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**TRANSPORTATION BEHAVIOUR OF LINDANE
IN DIFFERENT TYPES OF SOILS**



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PREFACE

Among various organic and inorganic water pollutants, the pesticides are very dangerous and harmful because of their tissue degradation and carcinogenic in nature. The pesticides are bioaccumulative and relatively stable, as well as toxic or carcinogenic, and, therefore, require close monitoring. The pesticides used for a variety of purposes are leaching into the groundwater resulting into its contamination. It is very important to find out the transportation behaviour of pesticides through soil media. The lindane is used widely in India in agricultural, forestry and domestic activities. In view of all these points, a study has been carried out to determine the transportation behaviour of lindane in sandy and loamy soils.

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CONTENTS

LIST OF FIGURES	i
LIST OF TABLES	ii
ABSTRACT	iii
1.0 INTRODUCTION	1
2.0 FACTORS EFFECTING THE LEACHABILITY OF PESTICIDES	8
3.0 EXPERIMENTAL	9
4.0 RESULTS AND DISCUSSION	15
4.1 Adsorption	18
4.2 The Transportation Behaviour of Lindane in Sandy and Loamy Soil Columns under Unsaturated Conditions	18
4.2.1 The Effect of Concentrations	19
4.2.2 The Effect of pH	22
4.2.3 The Effect of Soil Column Length	22
4.2.4 The Effect of Flow Rate	26
4.3 The Distribution of Lindane in Sandy and Loamy Soil Columns under Saturated Conditions	29
5.0 CONCLUSION	32
REFERENCES	34

LIST OF FIGURES

S. No.	Title	Page No.
1.	The pesticides in food chain.	3
2.	Column designs showing unsaturated and saturated conditions	11
3.	Effect of different concentrations of lindane on its transportation behaviour in sandy soil under unsaturated conditions	20
4.	Effect of different concentrations of lindane on its transportation behaviour in loamy soil under unsaturated conditions	21
5.	Effect of pH on transportation behaviour of lindane in sandy soil	24
6.	Effect of pH on transportation behaviour of lindane in loamy soil	25
7.	Effect of column length on transportation behaviour of lindane in sandy soil	27
8.	Effect of column length on transportation behaviour of lindane in loamy soil	28
9.	Distribution of lindane at different depths of sandy soil column in saturated conditions	30
10.	Distribution of lindane at different depths of sandy soil column in saturated conditions	31

LIST OF TABLES

S. No.	Title	Page No.
1.	WHO recommendations for pesticide hazards	2
2.	Characteristics of pesticides	5
3.	Concentration of pesticides in ground water	7
4.	Physical properties of soil samples	16
5.	Chemical properties of soil samples	17
6.	Transportation amount (μg) of lindane in sandy and loamy soils under different experimental conditions	23

ABSTRACT

The contamination of groundwater by pesticides is a worldwide problem because of their tissue degradation and carcinogenic in nature. The pesticides are bio-accumulative and relatively stable and, therefore, require close monitoring. The pesticides used for agricultural, forestry and domestic activities are leaching into the groundwater. It is, therefore, very important to study the transportation behaviour of pesticides in different types of soil media. The lindane is used widely in India for a variety of purposes. Therefore, an attempt has been made to study the transportation behaviour of lindane in sandy and loamy soils.

The effect of various operating variables, viz., concentration of lindane, pH of the mobile phase, soil column length and flow rate have been studied. It has been observed that the concentration ranging from 5 to 25 and 5 to 35 μ g were retarded by the sandy and loamy soils respectively. Therefore, 40 μ g was selected as the optimum concentration for the study. The pH was varied from 2 to 7 and it was found that the minimum transportation of lindane occurred at pH 7.0 in both sandy and loamy soils. The effect of column length on the transportation of lindane indicates that the amount of lindane transported decreases with increasing column length. The effect of flow rate did not show any significant effect on the transportation of lindane. The distribution of lindane was also studied under the saturated conditions. The uniform distribution of lindane (25.0 mL of 5.0 mg/L) has been observed after 240 hrs. and 12 weeks in sandy and loamy soils respectively.

1.0 INTRODUCTION

The quality of many of our water resources is deteriorating day by day due to the continuous addition of undesirable constituents in them. The main water pollutants are inorganics, organics and biological constituents. Among various organic and inorganic water pollutants, pesticides are very dangerous and harmful because of their tissue degradation in nature (IARC Monographs). The pesticides are bioaccumulative and relatively stable, as well as toxic or carcinogenic, and, therefore, require close monitoring. The EEC Directive 80/778 (EEC, Drinking Water Directives 1988) concerning the quality of water for human consumption, established the maximum concentration of each pesticide at 0.1 µg/L and the total pesticides concentration at 0.5 µg/L (Vettorazzi, 1979). The WHO (Guidelines for Drinking Water Quality, 1996) has classified the pesticides into five groups (Table 1) on the basis of their (LD_{50} values) hazardous nature.

The major sources of pesticide pollution are industries, agricultural, forestry and domestic activities. However, the pesticides pollution through air have also been reported. The dust particles in air adsorbed the pesticides (due to pesticides spray in agriculture, forestry and domestic use) and then contaminate water bodies, sediments and soil through rain water (Jain and Ali, 1997). Our natural water resources are contaminating due to pesticides by the above mentioned activities but the pollution of groundwater due to pesticides has become a world wide problem now a days. The possible rout of water pollution by the pesticides is shown in Fig. 1. It is apparent that the groundwater is the major source of water supply in the world. Therefore, the monitoring and the maintenance of the quality of groundwater are very important and necessary aspect of hydrology. Due to the importance of groundwater and the dangerous nature of pesticides, the scientists have

Table 1. WHO recommendations for pesticide hazards

S. No.	Class	LD ₅₀ for rat, oral (mg/Kg body mass)	
		Solid	Liquid
I.	Extremely hazardous	5	20
II.	Highly hazardous	5-50	20-200
III.	Moderately hazardous	50-500	200-2000
IV.	Slightly hazardous	>500	>2000
V.	Unlikely to present hazard in normal use	>2000	>3000

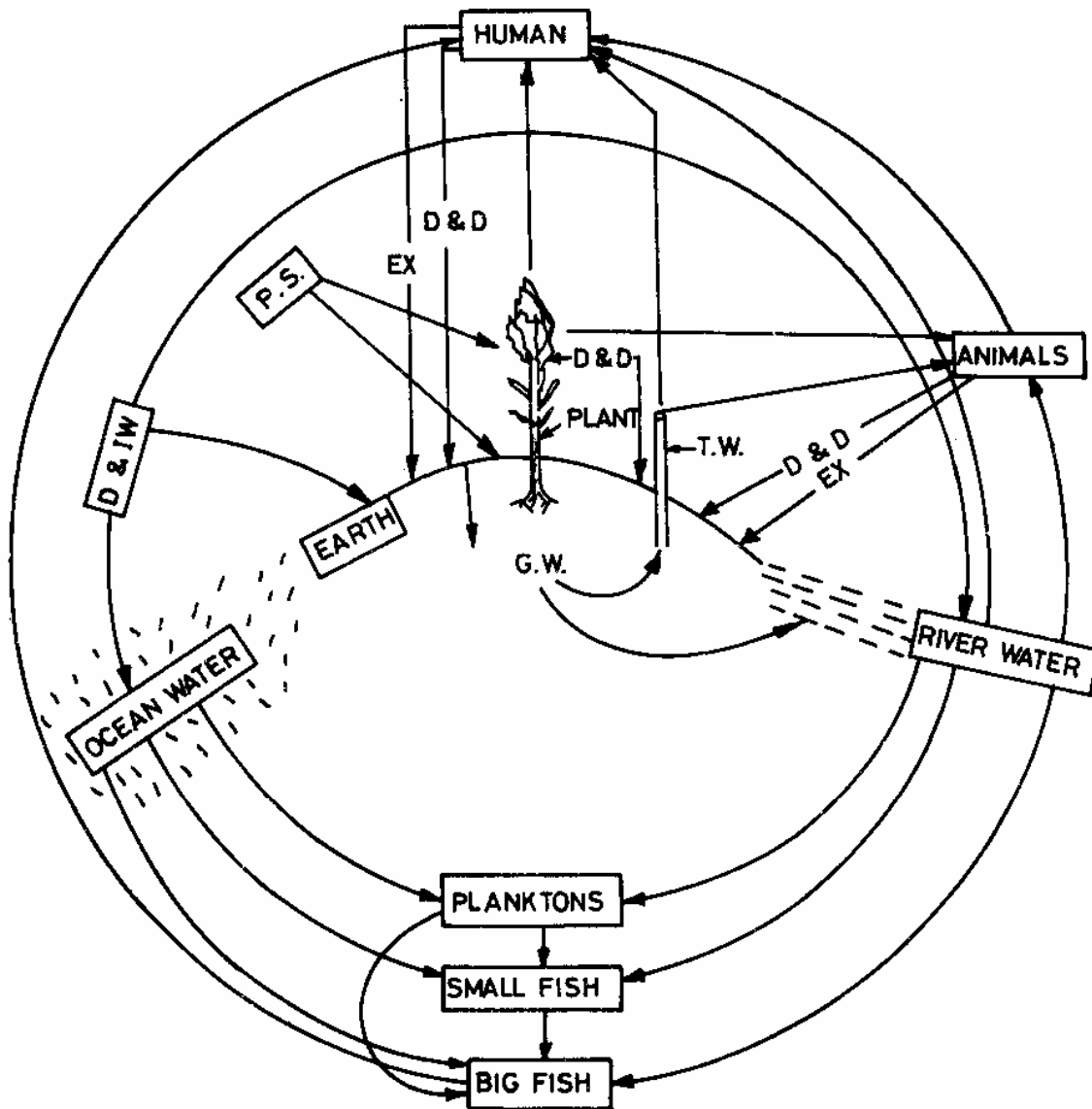


FIG.1: PESTICIDES IN FOOD CHAIN.

ABBREVIATION: D & D: DEATH & DECAY; D & IW: DOMESTIC AND INDUSTRIAL WASTES;
 EX: EXCRETION; G W: GROUND WATER; P S: PESTICIDES SPRAY;
 T W: TUBE WELL .

attracted towards the monitoring of pesticides in groundwater. The study of pesticides in groundwater started in 1979 in USA with multiple detection of various pesticides. The same issue has been addressed in other countries. It has been reported that increasing amount of the pesticide residue may be present in the soil and these can ultimately be leached to aquifer levels and contaminate the groundwater or they may be carried away by runoff waters and soil erosion (Raju, et al., 1993, Miliadis, 1994 and Sherma, 1995). The leachability of the pesticides are measured in terms of the ground water ubiquity score (GUS) (Gustafson, 1989).

The groundwater pollution due to pesticides is a worldwide problem. The EPA (Cova et al., 1990) elaborated the list of pesticides properties which indicate their ground water contamination potential (Table 2). Bottoni and Funari (1992) have evaluated the impact of 48 herbicides on ground water quality. Atrazine was found in ground water and surface water in maize production areas of the Transvaal in South Africa (Pick and coworkers, 1992). The leaching of atrazine in Germany (Grandet and coworkers, 1989) and Denmark (Felding, 1992) was also reported. The contamination of well water by atrazine, alachlor and carbofuran in Switzerland (Buser, 1990) has been found. The atrazine, simazine and cyanazine were determined in well water in USA (Poinke and Glotfelty, 1989). The different pesticides have also been found in wells in The Netherlands, Italy, Israel, Japan, Canada and Australia. Besides, the herbicides and nematicides are supposed to be the major groundwater pollutant as they are applied directly to the soils. The pesticides and about 36 volatile organic compounds have been detected in 208 urban wells in USA (Kolpin, et al., 1997b). Similarly, various pesticides have been detected in groundwater in Norway (Haarstad and Bull, 1998) and France (Welte et al., 1998). There are many reports published on the ground water contamination due to pesticides (Kolpin, et al., 1997a and Gomez de Barreda and coworkers 1998)

Table 2. Characteristics of pesticides

Parameters	Values
Water solubility	>30 mg L ⁻¹
K _d	<5, usually <1
K _{oc}	<300
Henry's constant	<10 ⁻² atm. m ³ mol
Speciation	Negatively charged, fully or partially at ambient pH
Hydrolysis half time	>25 weeks
Photolysis half life	>1 week
Field dissipation half life	>3 weeks

all over the world. Further, the pesticides in ground water have been reviewed by Timothy (1998) and Fioretti et al., (1998). The level of some of the pesticides in ground water is given in Table 3. It is clear from this Table that the values of the pesticides are higher than the permissible health values of pesticides as given by US EPA 1995.

India, currently, is the world's largest producer and user of technical HCH of which lindane is an constituent. Basically, lindane is the γ -isomer of HCH (γ -1,2,3,4,5,6-hexachlorocyclohexane). Indian production capacity ranged from 25,000 to 30,000 tones/year during 1985-1995 (David et al., 1997, Crosley, et al., 1998 and Mathur, 1998). Thus, lindane may be present in surface and ground waters in India. A little attention has been paid for monitoring of pesticides in groundwater in India. However, some reports have been published on the presence of organochlorine pesticides in some urban water resources near Calcutta (Thakker and Pande, 1986). The ground water contamination by some arsenic pesticides (Chaterji, 1994) has been reported in some of the districts of West Bengal (Calcutta). Further, the contamination of the groundwater by pesticides has also been reported in some areas nearer to water storage ponds in Gujrat. In these areas, the rain water containing pesticides from agricultural fields, is stored in ponds and during the course of time water (with pesticides) of these ponds enter into aquifers leading to the groundwater contamination by pesticides. The lindane, being the common pesticide in India both in agricultural and public health sectors, has been selected for the present study. In view of all these points, attempts have been made to find out the transportation behaviour of lindane in alluvial and sandy soils as these soils are very common in agriculture and forest areas. The transportation behaviour of lindane has been studied under the varied experimental conditions.

Table 3. Concentration of pesticides in ground water

Pesticide	Concentration (mg/L)
Acetachlor	0.05
Atrazine	0.10 and 1.11
Alachlor ESA	0.05
Alachlor	0.05
Deethyl atrazine	0.05
Cyanazine	0.05
Cyanazine amide	0.05
Metachlor	0.05
Prometrin	0.05
Simazine	0.05
Terbutylin	0.05
Heptachlor	0.05

2.0 FACTORS EFFECTING THE LEACHABILITY OF PESTICIDES

The leachability of the pesticides in groundwater is controlled by the nature of soil and pesticides itself. The soil nature includes the soil texture, total organic and inorganic matters and biological populations. The pattern of pesticides use, structures and their degradation products are also responsible for the transportation (leaching) behaviour of the pesticides. The fine texture of soils, in general, inhibits pesticides leaching because of either low vertical permeability or high surface area, which enhances adsorption of pesticides. The high organic matter in soils dissolves the pesticides and retards their transportation into the soil. The pH and the temperature of the soils are also important factors for the leachability of pesticides (Hutson and Roberts, 1990, Beltran, et al., 1993 and Sherma, 1995). However, the mass flow of water through the soil profile is also an important factor of pesticides leaching to groundwater. It has also been reported that some of the bacteria degrade the pesticides into different degradation products (Chen and Mulchandani, 1998). The variety and concentration of the bacteria in soils are also the determining factor for the transportation behaviour of the pesticides. The various pesticides have different types of structures with different physico-chemical properties and, therefore, show different transportation behaviour.

3.0 EXPERIMENTAL

All the chemicals and reagents used were of pesticide grade. The lindane was procured from Merck, Germany while other reagents and solvents were obtained from E. Merck, India.

The qualitative and quantitative analysis of the lindane was carried out by Gas Chromatograph (model Nucon, 5700, India). The extraction of pesticides from water samples was done in 500 mL capacity separating funnels. The extracted n-hexane was concentrated with the help of Kuderna-Danish assembly and rotary evaporation apparatus. The other glasswares and equipments used were measuring cylinders, graduated pipettes, beakers, Hamilton syringes, boiling chips, water bath, balance etc.

The samples of loamy and sandy soils were collected from agricultural fields with the help of soil sampler upto a depth of 25 cm and packed in different columns. The solutions of different concentrations of lindane were prepared in double distilled water (1.0 to 10.0 mg/L).

The physical characteristics of the soil samples were determined as per the standard methods (USEPA, 1974; Clesceri and coworkers, 1981; Hendershot and Lalonde, 1993; Bows, 1986) The various physical parameters determined include pH, density, porosity, content of gravel, sand, clay and silt while the chemical parameters determined include sodium, potassium, calcium, magnesium, nitrate, sulphate, chloride, alkalinity, hardness and total organic carbon.

For the measurement of pH, the soils samples (5 g of each soil) were shacked with

25 mL distilled water (pH 6.1) for 60 minutes on mechanical shaker and these samples were filtered by Whatman 24 filter papers. The pH of these filtrate were determined by standard methods. The density and porosity were determined with help of Multi volume Pycnometer (model 1305, USA) and Geo. Pycnometer (model 1360, USA) respectively. The percentage of gravel, sand, clay and silt were determined by sieve analysis and with the help of Master Sizer E-System (model MAE 5000, UK).

50 g samples of each soils were mixed with 250 mL of distilled water separately and shacked for 60 minutes on mechanical shaker and these samples were filtred by Whatman 24 filter papers. The residues of soil samples were further shacked with 250 mL distilled water separately in the similar way and filtered. The two filtrates were mixed together to make the total volume of 500 mL of filtrate. The above cited chemical parameters were determined in these filtrates. The standard methods of water analysis were followed for the purpose.

The two types of glass columns were used and they are shown in Fig. 2. The first type of glass columns, comparable to unsaturated zone, were simple of the size of 20 cm x 2cm while the second type of glass columns (20 cm x 2 cm), comparable to saturated zone, were with outlets at 5.0 cm distances each. These columns were packed with the above mentioned soils separately. For packing the column, the supporting media i.e. glass wool was packed by hydraulic filling. The slurry of the weighed soil samples was prepared in deionized water and then it was used to pack the column. The column was kept undisturbed for over night for its full settlement and saturation. The flow of the effluent of the column was controlled by the stopper point at the lower end of the column. The solution of lindane (5.0 mL) of different concentrations were loaded on to the each columns and the fractions of 25 mL were collected from each columns. The effect of

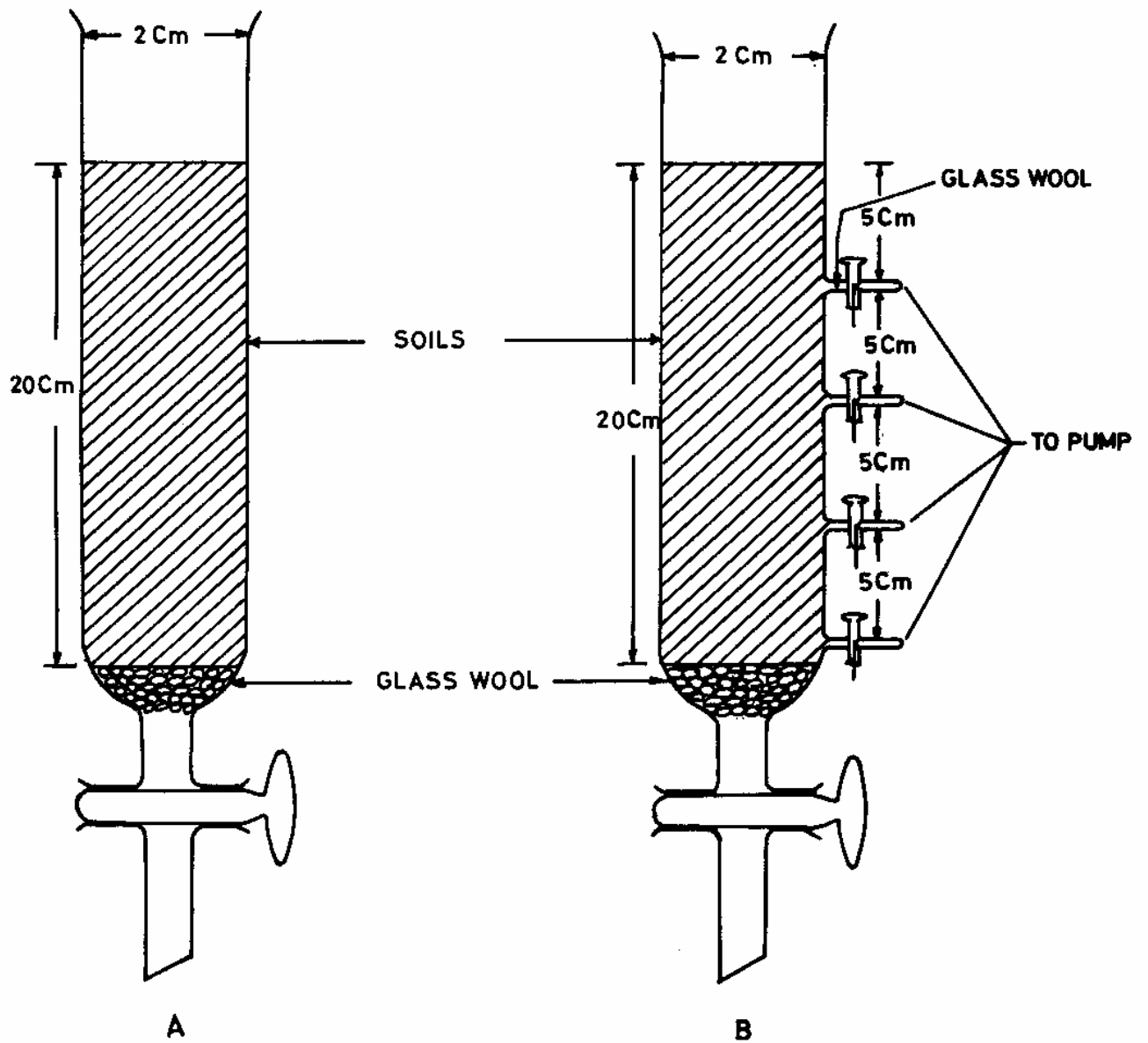


FIG. 2: THE VERTICLE VIEW OF THE SOIL COLUMN:
 A: UNSATURATED AND B: SATURATED CONDITIONS

lindane concentrations, pH of the mobile phase, soil column length and flow rate of mobile phase was studied. The concentration of lindane was varied from 1.0 to 10.0 mg/L. The flow rate was varied from 1.0 to 5.00 mL/min. Furthermore, the column study was also carried out using the mobile phase of different pH ranging from 2.0 to 8.0. The fractions collected from each column were of 25.0 mL volume. To find out the diffusion and distribution of lindane in saturated zone of the soils, the second types of glass columns were also packed with these soil samples in the same way. The effluent flow rate of these columns was set to zero. The lindane (25.0 mL of 5.0 mg/L) was loaded on these columns. Water samples were collected from each outlet with the help of vacuum pump and the lindane was analyzed by Gas Chromatography. To find out the effect of diffusion time of lindane in these columns, water samples were collected from each outlets at different times of intervals.

The extraction of pesticides from water (column fractions) was carried out by n-hexane. 25 mL of water fraction was shaken with 5.0 mL of n-hexane in separating funnel for 30 minutes. n-Hexane layer was allowed to separate from water for about 10 minutes. The n-hexane layer was separated and the same procedure was repeated for three times. The three fractions of extracted n-hexane were mixed together and a total volume of extracted n-hexane (mother liquor) was 15 mL.

The combined n-hexane (15 mL) extract obtained from water fractions was concentrated to 1.0 mL. The 15 mL extracted n-hexane was reduced to 1.0 mL by Kuderna-Danish assembly and rotary evaporation apparatus. The extraction was carried out by using water bath at 40°C temperature. The moisture in concentrated n-hexane (5.0 mL) was removed by adding

anhydrous sodium sulphate (0.1 g) in each extracted n-hexane (1.0 mL) fractions and keeping them over night. All the extracted n-hexane fractions were already clean and clear and, therefore, no further clean up was carried out.

To find out the transportation behaviour of lindane in loamy and sandy soils, the adsorption and desorption experiments were carried out. The adsorption experiments were carried out by batch technique using a series of Erlenmeyer flask of 50 mL capacity covered with teflon sheets to prevent the introduction of any foreign particle contamination. The effect of pH, concentration, dose, temperature and shaking time was studied. Isotherms were run by taking different concentrations of lindane at desired temperature and pH. These concentrations were decided after a good deal of preliminary investigations. After the required experimentation was over, the solutions were centrifuged and the concentrations of lindane were determined in supernatant using gas chromatography.

The standard solutions (5 $\mu\text{g/L}$) of lindane was prepared in n-hexane. The instrument was calibrated with this standard solution. The chromatogram of the standard lindane was recorded. The values of the retention time obtained was used for the identification of lindane in the extracted column fractions. The surface areas of the peak obtained by the standard lindane was used to determine the concentration of this pesticides in each column fractions.

The qualitative and quantitative analysis of the lindane in each column fractions was carried out by gas chromatography (model Nucon, 5700, India). The electron capture detector (ECD) was used to detect the lindane. The column used was made of glass, Ch. W.H.P., OV-17

(3%), mesh size 80-100 (120 cm x 3 mm). The temperatures of the column, injector and detector were 240, 250 and 275°C respectively. The flow of carrier gas (nitrogen) was kept constant at 60 mL/minute. The extracted fractions (containing lindane) of n-hexane was analyzed by gas chromatography under the chromatographic conditions mentioned above. The 2.0 µL of extracted hexane was injected with the help of Hamilton syringe. The chromatogram of the standard lindane was also recorded under the identical gas chromatographic conditions. The confirmation of the lindane was also carried out by the internal standard addition method.

The method of the calculation of the concentrations of the pesticides was already described (Ali and Jain, 1999). However, the concentration of each pesticide is determined by the comparison of peak area or height of the samples with those of standards. This can be done by using the following equation.

$$S_{\text{sam}} = \frac{H_{\text{sam}}}{H_{\text{std}}} \times \frac{V_{\text{inj std}}}{V_{\text{inj sam}}} \times X_{\text{std}} \times \frac{V_{\text{ext}}}{V_{\text{sam}}}$$

where,

X_{sam} = concentration of pesticide in original water sample (mg/L)

H_{sam} = peak height (or area) of sample

H_{std} = peak height (or area) of standard

$V_{\text{inj std}}$ = volume of standard injected (L)

$V_{\text{inj sam}}$ = volume of sample injected (L)

X_{std} = concentration of pesticide in standard solution (mg/L)

V_{ext} = final volume of sample extract (mL) and

V_{sam} = volume of original water sample extracted (mL).

4.0 RESULTS AND DISCUSSION

The selected soil samples i.e. sandy and loamy were analyzed for physico-chemical parameters. The physical parameters determined were pH, density, porosity, percentage of gravel, sand, clay and silt. The chemical parameters analyzed were alkalinity, sodium, potassium, calcium, magnesium, nitrate, sulphate, phosphate, chloride and total organic carbon. The values of physical and chemical parameters are given in Table 4 and 5 respectively. It is clear from these tables that these aqueous soils are alkaline in nature. The density of sandy and loamy soils was found to be 2.63 and 2.59 g/cm³ respectively while the porosity of sandy and loamy was 46.294 and 30.722 fractions respectively. The percentage of gravel, sand, clay and silt for sandy soil was 0.10, 83.43, 1.40 and 15.07 respectively while for loamy soil was 0.10, 37.87, 5.22 and 56.81 respectively. The sandy soil contain high amount of alkalinity, chloride, magnesium and phosphate while loamy soil contains high amount of calcium, sodium, potassium, sulphate, nitrate and total organic carbon only. The concentrations of alkalinity, sodium, potassium, calcium, magnesium, nitrate, sulphate, potassium, chloride and total organic carbon were 82.00, 23.50, 5.16, 5.61, 3.89, 0.80, 1.00, 0.80, 32.00 and 1.44 mg/kg in sandy soil while the concentrations of these parameters in loamy soil were 58.00, 29.13, 8.23, 16.04, 2.92, 1.60, 4.50, 0.50, 28.00 and 3.10 mg/kg respectively.

There are many factors responsible for controlling the leachability behaviour of lindane. They have already discussed in the 'factors effecting the leachability of pesticides' section of this report. Among the various factors the adsorption/desorption capacity of the soil and the amount of organic matter are very important. The transportation behaviour of lindane was studied in sandy and loamy soils. The effect of adsorption, concentrations of lindane, pH of mobile phase,

Table 4. Physical properties of soil samples (in mg/kg)

S.No.	Parameters	Sandy soil	Loamy Soil
1.	pH	7.3	7.1
2.	Density (g/cm ³)	2.63	2.59
3.	Porosity (%)	46.3	30.7
4.	Gravel (%)	0.1	0.1
5.	Sand (%)	83.4	37.9
6.	Clay (%)	1.4	5.2
7.	Silt (%)	15.1	56.8

Table 5. Chemical properties of soil samples in mg/kg

S. No.	Parameter	Sandy soil	Loamy soil
1.	Alkalinity	82.0	58.0
2.	Sodium	23.5	29.1
3.	Potassium	5.2	8.2
4.	Calcium	5.6	16.0
5.	Magnesium	3.9	2.9
6.	Nitrate	0.8	1.6
7.	Sulphate	1.0	4.5
8.	Phosphate	0.8	0.5
9.	Chloride	32.0	28.0
10.	TOC	1.4	3.1

flow rate of mobile phase and soil column lengths on lindane transportation in sandy and loamy soils was carried out under unsaturated conditions. Besides, the distribution of lindane in sandy and loamy soils was also studied under the saturated soil conditions.

4.1 Adsorption

To optimise the experimental conditions for column experiments, the adsorption behaviour of lindane was carried out on sandy and loamy soils. The adsorption experiments of lindane were carried out under the varied conditions of pH, concentrations of lindane, contact time and dose. After extensive experimentation, it was found that the maximum uptake of lindane took place by sandy soil at pH 6.0 with 30 minutes of contact time at 30°C. The adsorption capacity of lindane on sandy soil was found to be 0.306 µg/g. In case of loamy soil, the maximum adsorption capacity was observed at pH 7.0 with 30 minutes of contact time at 30°C. The uptake capacity of this soil was found to be 0.457 µg/g. The desorption experiment of lindane from these soils were tried with distilled water of different pHs but no desorption was observed. These findings were used to design the column experiments.

4.2 Transportation Behaviour of Lindane under Unsaturated Conditions

The glass columns of the size of 20 cm x 2 cm were packed with sandy and loamy soil separately. The transportation behaviour of the lindane was studied using these columns. The fractions of 25 mL each were collected and extracted with hexane. The lindane was determined by Gas Chromatography in the hexane fractions. The effect of lindane concentrations, pH of mobile

phase, soil column lengths and flow rate was studied on the transportation behaviour of lindane in sandy and soil columns separately.

4.2.1 Effect of Concentrations

The pH of the aqueous solution of sandy soil was found to be 7.30 (Table 4) and, therefore, all the column experiments with different concentrations were carried out at pH 7.0. 5.0 mL solutions of different concentrations of lindane i. e. 1.0 to 10.0 mg/L (5 to 50 μg) were loaded on different soil columns and the fractions of 25 mL were collected. The results obtained for concentration effect are given in Fig. 3. It is clear from Fig. 3 that the lindane of the concentrations of 5, 10, 15, 20 and 25 μg is retarded by the soil. On the other hand, the lindane was detected in column fractions when 30, 35, 40, 45 and 50 μg concentrations were used. It is also clear from this Fig. that first the concentration of lindane increase in column fractions and then decrease in all five different concentrations. The lindane was detected upto 10 column fractions (250 mL) in 30 to 40 μg concentrations while it has been detected in 11th column fraction in case of 45.0 and 50 μg concentrations. This is simply due to the high concentrations of lindane. The same set of experiment was carried out on loamy soil column again at pH 7.0 (pH of loamy soil is 7.10, Table 4) and the results are given in Fig. 4. It is clear from this figure that 5.0 to 35 μg concentrations of lindane are retarded by the column while the lindane was detected in column fractions when 40 to 50 μg concentrations were used. Further, it is clear from Fig. 4 that first the concentrations of lindane increase in column fractions and then start to decrease. The lindane was detected upto 13th column fractions (325 mL) when 40.0 to 45.0 μg concentrations were used while in case of 50.0 μg concentration the lindane has been detected in 14th fraction too. The amounts transported in different

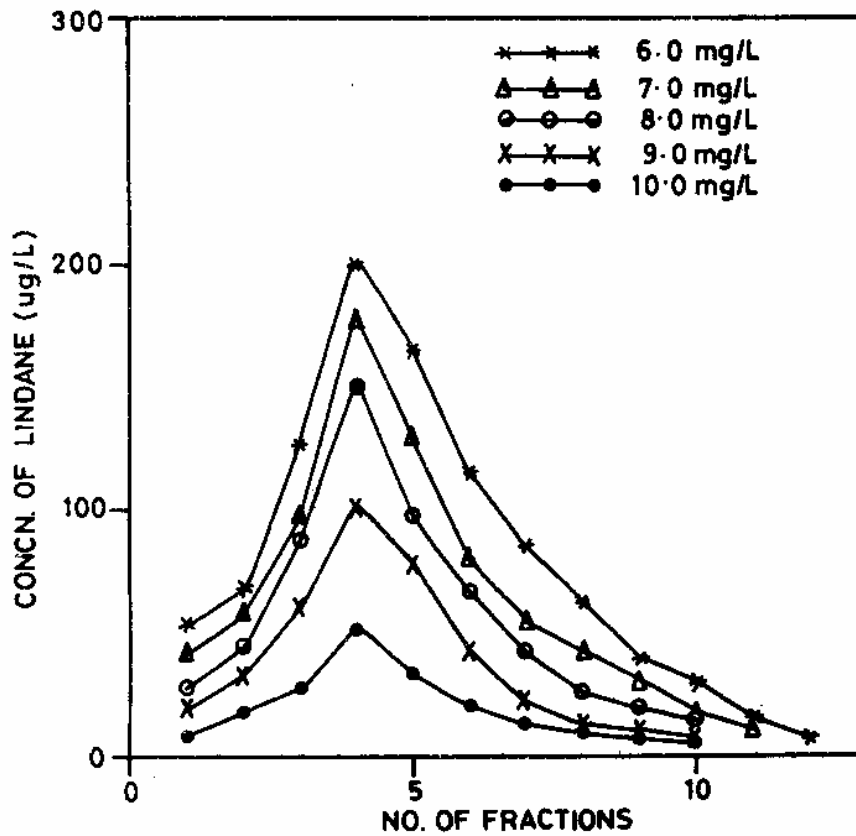


FIG. 3: EFFECT OF DIFFERENT CONCENTRATIONS OF LINDANE ON ITS TRANSPORTATION BEHAVIOUR IN SANDY SOIL UNDER UNSATURATED CONDITION.

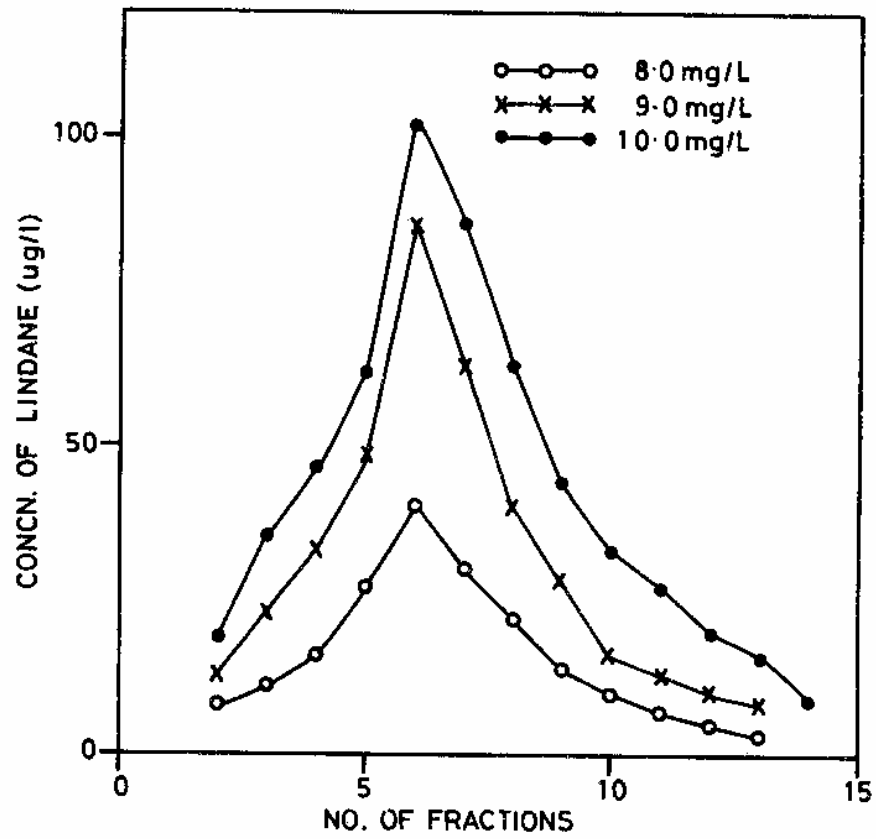


FIG. 4 EFFECT OF DIFFERENT CONCENTRATION OF LINDANE ON ITS TRANSPORTATION BEHAVIOUR IN LOAMY SOIL UNDER UNSATURATED CONDITION

concentrations are given in Table 6. It is clear from Table 6 that maximum transportation of lindane occurred when 50 µg of lindane was loaded.

4.2.2 Effect of pH

The glass columns (20 cm x 2 cm) were packed by sandy and loamy soils separately and the effect of pH was studied by using 5.0 mL solution of lindane of the concentration of 8.0 mg/L (40 µg). The value of pH was varied from 2.0 to 8.0 for both the soils. The results obtained of the pH effect are given in Fig. 5 and 6 for sandy and loamy soils respectively. It is clear from Fig. 5 that the maximum leachability of lindane occurred at pH 2.0 and it decreases upto pH 7.0 and then start to increase. Further, it is clear that the lindane is retarded maximum by the sandy soil column (25.5 µg) at pH 7.0. Therefore, it may be concluded that the transport of lindane at pH 7.0 (natural pH of sandy soil) is very poor. The same trend of pH effect was also obtained in case of loamy soil (Fig. 6). The maximum transportation of lindane was observed at pH 2.0 and it starts to decrease upto pH 7.0 and then further increases. Therefore, the maximum and minimum transportation of lindane in loamy soil occurred at pH 2.0 and 7.0 respectively. The amounts of lindane transported by using the mobile phases of different pHs are given in Table 6.

4.2.3 Effect of Column Length

To find out the effect of soil column lengths on the transportation behaviour of lindane, a study was carried out with different soil column lengths. The different soil column lengths used were 5, 10, 15, 20 and 25 cm for both sandy and loamy soils. The pH of the mobile phase was 7.0 and the loaded amount of lindane was 5.0 mL of 8.0 mg/L concentration (40 µg). The results

Table 6. Transportation amount (μg) of lindane under different experimental conditions

S. No.	Parameters	Sandy soil	Loamy soil
Concentration loaded* in μg			
1.	20	4.4	---
2.	35	9.8	---
3.	40	14.5	4.8
4.	45	18.7	9.2
5.	50	24.2	14.1
pH**			
1.	2	34.8	32.2
2.	3	31.4	24.5
3.	4	26.1	15.2
4.	5	16.5	13.0
5.	6	15.7	9.2
6.	7	14.5	4.8
7.	8	15.7	3.2
Soil column length (cm)***			
1.	5	1.4	31.5
2.	10	26.1	23.0
3.	15	21.2	14.0
4.	20	14.7	4.9
5.	25	12.4	1.8

* Soil column length: 20 cm x 2 cm and pH of mobile phase: 7.0

** Soil column length: 20 cm x 2 cm and concentration of lindane loaded: 40 μg

*** The pH of mobile phase and the amount of lindane loaded: 7.0 and 40 μg respectively.

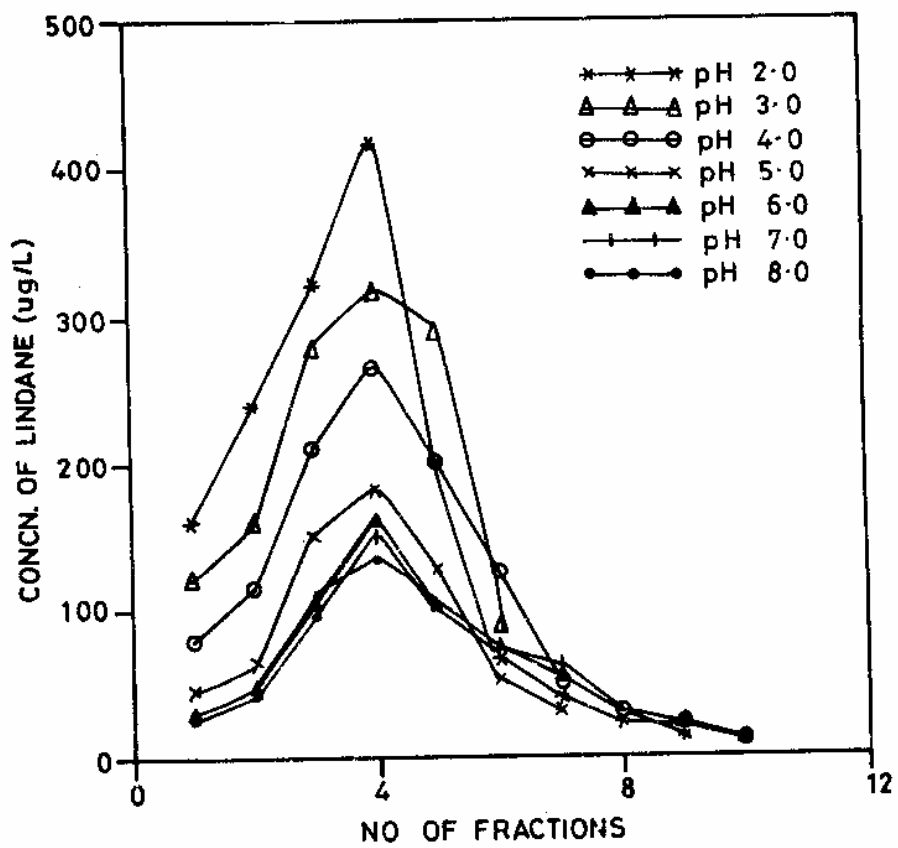


FIG. 5: EFFECT OF pH ON THE TRANSPORTATION BEHAVIOUR OF LINDANE IN SANDY SOIL.

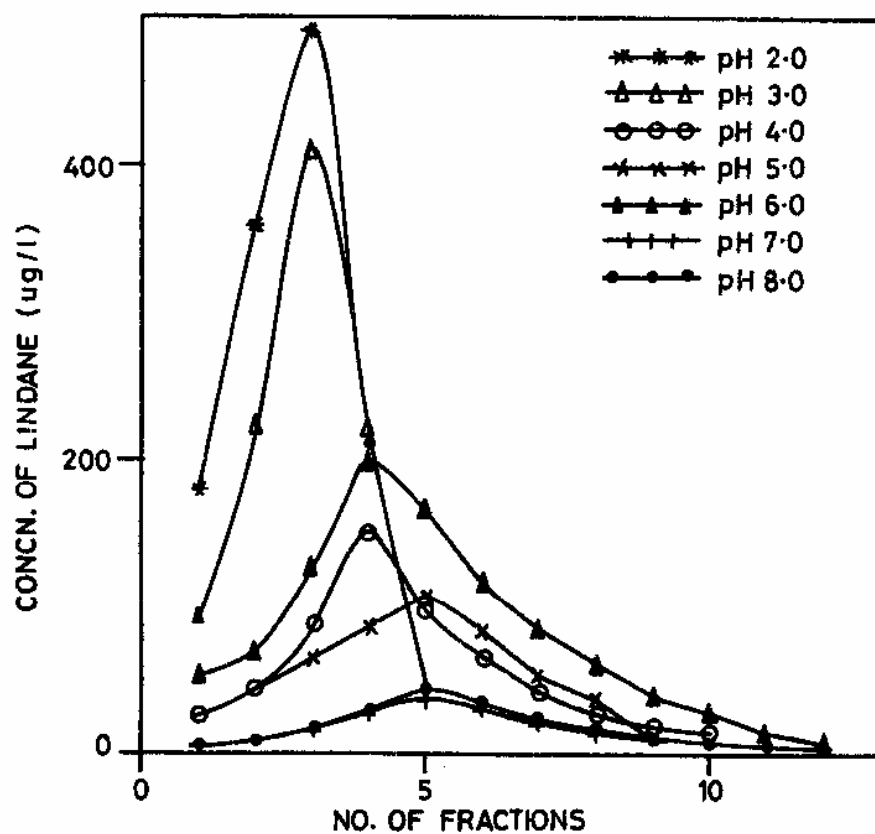


FIG. 6: EFFECT OF pH ON THE TRANSPORTATION BEHAVIOUR OF LINDANE IN LOAMY SOIL

obtained for this are shown in Fig. 7 and 8 for sandy and loamy soils respectively. It is clear from Fig. 7 that the transportation of lindane was 31.4, 26.1, 21.2, 14.7 and 12.4 μg in 5.0, 10.0, 15.0, 20.0 and 25.0 cm sandy soil column lengths respectively. It indicates that the maximum transportation (31.4 μg) of lindane occurred at 5.0 cm while the minimum transportation (12.4 μg) was observed at 25 cm length. The Fig. 8 clearly indicates that the transportation of lindane in 5.0, 10.0, 15.0, 20.0 and 25.0 cm loamy soil columns was 31.5, 23.0, 14.0, 5.1 and 1.8 μg respectively. Further, it is clear that the minimum and maximum transportation of lindane in loamy soil was 31.5 and 1.8 μg respectively. The detail of the transportation of lindane at different sandy and loamy soil depths is given in Table 6.

4.2.4 Effect of Flow Rate

The flow of the mobile phases under the natural conditions was 5.0 mL/min. and 2.5 mL/h in sandy and loamy soils column (20 x 2 cm) respectively. The flow rate of the mobile phase was varied from 1.0 to 5.0 mL/minutes in sandy soil column but there was no marked effect on the transportation behaviour of lindane in these flow rates. It may be due to the fact that 25.0 mL column fraction required 25 minutes (with a maximum 5.0 mL/min. flow rate) and the sandy soil takes 30 minutes for the maximum adsorption of lindane at room temperature (30°C). Therefore, it may be concluded that no effect of flow rate on the transportation behaviour of lindane on sandy soil was observed due to 30.0 minutes as the adsorption time, which is comparable to the time required for one fraction collection. In case of loamy soil, the flow rate of the mobile phase was very poor (2.5 mL/h.) and, therefore, the effect of flow rate on the lindane transportation was not carried out.

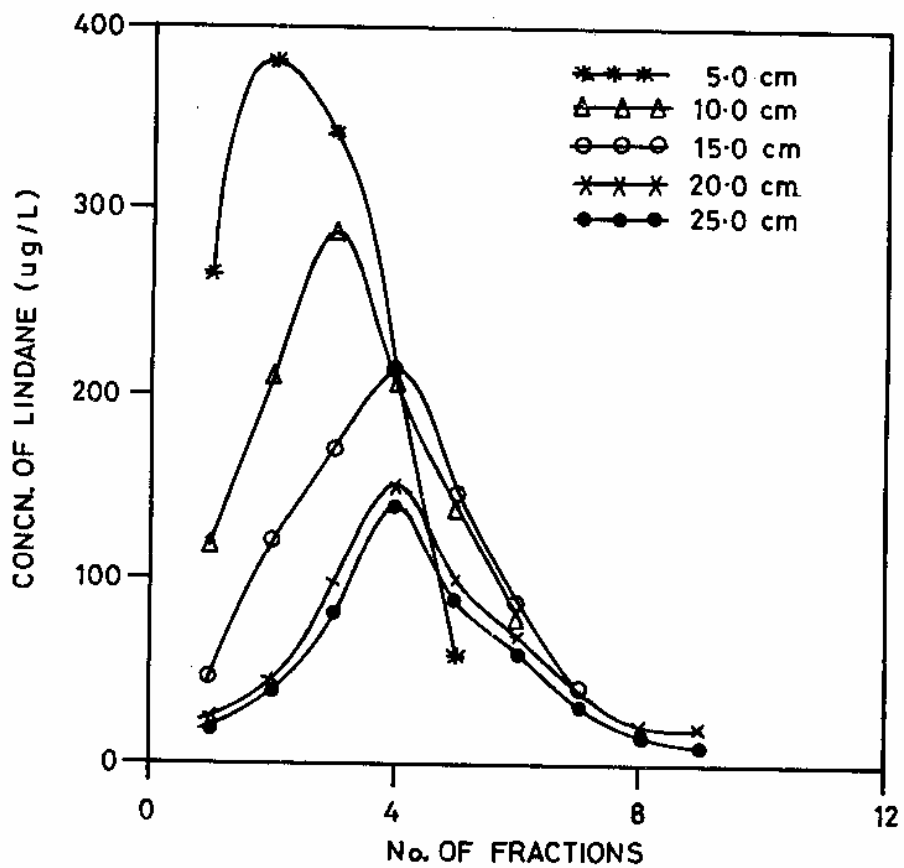


FIG.7: EFFECT OF COLUMN LENGTH ON THE TRANSPORTATION BEHAVIOUR OF LINDANE IN SANDY SOIL

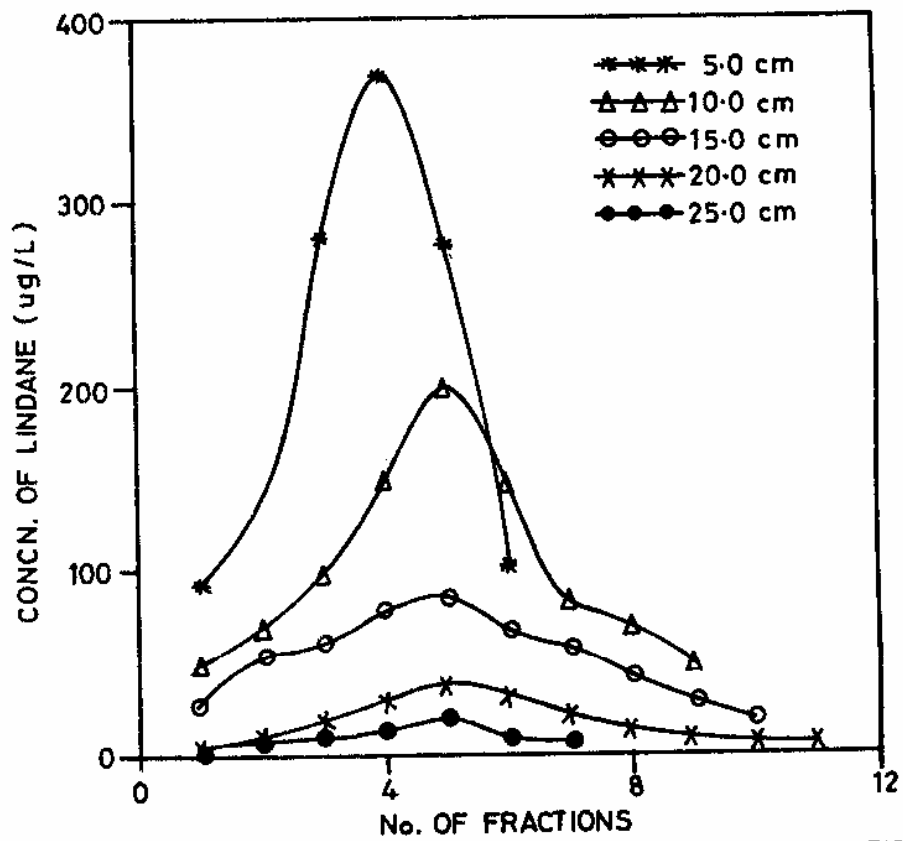


FIG. 8: EFFECT OF COLUMN LENGTH ON THE TRANSPORTATION BEHAVIOUR OF LINDANE IN LOAMY SOIL

4.3 Distribution of Lindane under Saturated Conditions

To study the distribution of lindane under saturated zone conditions, the glass columns (20 x 2 cm) with four outlets at 5.0, 10.0, 15.0 and 20.0 cm distances were fabricated. These outlets were connected to the vacuum pump for water sample collection at the required time intervals. The column arrangement is shown in Fig. 2. All the experiments in sandy and loamy soils were carried out at pH 7.0. The lindane loaded on each column was 25.0 mL of 5.0 mg/L concentration (125.0 µg). The time intervals for the collection of water samples from the different outlets of the columns were decided after an extensive experimentation. In sandy soil, water samples were taken from 5.0, 10.0, 15.0 and 20.0 cm distances after 24 hrs. The results are given in Fig. 9 and it is clear from this figure that first of all the lindane was detected after 24, 48, 120 and 168 hrs. at 5.0, 10.0, 15.0 and 20.0 cm distances respectively. It is also clear that the uniform distribution of lindane (3.10 mg/L) was observed after 240 hrs. In the similar way, water samples were taken from 5.0, 10.0, 15.0 and 20 cm distances from the loamy soil column. The samples were collected after 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 weeks. The results of this set are given in Fig. 10 and it is clear from this figure that first of all the lindane was detected after 1, 2, 4 and 5 weeks at 5.0, 10.0, 15.0 and 20.0 cm distances respectively. The uniform distribution (3.11 mg/L) of lindane was observed after 12 weeks. Therefore, it is clear that lindane takes 240 hrs. and 12 weeks for its uniform distribution in sandy and loamy soil columns (20 cm x 2 cm) respectively under the reported experimental conditions.

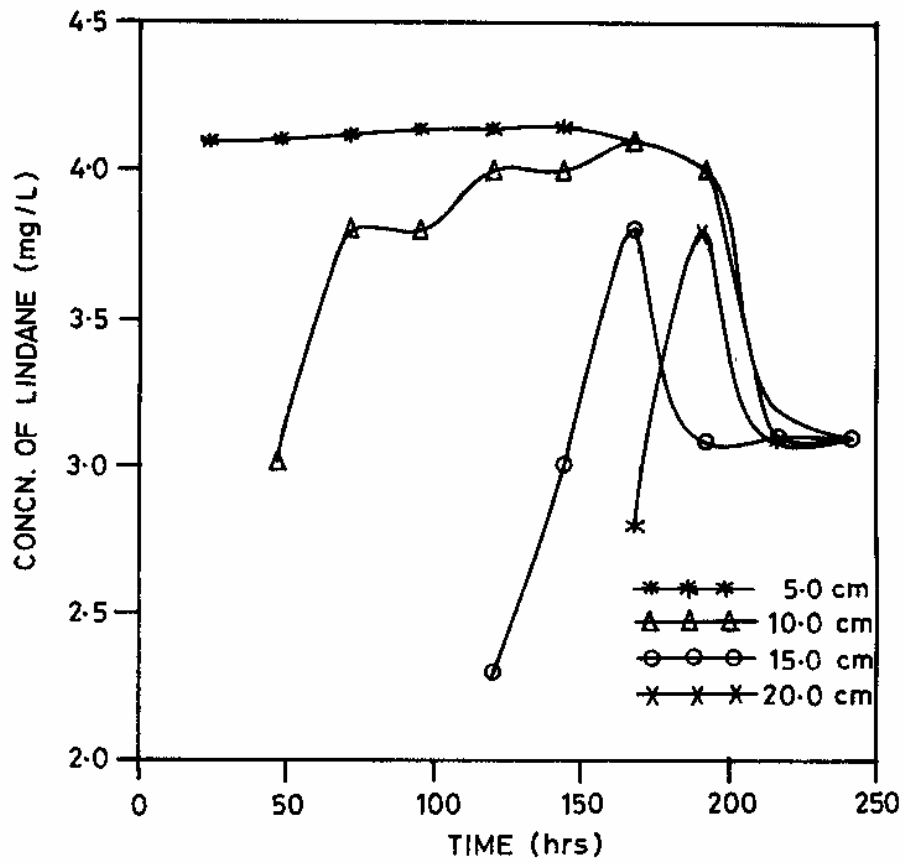


FIG.9: DISTRIBUTION OF LINDANE AT DIFFERENT DEPTHS OF SANDY SOIL COLUMN IN SATURATED CONDITIONS

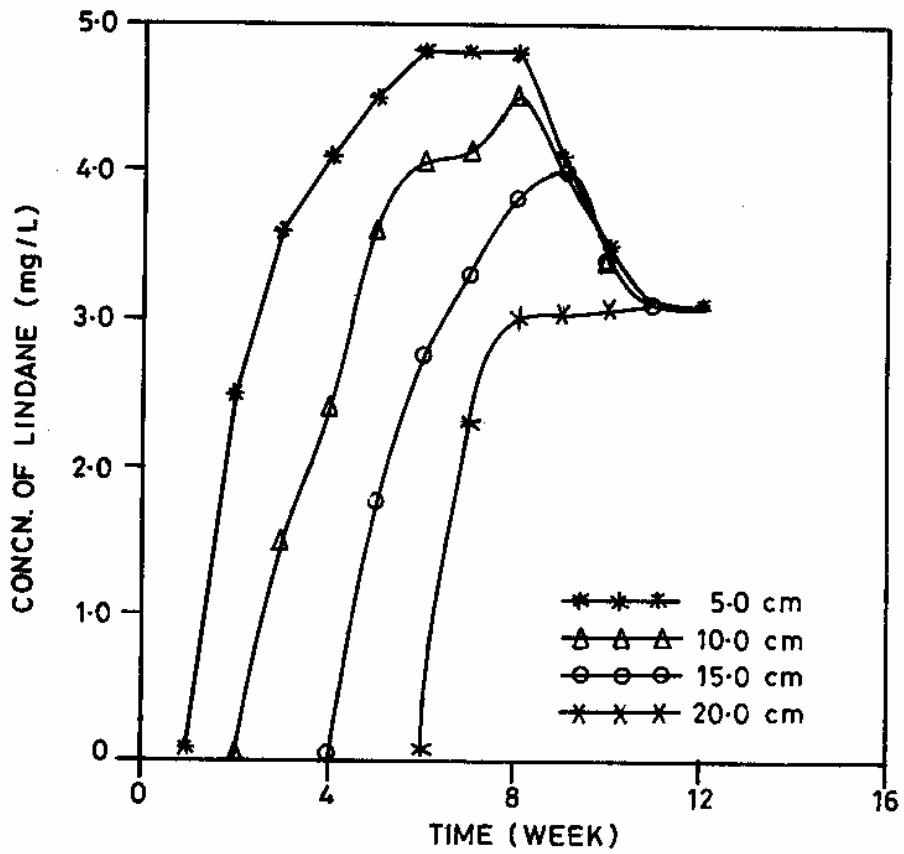


FIG.10: DISTRIBUTION OF LINDANE AT DIFFERENT DEPTHS OF LOAMY SOILS COLUMN IN SATURATED CONDITIONS

5.0 CONCLUSION

The transportation behaviour of lindane was carried out in sandy and loamy soils. The effect of concentrations of lindane, pH, column length and flow rate was studied. It is clear from the above discussion that the pH of the sandy and loamy soils are 7.30 and 7.10 in natural conditions. Therefore, it is very important to know the transportation behaviour of lindane in sandy and loamy soils at pH 7.0. The optimum concentration of the lindane loaded was 40 μg at 20 cm x 2 cm soil column. The amounts of lindane transported at different pH are given in Table 6. It is clear from this Table that the minimum amount of the lindane is transported at pH 7.0 in both the soils. A comparison of the transported amount of lindane in sandy and loamy soils indicates that the transportation of lindane is smaller in loamy soil than the sandy soil. This behaviour has been observed at different concentrations of lindane, pH and column lengths. This may be due to the higher adsorption capacity of loamy soil than the sandy soil. The higher amount of total organic carbon present in loamy soil is also responsible for the poor transportation of lindane because of the high capacity to hold lindane. It is very important to observe that 5 μg to 25 μg concentrations of lindane is retarded by the sandy soil while 5 μg to 35 μg is retarded by loamy soil at pH 7.0. It has also been observed that the transportation of lindane decreases by increasing the column length. Therefore, it may be concluded that the transportation of lindane in sandy and loamy soils is very poor under the natural conditions. The poor transportation of lindane may be due to the high partition coefficient of lindane between the soil organic matter and water. Therefore, the detection frequency of lindane in groundwater is rare. This fact has been supported by the study carried out by David et al. (1997). Further, it has been observed that the transportation of lindane is maximum under acidic conditions. Therefore, the use of lindane in acidic soils should be restricted.

The distribution of lindane was also studied under saturated zone conditions. It has been observed that the uniform distribution of lindane was occurred in 240 hrs in sandy soil while in case of loamy soil it has been observed after 12 weeks. It may be due to the fact that the inter particle space is greater in sandy soil than the loamy soil. Moreover, the high adsorption capacity of loamy soil is also responsible for this process. Therefore, it may be concluded that the contamination of groundwater from surface is faster in sandy soil in comparison to loamy soil.

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