Research article

Short and Long Term Fate of Environmental Pollutants and Their Management

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Abstract There has been an increasing demand of chemical substances during this and the last century. The use of chemicals for a long time has been identified as a negative impact on the environment since it became apparent that residues could be transferred through the food chain; remain in soil or sediment as intractable substances. Chlorinated pesticides stand as a classic case of intractable substances and their residues remain dispersed throughout the world. Even though banned, their use continued because of their effectiveness as insecticides and availability. The effective use of DDT (dichlorodiphenyltrichloroethane) for control against malaria was recognized following its removal but was reinstated for controlled situations. Arsenic is another classic case because its residues from the application of its compounds as insecticides for cattle dips remain as buried residues that are intractable. The soil from such repositories requires remediation. The recognition of problems associated with the lifetime of long persistence substances led to the need to use low persistent pesticides for insect control. The impact of increasing use of pesticides and herbicides is now offset by available data which shows that for many compounds, residues are undetectable in soil and groundwater. The USGS found no significant build-up of low persistence pesticides in groundwater over a 15 years period. Long-persistence or intractable compounds require specific techniques of soil remediation to deal with their effects on plants and animals. Examples of substances that may require soil remediation are arsenic, dioxins and DDT. A classic case of dioxin in soil was spotted at Bien Hoa, Vietnam, where 1 ppm TCDD (2,3,7,8-Tetrachlorodibenzo-*p*-dioxin) was found in soil. A remediation plan was put in place and the TCDD residues were excavated and disposed in a repository. While exceptions occur, it is important to recognise that degradable chemicals should be used wherever possible in order to avoid future remediation problems.

Keywords: pesticides, fate, long and short persistence, soil remediation

INTRODUCTION

The use of chemicals by mankind has become a necessary and inseparable activity for the maintenance of livelihood, industrial, agricultural and recreational activities. Such use has led to innumerable cases of contamination and transfers through the food chain damaging ecology and poisoning people as occurred with methyl mercury at Minamata, Japan. The use of chemicals with long persistence in the environment has been identified as a negative feature since it became apparent that residues could be transferred through the food chain; remain in soil or sediment as intractable substances. Chlorinated pesticides stand as a classic case of intractable substances as their residues remain dispersed throughout the world. Even though banned, their use continued because of their effectiveness as insecticides and availability. The use of DDT for control against malaria was recognised following its removal but was reinstated for vector control and remained in use under limited and controlled situations.

The recognition of problems associated with the lifetime of long persistence substances led to the need to use low persistent pesticides for insect control. Although firmly in place, the general theory is that all pesticides, including those having low persistence, are bad because of the reputation of previously-used compounds, e.g. DDT (dichlorodiphenyltrichloroethane), dieldrin, chlordane, etc. The impact following the increasing use of pesticides and herbicides is now offset by available data which shows that residues are undetectable in soil and groundwater for many compounds in use. Exceptions are compounds like endosulfan which is essentially a chlorinated compound and is often found as a residue in sediment (Boonthai-Iwai, 2007). The USGS (Gilliam et al. 2006) found no significant build-up of low persistence pesticides in groundwater over a 15 years period. However, organochlorine pesticide compounds that were found in stream bed sediments and fish tissue were no longer in use by 1990. Only dachtal, endosulfan, lindane, methoxychlor and permethrin were used during the study period (Gilliam et al. 2006).

Long persistence or intractable compounds require specific techniques of soil remediation to deal with their effects on plants and animals. In-situ treatments are preferred for their removal from soil. Management practices that control erosion of soil may also help to reduce transport of pesticides and their degradates to streams. However, in some cases, it may be necessary to remove soil and treat it elsewhere to remove contaminants. Examples of substances that may require soil remediation are arsenic, dioxins and DDT. While exceptions occur, it is important to recognise that degradable chemicals should be used wherever possible in order to avoid future remediation problems.

The key aspects to be considered with particular reference to pesticides and herbicides are: (i) persistence of chemicals in the environment; (ii) long persistence causes intractable residues and contaminated waste; (iii) benefits of short term persistence chemicals and (iv) role of environmental management to minimise risks.

GENERAL PERSISTENT CHEMICALS IN THE ENVIRONMENT

There are many examples where the use of persistent chemicals has led to serious pollution episodes.

The use of arsenic compounds is a classic case. Residues from application as insecticide for cattle dips in Australia remain buried and intractable (Ng et al., 2003). The soil from such repositories requires remediation as it is contamination from an anthropogenic source. Arsenic solutions for cattle tick control were widely used in Queensland and New South Wales from 1895 to 1955. Chemical investigations (Beard et al., 1992) of arsenic contaminated soils, obtained from around 1600 government-owned cattle dip sites near north eastern NSW, have revealed levels of arsenic ranging up to 3000 mg/kg in the soil. Comparative bioavailability data were determined in 16 randomly selected soil samples with arsenic concentrations ranged from 700 to 2100 mg/kg and showed that a large proportion of arsenic (III) was present (Table 1) (Ng et al., 2003). An extensive cleanup program has been in place for several years to deal with the clean-up of contaminated cattle dip soils.

Table 1 Arsenic speciation from 16 cattle dip soil samples (Ng et al., 2003)

Soil I.D.	Total Arsenic (mg/kg)	Arsenic (III) %
1	730	68
2	730	70
3	860	38
4	1300	75
5	700	70
6	2000	71
7	1400	57
8	980	72
9	750	30
10	2100	59
11	800	43
12	1000	74
13	1100	88
14	2000	67
15	830	80
16	900	57

A classic example of dioxin in soil is located in Bien Hoa, Vietnam, where 1 ppm; 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD or TCDD) was found. The build up from the residues of TCDD in Agent Orange storage at the former US air base resulted in a highly concentrated zone (Quynh, 2005). Run-off accumulated in a nearby lake led to accumulation of TCDD in fish and other food items consumed by local people who received a significant dose of TCDD and thus were affected. A remediation plan was put in place and the TCDD residues have been excavated and disposed in a repository.

Although many toxic organochlorine pesticides are now banned in Vietnam, they are still in use and cause concern to people. Herbicides used during the Vietnam War severely polluted areas of Southern Vietnam. The study of the distribution of chemical impurities from herbicide application during the war has been useful for finding appropriate control measures (Quynh, 2005). Methods for sampling and analysis of organochlorines in soils, animal, human fat tissue and blood sample collection were applied and samples sent to international laboratories for dioxin analysis by high resolution gas chromatography – high resolution mass spectrometry (HRGC-HRMS). A study of organochlorine pesticides and polychlorinated biphenyls (PCBs) in food samples from Ho Chi Minh City 1989 showed that the most notable compound detected in biological tissue was DDT. Concentrations of DDT, hexachlorocyclohexane (HCH) and polychlorinated biphenyls (PCBs) in the soil in Tay Ninh and Binh Duong provinces in 1992 were also high where DDT was sprayed. PCBs contamination of cultivated land occurred during the war. Organochlorine pesticides and PCB levels in food samples from various sites were measured in Vietnam in 1992 and showed the presence of pollution of foodstuffs with PCBs, DDTs, HCHs, aldrin and dieldrin that were widespread in Vietnam. Dioxin accumulation has been observed in soil, animals and humans. In some limited sites it has been observed under geographical conditions, where Agent Orange herbicide drums were stored. The development of measures to solve contamination problems and prevent effects to the health of people has continued.

BENEFITS OF SHORT PERSISTENCE CHEMICALS

Chemicals which act quickly to induce an action or to control a pest are clearly preferred to those which remain active for decades. Pesticides are widely used in agriculture to control pests (weeds, insects or pathogens) and thereby increase yield and farm income. They remain an essential tool for agricultural industries in the production of high quality products and are a key component of integrated crop management (ICM) in cropping systems worldwide with around 2.56 million tonnes used per year (Pretty, 2005). Pesticides are generally applied as sprays to produce coverage of droplets containing the active ingredient on the target (e.g. an insect, leaf surfaces or part of a plant). Spray may be lost to non-target areas within a crop such as deposition on the soil or non-target plant surfaces and the action of wind may result in spray moving from the sprayed area. There are increasing concerns over the effect of pesticides in the environment, particularly when they move beyond a field boundary. By utilising techniques that maximise deposition on the spray target, it is possible to both improve the efficacy of pesticide applications and limit the movement of liquid droplets away from their point of release, both within and outside a target area.

For optimum control of pests and weeds in agricultural cropping situations, the grower is required to take careful consideration of many factors (Dorr et al., 2006). These include chemical selection, crop type, pesticide resistance, crop yield, costs of production, farmers revenue, spraying equipment (e.g. type of sprayer, nozzle selection, operating parameters), spraying techniques (e.g. buffer zones, no spray areas), meteorology (temperature, relative humidity, wind speed and direction) and sensitive areas downwind (e.g. non-target crops, livestock, aquatic organisms and areas that people occupy). Managing these factors in an integrated, holistic manner is often very complex. It requires combining tools, resources and information from several sources to optimise the application. Many parameters can also change during application (e.g. wind speed and direction) and application techniques must then be modified to prevent possible contamination of non-target areas. Failure to rapidly and appropriately manage these complex inter-related parameters has been the reason behind many pesticide drift incidents.

An important observation in the USGS study (Gilliom et al., 2006) was that the pesticides most frequently detected in streams and groundwater were those with greatest use either during the study period or in the past and with the greatest mobility and/or persistence in the hydrological system. Subsurface drains may help protect deep underground water, but increase pesticide transport to streams.

ROLE OF ENVIRONMENTAL MANAGEMENT TO MINIMISE RISKS

Risks to public health and the environment associated with pesticide use can be minimised if correct management decision is made. For a spray operation to be effective it needs to control pests (and hence increase crop yield and gross income) with a minimum of off-target environment and public health damage (Dorr et al. 2007). By combining spray models which give pesticide exposure and dose-response models with decision theoretical tools, various management options can be evaluated to maximise the effectiveness of plant protection products and minimise risks to public health and the environment from agricultural spraying activities. Risk assessment is a process for organising what we know about health and environmental risk and making judgements about risk (Ricci, 2006). It commonly adopts the following model: (i) Hazard Identification; (ii) Dose – Response (Toxicity) Assessment; (iii) Exposure Assessment; and (iv) Risk Characterisation.

In the risk assessment process, exposure studies of biota need to take account of formulation of the pesticide and its bioavailability. It is necessary to combine good quality application data with pesticide chronic toxicity data, generally the data required for registration of a pesticide. The risks to the environment need to take account of effects on: (i) terrestrial species; and (ii) aquatic species (Suter II, 1995). Other key areas include drinking water area exposure assessments and protection of non-target sensitive crops.

The control of contaminated waste is best dealt with by minimising its creation. Prevention of pollution requires attention to source reduction, the use of recycling, treatment and disposal options. Pollution prevention more broadly requires managing chemicals to reduce risk by identifying their presence and estimating all releases. Waste minimisation can be enhanced by applying source reduction and introducing product changes.

The recognition of the limits of science and technology has been proposed as reasons why science and technology alone cannot solve pollution problems or meet the challenges of sustainable development (Huesmann, 2003). The key aspects cited were: (i) Failure of reductionism; (ii) Limits imposed by conservation of mass principle; (iii) Order at expense of more disorder; (iv) Myths about recycling and renewable energy – trapping in environmental cycles; (v) Technology factor cannot be eliminated in order to improve eco-efficiency; and (vi) Long term protection of the environment and sustainable life style are not primarily technological but social and moral issues.

It is recognised that both biology and chemistry determine the availability of toxic chemical species in soils and sediments. The transport of solutes in soil is dominated by diffusion and is demonstrated by the significant presence of more polar herbicides such as atrazine found extensively in US streams (Gilliom, 2006). The precise nature of chemical and biological interactions depends on bioavailability and the role of bioturbation-driven chemical release processes.

Existing standards and guidelines for exposure to individual pesticides may not address all potential effects because actual exposure is most often a mixture of multiple pesticides and degradates (Gilliom, 2006). Additional research is required regarding the toxicities of mixtures to humans, aquatic life, livestock and wildlife because of the wide range of chemicals now found in organisms (Hileman, 2007).

CONCLUSIONS

An increasing demand for chemical substances during the last century led to the use of chemicals with long persistence in the environment. This activity has been identified as a negative feature since it became apparent that residues could be transferred through the food chain, remains in soil or sediment as intractable substances. Chlorinated pesticides stand as a classic case of intractable substance and their residues remain dispersed throughout the world. Even though banned, their use continued because of their effectiveness as insecticides and availability. Arsenic is another classic case and its residues from application of its compounds as insecticides for cattle dips remain as buried residues that are intractable and requiring remediation. The recognition of problems associated with the lifetime of long persistence substances led to the need to use low persistent pesticides for insect control. The impact of increasing use of pesticides and herbicides is now offset by available data which shows that many compounds residues are undetectable in soil and groundwater. The USGS found no significant build-up of low persistence pesticides in groundwater over a 15 years period. Long-persistence or intractable compounds require specific techniques of soil remediation to deal with their effects on plants and animals. Examples of substances that may require soil remediation are arsenic, dioxins and DDT. A classic case of dioxin in soil could be seen in Bien Hoa, Vietnam, where 1 ppm TCDD was found in soil, requiring a remediation plan to excavate and dispose the TCDD residues in a repository. While exceptions occur, it is important to recognise that degradable chemicals should be used wherever possible in order to avoid future remediation problems.

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