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PREDICTION OF PESTICIDES POTENTIAL FOR SOIL AND GROUNDWATER CONTAMINATION AND CALCULATION OF CHEMICAL MOVEMENT DEPTH IN SOIL

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ABSTRACT: Purification of contaminated soil or ground water is difficult, expensive and may not always be successful. The best policy is to prevent contamination. To evaluate pesticides potential for soil and groundwater contamination hazards, the computer model CMS was used to calculate movement depth and relative mass of 29 pesticides under Minufiya Governorate climate. Representative meteorological data were obtained for Shibin El-Kom area during the rainy period from the beginning of October to the end of April, in which daily potential evapotranspiration was calculated. Three soils in Minufiya area (a sandy, a sandy loam and an alluvial silty clay soil) were used under three irrigation regimes. Pesticides were classified according to their adsorption coefficient or half-life time into six groups each. Their effect on movement depth and relative mass was studied. To replace the hard to apply computer models with simple regression equations, easy to apply by farmers or pesticide users, calculated movement depth or relative mass were correlated to some easy to get parameters (time after pesticide application, total irrigation depth, partition coefficient, half-life time, soil bulk density and soil content of organic carbon...). Regression equations were derived for each pesticide or group of pesticides having specific ranges of adsorption coefficients. Two simple criteria were suggested to evaluate the potential hazardness of groundwater and soil contamination by a pesticide. They are, at the end of a growing season, whether the pesticide reaches the bottom of the root zone at any concentration or whether the pesticide persists in the soil profile at a relative mass higher than 0.4 from the applied concentration at the soil surface. These two criteria can be changed to accommodate any level of hazardness standard. Results indicated that increasing irrigation rate increased the movement depth of pesticides by the same factor of increase. Decreasing the irrigation interval with keeping the total amount of irrigation water constant during a growing season, had no significant effect on movement depth. Increasing adsorption (partition) coefficient significantly decreased the movement depth but had insignificant effect on the relative mass of pesticides. Increasing half-life time markedly increased the relative mass of pesticides but was independent of movement depth. The magnitude of the movement depth in the sandy loam soil and the sandy soil were 2-3 times and 5-6 times that of the alluvial soil at the same relative mass values, respectively. The same procedure can be used with more complex models, for other areas of different climates, and a large number of soils can also be included.

Key Words: Partition coefficient, half-life time, meteorological data, regression equations, irrigation regimes.

INTRODUCTION

Irrigation practices affect many pesticides potential to leach through the soil profile. The best policy is to prevent hazardous substances from getting into ground water because purification of contaminated ground water is difficult, expensive and depend on the contaminant. Understanding the processes that influence pesticide movement and degradation can enhance the efficacy and safety of pesticides. Unfortunately, there are no easy answers to determine the potential for groundwater contamination by pesticides. In many instances, the data is just not available (Buttler et al., 1998). The pesticides are grouped according to small, medium or large leaching potential taking into consideration the half-life, solubility and Koc values. Other variables include soil and site conditions which affect pesticide mobility in runoff or infiltrating water (Jenkins and Lyons, 1988). All these factors must be considered when developing a pest management strategy that is designed to protect our ground and surface water resources (Hornsby, 1988; Jenkins and Smith, 1988).

The toxicity of pesticides makes them effective in controlling pests, but this toxicity means that pesticides must be properly applied and managed (alternative ecologically sound strategies must be developed and used), so that their potential to affect health and to contaminate the ground water is minimized. To reduce the risk of contaminating the ground water, it is essential to understand the factors that affect the behavior of pesticides in the natural environment (Edwards, 1965; Whiteside, 1977).

Applied pesticides may be taken up by plants, evaporated into the atmosphere, carried off as drift (Guenzi and Beard, 1974), or ingested by insects, worms and microorganisms (Edwards and Thompson, 1973). The pesticide may adhere to soil particles or be dissolved in irrigation or rain water (Audus, 1970; Spencer et al., 1982; Brown, 1988).

Primary factors that affect the behavior of pesticides in the environment are properties of the pesticide, properties of the soil, site conditions including rainfall and depth to ground water, and management practices including method and rate of application, and irrigation practices (Hill, 1978; Jenkins and Smith, 1988; Mulla et al., 1989). Several pesticides (alachlor, aldicarb, atrazine, carbofuran, cyanazine, metribuzin, picloram, and simazine) have ground-water advisory statements on their labels because of their tendency to leach, or because they have been found in ground water (Hill, 1978; Buttler et al., 1998).

Breakdown processes (by soil microorganisms, chemical reactions, and sunlight) occur mainly in the root zone. Breakdown is considerably slower in deeper soils and sediments. Some pesticides form intermediate substances during the breakdown process which can be more toxic than the original compound (Hill et al., 1975; Whiteside, 1977).

Persistence and adsorption are the two most important characteristics of a pesticide, affecting its potential to leach to ground water. Pesticides that

are strongly adsorbed will be less mobile in soil that is leached and will be less likely to reach ground water. Another property that affects the behavior of a pesticide in the soil is solubility. The higher the water solubility value, the more likely to leach. Volatility describes how quickly a liquid will evaporate when it is in contact with air. Highly volatile chemicals are easily lost to the atmosphere. Some pesticides, such as fumigants, must be volatile in order to move and provide uniform distribution through the soil profile (Spencer et al., 1973 and 1982; Jury et al.,. 1987).

Permeability, soil texture and soil structure are soil properties that affect chemical movements. Organic matter is the single most important factor affecting adsorption of pesticides in soils. Many pesticides are bound with soil organic matter, which reduces their rate of downward movement. Soils high in organic matter tend to hold more water, which may make less water available for leaching. Soil moisture affects how fast water will travel through the soil. If soils are already wet or saturated before rainfall or irrigation, excess moisture will runoff. It is recommended not to use pesticides prior to heavy rain or irrigation. Soil moisture also influences pesticide breakdown. Depth to ground water is a primary factor affecting the potential for pesticides to reach ground water. If the water table is shallow, pesticides have less distance to travel to reach ground water (Rao et al., 1976; Rao and Davidson. 1980).

The objectives of this study are (1) to calculate the movement depth of pesticide chemicals using the computer model CMS under Minufiya climate and soil type. (2) study the effect of irrigation regime, soil type, pesticide properties (adsorption coefficient and half-life time) on the movement depth and relative mass of pesticides and (3) correlate the calculated movement depth or relative mass to some easy to get parameters and derive simple regression equations easy to apply by farmers or pesticide users, to replace the hard to apply computer models.

Theory

Volatile organic compounds, including many pesticides, display quite complex behavior in soil because they may move in the vapor phase as well as within solution. They adsorb to stationary soil solid material and can be degraded by biological and chemical reactions. To describe all this processes, the chemical mass balance equation must be combined with the full solute storage expression and both vapor and dissolved solute fluxes as follows:

$$\frac{\partial C_T}{\partial t} = \frac{\partial}{\partial z}(D_g^s \frac{\partial C_g}{\partial z}) + \frac{\partial}{\partial z}(D_e \frac{\partial C_l}{\partial z}) - \frac{\partial}{\partial z}(J_w C_l) - r_s$$

where C_T is total solute concentration, C_l is dissolved solute concentration, C_g is gaseous solute concentration, D_g^s is the soil gas diffusion coefficient, D_e is the effective diffusion- dispersion coefficient J_w is water flux, r_s is the

reaction rate (rate of uptake by plant). The total concentration C_T may be partitioned into phases as follows (Jury et al., 1991):

$$C_T = \rho_b C_s + \theta C_l + a C_g$$

If $C_s = K_d C_l$ And $C_g = K_H C_l$

Then $C_T = \rho_b K_d C_l + \theta C_l + a K_H C_l$

$$C_T = (\rho_b K_d + \theta + a K_H) C_l = R_l C_l$$

Where $R_l = \rho_b K_d + \theta + a K_H$

Similarly $R_s = \rho_b + \theta / K_d + a K_H / K_d$

$$R_g = \rho_b K_d / K_H + \theta / K_H + a$$

where R_l, R_s, and R_g are liquid phase, adsorption phase, and gas phase partition coefficients, respectively. The mass fraction is expressed for each phase as

$$f_l = \theta C_l / C_T = \theta / R_l$$

$$f_s = \rho_b C_s / C_T = \rho_b / R_s$$

$$f_g = a C_g / C_T = a / R_g$$

where by definition

$$f_l + f_s + f_g = 1$$

The model used for calculation is called CMS (Chemical Movement in Soil) developed by IFAS (Institute of Food and Agricultural Sciences, University of Florida, USA) by Nofziger and Hornsby (1985). The software is based on water and solute transport principles presented by Rao et al. (1976). It also incorporates the work of Hamaker and Thompson (1972) and Karickhoff (1981 and 1984) who have shown that the partition coefficient for an organic chemical in a soil divided by the organic carbon content of that soil is nearly constant for a wide range of soils.

The model estimates the location of a non-polar organic chemical as it moves downward In the soil and determines the relative amount of the applied chemical remaining in soil as a function of time. The model was intended to illustrate chemical transport principles and to serve as an educational and extension tool. To understand how the model deals with the different aspects of calculations. Let d_t be the depth of the solute front at time (t days) after the chemical was applied to the surface and let I_t and ET_t represent the amount of water infiltrating the surface, and the potential evapotranspiration, respectively, then solute depth at (t+1) is given by

$$d_{t+1} = d_t + q_t / (R\theta_{FC}) \qquad \text{if } q_t > 0$$

or (1)

$$d_{t+1} = d_t \qquad \text{if } q_t < 0$$

where q_t is the amount of water passing the depth d_t , θ_{FC} is the soil water content on a volume basis at field capacity, and R is the retardation factor for the chemical in this soil. Assuming a linear and reversible equilibrium adsorption model, the retardation factor R is given by

$$R = 1 + (\rho K_D) / \theta_{FC} \qquad (2)$$

where ρ is the soil bulk density and K_D is the linear sorption coefficient or the partition coefficient of the chemical in this soil, which is given by

$$K_D = K_{OC}\, OC \qquad (3)$$

where K_{OC} is the linear sorption coefficient normalized by the organic carbon content (OC) of the soil (applicable only to non-ionic organic solutes).

The majority of computations in the model is directed to the determination of q_t from known values of I_t and ET_t. Consider a soil with the solute front at depth d_t, due to evapotranspiration, the soil water content in the root zone may be less than θ_{FC} . When an infiltration event occurs, some water is needed to increase the soil water content above the solute front to θ_{FC} . The excess water (if any) contributes to downward movement of the solute front. That is

$$q_t = I_t + swd \qquad (4)$$

where swd is the soil water deficit above the depth of solute front, which is given by

$$swd = [\theta_{FC} - \theta_a]\, d_t \qquad \text{if } d_t < d_{root}$$

or (5)

$$swd = [\theta_{FC} - \theta_a]\, d_{root} \qquad \text{if } d_t > d_{root}$$

where d_{root} is the depth of the root zone and θ_a is the average volumetric soil water content above depth d_t if $d_t < d_{root}$ or above d_{root} if $d_t > d_{root}$. If q_t is greater than zero, the solute depth does not change, instead the inflowing water just increases the water content θ_a as given by

$$\theta_a = \theta_a + I_t / d_t \qquad \text{if } d_t < d_{root}$$

or (6)

$$\theta_a = \theta_a + I_t / d_{root} \qquad \text{if } d_t > d_{root}$$

To deal with evapotranspiration in the model, the average water content, θ_a is calculated for each day. In addition during the time in which the solute front is in the root zone (i.e. $d_t < d_{root}$), a second average water content, θ_b is calculated for the soil between the solute depth and the maximum rooting depth. If $\theta_a = \theta_b$ both water contents decrease together to meet the evapotranspiration demand. In this case

$$\theta_a = \theta_a + ET_t / d_{root}$$

or (7)

$$\theta_b = \theta_b + ET_t / d_{root}$$

If θ_a is greater than θ_b , then θ_a is decreased to meet all of the ET demand until $\theta_a = \theta_b$ at which point the remaining ET is removed uniformly from the entire root zone. The water contents in the root zone are not permitted to decrease below the water content corresponding to the permanent wilting point of the soil.

MATERIALS AND METHODS

To fulfill the requirements for running the computer program CMS for calculation of chemical depth under Minufiya climate and soil conditions, weather data and properties of three soils were obtained. Representative meteorological data (average daily temperatures) were obtained for the Shibin El-Kom area during the period from the beginning of October,1998 to the end of April,1999 from the "Agriculture Technology Use and Transfer project (ATUT)", Agricultural Research Center, Ministry of Agriculture and Soil Reclamation, Egypt. Daily potential evapotranspiration (ET_o) during the growing season period was calculated using the modified Penman equation by Taylor and Ashcroft (1972), and presented in Fig. 1.

Properties of three soils representing soil types available in the Minufiya area (a sandy, a sandy loam and an alluvial silty clay soil) were used (Table 1) under three irrigation regimes. Water requirement for growing a crop during a growing season is considered 3500 m^3 per feddan for most crops and 4200 m^3 for rice or vegetables, evenly distributed on a maximum number of 10 irrigations. Accordingly the average depth per irrigation was considered as 8.3 cm or 10 cm, respectively. The irrigation regimes used during the duration of the present study, 140 days, were 4.17 cm per week or 8.3 and 10.0 cm every two weeks, respectively. Assuming a maximum root zone depth of 60 cm and that the pesticides were applied November 1^{st}, irrigation was applied up to march 20^{th}. The total calculated evapotranspiration depth was 33.62 cm, as compared to 83.4, 83.4, and 100 cm of total irrigation depths, during the same period, for the three irrigation regimes, respectively.

Depth calculations ware executed 29 pesticides with every soil type and irrigation regime (9 runs for every pesticide) for a total number of 261 runs. Pesticides data regarding partition coefficients (mg/g OC) and half-life (days), used by the program were obtained from publications of Rao and Davidson (1980) and Laskowski et al. (1982).

Calculated movement depth or relative mass of each pesticide were statistically correlated with soil properties (Table 1) and pesticide properties (partition coefficient and half life time) in addition to irrigation depth and time after pesticide application (days), using multiple regression analysis. Regression equations were obtained for each pesticide, relating either relative mass or pesticide movement depth to the significantly important properties and the regression coefficient was

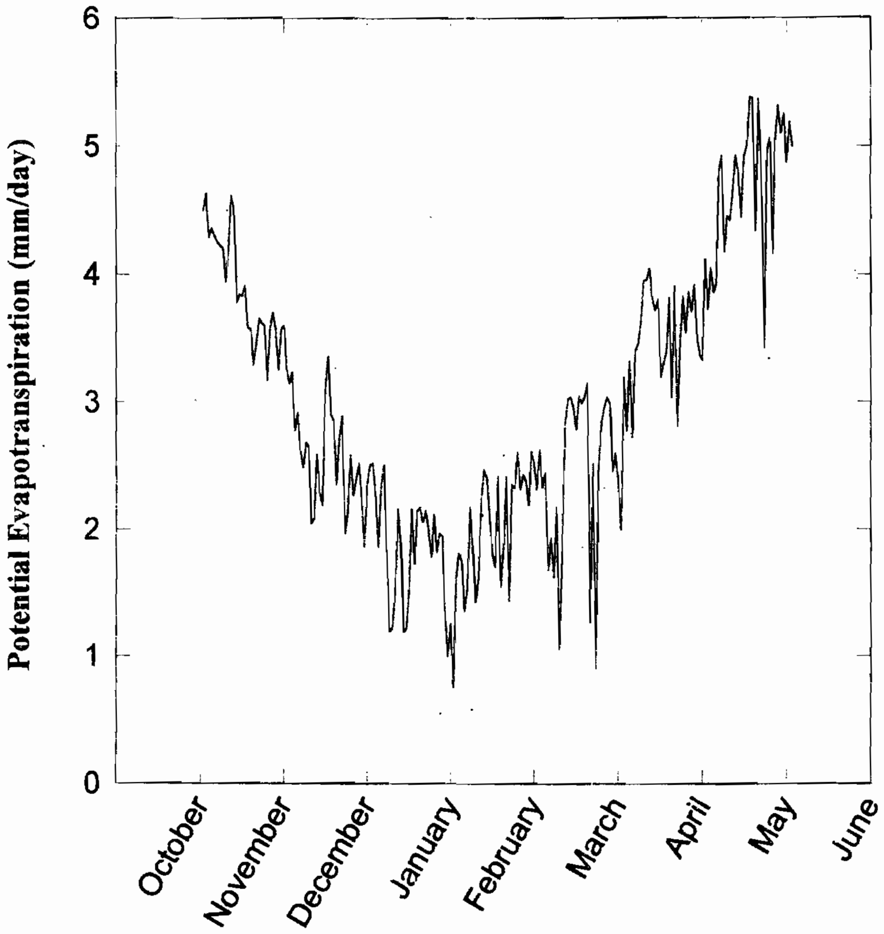

Fig. 1. Average dialy potential evapotranspiration for Minufiya, Egypt.

derived for each equation. Regression analysis was carried out using the statistical computer program Minitab.

Table (1). Some soil properties used for the calculation of chemical movement depth.

Soil	Organic Carbon %	Water content % at –0.1 bar	Water content % at –15 bar	Bulk density g cm^{-3}
Sandy	0.14	10.0	3.8	1.65
Sandy Loam	0.31	30.3	14.8	1.55
Alluvial (Silty Clay Loam)	1.1	58.0	20.7	1.42

Pesticide movement depths and the corresponding relative mass of the applied pesticides, at the soil surface, were obtained from the computer program calculations for 29 pesticides. The pesticides were classified either according to equal partition coefficient values or equal half life times. The first class was presented in graphs including only 18 pesticides divided into six groups of increasing partition coefficient values. Each group included 3 members having almost the same value of partition coefficients but different values of half life times, chosen to increase in each group. The second class included 24 pesticides grouped into six groups where most of the pesticides in the first class were also included in this one. Properties of all pesticides listed in Table 2. reflected a very wide range of values especially for the partition coefficient property.

RESULTS AND DISCUSSION

For the sake of comparing the results for different irrigation regimes and soil types, the same group of pesticides were used for all soil types. Figures 2,3, and 4 for alluvial, sandy loam and sandy soil respectively, for the first class.

Fig. 2 has 6 groups of pesticides, the first group included members of very low partition coefficients (26-29 mg/g OC) and increasing values of half-life time (10, 37 and 138), namely 1,3-D, Carbofuran and Picloram. The movement depth of the pesticides ranged between 40 and 65 cm at the end of the growing season for the low irrigation rate. Carbofuran and Picloram moved beyond the root zone, while 1,3-D of low half-life remained within the root zone (<60 cm). Increasing irrigation rate by 20% also increased the movement depth for all pesticides by the same rate of increase. The decrease of relative mass with depth or time was inversely related to the half-life time, since at the end of the growing season, the relative mass of Picloram exceeded 0.5 while it was <0.1 for Carbofuran.

Table 2. Studied pesticides grouped according to equal partition coefficients or equal half life times.

Name	Part.Co (mg/g OC)	Half Life (days)	Name	Part.Co (mg/g OC)	Half Life (days)
Class 1. Grouping according to equal partition coefficients and increasing half life time					
Group 1			Group 4		
1,3-D(TELONEII)	26	10	PROPACHLOR	420	7
CARBOFURAN	29	37	DIAZINON	580	30
PICLORAM	26	138	DIURON	383	328
Group 2			Group 5		
HALOXY	75	1	FONOFOS	846	60
BROMOCIL	72	106	LINURON	863	75
DBCP	70	180	LINDANE	1081	266
Group 3			Group 6		
NEMACUR	171	10	METAFOS	5102	4
ATRAZINE	163	48	TANDEM	5600	28
CYANAZINE	168	108	LORSBAN	6070	63
Class 2. Grouping according to equal half life time and increasing partition coefficients					
Group 1			Group 4		
OXAMYL	9	6	TERBACIL	46	50
CAPTAN	33	3	ATRAZINE	163	48
HALOXY	75	1	FONOFOS	846	60
MALATHION	1797	1	PCP	14290	48
Group 2			Group 5		
DICAMBA	2	14	PICLORAM	26	138
1,3-D	26	10	BROMOCIL	72	106
NEMACUR	171	10	CYANAZINE	168	108
PHORATE	3200	14	TREFLAN	14000	70
Group 3			Group 6		
ALDICARB	12	28	DBCP	70	180
CARBOFURAN	29	37	DIURON	383	328
DINOSEB	120	30	LINDANE	1081	266
TANDEM	5600	28	CHLORDANE	38000	3500

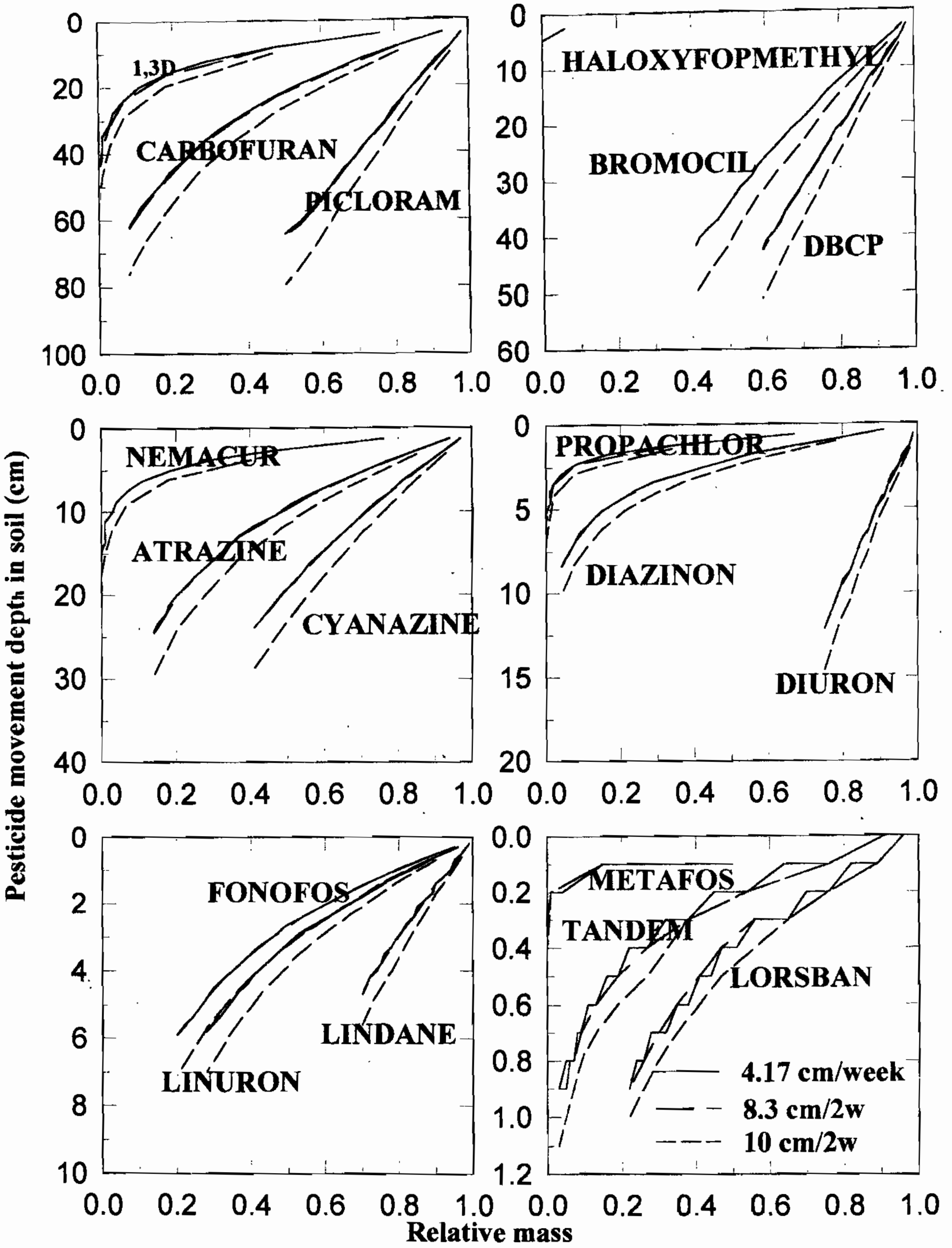

Fig. 2. Calculated chemical movement depth and relative mass under Minufiya climate for six groups of pesticides each having equal adsorption coefficients and increasing half-life times in the alluvial soil at three irrigation regimes.

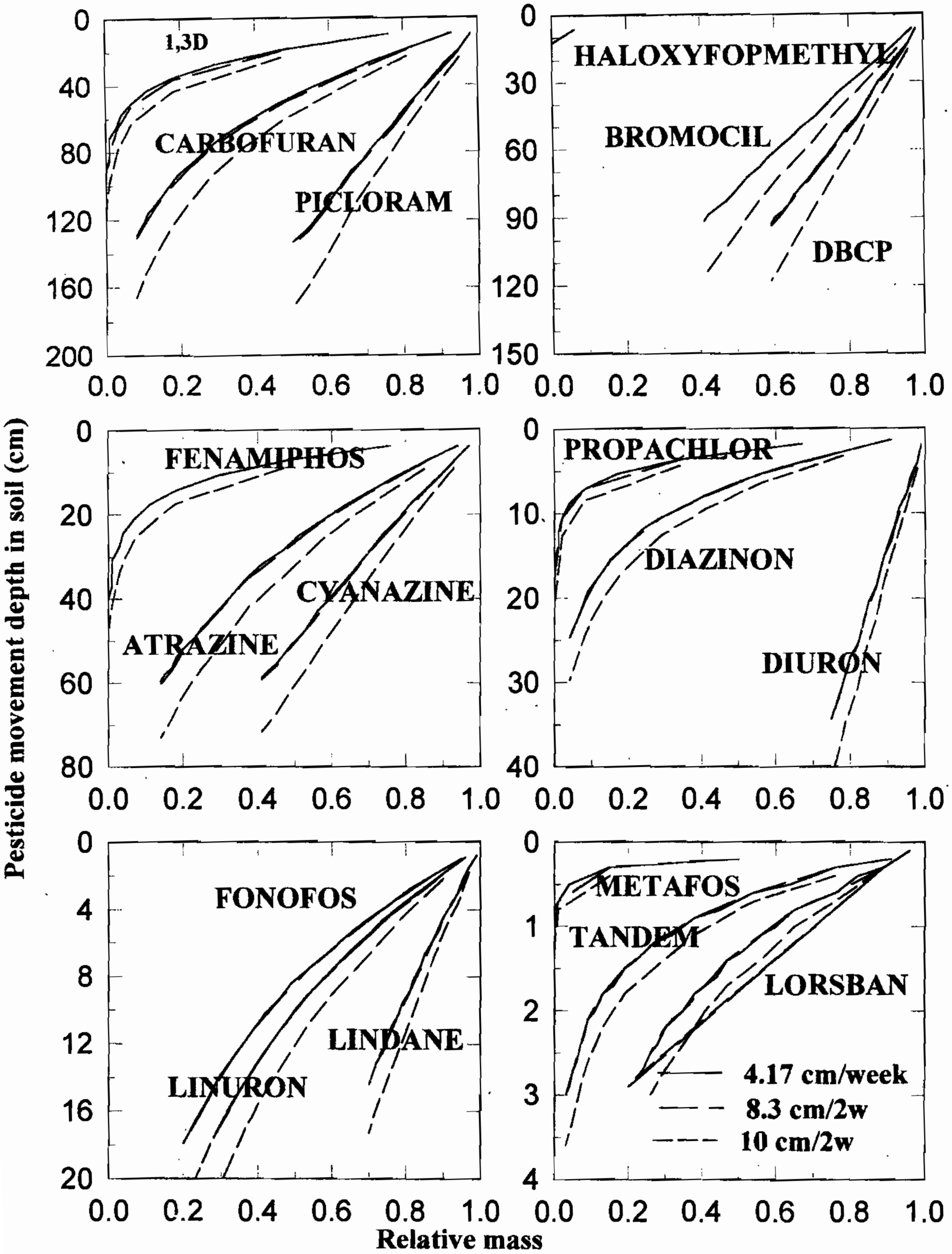

Fig. 3. Calculated chemical movement depth and relative mass under Minufiya climate for six groups of pesticides each having equal adsorption coefficients and increasing half-life times in the sandy loam soil at three irrigation regimes.

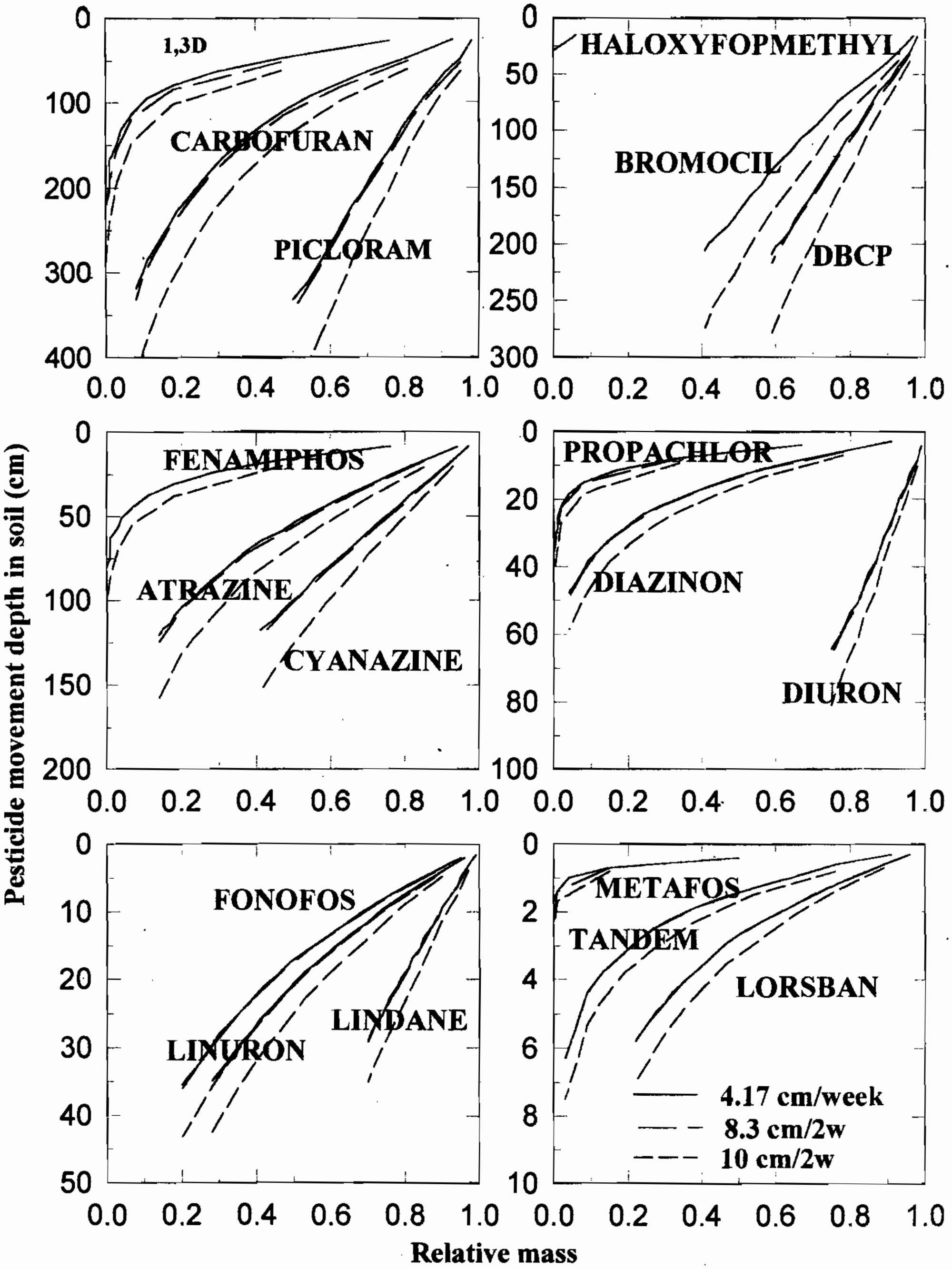

Fig. 4. Calculated chemical movement depth and relative mass under Minufiya climate for six groups of pesticides each having equal adsorption coefficients and increasing half-life times in the sandy soil at three irrigation regimes.

The second group presented in Fig. 2 included pesticides of low partition coefficients (70-75 mg/g OC) and increasing values of half-life time (1, 106 and 180), namely Haloxy, Bromocil and DBCP. The Haloxy of very low half-life time, disappeared quickly with time and traces of the pesticides moved only < 5cm at the end of the growing season. The other two pesticides with relatively high half-life time persisted and were present at depths > 40cm with relative mass ranging between 0.4 – 0.6 which is very high and represents a hazard.

The third group presented in Fig. 2 included pesticides of moderately low partition coefficients (163- 171 mg/g OC) and increasing values of half-life time (10, 48 and 108). They are Nemacur, Atrazin and Cyanazine. Their relative mass decrease with depth or time was high, intermediate and low following the half-life time. Nemacure disappeared at a depth of 12cm while relative mass of Atrazin and Cyanazine were 0.15 and 0.4 at a moving depth of 25 cm which represents an intermediate level of hazardness, especially for Cyanazine at the low rate of irrigation.

The fourth group presented in Fig. 2 included pesticides of moderately high partition coefficients (383- 580 mg/g OC) and increasing values of half-life time (7, 30 and 328). They are Propachlor, Diazinon and Diuron. The first two pesticides almost disappeared at 4 and 8 cm depths. Diuron was highly persistent (relative mass 0.75) in spite of the low rate of movement as it moved only 12 cm at the end of growing season, due to its very high half-life time. Diuron represents a hazardous contaminant due to its persistence and high possibility of accumulation in soil even at the low rate of irrigation.

The fifth group presented in Fig. 2 included pesticides of high partition coefficients (846 - 1081 mg/g OC) and increasing values of half-life time (60, 75 and 266). They are Fonofos, Linuron and Lindane. These pesticides of high partition coefficients; i.e. have high capability of adsorption, were slow movers as they only moved 5 to 6 cm by the end of the growing season. Due to the very high half-life time of Lindane, it persisted in the soil profile at a relative mass of 0.75 at the end of the growing season, which represents a soil contamination hazard.

The sixth group presented in Fig. 2 included pesticides of very high partition coefficients (5102 – 6070 mg/g OC) and increasing values of half-life time (4, 28 and 63). They are Metafos, Tandem and Lorsban. The three pesticides were still present in the top 1cm of the soil. By the end of growing season the relative mass was almost 0.2 for Metafos and Lorsban and even less for Tandem. The pesticide Metafos can present a hazard due to its presence near the soil surface (0.2 cm) for a long time. Hence, the possibility of the pesticide being washed off to water bodies through the runoff and soil loss processes increases.

Fig. 3, for the sandy loam soil, and Fig. 4, for the sandy soil included the same six groups of pesticides (each of similar values of partition coefficients and increasing values of half life times). Trends for all treatments were similar for all soils but with different magnitudes. This may be due to the methods of calculations used by the program that was dependant on the magnitude for certain pesticide and soil properties. The magnitude for the movement depth in the sandy loam soil and the sandy soil were 2-3 times and 5-6 times that of the alluvial soil at the same relative mass values, respectively. If one is setting criteria for groundwater and soil contamination by the pesticides, one may consider at the end of the growing season whether the pesticide reaches the bottom of the root zone (50 – 60 cm) or the pesticide persists in the soil profile at a relative mass higher than 0.4 from the applied concentration at the soil surface. These two suggested criteria can be changed to accommodate any level of hazardness standard.

Applying the previously mentioned criteria on the six groups of pesticides, it is found that pesticides that present a groundwater contamination hazard are Carbofuran and Picloram for the alluvial soil, Carbofuran, Picloram, Bromocil, DBCP, Atrazinem and Cyanazine for the sandy loam soil and 1,3-D, Carbofuran, Picloram, Bromocil, DBCP, Atrazinem, Cyanazine and Diuron for the sandy soil. Also pesticides that present a soil contamination hazaed in all investigated soils are Picloramm Bromocil, DBCP, Cyanazine, Diuron and Lindane. These results agree with the list of pesticides having ground-water advisory statements on their labels because of their tendency to leach, or because they have been found in ground water.

To examine the effect of partition coefficient on the movement depth and the relative mass at narrow range of half-life times, the pesticides were classified secondly into six groups of pesticides each of relatively similar half-life times and increasing partition coefficients. A total number of 24 pesticides were used, 13 of them were previously examined in the first class. The movement depth and relative mass was calculated for all 24 pesticides in the three investigated soils. Since the results ware only different in magnitudes and similar in trends for the three soils, only results for the sandy soil ware presented in Fig. 5. Results indicated that relative mass inside each group was almost the same for all members at the end of the growing season but the movement depth decreased with increasing the adsorption coefficient in each group. Relative mass increased from one group to the next with increasing the half-life time as it was zero in the first group, increased to 0.6-0.7 in the sixth group of very high half-life times. Applying the two criteria of contamination hazards, it is noticed that most pesticides pose either a groundwater or soil hazard for the sandy soil under the prevailing conditions. Very few pesticides can be used with low to moderate hazards under the prevailing conditions such as Malathion, Haloxy, Phorate, Tandem, PCP, Fonofos and Treflan for the sandy soil and the number will be higher for the sandy loam and the alluvial soils. The conclusions from the two classes are similar with emphasizing the effect of partition or adsorption coefficient on movement depth and illustrating the effect of half-life time on the relative mass of pesticides.

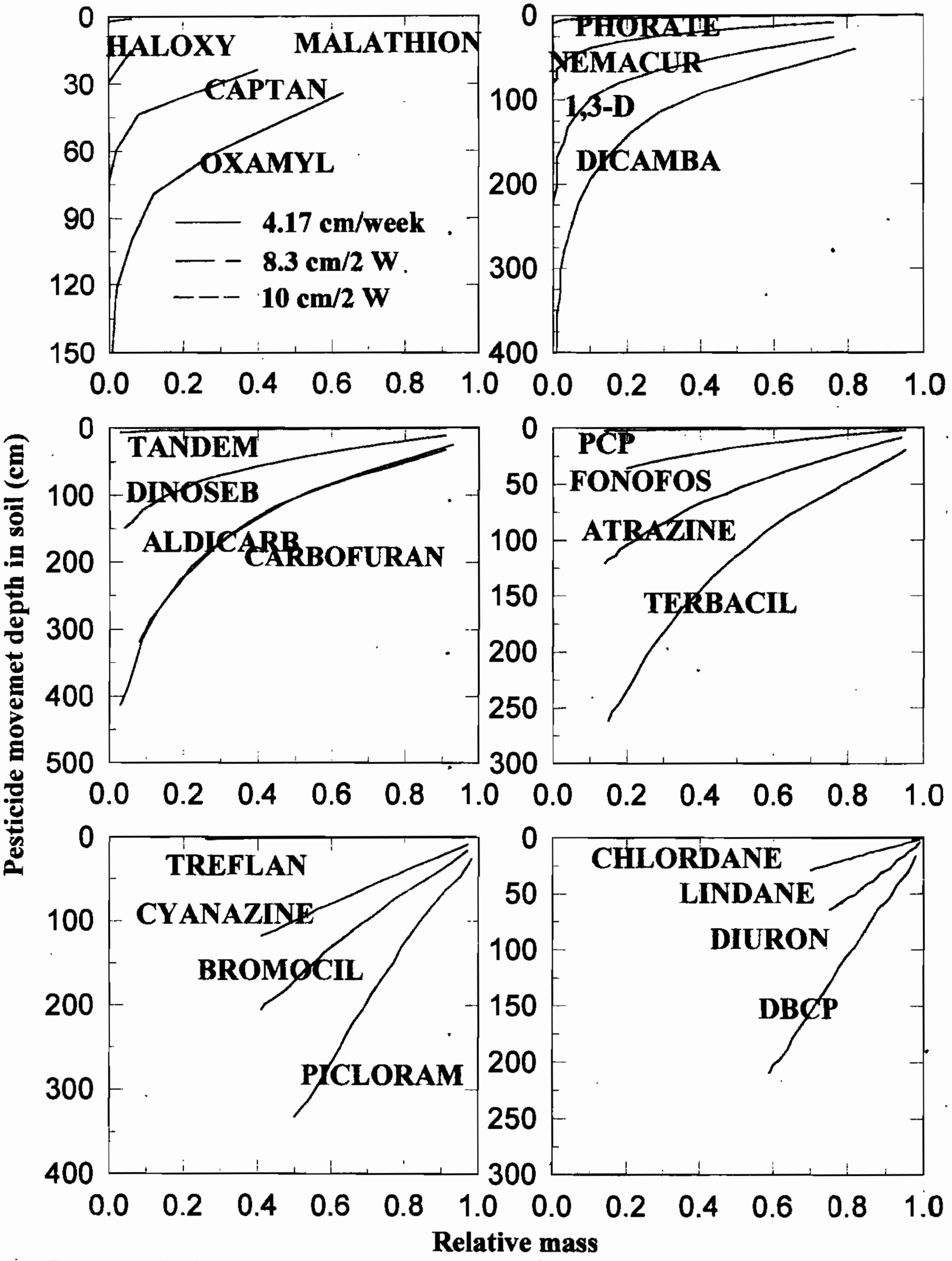

Fig. 5. Calculated chemical movement depth and relative mass under Minufiya climate for six groups of pesticides each having equal half-life times and increasing adsorption coefficients in the sandy soil.

Since calculation of pesticide movement depth using computer models is usually cumbersome for most farmers and pesticide users, obtaining simple equations that only require simple data is preferable and highly recommended. For that reason regression equations were obtained, correlating the calculated movement depth (or relative mass) using the computer program CMS with all available soil and pesticide properties. Correlation coefficients between calculated movement depths from both the CMS model and regression equations reflect the goodness of the easy to apply regression equations to replace the hard to get original calculations by the model (require weather data in addition to soil and pesticide data).

Parameters included to obtain the regression equations for each pesticide were (T) time from pesticide application, (TID) total irrigation depth (cm), (RM) relative mass, (D) movement depth, (OM) soil organic carbon percent, (Pco) partition coefficient, (HL) half-life time, (Bd) soil bulk density, (FC) field capacity, (WP) welting point, and (AW) soil available water. Some parameters did not show in the equations because they were perfectly correlated with other parameters, so only one parameter was presented. Two equations were obtained for each pesticide, one relating the calculated movement depth and the second relating the relative mass to the previously mentioned parameters. Correlation coefficients ware obtained for each equation and only the one with the higher value was considered. Equations for pesticides with high correlation coefficients for movement depth were listed in Table 3. while others with high correlation coefficients for relative mass were listed in Table 4. Generally equations for relative mass had much high correlation coefficients (0.862 – 0.997) than those for movement depth (0.853 – 0.886). According to these results it is preferable to calculate relative mass at previously set depths using equations in Table 3. rather than calculating movement depth at known relative mass concentrations.

To reduce the number of equations, the pesticides were grouped according to either value of partition coefficient or half-life time into several groups, and regression equations were obtained for each group. It was noticed that grouping according to half-life time produced low (unacceptable) correlation coefficients, while grouping according to partition coefficient produced equations of barely acceptable correlation coefficients (Table 5)

In conclusion, results indicated that Increasing water application (irrigation) rate increased the movement depth of pesticides by the same factor of increase, while decreasing the irrigation interval with keeping the total amount of irrigation water constant during a growing season, had no significant effect on their movement depth. Increasing adsorption (partition) coefficient significantly decreased the movement depth but had insignificant effect on the relative mass of pesticides. Increasing half-life time markedly increased the relative mass of pesticides but was independent of movement depth. The magnitude of the movement depth in the sandy loam soil and the sandy soil were 2-3 times and 5-6 times that in the alluvial soil at the same relative mass values, respectively. The two suggested criteria were enough

Table 3. Regression equations for pesticides having high correlation with movement depth under Minufiya climate and soil type.

Pesticide	Regression equation	R-sq %
1-3-D	DEPTH = - 2344 - 17.1 RM + 1.17 T + 0.0273 TID + 190 OC + 1471 Bd	86.5
ALDICARB	DEPTH = - 3038 - 30.1 RM + 1.32 T + 0.037 TID + 257 OC + 1910 Bd	85.9
CAPTAN	DEPTH = - 2101 - 20.5 RM + 1.10 T + 0.0245 TID + 167 OC + 1318 Bd	86.7
DIAZINON	DEPTH = - 262 - 3.67 RM + 0.170 T + 0.0011 TID + 16.0 OC + 168 Bd	87.2
DICAMBA	DEPTH = - 3905 - 22.0 RM + 1.69 T + 0.055 TID + 342 OC + 2439 Bd	85.6
DINOSEB	DEPTH = - 893 - 18.8 RM + 0.469 T + 0.0093 TID + 61.9 OC + 572 Bd	88.3
HALOXYFOP-METHYL	DEPTH = - 1286 - 89 RM + 0.754 T + 0.0124 TID 94.1 OC + 810 Bd	87.6
NEMACUR	DEPTH = - 678 - 9.68 RM + 0.428 T + 0.0056 TID + 43.9 OC + 431 Bd	88.6
OXAMYL	DEPTH = - 3269 - 17.5 RM + 1.53 T + 0.042 TID + 278 OC + 2043 Bd	85.8
PROPACHLOR	DEPTH = - 339 - 3.71 RM + 0.236 T + 0.0015 TID + 20.5 OC + 215 Bd	87.8
MALATHION	DEPTH = - 98.3 - 1.7 RM + 0.0713 T + 0.00002 TID + 5.98 OC + 62.1 Bd	86.0
PHORATE	DEPTH = - 56.9 - 0.080 RM + 0.0411 T - 0.00003 TID + 3.47 OC + 35.9 Bd	85.7
METAFOS	DEPTH = - 36.3 + 0.029 RM + 0.0264 T - 0.00006 TID + 2.22 OC + 22.9 Bd	85.3
TANDEM	DEPTH = - 33.3 - 0.050 RM + 0.0239 T - 0.00008 TID + 2.06 OC + 21.0 Bd	85.4

RM = Relative mass (g/g), D = Movement depth (cm), T = time (day), OC = Organic carbon %, TID = Total irrigation depth (cm), Bd = Soil bulk density (g/cm^3), AW = Available water %.

Table 4. Regression equations for pesticides having high correlation with Rel-Mass under Minufiya climate and soil type.

Pesticide	Regression equation	R-sq %
ATRAZINE	REL-MASS = 0.335 -0.000690 D - 0.00529 T - 0.000003 TID + 0.0317 OC + 0.309 Bd	94.0
BROMOCIL	REL-MASS = 0.792 -0.000116 D - 0.00406 T - 0.000003 TID + 0.0113 OC + 0.097 Bd	98.6
CARBOFU	REL-MASS = 0.292 -0.000207 D - 0.00545 T - 0.000022 TID + 0.0371 OC + 0.290 Bd	90.2
CYANAZINE	REL-MASS = 0.794 -0.000223 D - 0.00402 T + 0.000001 TID + 0.0099 OC + 0.097 Bd	98.8
DBCP	REL-MASS = 0.919 -0.000044 D - 0.00291 T + 0.000011 TID + 0.00443 OC + 0.0377 Bd	99.5
DIAZINON	REL-MASS = 0.321 - 0.00140 D - 0.00534 T - 0.000041 TID + 0.0225 OC + 0.235 Bd	86.2
DINOSEB	REL-MASS = - 0.049 -0.000818 D - 0.00513 T – 0.000035 TID + 0.0507 OC + 0.468 Bd	86.3
DIURON	REL-MASS = 0.969 -0.000063 D - 0.00180 T + 0.000010 TID + 0.00139 OC + 0.0146 Bd	99.7
FONOFOS	REL-MASS = 0.751 - 0.00062 D - 0.00527 T - 0.000001 TID OC + 0.076 Bd	96.1
LINDANE	REL-MASS = 0.980 -0.000054 D - 0.00216 T +0.000007 TID 0.00052 OC + 0.0054 Bd	99.7
LINURON	REL-MASS = 0.815 - 0.00047 D - 0.00485 T - 0.000014 TID + 0.0055 OC + 0.057 Bd	97.3
PICLORAM	REL-MASS = 0.885 -0.000034 D - 0.00347 T - 0.000001 TID + 0.0065 OC + 0.0503 Bd	99.1
TERBACIL	REL-MASS = 0.451 -0.000218 D - 0.00539 T - 0.000010 TID 0.0296 OC + 0.241 Bd	94.1
LORSBAN	REL-MASS = 0.881 + 0.00004 D - 0.00526 T - 0.000006 TID - 0.0001 OC - 0.001 Bd	96.1
TREFLAN	REL-MASS = 0.873 - 0.0018 D - 0.00507 T - 0.000001 TID + 0.0015 OC + 0.016 Bd	96.8
PCP	REL-MASS = 0.830 + 0.0005 D - 0.00562 T - 0.000008 TID - 0.0004 OC - 0.004 Bd	93.8
CHLORDAN	REL-MASS = 1.01 + 0.00113 D -0.000218 T + 0.000003 TID - 0.00034 OC - 0.0036 Bd	90.0

RM = Relative mass (g/g), D = Movement depth (cm), T = time (day),
OC = Organic carbon %, TID = Total irrigation depth (cm),
Bd = Soil bulk density (g/cm^3), AW = Available water %.

Table 5. Regression equations for pesticides, grouped according to their partition coefficient, having high correlation with movement depth or relative mass under Minufiya climate and soil type.

Part-Coeff. Range	Regression equation	R-sq %
0 - 20	$D = - 3392 - 14.1 RM - 2.57 PCo + 0.198 HL + 1.56 T + 0.0457 TID + 292 OC + 2131 Bd$	85.2
20 - 40	$D = - 2219 - 14.2 RM - 1.26 PCo + 0.0675 HL + 1.14 T + 0.0280 TID + 182 OC + 1415 Bd$ $RM = - 0.040 - 0.000209 D - 0.00446 PCo + 0.00476 HL - 0.00297 T - 0.000081 TID + 0.0380 OC + 0.296 Bd$	86.4 85.4
40 - 100	$D = - 1374 - 19.6 RM - 0.744 PCo + 0.0794 HL + 0.762 T + 0.0171 TID + 107 OC + 899 Bd$ $RM = - 0.078 - 0.000570 D - 0.00612 PCo + 0.00423 HL - 0.00272 T - 0.000001 TID + 0.0609 OC + 0.513 Bd$	86.7 87.3
100 - 200	$D = - 705 - 15.7 RM - 0.223 PCo + 0.0862 HL + 0.420 T + 0.0071 TID + 49.1 OC + 472 Bd$ $RM = - 0.191 - 0.00110 D - 0.00133 PCo + 0.00556 HL - 0.00404 T - 0.000041 TID + 0.0540 OC + 0.519 Bd$	87.8 87.8
300-500	$D = - 303 - 3.47 RM - 0.117 PCo + 0.245 T + 0.0021 TID + 21.2 OC + 223 Bd$ $RM = 9.11 - 0.000599 D - 0.0217 PCo - 0.00178 T - 0.000080 TID + 0.0127 OC + 0.133 Bd$	87.8 96.2
500 - 1000	$D = - 201 - 6.18 RM - 0.0151 PCo + 0.0316 HL + 0.123 T + 0.00073 TID + 13.1 OC + 137 Bd$ $RM = 0.100 - 0.00136 D + 0.000269 PCo + 0.00406 HL - 0.00508 T - 0.000018 TID + 0.0179 OC + 0.186 Bd$	85.4 93.7
500 - 1100	$D = - 186 - 9.70 RM - 0.0100 PCo + 0.0165 HL + 0.101 T + 0.00059 TID + 12.2 OC + 127 Bd$ $RM = - 0.508 - 0.00356 D + 0.000676 PCo + 0.000796 HL - 0.00399 T - 0.000010 TID + 0.0435 OC + 0.453 Bd$	84.9 92.3
1000 - 6100	$RM = 0.601 + 0.00768 D + 0.000060 PCo + 0.00337 HL - 0.00337 T - 0.000064 TID - 0.0321 OC - 0.333 Bd$	85.2
1100 - 15000	$RM = 0.846 + 0.0145 D + 0.000004 PCo + 0.00789 HL - 0.00421 T - 0.000057 TID - 0.0358 OC - 0.369 Bd$	83.7
15000 -38000	$D = - 6.47 + 1.43 RM + 0.00400 T + 0.000078 TID + 0.299 OC + 3.17 Bd$	84.3

RM = Relative mass (g/g), D = Movement depth (cm), T = time (day),
OC = Organic carbon %, TID = Total irrigation depth (cm),
Bd = Soil bulk density (g/cm^3).

to successfully predict the hazardness of all pesticides that were found in groundwater or known to be soil contaminants. The same procedure can be used with more complex models, for other areas of different climates, and for a large number of soils to obtain even better predictions.

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التنبؤ بإمكانية حدوث تلوث للأرض والمياه الجوفية بواسطة المبيدات وكذلك حساب عمق حركة الكيماويات في التربة

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الملخص العربي:

إن إزالة التلوث البيئي بالمبيدات سواء من الأراضي أو المياه يعتبر صعبا ومكلفا وقد لا يتم بنجاح ومن الأفضل منع حدوث التلوث منذ البداية. ولتقييم خطر أو إمكانية حدوث التلوث في الأراضي أو المياه الجوفية بالمبيدات ، أستخدم برنامج الكمبيوتر المعروف باسم CMS في حساب عمق الحركة والتركيز النسبي لعدد ٢٩ مبيدا تحت الظروف المناخية لمحافظة المنوفية حيث استخدمت بيانات مناخية ممثلة للفترة الممطرة من أكتوبر إلي إبريل (موسم زراعي كامل) وكذلك خواص ثلاثة من الأراضي السائدة في المنطقة وهي رملية – رملية لومية – رسوبية (سلتية لومية طينية) تحت ثلاثة طرق مختلفة للري (اختلاف كمية مياه الري و توزيع الريات). وقد تم تقسيم المبيدات حسب خواصها من حيث معامل الإدمصاص أو فترة منتصف العمر. وقد أمكن ترتيب كل منها في ستة مجاميع يضم كل منها ثلاثة مبيدات متساوية في معامل الإدمصاص أو أربعة متساوية في فترة منتصف العمر بهدف دراسة تأثير المبيدات علي عمق الحركة في التربة أو التركيز النسبي عند الأعماق المختلفة. ولإحلال معادلات سهلة التطبيق بواسطة المزارعين أو مستخدمي المبيدات محل نماذج الكمبيوتر الصعبة الاستخدام نسبيا فقد تم الحصول علي معادلات انحدار تربط بين عمق حركة المبيد أو تركيزه النسبي المحسوب من النموذج وعدد من العوامل سهلة التقدير مثل الوقت منذ زمن إضافة المبيد عند السطح – عمق الماء الكلي المستخدم في الري – معامل الإدمصاص – فترة نصف العمر للمبيد – الكثافة الظاهرية للتربة – محتوي التربة من الكربون العضوي ... حيث تم الحصول علي معادلات إنحدار لكل مبيد علي حده أو مجموعة من المبيدات لها مدي محدد من معامل الإدمصاص. وقد تم إقتراح عاملين يتم علي أساسهما تحديد مدي خطورة المبيد تحت الظروف السائدة وهي ما إذا كان المبيد قد تحرك إلي خارج منطقة الجذور (٥٠ – ٦٠ سم) في نهاية الموسم الزراعي أو ما إذا كان تركيزه النسبي عند أي نقطة داخل منطقة الجذور

يتعدي ٤٠% من التركيز المستخدم عند السطح. وهذه المقترحات يمكن تعديلها لتناسب أي مستوي من معدلات التلوث باعتباره حدا أقصي. وقد أظهرت النتائج أن زيادة معدل الري تزيد عمق حركة المبيد بنفس معدل الزيادة في جميع الأراضي بينما تقليل الفترة بين الريات مع الاحتفاظ بالكمية الكلية من مياه الري ثابتة لم يؤثر علي معدل حركة المبيد كما أن زيادة معامل الإدمصاص قلل بشكل ملحوظ عمق الحركة بينما لم يكن له تأثير مباشر علي التركيز النسبي للمبيدات أما زيادة فترة منتصف العمر فقد أدت إلي زيادة التركيز النسبي بشكل ملحوظ ومستقل عن عمق الحركة. وقد تراوح عمق الحركة في الأرض الرملية اللومية و الرملية بين ٢-٣ مرة و ٥-٦ مرة علي التوالي من تلك الخاصة بالأرض الرسوبية عند نفس التركيز النسبي. ومن نتائج هذه الدراسة يمكن استبدال النموذج CMS بنماذج أخري أكثر تعقيدا ودقة أو التطبيق علي مناطق مناخية أخري مع استخدام عدد أكبر من الأراضي للحصول علي نتائج ومعادلات انحدار أكثر دقة.