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Residues of DDT and lindane on treated conifer seedlings and in forest soil

Restmängder av DDT och lindan på behandlade barrträdsplantor och i skogsmark

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Abstract

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Conifer seedlings were treated with DDT and lindane before being planted in a reforestation area. At intervals samples were taken from the planted seedlings and the surrounding soil and analysed for DDT components and lindane. The loss of the insecticides from the seedlings and the incidence of them in the soil were determined. The ecological impact of planting insecticide-treated seedlings in the forest is discussed.

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Contents

1 Introduction

In countries where conifer seedlings are planted in clear-cut areas the seedlings often are heavily attacked by insects such as pine weevils (*Hylobius spp.*) and black pine beetles (*Hylastes spp.*). Generally the seedlings are treated with insecticides, before outplanting, by means of dipping or spraying. DDT and lindane have been the insecticides most commonly used for this purpose. Since 1975 such treatment has been prohibited in Sweden.

Indeed, even between 1970 and 1974 the only permissible use of DDT in Sweden was the pre-planting treatment of conifer seedlings. During this period the total weight of DDT used and the number of seedlings treated were recorded (Anon., 1974). Thus the gross quantity of DDT used in the treatment of seedlings can be determined. On average, 10.3 tonnes of DDT were consumed annually to treat some 271 million seedlings, which corresponds to 38 mg of DDT per seedling. The following figures may also be of interest in the context of this study. The gross consumption of DDT in the treatment of four-year-old transplanted spruce seedlings averaged 47 mg per seedling for seedlings sprayed in the nursery bed, and 57 mg per seedling for seedlings dipped at the nursery.

A considerable proportion of the original amount of insecticide is not deposited on the seedling, nor carried into the forest, but remains—depending on the method of treatment—at different places in the nursery. When lindane is applied by spraying seedlings in nursery beds, the air around the seedlings contains measurable amounts of lindane, one or two weeks after treatment. Studies on these aspects have been reported by Kolmodin-Hedman et al. (1977) and Möller and Bergman (1979).

On average, the total amount of DDT per hectare carried by the treated seedlings into the forest did not exceed 80 g. Insecticide residues on the seedlings decrease with time (Eidmann, 1971; Nef and Zenon-Roland, 1974). They evaporate, or codistillate with water, are degraded, fall or are washed off, or may be carried to the ground by falling needles and bark.

In Sweden lindane, but especially DDT, is widespread in air, water and soil. This is associated with the high, though in recent years greatly reduced, atmospheric intake. The incidence of DDT in Swedish forest soils has been studied by Odén and Ekstedt (1976) and Ekstedt (1977). An interesting result of these studies is the rather short half-life of DDT (about one year) and its strong adsorption on the upper soil layers.

Bergman, Möller and Wiklander (1979) analysed water from three clear-cut areas planted with lindane-treated seedlings and from one area with DDT-treated seedlings. Only in isolated cases did water pools close to the seedlings contain any measurable amounts of these insecticides (all very small), while neither DDT nor lindane could be detected in the ground water (springs).

DDT is still used in several countries for the protective treatment of seedlings. In other countries it has been replaced by other insecticides, such as lindane. The environmental properties of these substances have attracted special attention in discussions of the suitability of different insecticides for the treatment of seedlings. Thus, in 1977 and 1978, we studied the residues of DDT and lindane on treated seedlings in the forest and the incidence of these insecticide on and in the forest soil. The study was expected to answer several questions: How much DDT or lindane do treated seedlings carry into the forest? How rapidly do the residues decrease on the seedlings? What quantity of insecticide reaches the soil and how deeply does it penetrate in time?

2 Methods

2.1 Field methods

In May 1977 transplanted four-year-old Norway spruce (*Picea abies* (L.) Karst.) seedlings and three-year-old Scots pine (*Pinus sylvestris* L.) seedlings were treated, by the upper parts (stem and branches) being dipped in suspension containing 1 per cent a i of DDT or lindane, respectively. The following day the seedlings were planted in a clear-cut area in central Sweden (Röskär, Bogesund). Most seedlings were planted in scarified patches. In addition, several rows of DDT-treated and of untreated spruce seedlings were planted in vegetation without any prior scarification. The spacing was 2×2 m. The soil was sandy till with relatively few stones.

Samples of seedlings and soil for chemical analysis were taken before treatment and planting (00), on the day of treatment (0), one (1), two (2), 11 (3), and 20 weeks (4) and one year (5) after planting. The sampling dates are shown in the tables.

Seedlings were sampled according to random tables. Every seedling was cut at the ground line and divided into two parts: the stem and the branches and needles. In one series (whole seedlings), the seedlings were not divided.

Three soil samples per series and sampling date were taken from around seedlings in scarified patches chosen from random tables, and one sample was taken at random spots between the seedlings. The soil samples were taken as close as possible to the seedlings and at four depths down to 20 cm below ground level (see Tables 8 and 9). The sample core had a diameter of 70 mm.

2.2 Chemical analysis

The samples were analysed at the National Swedish Laboratory for Agricultural Chemistry by the following method:

Apparatus.—A Varian 2700 gas chromatograph, with scandium source electron capture detector and glass capillary column apparatus, was used. The samples were automatically injected through a splitter into the column, by means of Varian Auto Sampler 8000. The glass capillary columns were 40 m long, had an i.d. of 0.3 mm, and were coated with SF 96 silicone oil. In most cases the column temperature was 185°C, the detector temperature 250°C and the injector temperature 235°C. The carrier gas was nitrogen and its velocity was 1 ml/min through the column and 40 ml/min through the splitter. The velocity of the make-up gas was 20 ml/min. The peaks were integrated on a Spectra-Physics Autolab System I computing integrator.

Reagents.—The reagents and standards used were hexane purum, which was distilled from potassium hydroxide; distilled acetone purum; fuming sulphuric acid with 7 percent sulphur trioxide; and 0.9 percent sodium chloride solution. Internal standard solutions were hexabrombenzene (Aldrich-Europe, Beerse, Belgium) in hexane for the DDT analyses and heptachlor in hexane for the lindane analyses.

General procedure.—The dried soil was mixed and a known amount (5—10 g) shaken for 20 minutes in a 250-ml ground-joint flask with 50 ml of acetone and 25.0 ml of internal standard solution. The flask was allowed to stand overnight. Two hundred ml of sodium chloride solution was then added to separate the hexane phase. A 15-ml aliquot of the hexane phase was evaporated under a flow of nitrogen and the residue was dissolved in 4 ml of hexane. Four ml of 7 percent fuming sulphuric acid was added and the tube containing the mixture was inverted at least 30 times. The mix-

ture was centrifuged, and 1—5 µl of the hexane phase was injected into the gas chromatograph. The chromatogram was compared for identification and quantification with chromatograms of standard solutions.

For analysis of the seedlings, 2—15 g stems or branches were homogenized for 4 minutes by an Ultra Turrax TEX 45 with 100 ml acetone-hexane mixture (2 + 1) in a covered 300 ml beaker. After addition of 100 ml of water, the mixture was stirred and the phases allowed to separate. A 0.200-ml aliquot of the hexane phase was taken out with an SMI micropettor and was added to 25.0 ml of internal standard solution. After mixing, 1—5 µl was injected into the gas chromatograph. The chromatogram was compared with chromatograms of standard solutions.

Range of detection.—Soil samples were analysed as described by Mattsson and Nygren (1976). This method, originally developed for sludge samples, involves a separate clean-up step to remove elemental sulphur. This clean-up step was not necessary for the soil samples.

In ordinary residue analyses the amounts of pesticides are very low compared with the amounts in these samples of seedlings. Most methods are designed for low residue contents. Instead of developing a new method, the analyses of seedlings were carried out on diluted extracts. It was therefore possible to inject the diluted extracts into the gas chromatograph without any further clean-up. It was not intended to lower the detection limits for these samples.

The detection limits depend on the weight of analysed sample and the dilution of the sample extract. In the tables the detection limits are given for samples with negative (ND = not detected) results.

Analysis of DDT and metabolites comprised ppDDD, opDDT, and ppDDT as given in the tables, and further ppDDE, opDDE and ppDDMU. However, in most cases the latter were below the limits of detection; only in a few samples were small amounts of ppDDE found.

3 Results

3.1 Residues on seedlings

Tables 1—4 contain data for the DDT and lindane residues on the seedlings. Means and standard deviations have been calculated for five samples each. In Table 1, for sampling date 31 May, 1977, the group "stem" contains four samples only, one sample having been excluded because of exceptionally high (about fourfold) residues. In Table 4 the results of the series "whole seedlings" (undivided spruce seedlings) are shown in addition to the results of divided spruce seedlings.

Some insecticide residues were found on the seedlings even before treatment. Small amounts of ppDDT were detected on branches of the spruce seedlings before treatment (Table 1). On pine seedlings DDT was found only in some samples before treatment (Table 3). Lindane was not detected on spruce seedlings before treatment (Table 4).

The gradual decrease of insecticide residues on both stems and branches of treated seedlings is obvious. This process is fast in the beginning, but slower later on. The decrease of residues on stems is different to

Table 1. DDT and DDD on stems and branches of treated spruce seedlings in scarified patches.

Means and standard deviations for mg/kg green sample. n = 5 in all groups (n = 4 in sampling 2, stem).

Sampling No., date		mg/kg green sample					
		branches			stem		
		ppDDD	opDDT	ppDDT	ppDDD	opDDT	ppDDT
00 16 May 1977	$\bar{x}$	*	*	6.0	**	**	**
	s			2.2			
0 17 May 1977	$\bar{x}$	80	470	1500	68	290	950
	s	8.3	39	130	23	51	240
1 24 May 1977	$\bar{x}$	37	380	1600	< 27	230	810
	s	14	54	260	> 14	54	160
2 31 May 1977	$\bar{x}$	63	370	1100	54	170	610
	s	35	72	260	13	40	130
3 2 Aug. 1977	$\bar{x}$	28	62	300	56	94	470
	s	14	29	110	41	32	200
4 6 Oct. 1977	$\bar{x}$	20	55	300	31	44	290
	s	5.5	13	59	11	8.6	61
5 5 May 1978	$\bar{x}$	< 2.9	16	80	< 8.3	35	190
	s	> 0.9	7.5	42	> 3.1	18	74

* = ND < 3 mg/kg ** = ND < 8 mg/kg

Table 2. DDT and DDD on treated spruce seedlings in vegetation (cf. table 1).

Sampling No., date		mg/kg green sample					
		branches			stem		
		ppDDD	opDDT	ppDDT	ppDDD	opDDT	ppDDT
1 24 May 1977	$\bar{x}$	29	370	1500	< 31	200	700
	s	11	71	180	> 19	34	140
3 2 Aug. 1977	$\bar{x}$	33	32	230	86	76	360
	s	8.3	18	79	37	42	150

Table 3. DDT and DDD on treated pine seedlings in scarified patches (cf. table 1).

Sampling No., date		mg/kg green sample					
		branches			stem		
		ppDDD	opDDT	ppDDT	ppDDD	opDDT	ppDDT
00 16 May 1977	$\bar{x}$	*	*[1]	*[1]	**	**	**[1]
	s						
0 17 May 1977	$\bar{x}$	75	350	1100	85	230	770
	s	12	27	110	31	110	370
1 24 May 1977	$\bar{x}$	68	370	1300	60	170	510
	s	13	61	200	17	43	120
3 2 Aug. 1977	$\bar{x}$	32	51	230	81	74	300
	s	12	24	88	17	33	110

* = ND < 3 mg/kg ** = ND < 10 mg/kg
[1] 2 or 3 samples just above limit of detection

that of residues on branches with needles. Immediately after treatment the branches have higher residues of DDT or lindane, while later the residues are higher on the stems. This is illustrated in Figure 1, which, on a logarithmic scale, shows the residues in mg per kg of green sample on the various sampling dates.

On their branches as well as their stems, spruce seedlings in vegetation had somewhat smaller DDT residues than did seedlings in mineral soil (Tables 1 and 2). These differences are, however, not significant.

Pine seedlings had lindane residues similar to those on spruce seedlings (Table 4), on stems as well as branches. On the other hand, the data for DDT indicate smalle amounts of the insecticide on pine than o spruce, on both stems and branches and fo all sampling dates (Tables 1 and 3). Th differences in ppDDT, however, are signif cant only for branches sampled on 17 M and for stems sampled on 24 May.

An important difference between DI and lindane was found in the rate of c crease of residues on both stems a branches, on pine as well as spruce. T residues of both insecticides decreased m rapidly during the period immediately a treatment. However, this decrease was m faster for lindane than for DDT. A lind level was soon reached that was about

Table 4. Lindane on treated spruce and pine seedlings in scarified patches.

Means and standard deviations for mg lindane/kg green sample. n = 5 in all groups.

Sampling No., date		mg/kg green sample				
		spruce			pine	
		branches	stem	whole seedling	branches	stem
00 16 May 1977	$\bar{x}$	ND	ND			
	s					
0 17 May 1977	$\bar{x}$	1700	790	1400	1900	760
	s	120	150	71	390	190
1 24 May 1977	$\bar{x}$	660	220	630	670	340
	s	260	34	85	190	220
2 31 May 1977	$\bar{x}$	370	190			
	s	100	31			
3 2 Aug. 1977	$\bar{x}$	37	36	26	48	51
	s	17	26	5.5	12	22
4 6 Oct. 1977	$\bar{x}$	27	47			
	s	9.1	10			
5 16 May 1978	$\bar{x}$	15	47			
	s	4.7	41			

ND < 1 mg/kg

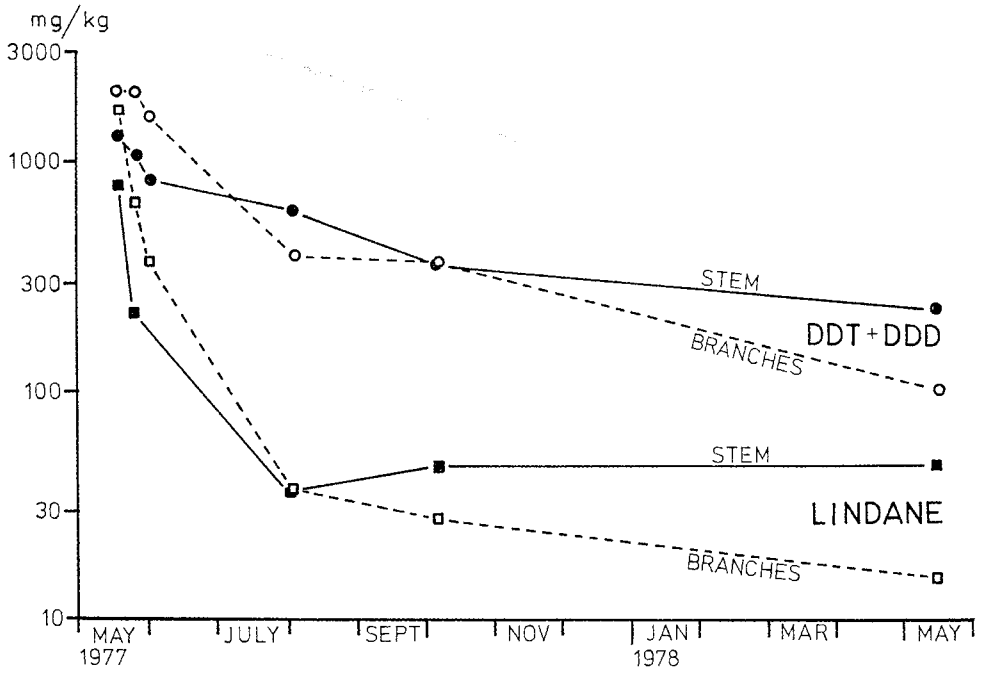

Figure 1. Mean residues of DDT + DDD and lindane on stems and branches of treated spruce seedlings on various sampling dates. Ordinate: mg/kg on logarithmic scale.

of that of DDT. At the end of the study period of one year, this difference in levels had become smaller, but was still very apparent (see Figure 1 and Tables 1 and 4. Compare also Tables 6 and 7).

The data for divided seedlings (stem and branches) were checked by analysis of lindane on whole seedlings (Table 4). The data for whole seedlings calculated from divided seedlings are consistent with the measured data for undivided seedlings. Thus, the divided seedlings can be used to calculate total amounts of insecticide residues on the seedlings.

For this it is necessary to know the weight of the seedlings (without roots). The weights of the analysed stems and branches varied considerably both within and between groups. There was no obvious tendency towards higher weights at later sampling dates. Therefore, the mean weights of all stems and branches on seedlings, in respect of which the whole sample was analysed, were used for estimating the total amount of insecticide per seedling (Table 5). This results in an estimate that is somewhat too low, as seedlings with large branches, in respect of which the whole sample was not weighed in for analysis, are excluded from the mean weights for branches. The series "whole seedlings" gives data based on the true weights of these seedlings.

The estimated total residues of DDT and lindane on the seedlings on various sampling dates are given in Tables 6 and 7. Immediately after dipping treatment the four-year-old spruce seedlings carried about 20 mg of DDT and DDD or about 15 mg of lindane. These were the analysed amounts of insecticides on the seedlings when they were planted in the forest. Eleven weeks later (2 August, 1977) the DDT and DDD residue was only 4—5 mg per spruce seedling, while the lindane residue had decreased to about 0.4 mg per seedling. One year after treatment only 1.5 mg of DDT and DDD, or less than 10 per cent of the initial residue, remained on the seedling. After one year, only about 0.2 mg of lindane remained on a seedling—less than 2 per cent of the initial amount. The pine seedlings had smaller

Table 5. Mean green weights (g) of branches and stems that were analysed as total samples.

		branches		stems	
		n	g	n	g
DDT	spruce	23	8.11	33	2.97
	pine	11	4.96	19	1.52
lindane	spruce	23	7.45	34	2.22
	pine	15	6.26	15	1.21

Table 6. Estimated total residues of DDT and DDD per spruce and pine seedling on various sampling dates.

Sampling No., date	mg DDT and DDD/seedling		
	spruce, scarified patch	spruce in vegetation	pine, scarified patch
00 16 May 1977	0.05	—	≤ 0.05
0 17 May 1977	21	—	9.4
1 24 May 1977	19	17	9.5
2 31 May 1977	15	—	—
3 2 Aug. 1977	5.0	3.8	2.3
4 6 Oct. 1977	4.1	—	—
5 16 May 1978	1.5	—	—

Table 7. Estimated total residues of lindane per spruce and pine seedling on various sampling dates. All seedlings in scarified patches.

Sampling No., date	mg lindane/seedling		
	spruce	spruce, whole seedlings	pine
00 16 May 1977	ND	—	—
0 17 May 1977	14	15	13
1 24 May 1977	5.4	7.2	4
2 31 May 1977	3.2	—	—
3 2 Aug. 1977	0.36	0.38	0
4 6 Oct. 1977	0.31	—	—
5 16 May 1978	0.22	—	—

initial residues (10—12 mg) and similar decreases.

The proportions between the detected amounts of ppDDT, opDDT and ppDDD changed during the experimental period. In relation to ppDDT the amount of ppDDD tended to increase during the growing season and to return to a lower percentage after winter. The opDDT decreased in relation to ppDDT.

3.2 **Residues in the soil**

Tables 8 and 9 contain the analysis data for the samples at four depths, both close to the seedlings and between the seedlings, for all of the sampling dates. Note the different levels of detection in Table 8.

Within some groups the data show considerable variation. Unfortunately some of this variation may be caused by contamination during the sampling procedure. It must be pointed out here that sampling was difficult because till soil was chosen as being most characteristic of Swedish forest soils.

This variation and the few samples per group should exclude the use of means. The trends of the results, however, are not easily recognized from Tables 8 and 9. For this reason the mean contents of DDT plus DDD and of lindane in soil are shown in Figures 2 and 3.

In the following the results of residue

Table 8. DDT and DDD at various soil levels close to and between treated spruce seedlings.

Sampling No., date	sample	mg/kg moist soil					
		litter			0—2.5 cm		
		ppDDD	opDDT	ppDDT	ppDDD	opDDT	ppDDT
00 16 May 1977	1 (close to seedling)				*	*	*
	2 (close to seedling)				*	*	*
	3 (close to seedling)				*	*	*
	between seedlings	*	*	*	*	*	*
1 24 May 1977	1 (close to seedling)				0.006	0.087	0.34
	2 (close to seedling)				0.008	0.15	0.46
	3 (close to seedling)				0.010	0.14	0.52
	between seedlings						
2 31 May 1977	1 (close to seedling)				0.16	0.87	4.3
	2 (close to seedling)				0.14	0.92	3.9
	3 (close to seedling)				*	0.13	0.60
	between seedlings	*	*	0.039	*	*	*
3 2 Aug. 1977	1 (close to seedling)				0.22	1.2	8.1
	2 (close to seedling)				0.013	0.21	1.1
	3 (close to seedling)				0.25	0.85	6.5
	between seedlings	*	0.009	0.054	*	*	0.033
4 6 Oct. 1977	1 (close to seedling)				0.052	0.31	2.2
	2 (close to seedling)				0.008	0.062	0.39
	3 (close to seedling)				0.38	1.7	12
	between seedlings	*	*	0.012	*	*	0.011
5 16 May 1978	1 (close to seedling)				0.017	0.19	1.6
	2 (close to seedling)				0.060	1.0	8.3
	3 (close to seedling)				0.040	0.43	2.8
	between seedlings	**	0.005	0.030	**	0.006	0.03

* = ND < 0.005 mg/kg ** = ND < 0.001 mg/kg

analyses are first presented separately for DDT and lindane.

DDT.—No measurable amounts of DDT were found on or in the soil before planting (Table 8).

During the first growing season, the soil samples between seedlings contained small amounts of DDT in the litter and down to a depth of 2.5 cm and, in one case, in the deepest layer (17.5—20 cm). In May 1978, one year after planting, a low content of DDT was found at all four levels.

Sampling close to the seedlings revealed varying DDT contents in the majority of samples at all levels and for all sampling dates, with the exception of the deepest level one week after planting. Two extremely high values were found in October, 1977, and May, 1978, at 7.5—10 cm level (see Table 8), presumedly because of contamination during sampling. Parts of contaminated roots of seedlings may accidentally have been included in the sample core.

In the two upper levels, down to five cm, DDT contents increased rapidly during the first weeks after planting, then more slowly until August, after which they decreased even more slowly. The deepest level, 17.5—20 cm, had a slow increase in the DDT content, which never reached high values. The intermediate level, down to a depth of 10 cm, had irregular results with relatively high values one year after planting. (See also Figure 2).

2.5—5.0 cm			7.5—10.0 cm			17.5—20.0 cm		
ppDDD	opDDT	ppDDT	ppDDD	opDDT	ppDDT	ppDDD	opDDT	ppDDT
*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*
*	0.032	0.10	*	0.005	0.012	*	*	*
*	0.032	0.14	*	*	0.011	*	*	0.011
0.005	0.050	0.22	*	0.005	0.014	*	*	*
*	0.055	0.23	*	*	0.013	*	0.014	0.067
*	0.12	0.55	*	0.011	0.053	*	*	0.014
*	0.061	0.27	*	0.087	0.34	*	*	0.005
*	*	*	*	*	*	*	*	*
0.029	0.12	0.69	*	0.007	0.47	*	0.008	0.038
0.017	0.14	1.4	0.005	0.012	0.11	*	0.019	0.12
0.005	0.057	0.43	*	*	0.021	*	*	0.007
*	*	*	*	*	*	*	*	0.008
0.011	0.045	0.35	*	*	0.035	*	*	*
*	0.007	0.009	*	*	*	*	0.010	0.00
0.10	0.20	1.6	0.63	4.5	14	*	0.050	0.20
*	*	*	*	*	*	*	*	*
0.008	0.16	0.68	0.16	3.1	11	0.006	0.036	0.1(
0.010	0.089	0.60	0.017	0.21	2.0	0.001	0.016	0.0'
0.004	0.026	0.20	0.053	0.61	2.2	0.005	0.045	0.1
**	0.002	0.013	**	**	0.004	**	**	0.0

Table 9. Lindane at various soil levels close to and between treated spruce seedlings.

Sampling No., date	Sample	mg/kg moist soil				
		litter	0—2.5 cm	2.5—5.0 cm	7.5—10.0 cm	17.5—20.0 cm
00 16 May 1977	1 (close to seedling)		0.002	0.001	0.003	0.001
	2 (close to seedling)		0.002	0.002	ND	0.001
	3 (close to seedling)		0.001	ND	ND	ND
	between seedlings	0.009	0.003	0.002	0.001	0.004
1 24 May 1977	1 (close to seedling)		0.170	0.036	0.071	0.012
	2 (close to seedling)		0.086	0.033	0.043	0.010
	3 (close to seedling)		0.170	0.009	0.001	ND
	between seedlings	0.008	0.001	0.003	0.001	ND
2 31 May 1977	1 (close to seedling)		0.23	0.047	0.24	0.027
	2 (close to seedling)		0.99	0.14	3.1	0.25
	3 (close to seedling)		0.30	0.024	0.009	0.002
	between seedlings	0.056	0.001	0.008	0.004	0.015
3 2 Aug. 1977	1 (close to seedling)		0.91	0.75	0.28	0.19
	2 (close to seedling)		1.19	0.94	0.55	0.024
	3 (close to seedling)		0.23	0.69	0.11	0.015
	between seedlings	0.011	0.001	0.002	ND	ND
4 6 Oct. 1977	1 (close to seedling)		1.0	0.5	0.43	0.070
	2 (close to seedling)		1.16	2.36	0.25	0.010
	3 (close to seedling)		0.22	0.13	0.025	0.018
	between seedlings	0.048	0.013	0.002	0.001	0.002
5 16 May 1978	1 (close to seedling)		0.24	0.76	0.087	0.023
	2 (close to seedling)		0.13	0.028	0.02	0.016
	3 (close to seedling)		1.03	1.24	0.33	0.22
	between seedlings	0.011	0.018	0.009	0.002	0.003

ND < 0.001 mg/kg

Assuming that DDT may largely be found in the soil close to the seedlings, e.g. within a radius of 10 cm, the total amount of DDT in the soil can be roughly estimated. This estimate gives a DDT content towards the end of the growing season of about 8—9 mg and, accepting some rather high values, of up to 13 mg for May 1978. Most of this amount is found in the upper layers of the soil. These estimates would account for about half or more of the DDT initially found on the seedlings.

Analogous with the results of DDT analysis of seedlings, the proportions between detected contents of ppDDT, opDDT and ppDDD in the soil varied during the experimental period. The data for ppDDD indicate a possible increase in relation to ppDDT during the growing season and a particularly low value after winter. The opDDT decreased in relation to ppDDT.

Lindane.—The sensitive lindane analysis detected measurable amounts of lindane in the majority of soil samples even before planting (Table 9). They were, however, very small and at the limit of detectability. On all dates the same generally holds true for the samples of soil between seedlings, with the exception of two samples of litter that contained somewhat higher, but still small, amounts of lindane.

Close to the seedlings, higher contents of lindane were detected in the soil one week after planting not only at the upper sampling

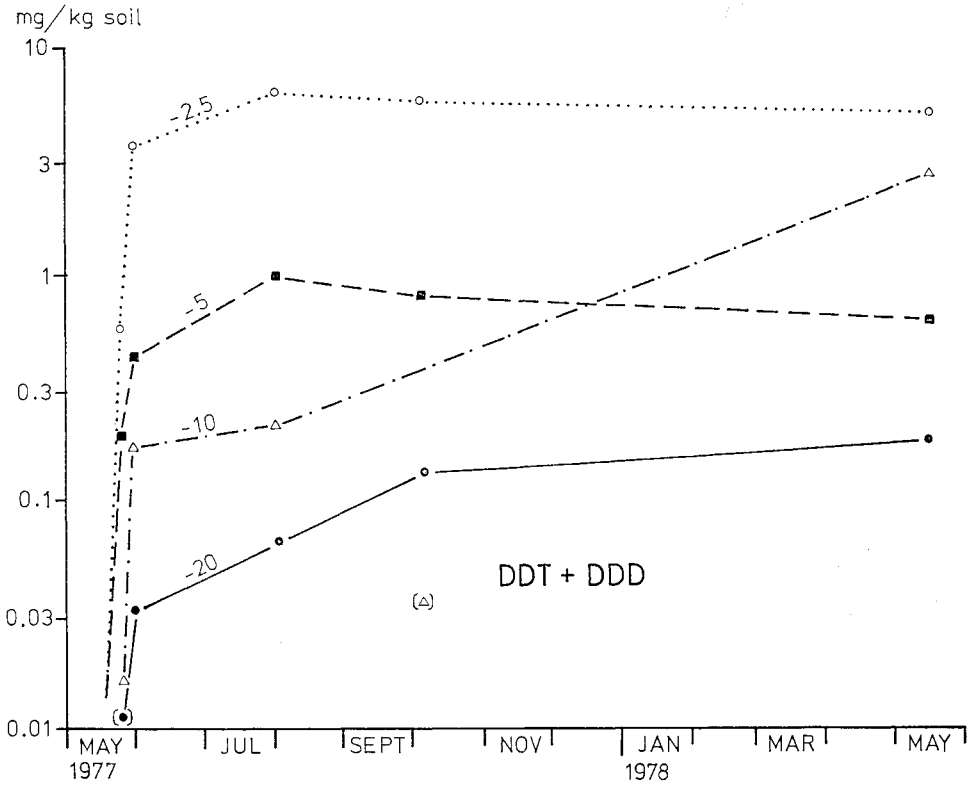

Figure 2. Mean contents of DDT + DDD in mineral soil close to treated spruce seedlings at various levels and for various sampling dates. Ordinate: mg/kg on logarithmic scale.
The various levels below ground are:

– 2.5 = 0—2.5 cm
– 5 = 2.5—5 cm
– 10 = 7.5—10 cm
– 20 = 17.5—20 cm

levels, but also farther down. Within two weeks lindane increased sharply at all levels and at the deepest level (down to 20 cm) attained a magnitude which—with some variation—was maintained throughout the study period, i.e. an average of roughly 0.1 mg/kg (Figure 3).

At the other levels lindane still increased towards August, but at a slower rate. Thereafter, up to the end of the study period one year after planting, some smaller increases or decreases were found at these levels down to a depth of 10 cm, but no drastic changes occurred (see Figure 3). The two upper levels had rather similar lindane contents, of the order of 1 mg/kg, and the third level (– 10 cm) lower contents of about 0.3 mg/kg or less.

A rough estimate of the total amount of lindane in the soil close to seedlings, calculated in the same manner as for DDT, gives at the end of the first growing season and in the following spring, a figure of about 2—3 mg. This would account for about one fifth of the lindane initially found on the seedlings.

Comparison of DDT and lindane.—In a comparison of the incidence of DDT and lindane in the soil (e.g. Figures 2 and 3), the low initial values for the detection of lindane must be noted.

Both insecticides increased sharply in the soil during the first weeks after planting. Lindane penetrated faster down to a depth

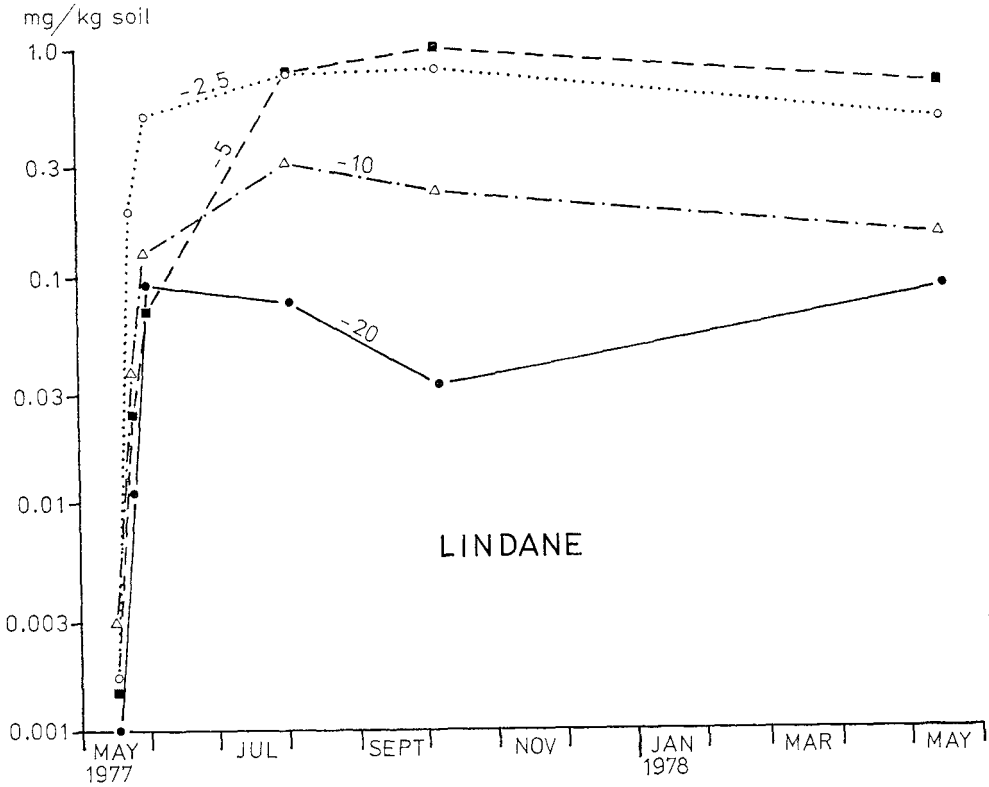

Figure 3. Mean contents of lindane in mineral soil close to treated spruce seedlings at various levels and for various sampling dates. (For further explanations see the legend to Fig. 2 and the text.)

of 17.5—20 cm and then did not increase further, while DDT reached this level more slowly, tending to increase later on.

A notable similarity between the incidence of both insecticides is found at the two upper levels in the case of lindane and at the level of 2.5—5 cm in the case of DDT. Quite different from this is the nearly ten-fold-greater DDT content in the uppermost level of 0—2.5 cm.

4 Discussion

The results of this study confirm the experience that dipping leaves relatively large insecticide residues on the seedlings. The residues are larger and the coating more homogeneous than those obtained by spraying in the nursery bed (Kolmodin-Hedman, 1977; Möller and Bergman, 1979).

The largest amount of insecticide is found on the branches with needles. Stems, on the other hand, retain the insecticides better than branches do. This fact and the obvious difference between gross consumption of insecticide and the residues on the seedlings suggest that application techniques should be improved.

The early and faster loss of lindane, as compared with DDT, was not unexpected. Lindane has a much higher vapour pressure and part of this loss may be explained by evaporation. After the initial losses, however, lindane was retained rather well on the stems of the seedlings. It is interesting to note that even the small remaining residues of lindane and DDT have a protective effect against insects (e.g. Eidmann, 1974).

Degradation was not studied in detail. Increasing percentage of ppDDD on seedlings and in the soil may be interpreted as signs of degradation. Decreasing percentage of opDDT may be an expression of higher evaporation than in ppDDT.

The data for the incidence of DDT and lindane in the soil demonstrate clearly that these insecticides did escape from the seedlings onto the ground and into the soil. The total amounts were estimated as approximately one-half of the initial amount of DDT and one-fifth of the initial amount of lindane on the seedlings. The insecticides were found mainly close to the seedlings and were horizontally dispersed only to very small degree (cf. samples between seedlings). DDT and lindane in particular penetrated rapidly into the soil. It should be noted that the mineral soil was not protected by a humus layer. At the deepest level studied (17.5—20 cm below ground) the insecticide contents were considerably smaller than those at or just below the soil surface.

Lindane appears to have penetrated faster into the soil than DDT. This may be connected with its higher water solubility. The smaller amounts of lindane than of DDT retrieved from the soil, and especially the smaller contents in the surface level, may be explained by evaporation, codistillation and degradation.

Doubtless even such small, localised amounts of insecticides may affect soil organisms close to the seedlings. Looking at the whole plantation area, however, we consider the ecological effects of the ingress into the soil of DDT and lindane from seedlings to be negligible.

Summary

Transplanted seedlings of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.) were dip-treated in DDT or lindane suspensions (1 per cent a i) and outplanted in May in scarified patches or in vegetation on a clear-cut area in central Sweden. Samples of the seedlings, divided into stems and branches, and samples of the soil at different depths between and close to the seedlings were taken at intervals during a one-year period. The samples were analysed for DDT and metabolites or for lindane.

The amount of insecticide analysed on the spruce seedlings before planting was about 20 mg of DDT and DDD and about 15 mg of lindane. The residues of both insecticides decreased most rapidly during the first weeks of exposure, with the decrease being stronger in respect of lindane than in respect of DDT. After one year 10 per cent of the initial DDT and DDD and only 2 per cent of the initial lindane were left on the seedlings.

In the soil close to the seedling, down to a depth of 5 cm, the DDT and the lindane contents increased rapidly during the first weeks after the planting. Lindane penetrated vertically more rapidly than did DDT. Just two weeks after planting, the mean lindane content was about 0.1 mg/kg soil at a depth of 17.5—20 cm. DDT reached similar levels at the same depth after 11 weeks and the amounts were still slowly increasing one year after planting. At the surface layers (down to 2.5 cm) the average contents of DDT + DDD and lindane reached a steady state of about 4 and 1 mg/kg soil, respectively. The content of insecticides in the soil between the seedlings was undetectable or small. The amounts of insecticides in the soil within a radius of 10 cm from the seedlings and down to a depth of 20 cm were (after the growing season) estimated roughly as 8—9 mg and 2—3 mg of DDT + DDD and lindane, respectively.

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Sammanfattning

Omskolade plantor av gran (*Picea abies* (L.) Karst.) och tall (*Pinus silvestris* L.) behandlades medelst doppning i suspensioner med 1 % aktiv substans av DDT och lindan. De planterades under maj månad i markberedda fläckar eller i vegetation på ett hygge med moränmark i Röskär, Bogesund. Plantprover, uppdelade i stam och grenar, och jordprover från olika djup mellan och intill plantorna insamlades vid olika tidpunkter under ett år. Proverna analyserades beträffande innehåll av DDT och metaboliter samt lindan.

Den mängd insekticid som analyserna gav på granplantor före planteringen uppgick till omkring 20 mg DDT + DDD och 15 mg lindan. De båda insekticidernas restmängder minskade snabbast under de första veckorna efter planteringen och denna minskning var starkare för lindan än för DDT. Efter ett år fanns 10 procent av den ursprungliga mängden DDT och DDD och bara 2 procent av den ursprungliga mängden lindan kvar på plantorna.

I marken nära intill plantorna och ned till ett djup av 5 cm ökade DDT- och lindanhalterna snabbt under de första veckorna efter planteringen. Lindan trängde ned snabbare på djupet än DDT. Två veckor efter planteringen uppgick lindanhalten i medeltal till 0,1 mg/kg jord på djupnivån 17,5—20 cm. DDT uppnådde liknande halter på detta djup först efter 11 veckor och halterna ökade fortfarande långsamt ett år efter planteringen. I ytlagren (ned till 2,5 cm) nådde medelhalterna för DDT + DDD och lindan snart en nivå på 4 respektive 1 mg/kg jord. I marken mellan plantorna var halterna av insekticider icke detekterbara eller mycket små. Mängden av insekticider i marken inom en radie av 10 cm från plantorna och ned till ett djup av 20 cm beräknades vid vegetationsperiodens slut till ungefär 8—9 mg DDT + DDD och 2—3 mg lindan.

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