REVIEW ARTICLE

Movement of Crop Protection Chemicals in Different Environmental Components

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Abstract

By the year 2050, the world population is estimated to reach 9.1 billion, which in-turn will increase demand for food production by 70% in developing countries. To fulfill the food security requirement over 1 billion population India need to produce an additional 5 million tons per year for the next 20 years to meet its food grain need of 300 million by 2020. Crop protection chemicals or pesticides are inherently toxic and therefore harmful for other non target organisms. The risk posed by these chemicals increased many-folds due to the fact that they do not stay at the intended target surface. Various mechanisms are involved in the movement of pesticides in different environmental components i.e., air, soil and water. Global literature survey showed that synthetic pesticides have potential risk to human and other life forms and unwanted side effects to the environment. In this paper, various studies are reviewed with the aim to understand the factors determining the occurrence of pesticides in far away places and disturbing ecological balance.

Keywords: Degradation, Leaching, Movement, Pesticides, Sorption.

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Introduction

Chemicals, more commonly known as "Pesticides" are used to protect crops because of their ability to kill, mitigate or repel any undesirable living being (termed as Pest). In the last 60 years the use of pesticides has greatly increased the crop yield and ushered "Green Revolution". Farming now-a-days rely heavily on use of various crop protection chemicals. Top pesticides producing countries are United States, Japan and China. Per hectare use of pesticides in countries like China and Japan is as high as 11-13 Kg. In India though per hectare consumption is low (0.6 Kg/ha), it has increased many folds in last 50 years (FICCI, 2018). The ever increasing reliance of farming on the use of chemicals can be attributed partially to the ever increasing demand for food by growing population. In India as many as 292 pesticides are registered for use in agricultural farms, food storage as well as household. An analysis by PAN India revealed that more than 115 pesticides out of the 292 are highly hazardous (Kumar and Narsimhareddy, 2017).

Most of these plant protection chemicals are not selective in their action and therefore equally harmful to non-targeted organisms also. For instance, insecticides are often just as toxic for beneficial insect species (honey bees, wild bees, butterflies, etc.) as they are for pest insects, thus disturbing ecological balance. Plenty of evidences have been documented in numerous scientific literatures mentioning various environmental hazards caused by the use of pesticides (Sparling *et al.*, 2001). Exposure to pesticides poses serious health hazards in human being as well even at low concentrations (Doull, 1989; Jin-Clark *et al.*, 2002; Nicolopoulou-Stamati *et al.*, 2016; Mesnage *et al.*, 2018). The most common short term health hazards are itching, headache, tiredness, skin sore and blurred vision (Yadav and Dutta, 2019). Long term health hazards include cancer, immune deficiency, hormonal imbalance and birth defects. Further, the harmful effects of such pesticides are not restricted to the area of their application. Pesticides have been reported in rivers (Agnihotri *et al.*, 1994; Dwivedi *et al.*, 2018), groundwater (USEPA, 1990), and faraway places like North Pole (Wania, 2003).

Despite the lurking risk to health and strong criticism by environmental protection activists, the use of chemical pesticide would have to continue to feed increasing human population. The need of the hour is to regulate and optimize the application of pesticides in best possible way. The basis of such decision making is the understanding of field scale processes governing the persistence and movement of pesticides in different environmental components i.e. air, soil and water.

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Distribution of Pesticide between air, soil and water

Pesticide fate is controlled by numerous simultaneous biological, physical, and chemical reactions. As pesticide is applied on the targeted crop, it distributes itself in the air, soil, water, plants, and animals. Different natural phenomena are in operation for the movement of chemicals between environmental compartments (Fig. 1). Spray drift by wind and surface runoff are responsible for long distance movement (Rial-Otero *et al.*, 2003). The primary factors governing such movement are the intensity, duration, and timing of the wind and rainfall events relative to application. Once on the soil surface, pesticides degrade in situ or move away by leaching into groundwater, runoff into adjacent streams, and/or volatilization into the atmosphere. The degree to which a pesticide is distributed between solid, liquid, and vapour phases strongly influences its subsequent dispersal into the environment (Taylor and Spencer, 1990; Jury and Flühler, 1992; Cousins *et al.*, 1999).

Soil-pesticide interaction

Soil act as an interface for the movement of pesticides in air and water. Hence the interaction of pesticide and soil particles is important in deciding its fate in the environment.

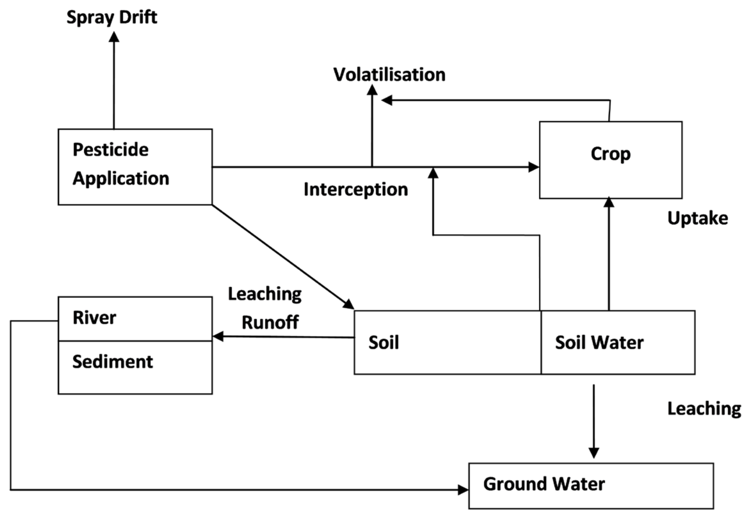

Fig. 1: Pathway of pesticide applied in soil.

Sorption

Pesticide is attached to the soil surface by the process called *Sorption*. The sorption is a complex phenomenon and is measured in terms of Sorption coefficient K_d.

K_d = Concentration of chemical in soil/Concentration of chemical substance in water

A higher value of K_d indicates that the pesticide is more strongly sorbed to soil and less concentration of it is in water present between soil particles.

Values for Kd vary greatly because the organic content of soil is not considered in the equation. Since adsorption occurs predominantly by partition into the soil organic matter, it is more useful to normalize the K_d to the organic carbon content of a soil and express the distribution coefficient in K_{oc}. K_{oc} is known as organic carbon-water partition co-efficient:

Koc or Kfoc= (Kd * 100)/ % Organic carbon

The value of K_d is dependent on the physio-chemical properties of both soil and pesticide. These contaminants are easily absorbed in soil due to the competition of water with pesticide for binding sites in moist soil. Soils high in clay adsorb more pesticides because of presence of high ratio of chemical active sites on the surface of clay (Kerle *et al*., 2007). Organic matter present in the soil also increase the sorption of pesticides. In a given soil type, the polarity and the water solubility of pesticide determine its sorption coefficient. The sorption of neutral pesticides has been extensively investigated (Gao *et al*., 1998).

Degradation

Half life is the term used for Pesticide persistence. This is the length of time required for one-half of the original quantity to break down. For example, if a pesticide has a half-life of 15 days, 50 percent of the pesticide applied will still be present 15 days after application and half of that amount (25 percent of the original) will be present after 30 days. So the longer half-life means the greater the potential for pesticide movement. On the basis of half life pesticides can be divided into three categories as non persistent pesticides with a typical soil half-life of less than 30 days, moderately persistent pesticides with a typical soil half-life of 30 to 100 days, or persistent pesticides with a typical soil half-life of more than 100 days. The half-life of a few pesticides is given in Table 1.

The breakdown of pesticide in the environment could be chemical, light-induced or by microorganism. Besides the chemical nature of pesticide itself the rate of degradation depends upon environmental conditions such as temperature, humidity, salinity, pH, nutrition, carbon dioxide, oxygen, substrate concentration, surfactant (Sartoros *et al*., 2005; Kah *et al*., 2007) as well as soil characteristics, most importantly microbial activity (Rao *et al*., 1983). A number of studies examining the relationship between sorption of pesticide and its degradation rate in various soils are available (Bolan and Baskaran, 1996; Baskaran *et al*., 1996; Dyson *et al*., 2002). It is found that when other factors are attuned, the sorption and degradation are negatively correlated (Guo *et al*., 2000), largely due to decreased concentration of freely available

Table 1: The properties of some selected pesticides useful for predicting environmental fate to cover entire range of the properties

Pesticide	*Half-life (days)*	*Sorption coefficient Koc*	*Movement rating*	*Water solubility mg/l*	*Vapor pressure index**	*Henry's Law Index Kh***
Malathion	1	1800	extremely low	130	80	1000
Benomyl	67	900	Low	2	0.001	0.78
Diuron	90	480	Moderate	42	0.69	21
Prometon	500	150	very high	720	77.3	130

*Vapour Pressure (Pv) is defined as the pressure that a chemical in the gas phase exerts over a surface. This surface can be water or dry soil. At room temperature, Pv values can range from 10-s to 300 mm of Hg (mercury). To make the value of Pv easier to read, the vapor pressure values is multiplied by 10^7 and is called vapor pressure index

**K_h is defined as the air-water partition coefficient, which is calculated as the ratio of the partial pressure of a compound in air to the concentration of the compound in water at a given temperature under equilibrium.

Table 2: Factors and processes increasing pesticide movement off-site (Gish *et al*., 2011).

Component	*Factors*
Pesticide characteristics	Vapor pressure
	Water solubility
	Sorption coefficient
	Half life
Soil and Landscape	soil water contents
	Organic matter content
	Soil texture
	Bulk density
	pH
Meteorology	Precipitation
	Humidity
	wind velocity
	Turbulence
	Temperature
	Solar Radiation
Agricultural Practices	Application method
	Application rates
	Pesticide formulation

pesticide. Organochlorine pesticides, *viz.* DDT, a wildly used insecticide is degraded to dichlorodiphenyldichloroethane (DDD), and dichlorodiphenyldichloroethene (DDE) by micro-organisms through reductive dechlorination and dehydrochlorination (Walia and Dureja, 1993).

Leaching

Leaching is the movement of pesticides in water through the soil. Leaching occurs downward, upward, or sideways. Pesticides are leached through the soil by the effect of rain or irrigation water. Pesticide leaching is highest for weakly sorbing as well as less persistent compounds. A number of mathematical models are available for predicting leaching potential of pesticides are available (Persicani, 1996). All these models incorporate the physicochemical properties of the pesticide, the properties of the soil and the weather. According to Nicollas (1988), lipophilicity is the most important physico-chemical property influencing the movement of un-ionised pesticides through soil. Water solubility is usually only an important factor in leaching for a few moderately polar solids with high melting points. Organic matter content is the most important property of the soil for un-ionised pesticides whilst the mobility of weak acids depends on soil pH. Permanent anions and weak acids can be very weakly adsorbed and hence might easily reach groundwater. Applications in autumn are more likely to reach groundwater than those in spring because soil temperatures are low in spring and rainfall exceeds evaporation in winter due to decrease in humidity, enabling mobile pesticides to penetrate to sub soils where degradation rates can be very slow.

Factors affecting distribution of pesticide

Pesticide partitioning between these three phases is primarily a function of pesticide chemistry, pesticide formulation, soil properties, and local metrological conditions (Table 2). The rate at which pesticides are lost from these three pathways is influenced by a number of small-scale factors like soil moisture content, organic matter content, soil hydraulic properties, as well as large-scale influences such as wind speed profiles, agricultural management practices, timing of rainfall events relative to application, and field slope.

Conclusion

By taking into account all the factors influencing movement of pesticides and hence its availability in the environment, the optimal dosage, time and method of application of a particular pesticide can be adjusted according to local weather conditions and soil properties. Optimum dosage and appropriate timing of application ensures that there is minimum pesticide lends in the environment Thereby the risk posed by inherent hazardous nature of crop protection chemicals can be minimised.

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