DEVELOPMENT OF AN ENVIRONMENTAL INDICATOR WHICH CAN BE USED ON NATIONAL AND REGIONAL SCALES FOR EVALUATING PESTICIDE EMISSIONS IN THE NETHERLANDS

DENEER J.W.[1], VAN DER LINDEN A.M.A[2], LUTTIK R.[2], SMIDT R.A.[1]
[1] Alterra Green World Research, P.O. Box 47, 6700 AA Wageningen, The Netherlands
E-mail j.w.deneer@alterra.wag-ur.nl
[2] National Institute for Public Health and the Environment, P.O. Box 1, 3720 BA Bilthoven, The Netherlands

ABSTRACT

As part of the new governmental program on pesticides the Dutch ministry of Agriculture, Nature Management & Fisheries and the ministry of Housing, Spatial Planning & the Environment have jointly commissioned the development of the Dutch National Environmental Indicator for Pesticides. This has resulted in a tool which is able to estimate emissions and the resulting potential ecotoxicological effects resulting from the agricultural use of pesticides on a detailed geographical scale. The tool is able to give insight into contributions of individual crops, active substances and can distinghuish between times of application. Present capabilities are illustrated with some examples of results of calculations. Future developments will also be discussed in some detail.

KEY WORDS: Indicator, emissions, pesticides

INTRODUCTION

Government, business and growers in the Netherlands have been involved in a joint effort to reduce the use and emission of pesticides in the Netherlands over the last 10 years. This has resulted in a considerable reduction of emissions and environmental impact in the period of 1986 - 2000. A new governmental program, which has been introduced in the Netherlands in 2001, encourages growers to achieve an even further reduction of the emissions of pesticides.

One of the main difficulties when trying to assess the effects of such programs is that a direct assessment through monitoring of environmental quality (i.e. chemical analysis or monitoring of habitat quality or species diversity) is very costly, and results will always be prone to causality discussions which may preclude meaningful conclusions. For this reason it has become more or less common practice to carry out such assessments on the basis of theoretical considerations, using suitable modelling techniques.

In recent years the (acute) ecotoxicological effects of agricultural use of pesticides in the Netherlands have been assessed using a tool which made use of yearly sales figures, agricultural knowledge about the use of pesticides in crops (crop areas, dosage and frequency of application) and using emission characteristics for various emission routes based on physico-chemical properties of each pesticide and average geographical characteristics for the Netherlands as a whole (a.o. soil properties, temperatures, water/soil ratios). The sales data and emission characteristics were combined to yield yearly emissions, which were then transformed into effect parameters by taking into consideration the toxicological characteristics of each pesticide.

The main drawback of this approach is that the whole of the Netherlands is treated as a single geographic entity typified through average geographical properties for soil, meteorology, etc. In reality, however, using a pesticide in a given crop in different regions may result in widely different emissions as a result of the differences in the geographical characteristics of the regions. E.g. soil type and composition (organic matter content, acidity, density) will influence the leaching of the pesticide to ground water. The leaching behaviour of a given pesticide may therefore differ from region to region, and the overall yearly leaching of the pesticide will be dependent on the exact locations of the crops to which it is applied.

In view of these shortcomings it was decided to develop a more refined approach incorporating spatial information, i.e. taking into account that crops may be more dominant in certain regions, and using region specific information about a.o. soil characteristics and meteorological information. This has resulted in the development of a new tool, the Dutch National Environmental Indicator for Pesticides, commissioned by the Dutch ministry of Agriculture, Nature Management & Fisheries and the ministry of Housing, Spatial Planning & the Environment as part of the new governmental program on pesticides. This tool is intended to calculate emissions of pesticides and their potential impacts, and evaluate results of policy, over the period from 1998 – 2010. The tool is expected to have an operational lifespan of approx. 10 years, and will be continuously extended and updated until approx. 2010. Presently it is able to perform calculations using a user-defined choice of location, crop, pesticide and time for the Netherlands over the period from 1998 up to and including 2001.

The indicator calculates emissions into several environmental compartments (surface water, ground water, soil, non-agricultural soil and atmosphere) from agriculture, horticulture and glasshouses. Potential ecotoxicological consequences of these emissions are judged by comparing predicted environmental concentrations (PEC) and acute and chronic toxicity data for aquatic, soil and terrestrial organisms. The paper presents an outline of the information necessary to perform such detailed calculations, and will describe in some detail some of the emission routes included in the indicator. Moreover, a short outline on future developments is given.

GEOGRAPHICAL DATA

One of the aims during development of the indicator was to incorporate the possibility to perform calculations on a detailed geographical scale, taking into account differences between regions which may affect the emission and fate of pesticides. To this end the Netherlands were divided into approx. 136,000 geographical units (cells) of 500 x 500 m^2, for each of which information about crop areas, soil characteristics (density, organic matter, acidity), average air temperature and the presence or absence of surface water is available. Calculations are performed for each of these cells separately, which results in a very detailed picture of the emissions of pesticides over the Netherlands.

The following geo-information is incorporated into the calculations:

1. X,Y-coordinate of each cell. The Netherlands are divided into approx. 136000 cells of 500 x 500 m^2 each. The location of each cell is characterized by a unique combination of X,Y-coordinates;
2. For each of the cells the area of approx. 50 crops is known. The crop area is derived from a combination of LGN-4 information (land use assessment based on aerial and satellite information) combined with yearly updates of crop information gathered by the Dutch Central Bureau of Statistics (CBS). The description of crop areas based on LGN-4 information contains only broad classes of crops, e.g. cereals. The information gathered by the CBS contains more detailed information, which is updated yearly. Both sources of information are fused into a yearly updated description of the distribution of approx. 50 crops over the Netherlands, from which crop areas for each cell of 500 x 500 m^2 can be derived;
3. For 15 meteorological regions daily average temperatures over a 20-year period (1981 – 2000) were provided by the Dutch Royal Meteorological Institute. For each week (1 – 52) the average temperature for that week over the 20 – year period is known for each of the regions. Each 500 x 500 m^2 cell is assigned to one of the meteorological regions, thereby establishing the course of the average temperature over an entire year (weeks 1 – 52) for that cell;
4. Soil characteristics (organic matter content, density and pH) for each of the cells were taken from the STONE instrument (Kroon et al., 2001);
5. The ratio of the surfaces of water and soil for each of the cells is calculated on the basis of Top-10 vector information (Dutch Topographic Service.

AGRICULTURAL DATA

Several types of information are gathered under the heading of 'agricultural data', most of which deal with information about what pesticides are used in what crops and on the application techniques and dosages used for treating the crops. A distinction is made between application techniques used in the open field (e.g. spraying, dipping of bulbs, granules) and techniques used in greenhouses (e.g. spraying, fogging, dripping). Moreover, some information about the implementation of techniques used for the reduction of emissions (buffer zones, special spraying techniques) is available for 2000 and later.

1. The Agricultural Economics Research Institute (LEI - DLO) provides information on a weekly basis about the usage of pesticides in crops, including information about the plagues and diseases against which pesticides are used in what crop and at what dosages. The most recent version of this dataset was prepared for 1998. This set is complemented with results from the poll conducted regularly by the Dutch Central Bureau for Statistics (CBS) on pesticide use among a representative set of growers in the Netherlands. The resulting data set provides information about the use (dosage, frequency, application technique) of pesticides in approx. 50 different crops;
2. The Dutch Plant Protection Service provides information on yearly sales of pesticides (active ingredient) in the Netherlands. These are used to adjust the above-mentioned data so as to bring them in line with yearly total sales of each individual pesticide;
3. Information on the use of application techniques for the crops described. Growers often have a choice between 2 or more techniques, which differ in their emission characteristics. Much information about the use of distinguishable techniques in various crops has been incorporated into the estimations of emissions;

4. Information on the use of special emission reduction measures within several groups of crops, like the use of buffer zones and the use of special spraying nozzles. The results were gathered in 2000 by the Dutch Plant Protection Service (PD) and are used to assess the implementation of emission reduction measures in 2000 and later. It is assumed that prior to 2000 no such special measures were taken. Information on the progress of implementation of emission reduction measures later than 2000 are presently not available.

PROCESS ORIENTED INFORMATION

Emission calculations can be viewed as the quantitative description of the interaction between a pesticide and its physical environment. Calculation of emission therefore depends not only on detailed information about the physico – chemical properties of the pesticide (e.g. vapour pressure, degradability, solubility), but also on properties of the environment to which it is applied. Some of this information is already discussed under the heading of geographical data (e.g. temperature, soil characteristics). Some information, however, cannot or does not need to be geographically differentiated, but is specific for the crop under consideration, possibly changing over time. An example of such information is the influence of the growth stage of the crop, which for each crop varies in its own fashion with week number, on the interception of sprayed liquid, and hence on the distribution of the liquid (and pesticide) over crop and soil, which will affect the emissions to air, soil and ground water. As another example, calculations of emissions from glasshouses depend very much on crop properties like average height. In order to be able to perform calculations on the emission of pesticides, a multitude of such detailed information is needed.

EMISSIONS

Emissions are calculated using detailed agricultural information like total yearly sales, the weekly use of active ingredients in approx. 50 distinguishable crops and the areas used for each of the crops. Much of this information is updated on a yearly basis. Moreover, information about the use of different application techniques in various crops and the implementation of several emission reducing techniques, such as the use of special nozzles during spraying and the presence of buffer zones, is also included and updated whenever new results from national surveys become available. Whenever possible, calculations make use of procedures and data which are used in EU registration procedures (PEARL, TOXSWA).

<u>Surface Water</u>

Emission to surface water is calculated for the following routes:

1. Spraydrift as a result of applications using spraying techniques in the open field;
2. Leaching towards surface water (drains, lateral leaching);
3. Leakage of pesticides used in disinfection of bulbs through dipping;
4. Emissions from glasshouses, consisting of drainage of ground water, direct emission of condensate into surface water, emission through spouting of recirculating water containing part of the collected condensate and ground water collected through drainage, leakage of water from concrete floors and leakage of water from wool mats after removal from greenhouses.

5. Emissions via precipitation tanks of water used for rinsing mushrooms.

For some of the routes (drift, direct emission of condensate containing pesticides) emission occurs over a short time after application of the pesticide. For the other routes the relationship between the time of application and the time of emission is far from straightforward. Emissions through these routes are likely to be (non-uniformly) distributed over a longer period of time after application. For this reason the emissions are divided into 2 categories, i.e. the emissions contributing to acute load of surface water, and emissions resulting in a more chronic burden of surface water with pesticides.

Soil

Emissions to soil are supposed to occur only when applying pesticides using spraying techniques or through granules in the open field. When using granules, the emission to (into) soil is supposed to be equal to the dosage applied minus the amount evaporating. For spraying techniques the emission to soil is equal to the amount of spraying fluid reaching the soil (i.e. applied dosage minus the amount intercepted by crops) minus the amount evaporating from soil. The nett deposition on soil is used as the input for the calculation of the concentration in the soil compartment as well as the amounts and concentrations of pesticides transported into groundwater through leaching and the amounts and concentrations of pesticides transported towards surface water through lateral leaching and drains.

The deposition of spray drift on non-agricultural soil (i.e. soil which is not used for growing agricultural crops, but lying next to agricultural plots) is also calculated, using estimates of the fraction of agricultural plots which lie to non-agricultural land, and estimates on the presence of ditches in these situations.

Groundwater

The calculations of leaching of pesticides into groundwater are performed by using a metamodel of PEARL (Tiktak et al. 2000; Leistra et al., 2001), in a later version a metamodel of the GeoPearl model (Tiktak et al., 2002) will be implemented. The metamodel implemented now is a refinement of the metamodel incorporated in the USES system (RIVM et al., 2002). It consists of a table in which results from standard calculations are stored. For each month of the year, PEARL was run for 462 hypothetical substances, differing in half-live from 1 – 200 days and in sorption constant (K_{om}) from 0 – 200 dm^3 kg^{-1}. For the calculations establishing the table a standard spray application of 1 kg ha^{-1} to the soil surface was assumed and volatilisation was switched off, i.e. the calculation assumed a net soil deposition of 1 kg ha^{-1}. The resulting table contains the maximum average concentrations in the upper metre of the groundwater as a function of half-life and sorption constant. When calculation the leaching of a particular pesticide at a given location, its half-life is adjusted for differences in temperature between the location (taken from the geographical database) and the temperature assumed in the calculation of the results table. Similarly, the sorption constant of the compound is adjusted for the organic matter content of soil at the location under consideration and the organic matter content presumed during calculation of the results table. The leaching of the pesticide under consideration is then determined through logarithmic interpolation in the results table, using its adjusted half-life and sorption constant. Transport towards surface water through drainage and lateral leaching is calculated in PEARL alongside leaching into groundwater. The ratio between leaching towards surface and into groundwater is estimated from the ratio between water flows towards surface and groundwater, which is known for each 25 ha^2 cell.

Air

Emissions to air consist of:

1. Evaporation of spray liquid during application with spraying techniques in the open field);
2. Evaporation from crop surfaces in the open field;
3. Evaporation from the soil surface in the open field;
4. Evaporation of soil disinfectants (cis-dichloropropene and metam-sodium) after application;
5. Evaporation from glasshouses.

Volatilization from soil and crops is estimated using methods described by Smit et al. (1997, 1998). Emissions from glasshouses into the air are estimated on the basis of vapour pressure, and uses interpolation between experimental data reported by Baas and Huijgen (1992) as described by Lieffijn et al. (2000).

ECOTOXICOLOGICAL RISKS

Only acute toxic effects are presently considered. A method for the evaluation of chronic effects, taking into account transformation of compounds and the time lag between application and emission occurring for some emission routes, will be developed in the near future.

The first step in the assessment of ecotoxicological risks consists of the transformation of emission (loads in kg) into an estimate of the concentrations of pesticides resulting from these emissions in the various compartments: surface water, soil, ground water and food for birds (e.g. species of concern is Partridge *Perdix perdix*). Risks are then estimated through the comparison of this Predicted Environmental Concentration (PEC) with some measure of effect (e.g. an acute toxicity value) or some other norm (e.g. drinking water norm which allows for a maximum concentration of 0.1 $\mu g\ l^{-1}$ in ground water). This comparison results in what is referred to as an ‘indicator value’.

Indicator values are calculated using the following (eco)toxicological criteria:

1. Acute toxicity to fish (96-h LC50);
2. Acute toxicity to daphnids (48-h LC50);
3. Semi-chronic toxicity to algae (5 to 7-d EC50);
4. Acute toxicity to water species, using the lowest toxicity value of criteria 1 – 3;
5. Acute toxicity to terrestrial organisms (14-d LC50 of earthworms;
6. Acute toxicity to birds (LD50);
7. Norm for water used for the preparation of drinking water (0.1 $\mu g\ l^{-1}$).

RESULTS

As an illustration of the use of the newly developed indicator, the potential environmental effects due to the agricultural use of pesticides have been calculated over the period 1998 – 2001. The trends in the scores for several indicators for the Netherlands are given in Figure 1. All numbers are scaled using 1998 as the reference, i.e. 100%. The yearly sales of pesticides show a gradual decline over the entire period. The indicator values for potential acute toxic effects towards birds and worms show a gradual decrease over the entire period. The decline in score is somewhat larger than would be expected on the basis of the decrease of sales, which reflects the disappearance of some of the more toxic compounds from the market. Leaching and the potential acute toxic effects towards aquatic species have risen in 1999, after which these also show a gradual decline in common with the other indicator scores. The rise in 1999 in the leaching and drainage to surface water is largely the result of the higher use of propachlor in a.o the cultivation of onions. Restrictions in this use contributed to the decline in later years. The ban of atrazine in 2000 also resulted in a decrease of leaching, not only of atrazine but also of bentazone, since these compounds were often used together in a single formulation.

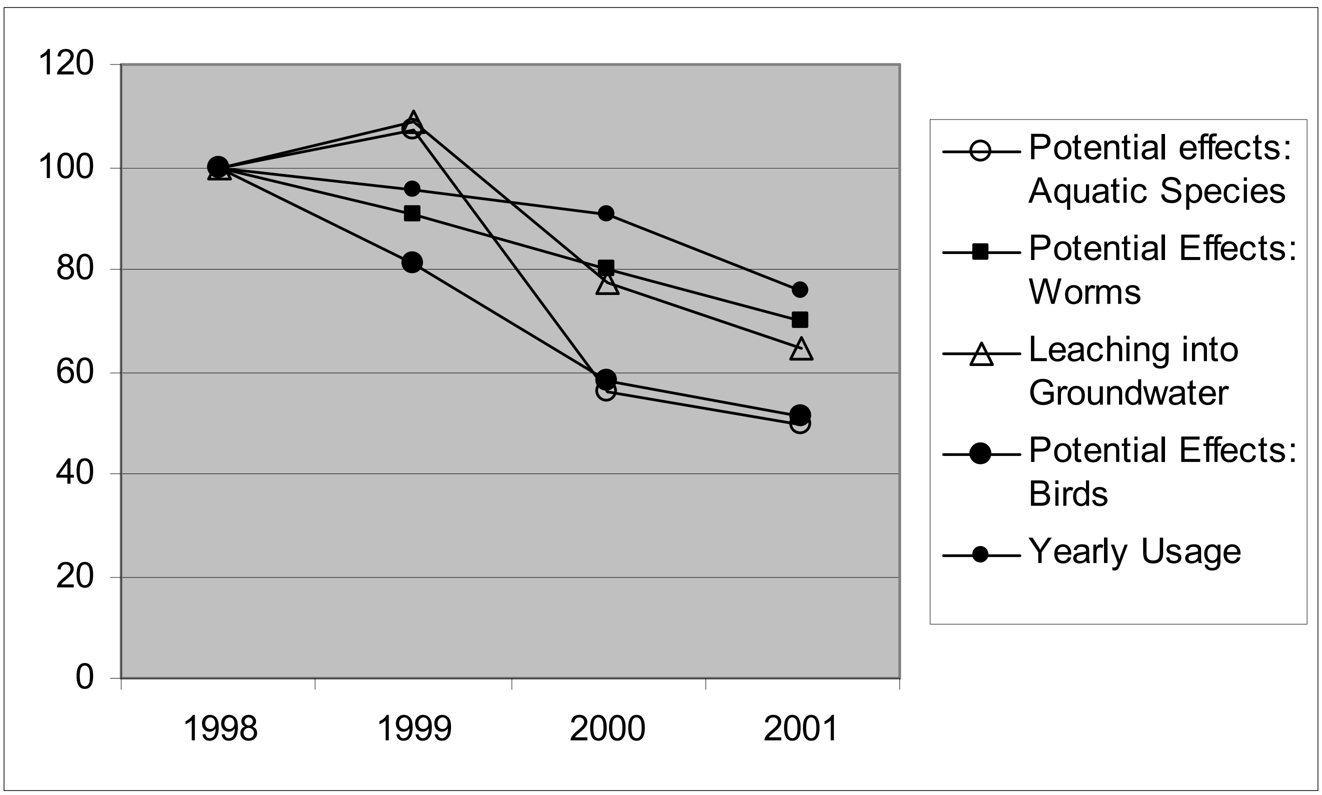

Figure 1: Course over time of potential acute toxic effects scores for aquatic and terrestric organisms and leaching into ground water. Values are given relative to 1998, which is taken as 100%

Table 1 gives the contributions of several sectors to the indicator calculated for the leaching of pesticides into groundwater in 1998. It is obvious that the score per hectare differs widely between sectors.

Table 1: Indicator scores for the leaching of pesticides into groundwater (indicator points per hectare) in 1998.

Sector	Score for leaching of pesticides into groundwater in the Netherlands in 1998 (Points / ha)
Arable farming	163
Bulbs	873
Floriculture (open air)	292
Fruits	499
Vegetables (open air)	176
Cattle (including maize)	4

Analysis of output data is possible by choosing crop, active substance, region and time. Tools for rapid dilation of the huge amount of data generated, enabling fast preparation of tables, maps etc., are being developed. More detailed investigation of data is also possible using geographical information (GIS) systems.

FUTURE DEVELOPMENTS

Some of the extensions planned for 2003, possibly enduring in 2004 are:

- Use of semi-chronic toxicity parameters. Besides the use of semi-chronic toxicity data on single species (LC50, EC50) and multiple-species level (MTR, HC5), this necessitates the implementation of procedures describing the disappearance of pesticides in soil and surface water over time through breakdown and volatilization;
- Coupling of air-transport models to the risk indicator, enabling a quantitative estimation of atmospheric deposition and its potential impact on terrestric and aquatic life in non-agricultural areas;
- Replacement of PEARL with GeoPEARL. Since calculations with (Geo) PEARL are very time-consuming a metamodel will probably have to be used;
- Coupling to PERPEST (van den Brink et al., 2002) or similar models in order to identify the most vulnerable ecosystem components and species on the basis of expected exposure concentrations;
- Integration of chemical monitoring data into the instrument. Joining of emission estimates and actual measurements of pesticides in surface water will result in the opportunity of a validation of the calculation schemes used in the indicator.

CONCLUSION

The Dutch National Environmental Indicator for pesticides has primarily been developed for the evaluation of Dutch policy on plant protection products. Potential effects have decreased by 40 – 60% over the last four years, but a further decrease is necessary to meet the goals set.

Although the risk indicator is currently aimed at describing and evaluating the situation in the Netherlands, the general methodology used makes it suitable as a blueprint for the development of similar tools in other member states of the EU as well. First goals are, besides actually using the tool for evaluation of policy, the further development of the functionality of the tool and the methodologies employed, focussing on the points given above, and identifying the data needs for successfully using the tool in other member states of the EU.

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