detected from plants growing in the untreated control plots in the interval shortly after application, possibly as a result of drift during spraying (Table 7). The plant samples from the treated plots show higher levels of alien insecticides than the untreated plots (Table 7). This may be because the crops were rotated from the previous year's trial and so any higher level of an alien insecticide from plants in these plots could have resulted from both drift and carry-over from the previous year's pesticide application.

4. CONCLUSIONS

It has been shown that applications of lindane and endosulfan to maize and soya bean crops cause few medium-term changes in the populations of non-target insect species with only possible cause/effect relationships between endosulfan and coleoptera in soyabean. Analysis showed that insecticide concentrations in these species declined for spiders but increased for grasshoppers over the period of observation with both trends probably dependent on the feeding habits of these insects.

Concentrations of the insecticides in the soil initially fell rapidly but this rate of loss declined at later intervals probably as the soil dried out reducing both physicochemical and microbial mechanisms of degradation. Concentrations of both lindane and endosulfan in crop plants also declined to low levels during the monitoring period up to 10 weeks and will have declined even further in the period up to harvest. Surprisingly, low concentrations of both lindane and endosulfan were found in the harvested seeds of the treated crops.

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