D. Organophosphorous pesticides in the environment

Prepared by:

Theo Vermeire
Toxicology Advisory Centre
National Institute of Public Health and the Environment
The Netherlands

and

Robert McPhail and Mike Waters
National Health and Environmental Effects Research Laboratory
Office of Research and Development
Environmental Protection Agency
USA

Abstract:

This study was chosen as an example of integrated risk assessment because organophosphorous esters (OPs) share exposure characteristics for different species, including human beings and because a common mechanism of action can be identified. The "Framework for the integration of health and ecological risk assessment" is being tested against a deterministic integrated environmental health risk assessment for OPs used in a typical farming community. It is argued that the integrated approach helps both the risk manager and the risk assessor in formulating a more holistic approach towards the risk of the use of OP-esters. It avoids conclusions based on incomplete assessments or on separate assessments. The database available can be expanded and results can be expressed in a more coherent manner. In the integrated exposure assessment of OPs, the risk assessments for human beings and the environment share many communalities with regards to sources and emissions, distribution routes and exposure scenarios. The site of action of OPs, acetylcholinesterase, has been established in a vast array of species, including humans. It follows that in the integrated approach the effects assessment for various species will show communalities in reported effects and standard setting approaches. In the risk characterisation, a common set of evidence, common criteria, and common interpretations of those criteria are used to determine the cause of human and ecological effects that co-occur or are apparently associated with exposure to OPs. Results of health and ecological risk assessments are presented in a common format that facilitates comparison of results. It avoids acceptable risk conclusions with regard to the environment, which are unacceptable with regard to human risk and vice versa. Risk managers will be prompted to a more balanced judgement and understanding and acceptance of risk reduction measures will be facilitated.

1. Background

This study was chosen as an example of integrated risk assessment for two reasons: first because organophosphorous esters (OPs) share exposure characteristics for different species, including human beings, such as sources, emissions, distribution and pathways of exposure, and secondly because a common mechanism of action can be identified. Similarities in exposure and effect provide a means of evaluation and comparison across species. Additionally, other types of integration such as cumulative and aggregated exposure can be considered for OPs. Aggregate and cumulative exposure to OPs is relevant in integrated approaches since both humans and environmental species can be exposed through various, not seldom common pathways of exposure to OPs, which are believed to share a common mechanism of action.

The US-NRC (NRC, 1993) performed a risk assessment for children exposed through residues in food to 5 commonly used organophosphates (OPs:acephate, chlorpyrifos, dimethoate, disulfoton, ethion) and used actual data on their presence on eight foods and three juices to explore the development of methods for assessing exposure to multiple chemicals. Recently the US-EPA (2001) released a preliminary OP cumulative risk assessment for 24 OPs incorporating exposure of humans via food, drinking water and residential/non-occupational pathways

In this case study information package the possibility is explored to include other routes of human exposure (direct exposure, exposure via the environment) and exposure of aquatic, terrestrial and wildlife species. The analysis includes the use of both monitoring and modelling results. The aim therefore is to explore:

1. The integration of risk assessments for man and the environment (integrated and aggregated exposure)
2. The integration of risk assessments of several OPs together (cumulative exposure).

2. Problem Formulation

2.1 Impetus for the assessment

Organophosphorous pesticides (OPs) are widely used pesticides and are believed to act through a common mechanism of action. There are ample reasons for integrating research and risk assessments for the OPs. OP exposure pathways overlap for many wildlife species and humans. For example, the spraying of crops with OPs can cause pesticide drift to nearby communities. Similarly, pesticide run-off into water bodies can cause harmful effects on aquatic species, terrestrial species that forage around water bodies, and humans that reside or recreate in the vicinity. OP contamination of well water can harm humans, long after the adverse impact of spraying on wildlife has occurred. In many instances it may be possible to use wildlife species as sentinels of the imminent or impending risks of OPs to human health. In addition, the site of action of OPs (acetylcholinesterase) has been well established in a vast array of species, including humans. Moreover, cholinergic receptors, which are stimulated indirectly by cholinesterase inhibition, are found throughout most taxonomic groups of animals.

The risk manager may have been made aware of the fact that, although exposure to a single compound may not exceed the level considered to be without acceptable risk for either humans or environmental species, concurrent exposures to numerous OP-compounds could exceed a safe level because of increased ChE inhibition. Moreover, absence of a probable risk for one species, e.g. man, does not automatically imply absence of a probable risk for other species.

These considerations will prompt the risk manager to formulate a question to risk assessors advocating an integrated approach and, if needed, a risk reduction strategy benefiting all organisms.

2.2 Assessment questions

The risk manager will work out the basic questions to be addressed together with the risk assessor. In this particular case the question may look like this:
Given the considerations above (see under 'Impetus for the assessment'), present a deterministic, integrated environmental health risk assessment for a group of commonly used OPs in a typical farming community. This local scale assessment should consider the risk for humans, wildlife and other environmental species resulting from both direct and indirect exposure at and following application of OPs. The assessment should include both short-term and long-term risks. Poisoning is not considered in this case information package. Integration is not always needed: the risk manager finally decides on the issues of concern in the problem formulation stage.

2.3 Assessment endpoints

Coherence in endpoints used to assess health and ecological risk can be specified for this case to pertain to acetylcholinesterase inhibition and differences in susceptibility in man, wildlife, aquatic species and terrestrial species as a result of exposure via dietary and non-dietary sources. Cholinesterases as the site of action of OPs have been identified in a vast array of species, including humans, but not in plants and microorganisms. Cholinergic receptors, which are stimulated indirectly by cholinesterase inhibition, are found throughout most taxonomic groups of animals. Though acetylcholinesterase inhibition in itself is not an adverse effect, studies have been performed in different species to investigate the relation between toxicity and cholinesterase inhibition.

2.4 Conceptual models

The conceptual model involves sources and pathways of exposure of:

1. Environmental organisms and applicators directly exposed after spraying/granulate treatment; this route includes exposure of water- and sediment organisms, and perhaps by-standers, via spray drift.
2. Environmental/domesticated organisms and humans indirectly exposed via
   ?? (residues in) food derived from crops on which the pesticide is applied directly

?? crops, ambient air, and soil in non-target areas
?? indoor air/surfaces during and following use of OPs in sprays/foggers/etc. and perhaps via medication and personal care products (head lice treatment, via contaminated lanolin). This route obviously only is applicable to man and domesticated animals.

The conceptual model for the local problem may be put in a wider context of a regional or watershed approach.

2.5 Analysis plan

An integrated approach offers substantial opportunities for more efficient data gathering activities. This case offers the following opportunities:

1. Sharing of data on emissions,
2. Sharing of distribution, fate and exposure models and the parameter values and distributions needed for these models,
3. Sharing of data on concentrations in environmental media and food
4. Sharing of analytical activities to obtain the data mentioned above
5. Sharing of toxicokinetic and physiologically-base pharmacokinetic models
6. Sharing of dose-response models for ChE-inhibition
7. Sharing of analytical activities to obtain information on dose-response and variability across and within species.

2.6 Summary

An integrated approach already offers advantages in the problem formulation stage:

1. It helps both the risk manager and the risk assessor in formulating a more holistic approach towards the risk of the use of OP-esters. It avoids conclusions based on incomplete assessments or on separate assessments using unnecessarily different assumptions, parameter values, distribution and fate models and exposure scenarios.
2. It helps in identifying opportunities in increasing the database available for both the human and the environmental risk assessment risk (increased efficiency/resource-effective)
3. It helps to identify a coherent expression of the results across species in terms of exposure (common pathways), adverse effects (in relation to ChE-inhibition), dose response and eventually the risks.

3. Characterisation of Exposure

3.1 Sources and emissions

In an integrated approach it is useful to consider the whole life cycle of OPs and all possible sources. This inventory will allow a well-founded selection of sources and relevant life cycle stages with potentially significant emissions. The expertise required here is the same for both the human and the environmental RA.

Potentially, emissions of OPs can occur at production, formulation, use and disposal. For convenience, we will leave out production, formulation and disposal in our example, assuming these processes occur outside the geographic area of interest. Specifically, the exposure assessment concentrates on sources and emissions following use of OPs as pesticides and biocides. Sources with possible emissions to the environment or direct exposure can be identified at spraying or application of granulates in agriculture, use in dips in animal husbandry, use as a biocide and use in medications (NRC, 1993). Biocidal uses include use in indoor sprays and foggers and in flee control products for pets. OPs are used medicinally in head lice treatment products. Residues of OPs may be present in lanolin originating for sheep treated in dips.

3.2 Distribution pathways

See Figure 1 below.

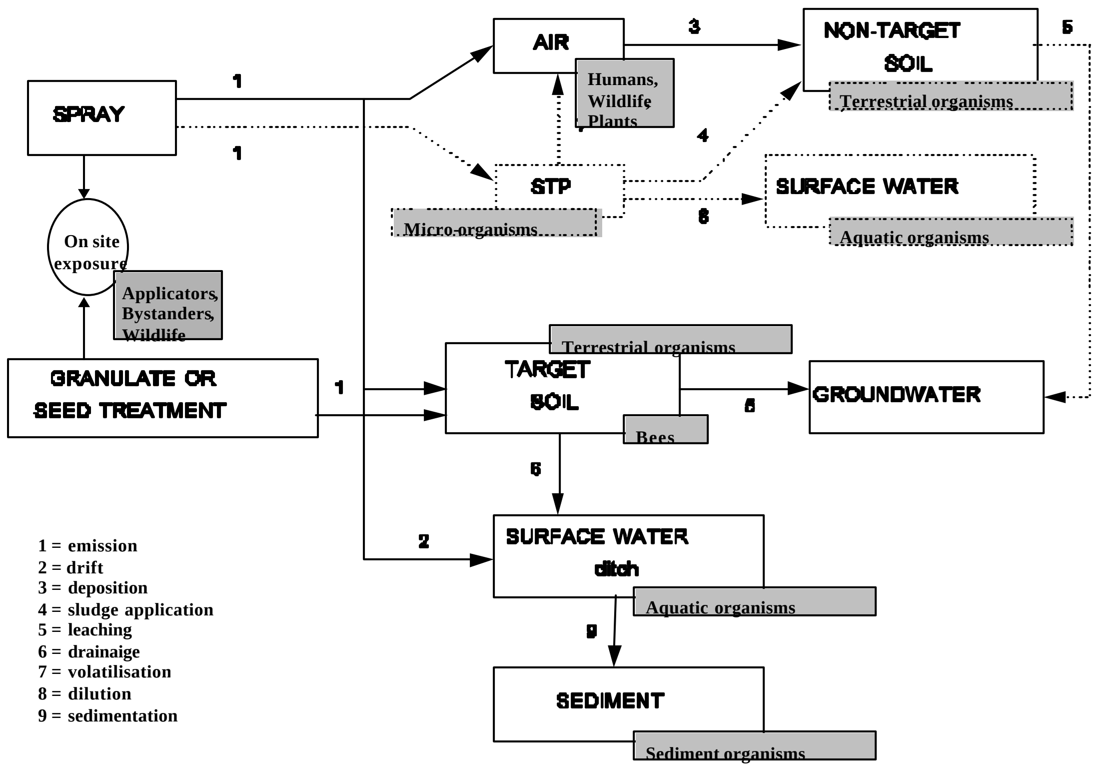

Fig. 1: Distribution routes for agricultural pesticides. Grey boxes contain the receptor organisms; dotted lines and boxes are used if the only release is via the Sewage Treatment Plant (STP)

Figure 1 shows distribution towards the environmental media ambient air, soil, surface water, groundwater, sediment, and soil.

Communalities: see section 3.4 'External and internal exposure models'

3.3 Transport and fate models

Data needed are measured concentrations in the environmental compartments or input for distribution models to estimate environmental concentrations. The latter requires physico-chemical properties, partition coefficients, degradation rates, deposition rates, and environmental characteristics (Van Leeuwen and Hermens, 1995). General local distribution screening model specific for agricultural and non-agricultural pesticides are available (e.g. RIVM et al., 1999).

3.4 External and internal exposure models

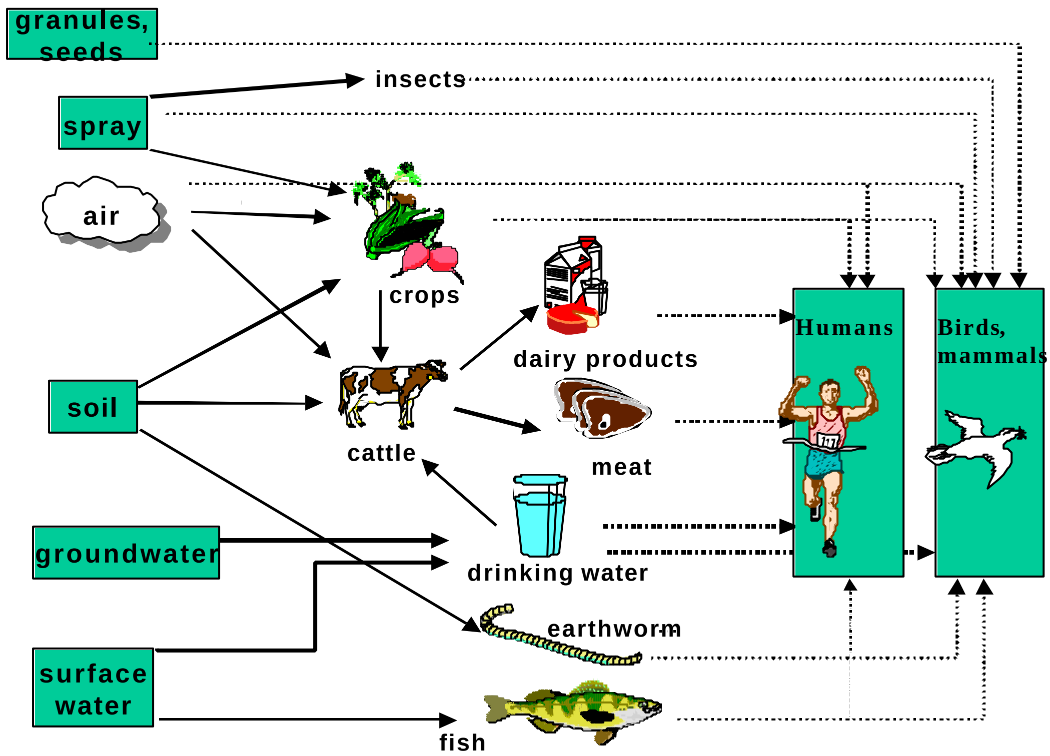

Fig. 2: Schematic representation of possible routes of environmental exposure of humans and wildlife

Examples of common distribution and exposure routes, sharing common transport models, fate models and monitoring data:

?? Direct exposure of applicators, by-standers and wildlife and invertebrates to OPs in spray drift;

?? The route from OPs spray application towards surface water leading to exposure of aquatic organisms and, through drinking water and food, of human beings, birds and mammals;

?? The route from OPs application towards non-target soil leading to exposure of terrestrial organisms and, through crops and drinking water prepared from groundwater, of human beings, birds and mammals;

Figure 2 shows possible routes of environmental exposure of humans and wildlife Further communalities can be found in the estimation of aggregate exposure of human beings, wildlife and birds through food (oral), drinking water (oral) and air (inhalation, dermal). Cumulative exposure to several OPs together is an issue relevant to both human beings and wildlife.

Direct exposure estimation need quantification of the potential exposure in the form of concentrations in the exposure media that may contact the human body. Quantification may follow from exposure data. Otherwise, simple models may be applied to obtain a reasonable worst case prediction of the exposure. This modelling involves quantification of the contact with the exposure media containing the substance by defining exposure routes and exposure patterns, including contact durations, contact frequencies and site of contact. Both a chronic exposure measure and an acute exposure measure may be needed, depending on the expected effects and exposure patterns. Consumer exposure models are available and may be modified to be applicable to wildlife as well (Van Veen, 1996; Van Veen 1997; Pandian et al., 1997; EC, 1997). Local screening models for the estimation of environmental exposure of man and other organisms to pesticides are also available (e.g. RIVM et al., 1999). This estimation involves bioaccumulation and biotransformation models (Van Leeuwen and Hermens, 1995). Aggregate exposure assessment methodology is specifically addressed by ILSI (1998). There is little experience with cumulative exposure methodology. With respect to OPs, a cumulative risk assessment has been published by NRC (1993) and recently by the US-EPA (US-EPA, 2001).

Most risk assessments dealing with OPs rely upon the administered dose or the external dose because of insufficient understanding of how to estimate the internal dose and the relation between the internal dose and effects. In some cases, however, PBPK models may be available and may be used for a risk assessment based on the internal dose for human beings or wildlife (Paustenbach, 2000).

3.5 Measures of exposure related parameters

Examples of not-receptor-specific parameters with common values and units are:

- Emission rates: e.g. the fraction of the amount of OPs applied in kg per ha, emitted to air and water at spraying;
- Concentrations in environmental media: e.g. Predicted Environmental Concentrations (PECs) in air, soil and surface water;
- Biotic and abiotic degradation/disappearance rates in environmental media: e.g. the rate of biodegradation in soil and surface water, the rate of hydrolysis and photodegradation, the rate of volatilisation, resuspension, and sedimentation;
- Characteristics of environmental compartments: e.g. the fraction organic carbon in soil and sediment, temperature, rainfall, dilution rates, water flows etc.;
- Partition coefficients: e.g. the octanol-water partition coefficient and the air-water partition coefficient.

3.6 Analytical tools

Integrated exposure assessment requires the application of the same quantitative methods such as methods for sensitivity and uncertainty analysis. Monitoring of environmental media, drinking water and food (target and non-target crops) is relevant both for the human and the environmental risk assessment of OPs. Monitoring strategies for OPs should, however, consider the spatial and time scales relevant for common exposure routes e.g. consider the need for local, short-term concentrations in surface water as medium of exposure for fish, mammals and birds just after spraying and the need for long-term averages at a larger spatial scale to estimate the exposure of birds, mammals and human beings (following treatment) away from the application area.

3.7 Summary

In an integrated exposure assessment of OPs, the risk assessments for human beings and the environment share many communalities with regards to sources and emissions, distribution routes and exposure scenarios. Taking these into account will be an efficient way to deal with the risks to all organisms, including humans. Monitoring efforts can be more cost-effective.

4. Characterisation of Effects

4.1 Reported effects and modes of action

Organophosphates (OPs) are widely used pesticides that are applied primarily to crops for the control of agricultural pests, as well as in and around residences and offices for the control of urban pests. OPs are also one of the two major classes of cholinesterase-inhibiting pesticide. The main mode of action of the OPs is inhibition of acetylcholinesterase, the enzyme that terminates the action of acetylcholine neurotransmitter, which is released by nerve stimulation, on postsynaptic cholinergic receptors in the nervous system. OPs produce an irreversible inhibition of acetylcholinesterase, in contrast to the carbamates (the second major class) that produce a reversible inhibition.

Since the principle site of action of OPs is the nervous system, it is not surprising that OPs have produced a variety of toxic effects. These effects have been documented in humans, laboratory animals and several wildlife species (aquatic and terrestrial), due to either accidental or intentional exposures (Ecobichon and Joy, 1994; Mineau, 1991). Acute exposures produce a well-known syndrome of autonomic distress including salivation, lacrimation, urination and defecation (the SLUD syndrome). In addition, acute exposure compromises neuromuscular function, decreases motor activity and body temperature, and alters cardiovascular function.

Extremely high doses produce convulsions and death, due to interference with brain-stem structures involved in respiration.

Acute exposure to some OPs also produces a delayed neuromuscular effect, seen mainly in the extremities, which is irreversible and can lead to paralysis (Johnson, 1975). Organophosphate-induced delayed neuropathy (OPIDN) has been shown in several susceptible species, including birds and humans, although the basis for species differences in sensitivity is unknown at this time.

Repeated exposure to OPs can produce tolerance to the acute effects due mainly to a down-regulation of muscarinic cholinergic receptors in the central nervous system. While the observation of tolerance may indicate a reduced risk of exposure, there may be residual risk factors that are operative. For example, organisms made tolerant to an OP are often more sensitive to the effects of muscarinic blocking agents (e.g., belladonna alkaloids). Furthermore, available evidence indicates many OPs are not interchangeable; tolerance to one OP may either confer tolerance to another, have no effect on the actions of another, or may increase susceptibility to still other OPs (Costa and Murphy, 1983).

Currently, there is much concern over age-related susceptibility to the OPs (NRC, 1993). Evidence in support of this concern comes mainly from studies on laboratory rodents, although there is considerable evidence of developmental toxicity in avian reproduction studies (Mineau et al., 1994).

4.2 Biomarkers and indicators

Since the main mode of action of OPs is inhibition of acetylcholinesterase, enzyme inhibition has been widely used as biomarker of exposure in both human-health and ecotoxicology research. Whether enzyme inhibition can be used as a biomarker of effect, on the other hand, is debatable. One complication for arriving at a consensus is the observation of a threshold for inhibition above which toxic effects are produced. For example, it is widely assumed that toxic effects ensue only when the inhibition exceeds 20% in brain. Reviews of the literature, however, provide little empirical support for such a sweeping generalisation. As a consequence, little concerted effort has so far been made at exposure – response modelling.

Despite the advantages of integrated risk assessments for OP pesticides, some caveats are in order. For example, there are numerous methods used to determine OP-induced cholinesterase inhibition. There are, however, no clear indications at this time on the comparability of the inhibition as determined by the different analytical methodologies. In addition, there are a number of other esterases that OPs inhibit to varying degrees. Some of these esterases are considered sinks for OPs that diminish the inhibition of acetylcholinesterase. Understanding the relative abundance and activity of esterases in general will be necessary in order to make firm predictions of risk in receptor species.

4.3 Exposure-response modelling

Since OPs produce systemic toxicity, involving primarily the nervous system, the Reference Dose (RfD) approach is widely used for OP standard setting (see MacPhail and Glowa, 1999 for details). A RfD is calculated by dividing a no-adverse-observed-effect level (NOAEL) by a series of uncertainty factors (UFs). Similar approaches are being applied to determine no-effect levels for environmental organisms using NOAELs, NOECs (No-Observed-Effect Concentrations), LC50's or EC50's. These approaches generally ignore the shape of the dose-response curve. New approaches make use of species sensitivity distributions in ecotoxicological risk assessments (OECD, 1992). In human risk assessment, benchmark dose modelling (Slob and Pieters, 1999) and categorical regression (Teuschler et al., 1999) have been proposed. Teuschler et al. (1999) applied categorical regression to OPs.

4.4 Extrapolations

Standard-setting for OPs based on adverse effects on human health involve a number of extrapolations. This is because the data used for standard setting ordinarily come from experiments on laboratory organisms (most often rodents) exposed to relatively high doses and for relatively brief durations UFs are ordinarily a factor of 10 and are included to compensate for limits in our understanding of how toxic substances works, which severely compromises our ability to make accurate predictions of risk. One UF is included when the human health standard is set using laboratory animal data. In other words, humans are assumed to be approximately 10 times more sensitive to OPs than are laboratory rodents. Another UF of 10 is included to compensate for individual differences in susceptibility to OPs, implying no more than one to two orders of magnitude difference in the range of sensitivity. Recently, an additional UF has been recommended for inclusion in standard setting in order to protect children from the risk of OPs and other pesticides. It is important to note, however, that despite the widespread use of UFs in regulatory decision-making there is little evidence available for the biological plausibility of UFs. The situation could be remedied by empirical selection of UFs and their magnitude(s). In this regard, an empirical approach has recently been described to selecting an UF for interspecies variation in sensitivity that is based on analysis of avian toxicity data used for pesticide regulation purposes (Mineau et al., 1996). Contrary to standard assumptions Mineau et al. found that smaller species were more sensitive. Extrapolation methods for environmental organisms are also available: see for example EC (1996) and Crommentuijn et al. (2000).

The evolutionary conservation of enzyme and receptor make OPs an ideal candidate for comparative studies on physiology, biochemistry, metabolism and susceptibility to OPs. Such studies may make it possible to establish species-specific toxic equivalency factors (TEFs) for the OPs (NRC, 1993).

4.5 Direct and indirect effects

OPs are indirectly acting agents in that inhibition of acetylcholinesterase causes an accumulation of acetylcholine with subsequent overstimulation of cholinergic receptors. Recent evidence suggests, however, some OPs have direct stimulatory effects on cholinergic receptors at extremely low concentrations (Huff and Abou-Donia, 1995; Ward and Mundy, 1996). Recent evidence also suggests that acetylcholinesterase may serve as a tropic factor that guides development of the nervous system in several species (Bigbee et al., 1999). Disruption of brain development by OPs may explain their developmental toxicity in avian species. Behavioural decrements may result in increased susceptibility to predation, reduced provisioning of the young, and reduced feeding. There may be other indirect effects produced by OPs. For example, some OPs have repellent actions that underlie the avoidance of OP-contaminated food displayed in avian species Bennett (1989). Reduction of forage species can affect growth of other species or, vice versa, the reduction of certain species can lead to excessive growth of forage species (algal bloom following reduction of crustacea). Finally, toxic effects in wildlife may alter community composition and food-web dynamics leading to further indirect effects of a magnitude and impact on the environment and human beings that is presently unknown. Clearly, only an integrated approach may reveal such interactions.

4.6 Summary

The site of action of OPs, acetylcholinesterase, has been established in a vast array of species, including humans. It follows that in an integrated approach the effects assessment for various species will show communalities in reported effects and standard setting approaches on the basis of no (observed) adverse effect levels. Species-specific toxic equivalency factors (TEFs) have been proposed for OPs.

5. Risk Characterisation

5.1 Combining exposure and effects

The results of the characterisations of exposures to OP compounds and associated effects are combined to estimate the risks to each endpoint. The uncertainties associated with the risks are determined, and summarised for presentation to the risk manager and stakeholders. In this relatively simple case, an exposure estimate is used to estimate the likelihood of adverse effects by comparing the exposure value to a limit value. A common set of evidence, common criteria, and common interpretations of those criteria are used to determine the cause of human and ecological effects that co-occur or are apparently associated with exposure to OPs. A best estimate of risk is derived from results of toxicity tests of different species, results of single chemical and mixtures toxicity tests, and exposure estimates derived from different fate models and from environmental measurements. These lines of evidence are quantitatively weighted and combined evidence from ecological and human health risks is integrated.

5.2 Determining causation

See 5.1

5.3 Combining lines of evidence

See 5.1

5.4 Uncertainty

Through uncertainty analysis, the risks of various stressors is expressed in a common form (e.g., the probability of occurrence of cholinesterase inhibition in humans and in the ecological setting). The integrated assessment starts with a common concept and terminology of uncertainty (e.g., distinguish variance from true uncertainty), and as far as appropriate uses common analytical methods.

In a deterministic assessment upper-bound estimates are based on conservative estimates of exposure and risk. In our example, worst case values will, for instance, be used for anatomical and dietary properties of humans and cattle, partition coefficients, bioconcentration factors and biotransfer factors. In uncertainty analysis, not only this upper-bound estimate will be estimated, but the full distribution of intakes of the affected population. This allows the risk manager to choose an appropriate level of uncertainty (e.g. the 50^{th} or 99^{th} percentile of the intake distribution), to separate individual variability (e.g. in human body weights or food intake factors) from true scientific uncertainty (e.g. in estimates of partition coefficients) and to consider benefits, costs and comparable risks.

In our example the uncertainty analysis would require the following:

- ?? Definition of statistical distributions of key input parameters such as:
- ?? variability in application rate, human body weights and food and drinking water intake factors, inhalation rates, fractions of food home-grown, and fat contents;
- ?? variability and uncertainty in ingestion of grass, soil and air by cattle;
- ?? uncertainty in percentage of drift, leaching/deposition/degradation/dilution rates, the ratio of plant dry mass to fresh mass, partition coefficients, bioconcentration and biotransfer factors;
- ?? Generate a distribution of exposure through simulation.
- ?? Compare this exposure distribution with a fixed value of the Acceptable Daily Intake and determine the probability that this ADI is exceeded. Note that the assessment may be further developed by taking into account the variability and uncertainty in the humans effects assessment.
- ?? A similar approach can be undertaken for environmental species.

5.5 Presentation of results

Results of health and ecological risk assessments are presented in a common format that facilitates comparison of results, i.e., a common presentation of results with an explanation of differences in the magnitude of effects. Similarly, the uncertainties are presented in a common form (e.g., cumulative frequency). This integrated risk characterisation facilitates the task of communicating risks to risk managers and the public. An example of a common risk measure that could be used in this example is the risk characterisation ratio of the exposure estimate (PEC) and the no-effect level for acetyl cholinesterase inhibition (PNEC, ADI, RfD). Alternatively an uncertainty analysis may result in the common risk measure being the probability that the exposure estimate (PEC) exceeds the effects estimate (PNEC, ADI, RfD). If dose-response relations are known, a probability distribution of effects can be obtained and decisions can be taken on the basis of an acceptable level of effects (e.g Klepper et al., 1998, for ecosystems and Slob and Pieters, 1999, for humans). Integration of the results could include an integration of effects over different OPs and over the geographic area of interest, e.g. the farming community in this case.

5.6 Summary

An exposure estimate is used to estimate the likelihood of adverse effects by comparing the exposure value to a limit value. In an integrated approach, a common set of evidence, common criteria, and common interpretations of those criteria are used to determine the cause of human and ecological effects that co-occur or are apparently associated with exposure to OPs. Results of health and ecological risk assessments are presented in a common format that facilitates comparison of results. It avoids acceptable risk conclusions with regard to the environment, which are unacceptable with regard to human risk and vice versa.

6. Risk Manageme nt and Stakeholder Participation

Risk management is the process of deciding what actions should be taken to mitigate or reduce the risk. It involves making decisions concerning actions in response to estimated risks to humans or ecological systems.

Risk managers may be concerned on the potential health effects of occupational and non-occupational exposure to OPs among farmer families in an area known for intensive use of these substances (e.g. Azaroff, 1999; Simcox et al., 1995). Other risk managers may be interested in effects of OPs on wildlife in such an area (e.g. Custer and Mitchell, 1987). In an integrated approach these studies would be combined addressing both issues and making effective use of the available exposure and effects assessment expertise, exposure models, monitoring data and monitoring strategies. The risk managers may be able then to make a balanced judgement on the risks for not only the farmer families, but also their environment on the basis of the estimated risks and the socio-political and economic implications of alternative risk reduction options.

An integrated risk assessment could make clear, which receptors are at risk and which not. Communalities as well as differences will become clear and risk management options can be focussed without neglecting receptors and interactions between them. For example, restrictions on the presence of humans in fields during spraying and for some period thereafter reduce risks to humans, but not ecological receptors. Granular formulations of OPs are less risky to humans than sprays but are more risky to birds, because the latter ingest granules as grit.

6.1 Summary

An integrated approach makes effective use of available resources for estimating risks. It also allows a balanced judgement on the risks to all organisms potentially at risk, showing commonalities as well as differences and interactions.

7. Risk Communication

Risk communication involves risk managers, risk assessors, the general public and stakeholders. Risk questions and answers presented in an integrated way show communalities and differences between the various receptors and will highlight the interaction between risk reduction options for individual receptors. Simple or unnecessary solutions to parts of the problem are avoided. This will increase understanding of often-complex problems and support coherent decision making which is acceptable to all parties. A ban of a specific OP in spite of the absence of proven risks for professionals or environmental organisms will be more easily explained and accepted when it can be demonstrated that there is an aggregated risk to children exposed via food and via household applications.

7.1 Summary

An integrated approach will increase the likelihood of understanding and acceptance of risk reduction measures in the risk communication stage.

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