FINAL REPORT

DEVELOPMENT OF AWARENESS TOOLS FOR A SUSTAINABLE USE OF PESTICIDES

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Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person:
Mrs Christine Mathieu
Secretariat: +32 (0)2 238 37 61

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY (SPSD II)

Part 1:
Sustainable production and consumption patterns

FINAL REPORT

DEVELOPMENT OF AWARENESS TOOLS FOR A SUSTAINABLE USE OF PESTICIDES

CP/33

Prof. H. Maraite (UCL)
Prof W. Steurbaut (UGent)
Dr. ir. P. Debongnie (CERVA/CODA)

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With a users committee composed of

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Introduction

Prior to the Second World War, the authorities required farmers to provide food for the whole population. This meant intensive production, which was sometimes implemented with little consideration for the future. Intensive farming and the need to produce high yields led to an increase not only in mechanisation but also in the use of pesticides for plant protection.

During the 1980s, as surpluses in agricultural products began to appear, high production rates were no longer seen as a priority. Since 1992, various measures (including set-aside of agricultural land, and reduction of subsidies) have been taken to reduce the surpluses. By the end of the 1990s, a degree of equilibrium had been achieved.

In addition to the surplus problem, questions were being asked by a general public that was becoming increasingly anxious about production practices in Europe, and the effect of these practices on both agricultural products and the environment (land, soil, water and the atmosphere). The image of Europe’s agricultural practices and products is greatly enhanced if its farmers are seen to be using environmentally acceptable production techniques.

In 2003, the area under agricultural production in Belgium covered 1,390,288 hectares, representing about 43% of the country’s land area. With this amount under production, there are clear positive (quality of the landscape) and negative (river pollution) effects on the environment.

The use of plant protection products (ppp) in agriculture in Belgium is widespread. Between 9,000 and 10,000 tons of active ingredient ppp are marketed annually in the Belgian agricultural and non-agricultural sectors.

Side effects of the use of ppp include: toxicity risk to the person applying the ppp (farmer), presence of residues above the threshold level in food, development of resistant pathogens (recently strobilurine resistance in Septoria) and damage to natural resources (accumulation of active ingredients in ground water).

Awareness of these side effects has led the authorities to promote, in the context of sustainable agriculture, more environmentally friendly use of ppp and the development of alternative protection methods. Some recommendations (such as sprayer control and ‘best practice’ guidelines) have been successfully implemented in the agricultural sector.

In order to assess the improvements being made, tools are needed to measure the significance of these improvements and how they are contributing to the sustainable use of ppp in both the agricultural sector and the non-agricultural sector (industrial use, domestic use, at community level, etc.)

Thus, it is important to put in place a **Risk Indicators System (RIS)** to monitor and manage the safer use of pesticides within the framework of good agricultural practice.

During this project, a new RIS was developed: POCER-2. This is not just one more pesticide risk indicator system adapted to local conditions. It also brings some progress in the following aspects: a wide multi-compartmental risk assessment for fourteen compartments; a specific compartmental aggregation procedure where the relative importance of compartment ranking is clearly reserved to the appreciation of the stakeholders of the "pesticide question"; a spatial, temporal and a.s. risk aggregation procedure based on distribution frequency of risks; a F.E.A.R. index based only on risk considered as excessive and which puts the emphasis on higher risks compared to lower ones.

POCER-2 is an evolution of POCER-1 which is simpler and presently used in Flanders in the framework of integrated crop management for fruits and vegetables productions.

In order to answer the Belgian federal request for a RIS, a simplified version of POCER - 2 was proposed. It was named PRIBEL. This RIS assess the risk from pesticide use on seven compartments; those for which data are available at the country level. Aggregation in PRIBEL is reduced to single sums in order to obtain a global indication on the risk pressure.

From the begin of 2004, the European Commission also funded the HAIR (Harmonised environmental indicators for pesticide risk) research program aimed to defined a RIS for EU. In this framework, aggregation methods, applicator indicator, bystander indicator and farm-worker indicator issued from this OSTC research program are yet on study.

The first stage of the present study involves identifying which of the current indicators are relevant to the objectives (cf. point 2.2.). Toxicological and ecotoxicological data were selected from the literature (scientific papers or registration documentation) and from existing databases (such as Ecotox and Agritox). The indicators are then aggregated in an RIS. A survey was also then be conducted among farmers to identify the major parameters that influence their pest control strategies. The survey results have determined which indicators are most useful and will provide a better understanding of the factors that influence the decisions made by farmers when they are confronted with a choice of plant protection strategies. In the second stage, the RIS have been validated as far as possible in relation to surface water quality monitoring; but also on the basis of an expert evaluation. In the final stage, this tool is used to assess the impact of various measures (current or proposed) on human health and the environment.

For a better comprehension of the text, the signification of the acronyms used is grouped hereafter:

- **PPP**: **P**lant **P**rotection **P**roduct
- **AA**: **A**gricultural **A**rea
- **PRI**: **P**esticide **R**isk **I**ndicator
- **RIS**: **R**isk **I**ndicators **S**ystem
- **Kv**: **K**ey **v**alue
- **a.s.**: **a**ctive **s**ubstance
- **POCER**: **P**esticide **OC**cupational and **E**nvironmental Risk
- **TERI**: **TE**rrestrial **R**isk **I**ndicator
- **RS**: **R**isk **S**cores
- **CAPER**: **C**oncerted **A**ction on **P**esticides **E**nvironmental **R**isk indicators
- **CIPF**: **C**entre **I**ndépendant de **P**romotion **F**ourragère
- **PUI**: **P**esticide **U**se **I**ndicator
- **F.E.A.R.**: **F**requency and **E**xcess **A**pproach of **R**isk
- **MRL**: **M**aximal **R**esidue **L**imit
- **DSS**: **D**ecision **S**upport **S**ystem

Part I Objectives

I.1. *Objectives*

Select or develop a **R**isk **I**ndicators **S**ystem (RIS) in order to estimate the impact of the use of pesticides on the food chain, on the environment, on the farm and societal economy.

Gain knowledge on the way farmers are facing, integrating and managing the socio-economic, agronomic and environmental constraints.

Use of the RIS to estimate the advantages and the disadvantages of various measures, as for example, the application of grass strips along rivers or restriction in the use of compounds or an environmental policy.

Propose scenarios and tools to support farmers, extension services and also politicians in their decision for a more sustainable use of pesticides.

I.2. *Expected outcomes*

1. The project aims to provide a RIS for the assessment, at farm scale, of the impact on the environment and on the economy of present and new crop protection methods.

2. According to human health and environmental risk, a ranking of the pesticides will be performed with the RIS.

3. The tool will be used as a decision aid system for the farmer, grower and other land manager in order to minimize the side effect of pesticides applications.

4. Extension services will use the RIS to provide more accurate advices for a sustainable crop protection.

5. If possible, the RIS will be regionally adapted in order to provide the public authorities with a decision support system.

Part II Material and methods

II.1. *Selection of representative scenarios (region / crop / pesticide)*

II.1.1. GIS- approach

A database for **PPP** (**P**lant **P**rotection **P**roduct) use was created from research reports [1-6] and from a publication [7]. This was completed with a database of croped area in Belgian regions.

II.1.2. Stratification on basis of farming structures

Stratification of the farm was performed on the basis of the following criteria:

- Share-out of the AA use;
- Technical-economical orientation;
- Specific categories of the declarants;
- Farm size;
- Farm activity expectative for the future.

All this information were collected from the agricultural census made, in 1999 and 2000, by national statistical information [6, 8].

II.2. *Development of a global indicator*

II.2.1. Study and evaluation of existing indicators and databases concerning pesticides

The indicator study was based on a literature review of the last twenty years. The information was analysed in order to obtain a clear definition of some basis concepts and to create a practical typology of the pesticides indicators. Indicators were analysed on following aspects:

- The environmental compartment(s) on which they are focussed;
- The calculation method(s) on which they are based;
- The method(s) used to aggregate the results when the indicator is focussed on several environmental compartments;
- The scoring method(s) used to transform the variables into categories.

The review was written in order to obtain an operational database of existing indicators including all the required information to understand the way they are built, and to use them in the framework of the global indicator design.
Several typologies of indicators were tried until one was found most effective to explain and hierarchies the hundred indicators reviewed.
A first text of the literature review was already presented in the 2002 research report. An updated version of this text is presently in preparation for a publication in a scientific journal.

In January 2003, the research group got the opportunity to participate to the OECD TERI working group activities. **TERI** (**TE**rrestrial **R**isk **I**ndicator) is a group of scientists and administratives in charge of pesticide risk assessment methodological studies. The study program for 2003 was to compare four pesticide indicators for a national risk assessment.

In 2000, the laboratory of plant protection chemistry at Ghent University has finished the first version of the POCER indicator [9]. In this frame, a database was set up to carry out the calculations. This database, containing physico-chemical and (eco)toxicological data of about 400 active substances, has been used as base for the POCER-2 project.

II.2.2. Elaboration/Updating of the data bank about the physico-chemical, toxicological and ecotoxicological characteristics of pesticides that are registered for the identified cultures of task A.

Each active substance of the data base was indexed with a CAS number in order to avoid confusion due to multi-language appellation of molecules.
Several data sources were used, following this priority: European authorization report (http://europa.eu.int/comm/food/plant)– active substance data from firms – CTB database (http://www.ctb-wageningen.nl) – Pandora’s box [10] – Pesticide manual [11] – Extoxnet (http://extoxnet.orst.edu) – Toxnet (http://toxnet.nlm.nih.gov) – other scientific literature. Due to the confidentiality between Ghent University and the phytopharmaceutical industry, data can only be used in calculations and can not be made public.

II.2.3. Selection and/or development of indicators

Due to the fact that the selection of indicators is dependent of the global indicator characteristics, this task was realized together with Task B.4.

The first selection of indicators was based on the following principles:

- PRI is preferred to a RIS;
- if no suitable PRI is registered for a specific compartment in the indicator database (result of task B.1.), a further literature search is required;
- if, finally, no suitable PRI is available, a specific PRI should be developed.

Each PRI was equipped with a threshold value named **K**ey **v**alue (**Kv**) in order to make it possible evaluating the relevance of the indices. The indices are then shared into two classes: Excessive values for the indices that exceed Kv and targeted values for the indices below Kv.

In the context of the pesticide risk evaluation it makes sense to modulate the level of relevance of the indices according to their distance to Kv. The fuzzy logic methodology [12, 13] was used to address this problem. With this approach, the membership of an index to a class is progressively modified when the value get closer to the limit. Membership functions were chosen in consideration of the studied system. Membership values were then defuzified in order to obtain Risk Scores (RS).

A complete explanation on these aspects is reported in annex : "Multi-compartmental assessment of pesticides risks with POCER"

II.2.4. Aggregation of the selected indicators into a global indicator

The aggregation methodology was based on the result of the literature review out of the study of existing indicators. PRISs and RISs were analysed in dept for their aggregation procedures. Several aggregation levels were then characterised (see III.2.1.).

The aggregation levels were then studied separately and various aggregation procedures were tried. The aggregation procedures were presented and discussed in several meetings (e.g. research coordination meetings and OECD TERI workshops).

II.3. *Validation and improvement of the global indicator*

POCER-2 was developed in an iterative process. First, a prototype was designed. This was tested on a set of 15 pesticide applications which environmental risks were already assessed by 8 RISs in the CAPER research [14]. The prototype was then improved on the basis of criticisms of the results. The set of 15 applications was used as reference scenario for every evolution of the prototype.

II.3.1. Validation for Human and environmental exposure

POCER-2 was validated at two levels:

- The physico-chemical and (eco)toxicological database;
- The fourteen indicators composing POCER-2.

II.3.2. Validation for technical and socio-economical aspects

Different surveys have been realized among the field crop, fruit and vegetable producers. The purpose of these surveys was to estimate the knowledge, the attitudes and the practices of the Belgian farmers about the custom of pesticides.

The purpose of these inquiries is, on one hand, to understand the behaviour of the farmer when he has to decide to treat his crops and to highlight the elements that play a part in the decision-making. On the other hand, to identify the form of the system of evaluation of impacts pesticides to maximize the cover of different actions led to reason the use of the ppp in the agricultural sector.

The survey was elaborated on the basis of the methodology enounced in the Luc Albarello book “Apprendre à chercher” [18]. The survey questionnaire was written after a Sonecom (*sondages, études et communication*) methodology training focussed on surveys in agricultural environment.

Due to the complexity of the required objectives, a method of individual survey (face to face) not exceeding an hour was selected. The individual survey makes it possible to the farmer to make, without influence, his remarks and suggestions about the use of the ppp.

The questionnaire was elaborated on various assumptions which were tested near 10 farmers. The questions were elaborate in order to check these assumptions. The majority of the questions were with multiple choices in order to facilitate the data processing.

In order to avoid the Halo effect [18], some particular aspects are questioned several times. The questionnaire was improved progressively in an iterative process where proposals were submitted to every scientific partner for criticisms and suggestions.

The questionnaires were specific to field crop, fruit crop and vegetable crop farming systems. Nevertheless, most of the questions were similar in order to facilitate the treatment of the results. The results were treated by the statistic software SAS 8.0 and by the software Excel.

II.4. *Evaluation of various crop protection schemes with the global indicator*

II.4.1. Use of POCER-2 in various scenarios

In a later stage of the prototype development, various scenarios of applications were tested:

- *Atrazine* substitution scenario provided by CIPF (**C**entre **I**ndépendant de **P**romotion **F**ourragère) wich is one member of the Stakeholders Committee of the research.
- Apple - best case scenario of CAPER research [15].
- Winter wheat scenarios of CAPER research (reported as example in annex: "Multi-compartmental assessment of pesticides risks with POCER")

II.4.2. Analysis of scenarios tested with specialized Technical Centers

Some specific scenarios have been worked out with POCER-2 and have been sent to members of specialized Technical Centers in order to have their comments on the indicator. The mean objectives of this task are:

- Clearness and audibility of the indicator
- Interpretation of the results
- Formulation of remarks
- Possible improvements/corrections in the indicator

II.5. *Finalisation*

II.5.1. Finalisation of the RIS

Due to the time required for the POCER-2 development, the software is not ready for a large dissemination. Nevertheless, the extension opportunities and constrains were analysed. Short and long term dissemination proposals were developed.

II.5.2. Lessons of analysis of the scenarios tested with specialized Technical Centers

Self-tested scenarios and scenarios evaluated by experts from Technical Centers might reveal problems and shortcomings in the current POCER-2 version. Based on the comments, adaptations will be made in order to optimize the global indicator.

<u>Part III</u> Results and discussion

III.1. *Selection of representative scenarios (region / crop / pesticide)*

III.1.1. GIS- approach

Quantities of a.s. applied were calculated at a regional level for adapted crop samples.
Pesticide use in Belgian regions was calculated for various crops in order to support the selection of representative farms for the inquiries (Tasks A.2. & C.2.).
More explanation on this task is available in the annual report for 2002.

III.1.2. Stratification on basis of farming structures

For one region, we combine, for each crop, the cultivate area with the active ingredients use for it. We obtain the repartition of the PPP application.

The “field crops” account for more than 80% of the PPP use in Belgium. The winter wheat, the barley, the potatoes, the sugar beat and the maize crops cover more than 90% of the area.

The Brabant Wallon is representative of the field crops exploitations. The green forage, cereal, sugar beat and potatoes crops cover about 80% of the AA. At more, the PPP application on these crops represents about 90% of the total PPP quantity use in this region.

III.2. *Development of a global indicator*

III.2.1. Study and evaluation of existing indicators and databases concerning pesticides

As a result of the literature review concerning the pesticide indicators, several concepts were specified. The major ones were:

1. Pesticide Use Indicators (PUI) : total amounts of PPP used or total number of sprayings;
2. Pesticide Risk Indicator (PRI): a parameter based on a combination of hazard and exposure that provide information about the risk of pesticide use on a single environmental compartment (e.g. crustacean, birds, ground water);
3. Risk Indicators System (RIS) : evaluation of the impact of several PRI’s (implies not only toxicology, but also attributing relative importance to different categories of non-target organisms, which leaves the realm of objective science to enter that of values judgment);

4. Risk is addressed at various aggregation levels that shouldn't be confused. The lowest one is a risk assessment for one compartment of a single a.s. on a single place and at a single time. The highest level of aggregation is reached when the risk is assessed for multiple compartments and a.s. on several places and for several application periods (e.g. annual risk assessment at a national level for multiple compartments).

More than hundred indicators were studied and registered in a database (already presented in the research report 2002). PRI's were more abundant than RIS's and the most frequently assessed compartments were those concerning living organisms in surface water.

A specific analyse of the Frequency of Application indicator was realised. The study concluded to the non-relevancy of this indicator as PRI at the Belgian level and to the necessity of a pluri-PRIs approach. The report of this study was published in Pesticide Outlook journal (cfr paper in annex).

The participation to the study program of OECD TERI group resulted to a methodological comparison of five PRIs applied to the Belgian pesticide sales statistics over the last twenty years. The results show that major risk variations over the studied period are explained by only few molecules. Risk patterns for the various living organisms vary widely in function of the pesticide category (herbicides, fungicides, insecticides) analysed. These variations are hidden when all the pesticide categories are analysed together. When the risk is assessed simultaneously on several living categories (earthworms, birds and bees) the pattern is again very different.
This study was reported to OECD [16]. The report is presented in annex.

In frame of this project, no better database, taking into account the Belgian situation, was found then the one used for the POCER-1 project. The most representative data can be found in the European registration dossiers. At this time, only few of them are yet available. Due to the agreement between Ghent University and pesticide producing firms, data can already be obtained even before the European Commission has given his agreement. In most cases, those data from firms are approved and published in the European registration dossier.

III.2.2. Elaboration/Updating of data bank the physico-chemical, toxicological and ecotoxicological characteristics of pesticides that are registered for the identified cultures of task A.

Around 500 active substances are registered in the data bank. The main physico-chemical, toxicological and ecotoxicological characteristics, needed for further calculations are mentioned:

DT_{50}	Degradation time for 50% of the ingredient (half-life)
K_{om}	Organic matter/water partition coefficient
K_{ow}	Octanol/water partition coefficient
ADI	Acceptable daily intake
AOEL	Acceptable operator exposure level
EC_{50}	Effect concentration for 50% of the observed population
NOEC	No observable effect concentration
LC_{50}	Lethal concentration for 50% of the observed population
MTC	Maximum tolerable concentration
LD_{50}	Lethal dose for 50% of the observed population
GUS	Ground ubiquity score
HRAC/IRAC/FRAC	Resistance code

III.2.3. Selection and/or development of indicators

Fourteen compartments were selected for risk assessment: food consumers, pesticide applicator, bystander of a field application, farm-worker in treated fields, beneficial arthropods, bees, birds, earthworms, water organisms, ground water, soil air, resistance induction on pests, and farm costs linked to the quality/price ratio of the pesticide selection. For each compartment a risk indicator was selected from the literature or developed. For each indicator, a Kv was defined and adapted membership functions were calculated in order to obtain a Risk Score from –10 up to + 10.

Cf. annex "Multi-compartmental assessment of pesticides risks with POCER" for detailed information.

III.2.4. Aggregation of the selected indicators into a global indicator

The **POCER-1** (**P**esticide **OC**cupational and **E**nvironmental Risk, version **1**) RIS [17] was used as model to design the global indicator. Due to its major inspiring source, the prototype was named POCER-2.

POCER-2 was designed in order to assess the risk of pesticide use for three major centres of interest: Human health, Agriculture sustainability, and Natural resources.

Finally, after many revisions an aggregation procedure was defined for the spatial, temporal and a.s. levels. Another aggregation procedure was designed for the compartmental level on the basis of a subjective ranking of the compartments.

The results are expressed:

- In a Risk Score for single application of one a.s.;
- In F.E.A.R. index (Frequency and Excess Approach of Risk) for multiple applications;
- In a risk frequency distribution figure for multiple applications.

A complete explanation on these aspects is reported in annex: "Multi-compartmental assessment of pesticides risks with POCER"

III.3. *Validation and improvement of the global indicator*

III.3.1. Validation for human and environmental exposure

III.3.1.1. Validation of the physico-chemical and (eco)toxicological database

The validity of the physico-chemical and (eco)toxicological data on which POCER-2 calculations are based is of major importance. Task B.2. was devoted to the development and validation of the physico-chemical and (eco)toxicological database.

III.3.1.2. Validation of the fourteen indicators composing POCER-2

Nine PRIs out of the fourteen indicators of POCER-2 are based on previous researches where indicators validation were partly validated. In general, only the exposure aspect of the PRIs is validated by authors. Validation of risk would require specific studies that practically don't exist. From the five other indicators, two are simple pesticide parameters that don't need any validation. The three last indicators are new PRIs build specifically for POCER-2.

One of them is devoted to consumer risk assessment and the exposure is given by the **MRL** (**M**aximum **R**esidue **L**imit) of the product. The two other PRIs are concerning the pesticide resistance induction and the pesticide effect on beneficial arthropods. For both of them, exposure route to pesticides is simply proportional to the applied dosage. These three new PRIs were built on the base of an expert judgement given the present knowledge. Verification of the adequacy of such assumptions would imply some specific researches that are out of the scope of this project.

III.3.2. Validation for technical and socio-economical aspects

III.3.2.1. Fruit and vegetable culture

A survey was carried out among fruit and vegetable growers. No province was found were more then 70% of the amount of pesticides and more then 70% of the agricultural area (AA) was used only for fruit or vegetable culture. Therefore, it was decided to conduct the survey based on the percentage of the total surface for fruit or vegetable culture in each province.
Since most growers deliver their products to the auction, it was decided to contact the auctions of Mechelen (VMV, Vlaamse Mechelse Veilingen), Roeselare (REO-veiling) and Sint-Truiden (BFV, Belgische fruitveiling).
Between January and December 2003, surveys were passed around on several meetings of the growers. This resulted in 100 surveys for fruit culture and 114 surveys for vegetable culture.

It can be concluded that fruit and vegetable growers are quite well informed about the use of pesticides and the possible impacts on the environment. Still, the impact on the environment is not the most important in the decision taking concerning pesticide use. When treating crops, their own health and economical advantages are the main concerns of the growers.
Further information from the government on environmental and human impact is still necessary. Therefore, the main information sources of the growers, such as the auctions, personal advisors, … must be involved.
A majority of the interviewed growers thinks that the POCER-2 indicator could change their way of using plant protection products. There is one condition: the results must be presented in a clear, simple and understandable way, by a number, colours or a graph.

The full results can be found in the annex 1.

III.3.2.2. Field crop survey

The field crop survey results are based on the study of 100 farms belonging to the "field crops" and "mixed farming". These farming types use more than 80% of the pesticides applied in the Belgian agriculture.
The results presented here are necessary for the good development and validation of the POCER-2 indicator. The other survey results (socio-economic, environmental and spraying aspects) are

summarized in annex 2.The crop distribution and the special distribution in the sample are, in general, representative of the Walloon Brabant Province (annex 2).

The survey shows that, regardless of the crops, the farmers regularly consult two principal sources: the company sales representative (about 90% of the farmers consult him more than once a season) and the decision support system (considered as an information source and not as a tool allowing reduction of pesticide applications).

Looking at the health categories, we observe that the farmers differentiate between their personnel (operator and farm workers) and other people (consumers and bystanders) health. The farmers are aware that the operators and the farm workers are exposed during spraying to a higher risk than the consumers and bystanders. Although the perception by the farmers of any change in the risk level is the same for the bystanders, on the one hand, and for the operator and the farm worker, on the other hand, it seems to be based on different scales.

The farmers do not make significant differences between the PPP toxicity on the different environmental constituents (soil, water, air, birds, etc.).

The farmers have a slight preference for figures representation of POCER-2. The figure representation is easier to read than the other representations. But, more than the preference the results comprehension must be taken into account. The good comprehension of the results presented by figures is interesting to note but there is no significant difference with the comprehension of the rose representation.

III.4. *Evaluation of various crop protection schemes with the global indicator*

III.4.1. Use of POCER-2 in various scenarios

Several scenarios have been tested in order to compare the results and make the necessary adaptions. E.g. scenarios were tested with protective clothing and without protective clothing for the applicator and worker, also different formulation types were compared, … In general, the results were satisfying and sensible to small variations in the input data.
Problems occurred in the integration phase. Once one risk index cannot be calculated, due to lack of parameters, the integration can not succeed. It is thus very important not only to give the final result after integration, but also the intermediary results so that comparison of different scenarios is possible.

III.4.2. Analysis of scenarios tested with specialized Technical Centers

Globally, the experts of the Techical Centers gave a positive evaluation of the POCER-2. The main remark was the problem of understanding the FEAR-integration method. Clear information must thus be provided to the users of the POCER-2 indicator.
Some scenarios were also worked out for applications in greenhouses. Several remarks were given on the results. The problem here is the lack of adequate input data. The existing literature and models are not sufficient enough to obtain realistic results.

III.5. *Finalisation*

III.5.1. Finalisation of the RIS

The software is presently available from any computer equipped with Microsoft Excel or equivalent. There is still a need to build an user interface for more conviviality and to facilitate the input of scenarios.

Considering:

- The complexity of the risk assessment and the absolute necessity to analyse every situation with expertise;
- The fact that the physico-chemical and (eco)toxicological databases on which POCER-2 is based need to be frequently up-dated;
- The numerous confidential data included in the ecotoxicological database;

it would be better to have access to the POCER-2 *via* an Internet application. The solution would be convenient for implementation of database updating and to respect the confidentiality restrictions. Nevertheless, this solution doesn't allow to provide an expert analyse of outputs and requires the RIS to be adapted by informatics’ specialists.

Another solution to make POCER-2 available to users is to print a CD Rom with the software and the required files for installation. There is then a need, if technically feasible, to protect the data for confidentiality reasons. Updating of databases is then only feasible with re-editions of the CD-Rom and no expert analyse can be provided.

Taking into account the above considerations, a convenient solution until an Internet application is developed is to make POCER-2 available from the three research units where it was developed.

III.5.2. Lessons of analysis of scenarios tested with specialized Technical Centers

In general, the POCER-2 indicator gives satisfying results for different scenarios. The users of the indicator should get enough information on the interpretation of the results, so that the output becomes clear and understandable.
Due to a lack of basic information, some risk indices cannot always be calculated, so that the integration procedure cannot be carried out. Especially the risk indices for consumer, resistance and price should be reconsidered in the future.
It is very important to emphasize that the POCER-2 indicator is very sensitive to small changes in the input data.
The problems which occur at this stage of the project, mainly have to do with parameterisation, more then with calculation aspects. Finding the most adequate parameters is the challenge for the future.

Part IV Conclusions

IV.1. *Recommendations*

From the selection of representative scenarios, it appears that a tool to select representatives region-crop combinations was successfully developed and applied for support the inquiries sample selections.

From the study and evaluation of existing indicators, it appears that more than hundred indicators are already developed for assessing the risk of pesticide use. Important distinction is to be made between PRI's and RIS's. Several risk aggregation levels were defined.

From Tasks B.3., B.4. and C.1. it appears that an RIS, named POCER-2, with fourteen compartments was designed and tested. Two aggregation procedures were designed: one for spatial, temporal and a.s. aggregation, and the other for compartmental aggregation.

It appears from task E that POCER-2 should be extended at long-term by an Internet site, but, considering the present situation, the software should be available to users from the three research teams that have developed it.

IV.2. *Conclusion on fruit and vegetable culture survey*

It can be concluded that fruit and vegetable growers are quite well informed about the use of pesticides and the possible impacts on the environment. Still, the impact on the environment is less important in the decision taking concerning pesticide use. When treating the crops, their own health and economical advantages are the main concerns of the growers.

Further information from the government on environmental and human impact is still necessary. Therefore, the main information sources of the growers, such as the auctions, personal advisors, … must be involved.

The first steps toward sustainable horticulture are made. Growers, government and other involved parties must now work together to successfully pass the following steps.

IV.3. *Conclusion of the field crop survey*

The socio-economic situation of the farmers is very diverse and this makes it difficult to classify them.

The management and information sources of the farmers are important and diverse, but two are particularly notable: the company sales representative and the decision support system. These sources would be effective for raising farmers' awareness with regard to their health and to the environment.

Despite their ability to read and understand the indications on the product labels, the farmers have poor knowledge of the danger pictograms.

The sprayers are well equipped. It is important to note that tank bottom treatment is linked to the annex tank equipment.

The farmers do not protect themselves with protective accessories. Despite being worried about their health, they do not take all the measures necessary to preserve it.

It appears that improvement of phytosanitary practices must be integrated in a global plan of training and information. The fact that 27% of the farmers suffered illness after pesticide use could be useful in the development of general awareness of the risks linked to pesticide use.

Although the farmers are aware that there are risks to the health of the applicators and farm workers, only 50% use protection during spraying. It would be interesting to encourage initiatives that promote good practice in pesticide handling.

The indicator results must be sufficiently readable, comprehensible for the majority of the farmers. The POCER-2 report, given to the farmer, must be presented as a form of figure table or a rose for a better comprehension.

IV.4. *Future prospects and future planning*

IV.4.1. Surveys

According to the treatment of the data, some questions had not impact expected. Of more some information were not approached by the surveys. By way of example, the surveys did not approach the availability to data processing, the access of the farmers to the Internet (to have an access to the decision support system).

In short, these surveys have allowed to define the action scope. But it should be interesting to spread the surveys to the different Belgian areas and in order to examine differences in the PPP use between these areas. This work may be done in a “mémoire de fin d’étude” in one of the institution worked on this project.

The investigation made obvious two information sources (the company sales representative and the decision support system). It would be interesting to sensitize the farmers through these ways.

IV.4.2. Indicator POCER-2

Aggregation procedures and Human health compartments risk indicators of POCER-2 will be used as a starting point in the European research HAIR (2004 – 2007).

POCER-2 will be used in the Belgian research “ LABELS AS A STRATEGY FOR SUSTAINABLE DEVELOPMENT AND THE ROLE OF LABELLING” (2004-2006) funded by OSTC.

There are three possible ways to valorise the POCER-2 indicator:

- To keep POCER-2 in one of the three organisms that work on the elaboration of it (UGent, VAR and UCL). For example, the “Comité regional PHYTO” could take aver

the responsibility to elaborate the impact report for customers interest in an evaluation of different PPP strategies.
- To make a public database. But there is the database confidentiality problem. Without public database this solution is no possible.
- To develop a paying interactive web site (in the same way as the Milieumeetlab). But there are too the security and confidentiality problem.

Presently, only the first solution is feasible. If there is possibility to solve the database confidentiality question, the valorisation of POCER-2 should be easiest.

The surveys have revealed two principal information sources: the company sales representative and the decision support systems. It would be interesting to valorize the indicator POCER-2 by these ways.

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Van Bol, V., P. Debongnie, et *al.* (2004). Study and Analysis of Existing Pesticide Risk Indicators. Tervuren, Veterinary and Agrochemical Research Center (VAR).

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Claeys, S., Marot J. et *al.* (2004). Landbouwers en bestrijdingsmiddelen : kennis, houding en gedrag: resultaten van een enquête in fruit-, groeten- en akkerteelt (2002-2003).

The research is also presented on internet at
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Part VII Annexes

Annex 1: Survey fruit and vegetable culture

Annex 2: Study of the farmer's decisional process towards sustainable use of pesticides

Annex 3: Multi-compartmental assessment of pesticides risk with POCER

Annex 4: Pesticide indicator for Belgian data set

Annex 5: Pesticide indicator

Annex 1

Survey fruit and vegetable culture

1. Methodology

The search for a representative area for the survey of fruit and vegetable cultures was more complicated than for "field crops". It is certain that fruit and vegetables are mainly cultivated in Flanders (fruit culture >90%, vegetable culture >70%). No province was found were more than 70% of the agricultural area (AA) and more than 70% of the amount of pesticides was used only in vegetable or fruit culture**.** Therefore it was decided to conduct the survey, based on the percentage of the total surface in each province.

In Figure 1**,** the real situation of fruit and vegetable culture in Flanders is shown. It has to be noted that vegetable culture can be divided in open air "vegetable culture" and "greenhouses vegetable culture".

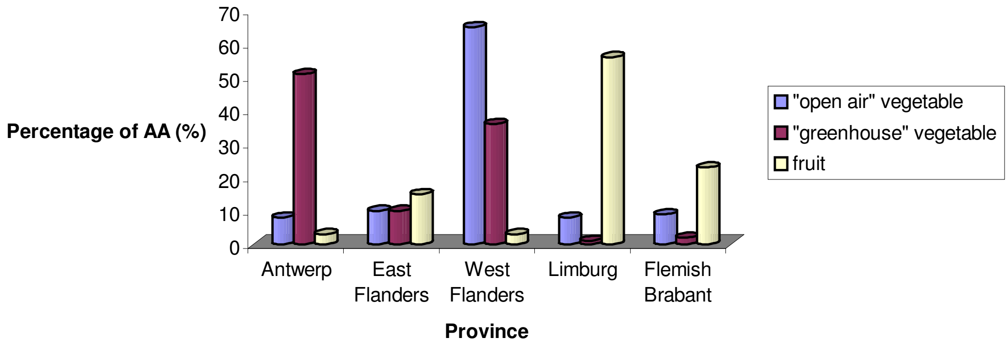


Figure 1: Distribution of open air vegetable culture, greenhouses vegetable culture and fruit culture in Flanders (Belgium), based on the total agricultural area (AA) in each province

The representativity has been improved by the following additional conditions:

- The grower belongs to the technical-economical group of "specialised horticultural exploitations", preferable with permanent cultures.
- The age of the manager of the exploitation must be between 20 and 60 years. People older than 60 must have a possible successor.
- Horticulture is the main profession of the grower.

Due to the range of distribution of the vegetable and fruit culture over Flanders, it was impracticable to interview the growers "face to face". Since most growers deliver their products to the auction, it was decided to contact the auctions of Mechelen (Vlaamse Mechelse Veilingen (VMV), especially for greenhouse vegetables), Roeselare (REO-veiling, especially for "open air" vegetables) and Sint-Truiden (Belgische fruitveiling (BFV), especially for fruit).

None of the auctions could, in frame of the law on personal privacy, release address data of the growers. Therefore, it was concluded that the best way to reach a large and heterogeneous group of growers, should be to attend some lectures or information sessions, organised by the auctions.

Between January and December 2003, surveys were passed around on four growers meetings. This resulted in 100 surveys for fruit culture and 85 surveys for vegetable cultures. Additional surveys were also obtained by personal acquaintances. Finally 114 surveys were obtained for vegetable growers.

The growers, present at such an information session or lesson, often have a large agricultural surface and are thus important users of plant protection products, which is important for the representativity of this project.

2. Representativity of the survey

2.1. Distribution of the producers

2.1.1. Fruit culture

In 2000, there were 3351 producers, specialised in fruit culture (NIS, 2000), with a mean AA of 5.14 ha.

The results of the survey hold in frame of this project, give a mean AA of 17.8 ha. With the survey a very important group, with regards to the amount of pesticides used, has been reached.

2.1.2. Vegetable culture

In 2000, there were 8477 producers, specialised in vegetable culture (NIS, 2000), with a mean AA of 4.22 ha. This mean AA may be interpreted carefully, since vegetable culture can be divided in three subcultures: extensive open air culture (84.5% of AA), intensive open air culture (12.72% of AA) and greenhouse culture (2.81% of AA). The size of the farms in the three cases is given in Table 1.

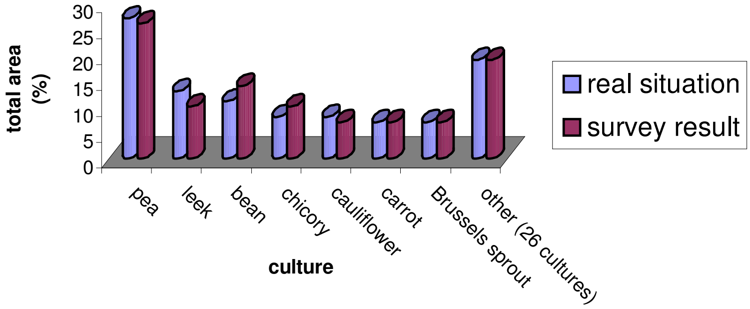
Table 1: survey of the growers, based on the surface of their farm

Class (ha)	Extensive open air n° of producers (%)	Intensive open air n° of producers (%)	Greenhouse n° of producers (%)
0.01 – 2	272 (5)	*377 (26)*	*801 (53)*
2 – 5	364 (7)	*284 (20)*	360 (8)
5 – 10	593 (11)	206 (14)	171 (11)
10 – 20	*1170 (21)*	255 (18)	80 (5)
20 – 30	*919 (17)*	129 (9)	25 (2)
30 – 50	*1051 (19)*	100 (7)	12 (1)
50 – 80	622 (11)	48 (3)	2 (0.1)
> 80	560 (10)	27 (2)	1 (0.1)
Total	**5551**	**1426**	**1500**

In the survey, the mean AA is 4.4 ha, including some greenhouse farms and some large extensive open air farms. A very heterogeneous group has been reached, which is important, concerning the use of plant protection products

2.2. Crop diversity on the farms

In the Figure 2, the real distribution of fruit and vegetables in Flanders (Belgium) is given and compared to the results of the survey. They match quite well, which means that a representative survey has been set up.
A chi^2 test confirms this. The p-value for fruit culture is 0.065, for vegetable culture 0.96. Those two values are higher than 0.05, which proves the homogeneity between the survey results and the real situation. The correlation coefficient is respectively 0.998 and 0.966.



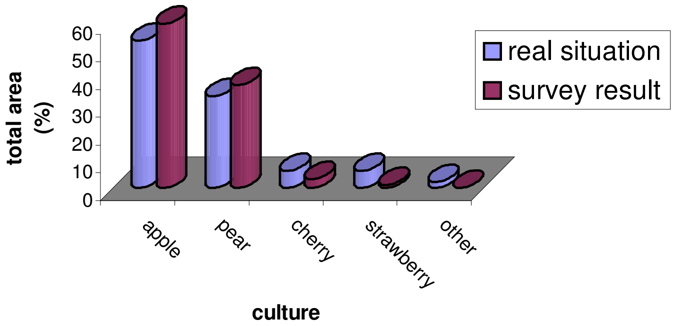


Figure 2: Comparison of the diversity of crops in real situation and in the survey (based on the total surface)

3. Results

On the following pages, the full questionnaire is given with all the results of the fruit and vegetable growers.

Remarks:

F = answers from the fruit growers
V = answers from the vegetable growers
All answers are given in percentage of the interviewed growers (%), unless when indicated otherwise.

PART I: identification and social background

A. GENERAL

			F	V
1	How old are you?	20-30 *(1)*	14	4
		30-40 *(2)*	38	47
		40-50 *(3)*	23	37
		50-60 *(4)*	17	7
		60+ *(5)*	8	5
2	*(if > 50 years)* Do you have a possible successor?	yes	13	14
		no	10	0
		blank	2	0
3	Are you married or living together?	yes	78	93
		no	20	7
		blank	2	0
4	If you are, does your wife/husband works in the farm?	no (0%) *(1)*	20	0
		partly (75%) *(2)*	9	6
		partly (50%) *(3)*	16	0
		partly (25%) *(4)*	13	0
		full-time (100%) *(5)*	18	94
		blank	2	0
5	Which is your highest diploma?	primary school*(1)*	4	2
		secondary school (1st degree) *(2)*	11	14
		technical secondary school		
		(option agriculture) *(3)*	31	54
		secondary school		
		(other) *(4)*	13	11
		high school		
		(not agriculture) (*5)*	9	14
		agricultural high school *6)*		
		university *(7)*	26	4
		blank	3	2
			3	0
6	Do you have a diploma of “certified user of plant protection products”?	yes	72	65
		no	26	33
		blank	2	2
7	Do you have a diploma of “special certified user of plant protection products”?	yes	43	49
		no	51	51
		blank	6	0
8	Do you provide your products by auction?			
		yes		100
		no		0
		blank		0

9	Which part of your yield do you sell directly to the consumer?	0-10% *(1)* 10-50% *(2)* 50-90% *(3)* 90-100% *(4)*		98 0 0 2

B. INFORMATION SOURCES AND RELATIONS

10a	How often do you read a technical magazine?	daily *(1)* weekly *(2)* monthly *(3)* a few times a year *(4)*	11 79 9 1	
10b	Which agricultural magazine(s) do you read and how often?		V	
	1. General magazines: "Boer en tuinder", "Landbouwleven", "Landbouw en techniek", "Groene krant", …	daily *(1)* weekly *(2)* monthly *(3)* a few times a year *(4)* never	9 88 2 0 2	
	2. Syndical magazines: "Verbondsnieuws (Boerenbond)"	daily *(1)* weekly *(2)* monthly *(3)* a few times a year *(4)* never	0 65 9 7 19	
	3. Specialised magazines: "De boer", "Proeftuinnieuws", "Landbouwteelt", "Groenten en fruit", …	daily *(1)* weekly *(2)* monthly *(3)* a few times a year *(4)* never	0 86 5 7 2	

		1 à 2 times *(1)*		3 à 5 times *(2)*		by every application *(3)*	
11	Where and how often do you search for information on the use of plant protection products in a certain culture? *(1 – 2 times per season, 3 – 5 times per season, by every application)*	F	V	F	V	F	V
	1. News papers	13	0	52	47	23	4
	2. Circle (neighbour, friend)	28	11	13	25	1	0
	3. Fair	34	19	9	9	1	0
	4. Company representative	28	5	38	44	10	26
	5. Lesson, lecture	27	11	51	39	6	0
	6. Offical bodies	27	4	20	21	1	11
	7. Information services	19	12	39	19	22	16
	8. Personal advisor	12	7	34	14	11	21
	9. Other	7	0	3	7	2	4

			F	V
12	Who decides how and when plant treatment takes place?			
	1. you alone, you do not really take into account the opinion from others, you trust on your own professional experience		7	11
	2. you, but you take into account the opinion and advices from others		46	51
	3. you fully rely on the opinion from others		0	0
	4. you follow decision support system		47	37
	5. blank		0	2
13	Are you a member of one of the following associations or institutions?			
	1. co-operative (auction)	yes	97	95
		no	3	4
	2. training centre	yes	38	9

		no	62	90
	3. agricultural association	yes	65	79
		no	35	20
	4. association which gives assistance in case of illness	yes	27	21
		no	73	78
	5. professional association (Boerenbond)	yes	72	88
		no	28	11
	6. other	yes	42	35
		no	58	64
	blank		0	1
14	Are you familiar with EUREPGAP?	yes	83	82
		no	11	18
		blank	6	0
15	After reading this legislation (EUREPGAP) or other lecture, have you changed your way of treating?	yes	62	84
		no	12	12
		blank	26	4
	If yes, what did you change?	dose *(1)*	38	42
		frequency *(2)*	24	54
		timing *(3)*	38	54
		choice of active substance *(4)*	45	63
	If not, why not?			
	1. you followed already the legislation		93	86
	2. too expensive		3	14
	3. difficult to understand		0	0
	4. need better knowledge		2	0
	5. asks too much time and work		0	0
	6. involves a quality loss		2	0
	7. other		0	0
16	Have you already heard of the following measures?			
	1. IPM (Integrated Pest Managment)	yes	78	18
		no	16	82
		blank	6	0
	2. Biobed	yes	36	12
		no	57	88
		blank	1	0
	3. Biological treatment	yes	74	81
		no	19	19
		blank	7	0
	4. Drift reducing nozzles	yes	84	96
		no	9	4
		blank	7	0
	5. Spray-free area	yes	68	72
		no	25	28
		blank	7	0
17	Do you have one of the following quality labels?			
	1. Flandria			100
	2. Biogarantie			0
	3. Eurepgap			35
	4. other			14

PART 2: Use of plant protection products in practice

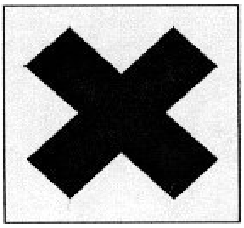
			F	V
18a	Please, fill in the following table ***column 1***: Which crops do you have? ***column 2***: Which is your cultivation method (greenhouse, outside) ***column 3***: Which surface do those crops take up? **crop** / **cultivation method** / **surface**	**Results: see "Representativity"**		
18b	Which surface do you use for fruit culture? (ha)	**Results: see "Representativity"**		
19	Which crops do you grow and which surface do they take up?	**Results: see "Representativity"**		
20	Did your **crops** stay the same during whole your carrier or did you change on a certain moment?	yes		56
		no		44
	What was the reason for the replacement?	price *(1)*		44
		feasibility *(2)*		20
		yield *(3)*		20
		ambition *(4)*		16
21	Have you ever tried alternative weed control methods? (mechanical or thermic)	yes	20	63
		no	78	37
		blank	2	0
	If yes, were/are you			
	1. completely not satisfied		15	0
	2. not satisfied		15	0
	3. neutral		35	11
	4. quite satisfied		25	36
	5. satisfied		10	53
	6. very satisfied		0	0
22	Do you think there is enough information available on those alternative methods, considering:			
	1. weed control	yes	63	75
		no	42	11
		blank	5	14
	2. insect control	yes	72	33
		no	23	53
		blank	5	14
	3. fungal disease control	yes	50	18
		no	45	68
		blank	5	14
	4. control of other pest and disorders	yes	46	21
		no	49	65
		blank	5	14
23	When you decide to plant a new variety, you choose one which:			
	1. is resistent to certain disease		27	44
	2. has a higher economical value		74	49
	3. has a higher efficiency		52	68

24	Which protection clothes or accessoires do you wear when working with plant protection products?			
	1. none		13	11
	2. boots		36	77
	3. trouser suit		22	37
	4. gloves		75	68
	5. mask		57	37
	6. glasses		14	4
	7. other		2	30
	If you do **not** wear protection clothes, for which reason is this?			
	1. impractical		58	89
	2. there is no danger		28	0
	3. too much work		0	0
	4. it does not make any difference		11	11
	5. other		3	0
25	When you wear gloves during mixing and loading of the products, do you change them:			
	1. each time		11	9
	2. after 2 or 3 times		15	7
	3. after less then 5 times		4	26
	4. after more then 5 times		53	28
			17	30
26	With which statements do you agree?			
	1. I wash my hands after every treatment	agree	84	79
		don't agree	14	19
		blank	2	2
	2. I change my clothes directly after every treatment	agree	37	21
		don't agree	61	77
		blank	2	2
	3. I wash those clothes often	agree	64	67
		don't agree	34	32
		blank	2	2
27	Do you mix and load the formulations on a "hard" surface (a concrete floor e.g.), provided with an outlet?	yes	74	63
		no	23	30
		blank	3	7
28	Soon, the use of METHYLBROMIDE as soil disinfectant will be forbidden. What would you use as an alternative?			
	1. an other soil disinfectant			33
	2. biological treatment			2
	3. steaming			4
	4. treatment with Basamid (dazomet)			9
	5. change to hydroculture			0
	6. other			53
29	When you finished spraying, what do you do with the spray rest?			
	1. dilute and spray on the land		61	91
	2. dilute and spray elsewhere		5	0
	3. spray in the neighbourhood of the land (earth pad e.g.)		0	7
	4. spray on the farm (same place were the formulation was made)		21	0
			6	0
	5. spray elsewhere		7	2
30	Did it ever happen that you felt sick after a pesticide treatment?	yes	22	44
		no	75	56
		blank	3	0

	If yes, which were the symptoms?			
	1. headache		33	23
	2. sore throat		0	2
	3. vomit		3	9
	4. breath difficulties		11	2
	5. eye or nose irritation		31	23
	6. skin irritation		3	28
	7. fatigue		14	9
	8. other		5	4

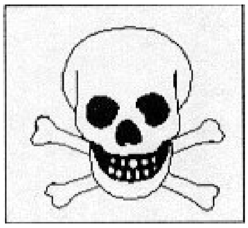
31. What do the following pictograms mean?	F		V	
	right	wrong	right	wronge
Pictogram 1	73	17	82	9
Pictogram 2	78	12	84	9

Pictogram 1



This product is:
1. very toxisch
2. toxic
3. harmful
4. irritating
5. corrosive
6. causes redness

Pictogram 2



This product is:
1. very toxisch
2. toxic
3. harmful
4. irritating
5. corrosive
6. causes redness

			F	V
32	Do you think the imposed waiting period between treatment and harvest is:			
	1. good		81	79
	2. too long		10	21
	3. too short		0	0
	blank		9	0
33	Did you ever encounter resistance against a certain plant protection product?	yes	63	74
	If yes, what measures did you take?			
	1. planting a new variety		2	4
	2. using a combination of plant protection products		10	29
	3. alternating some plant protection products		30	41
	4. using completely new plant protection products		16	14
	5. increasing the dose		1	4
	6. using biological treatment		1	0
	7. applying integrated control		38	5
	8. change nothing		2	3

PART 3: Grower versus environment

Do you completely not agree (1) – not agree (2) – neutral (3) – agree (4) – completely agree (5) with the following statements?

Question	F					V				
	1	2	3	4	5	1	2	3	4	5
34) In your job as grower										
1. there is a certain risk towards quality of air, water or soil	3	14	24	***41***	12	4	5	21	***40***	23
2. people overwhelm you with questions concerning environment, while the problem is much bigger on other places	3	10	18	***40***	25	0	7	25	***37***	25
3. you do not always follow the rules exactly, but your farm has to be profitable, so you have to treat frequently	***27***	20	25	16	6	2	11	21	***46***	14
35) To diminish the environmental pollution or the risk on it										
1. people must trust the growers, they know what they are doing	1	11	16	***44***	21	0	16	19	***46***	16
2. less harmful methods exist, but there is a lack in technical aspects and observance	4	11	***38***	34	4	5	19	***44***	19	5
3. solutions exist, but the government must help to finance them	4	7	23	***44***	14	2	0	***47***	32	12
4. you would accept a lower income, if that would help to the improvement of the environmental quality	***35***	31	13	8	4	***40***	***37***	16	0	0
36) You use plant protection products because:										
1. you take the economic importance of a good crop into account	2	0	8	41	***43***	0	2	7	***40***	***47***
2. you do not want to take the risk of a failed harvest	0	1	15	36	***39***	0	0	0	35	***58***
3. you are advised to treat with plant protection products	23	12	***29***	14	13	14	23	***30***	11	16
37) To protect your crop:										
1. you normally spray systematically	11	25	***31***	17	10	11	16	***37***	21	9
2. you spray when a damage threshold has been exceeded	0	0	4	36	***52***	0	9	19	***46***	19
3. you use products with a broad working spectrum	***35***	20	18	13	5	0	11	23	***46***	14

PART 4: Needs of the growers in frame of the study

38 Do you think you have enough information on the risks allied to pesticides?

	F	V
yes	79	82
no	12	9
blank	9	9

39 Suppose, there are 5 classes (1,2,3,4 and 5) in which all environmental compartments can be placed, based on the risk they are exposed to pesticide treatment. (Class 1: compartment which runs the highes risk, class 5 the lowest risk). Put the environmental compartments below in one of the five classes.

	class 1		class 2		class 3		class 4		class 5		blank	
	F	**V**	**F**	**V**	**F**	**V**	**F**	**V**	**F**	**V**	**F**	**V**
1. consumer	8	33	1	0	7	12	4	7	51	14	29	33
2. applicator	45	42	14	25	14	0	3	9	4	2	20	23
3. field worker	8	9	26	28	20	7	9	4	10	2	27	51
4. by-stander	4	4	13	2	12	9	21	7	15	16	35	63
5. soil	5	2	13	9	21	0	17	21	10	12	34	56
6. surface water	10	4	19	12	13	14	11	11	8	11	39	49
7. soil water	3	0	8	12	14	5	19	9	12	23	44	51
8. air	3	2	5	5	17	16	17	11	22	9	36	58
9. water organisms	1	0	17	11	12	4	15	7	13	9	42	70
10. birds	2	0	6	7	13	5	18	9	23	19	38	60
11. earthworms	4	2	10	23	21	0	12	2	12	2	41	72
12. mammals	1	0	6	7	11	9	20	4	19	11	43	70
13. bees	11	4	15	11	16	2	12	12	18	11	28	61
14. usefull arthropods	18	5	13	11	10	4	17	0	17	32	25	49

40 Usually, more then one product exists against a certain weed or illness. Which are, for you, the 3 most influencing parameters, by the choice of a product? *(Give the most important parameter 3 points, the second 2 points and the third 1 point)*

	3 points		2 points		1 point		total	
	F	**V**	**F**	**V**	**F**	**V**	**F**	**V**
1. price	16	30	11	7	25	18	17	18
2. toxicity for the user	4	0	12	12	6	0	7	4
3. possibility to reduce the number of applications	17	9	14	14	15	11	15	11
4. phytotoxicity	3	4	4	4	7	0	5	4
5. environment impact	9	4	7	4	3	0	6	2
6. spectrum of activity	9	2	12	2	6	4	9	8
7. effectiveness	13	13	1	12	13	28	12	20
8. pre-harvest interval	6	21	8	21	4	11	6	12
9. control of resistance occurrence	4	0	4	0	4	2	4	1
10. duration of the application	3	0	1	0	1	9	2	3
11. other	0	0	0	0	0	0	0	0
blank	16	19	17	19	16	19	16	18

41 Do you agree with the following statements?

Statement		F	V
1. I read the product label seldom when buying a product	yes	18	19
	no	70	70
	blank	12	11
2. I think the safety precautions are clear and understandable	yes	79	75
	no	9	14
	blank	12	11
3. I think the prescriptions for use are clear and understandable	yes	80	86
	no	8	4
	blank	12	11

42	We would like to try to investigate the existing data on the influence of pesticides on the environment, in order to make an evaluation of a certain plant protection product (indicator). How would you like us to present the result? **(+ show example of each)**			
	1. a rose representation		0	5
	2. a figure		29	18
	3. a rose representation and a figure		0	9
	4. a graph		21	28
	5. a colour		28	21
	6. a figure and a graph		4	0
	7. a figure and a colour		3	0
	8. other: …………………………………………………		0	0
	blank		15	19
43	Do you think, the development of such an indicator would influence some growers to change their way of using plant protection products?	yes	54	61
		no	28	7
		blank	18	32

Annex 2

Study of field crop farmers' decision-making process in the sustainable use of pesticides

1. Representative sampling

The method involves choosing criteria to verify the sample representativeness of the surveyed population in the Walloon Brabant Province. In this case, it was performed using spatial and crop distribution criteria.

1.1. Spatial distribution

The first representativeness criterion is based on the spatial distribution of the farms in the Walloon Brabant Province. A χ^2 test allows investigation of the homogeneity of the frequency distribution of the sample relative to the population. The test showed a significant p-value of 0.93 ($\alpha = 0.05$) (Figure 1).

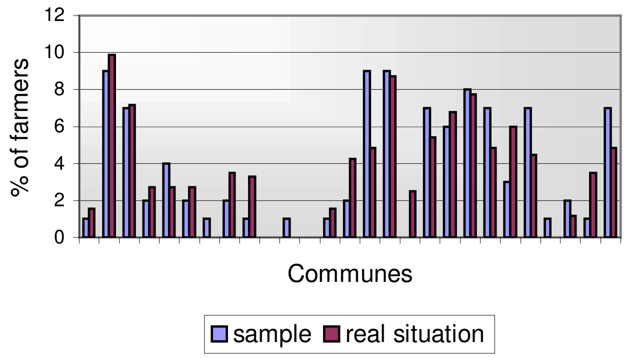


Figure 1: Comparison of farmers' distribution in the 27 communes of the Walloon Brabant Province and proportion in the survey

1.2. Crop distribution

The crop distribution in the sample is, in general, representative of the Walloon Brabant Province (Table 1).

The proportion of the various crops is the same, with the exception of industrial crops (sugar beet and chicory) and fodder crops (maize). The proportion of fodder crops in the sample is smaller than in the Walloon Brabant Province because cattle farms have not been taken into account in the selected sample.

There is also limited representativeness in the sugar beet and chicory quota, which is higher in the sample than in the population. This is easily explained by the minimum farm size (> 20 ha) criterion of sample selection and the strong link between quota and agricultural area (AA).

Table 1: Crop distribution in the Walloon Brabant Province

Crops	*Brabant Wallon*	*Sample*
Meadow	18	13
Fodder crops (maize)	7	5
Cereals	40	39
Industrial plants (Sugar beet, etc.)	23	28
Potato	4	4
Vegetables	3	3
Fruits	0	0
Others (fallow land, etc)	5	8
Total	100	100

Source: [INS, 2001]

2. Socio-economic situation

During the cultivation season, the farmer has to make choices regarding the production tools (cultivation methods, crop varieties, crop protection products, fertilisation) that influence farm income and management. In addition, farm management also depends on external factors such as climatic conditions, economic context, etc.
However, farmers are not alone when making these decisions. They are influenced by people from the business community, extension officers, neighbours, etc., who may have an impact on their decisions about pesticide management.

The hypothesis is that the extent to which farmers display an environmentally friendly approach depends upon their social situation, their farming system, their choice of crop species and their AA.

2.1. Family situation

2.1.1. Marital status

The survey reveals that 79% of the farmers are married (compared with 75% in Belgium in 2000).

For 28% of these farmers, the women work away from the farm to earn extra income. This is mandatory for some farms, where reforms and crises in agriculture have created financial problems.

2.1.2. Inheritance

More than 60% of the farmers in the Province have a successor, whereas, according to an NSI survey in Wallonia, only 20% of farmers have a successor. The difference between the sample population and the regional population stems from the fact that small farms (< 20 ha) are not included in the survey. The probability of having a successor for such small farms is lower than for bigger farms.

However, there are differences according to the type of farming: 70% of those with mixed farms have a successor, whereas only 54% of those with arable farms have a successor. This can be explained by the relatively higher financial value of an arable farm compared to a mixed farm.

2.1.3. Farmer's age

A young farmer's priorities differ from those of an older farmer. Plant protection management probably differs between young and old farmers.

The average age of the surveyed farmers is 46 years. Only 34% are older than 50 years (Table 2). About 60% of farmers older than 50 have a successor.

Table 2: Distribution of farmers according to age

Age classes	*% farmers*
20 < 30	6
30 < 40	24
40 < 50	36
50 < 60	24
60 +	10
Total	100

2.2. Training

The level of study and choice of additional training may have a favourable influence on the farmer’s economic decisions and crop selection. About 25% of the farmers do not have an official certificate of upper secondary education (Table 3). About 50% of them have agricultural training (37% have a technical certificate and 12% have an advanced study diploma).

Compared to the national average, the surveyed farmers have better basic training. In fact, 60% of Belgian farmers have only practical training.

Table 3: Farmers’ training levels (agricultural training indicated in bold (49% farmers))

Training	***% farmers***
Primary	8
Secondary non-agricultural	17
Secondary basic	**18**
Secondary technical agricultural	**36**
Superior agricultural	12
Superior non-agricultural	2
University	7
Total	100

In addition, 59% of the surveyed farmers have additional agricultural training (through evening classes, for example). Of these, 64% are qualified as specially accredited users of plant protection products (i.e. able to use the annex 10 products).

It is important to note that, contrary to expectations, training level is not significantly linked to the farmer’s age. The “young” farmers are not necessarily better trained than “older” farmers.

2.3. Type of farming

The survey reveals that 36% of the farmers use the “field crop” type of farming and 64% use the “mixed” farming.

The "field crop" farms are characterised (Table 4) by an AA of 126 hectares sown with five crops (winter wheat, sugar beet, flax, potato and barley) and fallow land. On average, the farmers are 47 years old and have secondary level training, with 44% having agricultural training and 16% having an academic certificate. The "field crop" farmers' training is higher than that of the "mixed" farmers.

The AA of the "mixed" farms is 85 hectares distributed among six crops (winter wheat, sugar beet, grassland, maize, chicory and barley) and fallow land. The average age of the "mixed" farmers is 45 years and they have secondary level training, with 48% having agricultural training and only 3% holding a university degree.

Table 4: Socio-economic context and training according to type of farming

	Mixed farming	*Field crops*
Distribution (%)	64	36
Age	45	47
Married (%)	80	78
Inheritance (%)	**57**	47
Surface (ha)	85	**126**
Crops number	6	5
Farmer's training (%)		
Primary	11	3
Secondary basic	24	9
Secondary advanced	12	25
Agricultural technical	**37**	**33**
Superior agricultural	**11**	**14**
Superior non-agricultural	2	3
University	3	**14**

None of the farms in the survey is diversified (tourism, shop, etc.) but some of them cultivate crops with high added value (chicory) and 11% of the farms sow crops with greater technical requirements (strawberries**,** vegetables), so there is, in this sense, a level of diversification.

2.4. Agricultural area

The farmers who participated in the survey have an AA higher than the national average (about 20 hectares). The average AA of the sample is about 100 hectares. This high level is due to the selection criteria used for the sample, which excludes farmers cultivating less than 20 hectares.

An analysis of the farmers by AA class (Table 5) shows that 54% of the sample farmers cultivate an AA of more than 80 hectares.

Table 5: Breakdown of farmers according to AA in comparison with the national average [INS 2001]

Classes (ha)	*National average (%)*	*Sample (%)*
< 20	35.86	4
20 < 30	18.81	1
30 < 50	24.74	8
50 < 80	13.64	23
80 +	6.93	54
Total	**100**	**100**

3. Management

3.1. Association membership

It is possible that membership of a farmers' union or association is a factor influencing concern for the environment.

About 65% of the sample farmers are affiliated to the farmers' union Fédération Wallonne de l'agriculture (FWA). This union is very active and organises many informative meetings, notably on the use of plant protection products. It produces a weekly newspaper that, in theory, all the farmers receive (the survey showed, however, that only 79% of the farmers received the newspaper). This newspaper provides advice on crops and new regulations, and publishes decision support system.

Collective farming is not developed in the Walloon area. Only 12% of the farmers are in a cooperative or use common equipment.

There is no significant link between membership of an association and use of plant protection products.

Table 6: Farmers belonging to an association

Association	*% farmers*
Cooperative	12
Mutual aid	2
Agricultural show	53
CETA	7
FWA	65
Other	16

In 1992, an organisation called the "Comité régional PHYTO" was established in the Walloon region to popularise good plant protection practices. This organisation has published nine "good practice guides". The first is a general guide which explains pesticide-related problems and suggests ways for the farmers to improve their practices in the interests of health and environmental protection. The other eight guides provide information on individual crops (including sugar beet, maize, ornamental plants and vegetables crops) and appropriate plant protection products.

Only 8% of the surveyed farmers know about the "Comité régional PHYTO", but 35% know about its good practice guides. Among those who have read one of the guides, 34% have changed their practices. Overall, 66% consider that their practices are in harmony with the practices explained in the guides.

3.2. Information sources

The farmers were given a list of possible information sources (first column of table 7) according to particular crops (winter wheat, barley, sugar beet, maize and potato) and asked to indicate which information sources they regularly use.

The survey shows that, regardless of the crops, the farmers regularly consult two principal sources: the company sales representative and the decision support system (Table 7).

Table 7: Information sources consulted before the treatment decision, by crop

Sources / crops	*Winter wheat*	*Barley*	*Sugar beet*	*Potato*	*Maize*
Reading (newspaper)	33	42	33	31	31
Circle (friend, neighbour)	20	29	21	8	18
Agricultural show	0	0	0	0	0
Company representative	**90**	**89**	**89**	**85**	**84**
Courses, meetings	24	22	26	15	21
Official services (IRBAB, CIPF)	0	0	15	15	10
Decision support system	**50**	**60**	**46**	**77**	0
Private consultants	7	7	7	8	10
Others	5	11	4	0	2

The company sales representative is the most important information source. About 90% of the farmers consult company representatives more than once per season. For some, particularly cattle farmers, there is a tendency to rely heavily on company personnel when it comes to making decisions on treatments and crops. However, the company representatives' recommendations are driven by commercial considerations and therefore cannot be seen as objective.

Farmers regularly consult the crop-specific decision support system, but they do not follow their recommendations strictly. The company representatives' advice is seen as more important. For example, only 33% of the farmers planting potatoes follow the recommendations of decision support system on when and how to spray their fields. These services are viewed as a source of information rather than a tool for deciding on treatment specifications.

It is important to note that the official services are not a primary information source: 15% of the farmers call on them for potato and sugar beet crops. In most cases, when the farmers call on these services, it is for specific problems. However, the indirect impact these services have on the farmers via articles in agricultural newspapers and through company representatives should not be underestimated. In fact, the company representatives regularly call on the official services (or their publications) to help them solve crop problems. The official services are also involved in the implementation of the decision support system.

A statistical analysis reveals that, when farmers use an information source for one crop, they use this source for all the crops on their farms.

3.3. Decision-making

The careful choice of a pesticide treatment ensures both the development of the crop and the farmer’s income. In selecting a plant protection product and type of treatment, the farmer will be influenced by the product characteristics (Table 14) as well as by advertisements, sales representatives, official organs, etc.

The farmer’s crop treatment decision is rarely taken alone (Table 8). More than 80% of the farmers cultivating winter wheat, sugar beet, barley and maize make this decision with the help of an outsider, such as a company representative or neighbour. For 64% of the farmers who grow potatoes, the representative (pesticide manufacturer’s sales representative or processor’s representative) alone makes the decision on treatment (under a cultivation contract).

Table 8: Decision-making on crop treatments

Decision-making /Crops	***Winter wheat***	***Barley***	***Sugar beet***	***Potato***	***Maize***
Farmer alone (%)	2	3	1	0	6
Farmer with external help (%)	**85**	**82**	**83**	36	**80**
External help only (%)	13	15	16	**64**	14

It is important to note that there is no relation between the decision-making method (farmer alone or with outside help) and the use of plant protection products (number of fungicide treatments, type of products).

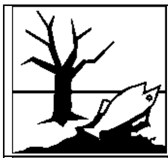
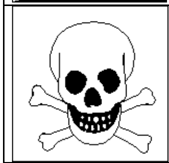
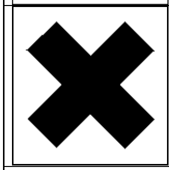
4. Farmer knowledge, attitudes, practices regarding pesticide use

4.1. Pictogram knowledge level

It might be assumed that if the farmers know the meaning of the pictograms on plant protection product labels, they will take more precautions with these products. The results of the survey question on pictogram knowledge are shown in Table 9. They show that this knowledge is average, and that the meaning of the pictogram “dangerous for the environment” is not known.

It is not clear why the farmers do not know the meaning of some pictograms. Their basic training level is high: 48% have some basic training and 56% have received additional training (of this, 64% are certified users). Farmers’ supervision varies (company representative, official organisations, etc.). Also, 82% of the farmers regularly read the pesticide notices, 88% say that the security indications on the labels are well written and easy to understand, and 83% say that the information for product preparation and utilisation is simple and easy to apply.

Table 9: Pictogram knowledge

	***N Dangerous for the environment***	Only 17% of the farmers know the meaning of this pictogram
	***T toxic T+ very toxic***	11% know the four meaning of these pictograms 45% have some idea what they mean 44% have no idea what they mean
	***Xn harmful Xi irritant, sensitised***	
Diffuse / point pollution		47% know the difference between these two types of pollution

It is important to mention that the "danger for the environment" pictogram is relatively new (it dates from 28 September 2000) and the farmers are not yet used to seeing it (only 17% of them know it). This lack of knowledge is probably due to a lack of information. About 30% of the farmers consider that they are poorly informed about the risks linked to pesticide use.

In conclusion, the farmers, despite reading and a good understanding of the indications on the labels, do not have a good knowledge of the pictograms. They take only the information from the labels that they require for spraying (rate, mixture, etc).

Following the data analysis we have looked again at the question about the pictograms, and its relevance to the survey objectives. The statistical analysis shows that knowledge of the pictograms does not have any significant influence on the farmers' practices regarding crop protection products.

4.2. Farmers' evaluation of pesticide toxicity on health and the environment

In the survey, the farmers were asked to classify 15 environmental and health categories (first column of Table 10). This classification was made according to the risk linked to pesticide use. The risk level was graded from 1 to 5, with 1 being the highest risk and 5 being the lowest risk. The farmers devised the categories without help from the survey team. The results are shown in Table 10. The last column of the table gives the average evaluation for every category.

Table 10: Farmers' evaluation of pesticide toxicity. The risk level is graded from 1 to 5.

Category / Class	*1*	*2*	*3*	*4*	*5*	*Don't know*	*Average*
Human health							
Consumer	4	8	15	18	**45**	1	Low (4-5)
Operator	**29**	**25**	20	9	7	1	High (1-2)
Farm worker	**25**	**28**	21	9	5	3	High
Bystander	1	14	21	**28**	**26**	1	Low
Environment							
Soil	5	22	**29**	15	18	2	Medium Moderate(3)
Surface water	**24**	22	19	18	7	1	Moderate
Underground water	16	15	**21**	19	18	2	Moderate
Air	5	17	**27**	15	24	3	Moderate
Water organisms	11	**27**	20	21	10	2	Moderate
Birds	12	18	**26**	17	17	1	Moderate
Earthworms	10	13	**29**	20	15	4	Moderate
Mammals	12	12	**24**	**26**	15	2	Moderate
Bees	17	**28**	17	19	6	4	Moderate
Useful arthropods	10	17	27	16	8	13	Moderate
Natural enemies	13	**25**	21	14	15	3	Moderate

4.2.1. Health

Looking at the health categories, we observe that the farmers differentiate between their personnel (operators and farm workers) and other people (consumers and bystanders).

The farmers are aware that the operators and the farm workers are exposed during spraying to a higher risk (class 1-2) than the consumers and bystanders (class 4-5). Although the perception by the farmers of any change in the risk level is the same for the bystanders, on the one hand, and for the operator and the farm worker, on the other hand, it seems to be based on different scales.

4.2.2. Environment

The farmers do not make significant distinctions between pesticide toxicity on different environmental categories. Usually, they place all the categories in the moderate risk class (class 3).

However, the independence test conducted between these different categories shows that there is a significant link between the evaluations of some categories. All the categories related to water quality (soil, surface water, underground water, water organisms) have an assessment that evolves in the same way. For example, if the farmer assesses one of these categories to be high risk (class 1), he gives the same evaluation for all other related categories. The same occurs with those categories related to fauna (birds, earthworms, mammals, bees, natural enemies).

An awareness-raising campaign targeting farmers about water quality has been carried out in recent years (by the press, and other organisations). This work seems to have be bearing fruit.

5. Attitudes about the pesticide problems

Decisions on pesticide use start being made at the end of the cultivation season. The interval between the harvests has to be well managed. The varieties need to be selected according to disease resistance. The type of treatment has to be selected according to specifications provided by the decision support system or company representatives, whichever is the most appropriate. The aim of the decisions should be both to increase farmer income and protect the environment. These different points were evaluated in the survey.

5.1. Choice of winter wheat variety

For wheat, the choice of the variety to be sown is one of the factors that will influence income. Choosing a variety with good resistance to fungal diseases will require, depending on the climate, less fungicide treatment.

For 65% of the farmers (Table 11), the choice of variety depends primarily on potential yield. Only 14% of the farmers give priority to varieties that resist diseases. They also decide upon their production techniques according to yield (prestige of a high yield) and financial returns.

Table 11: Wheat variety choices

Wheat variety choice	*% farmers*
Disease resistance	14
Commercial value	22
High yield	**64**

Depending on the spraying equipment available, the farmer will choose significantly different varieties to sow. If the equipment is complete, the farmer is more likely to choose winter wheat varieties according to their disease resistance. The variety choice and the sprayer equipment form part of a "philosophy" of income optimisation and input reduction.

For the winter wheat crop, on average the farmers apply 1.78 fungicide treatments. The majority (63%) of them apply two fungicide treatments.

5.2. Alternative methods to pesticide use

The alternative methods (fake sowing, mechanical weeding, thermal weeding) allow reduced pesticide use. However, only 18% of the farmers use these alternative methods and 31% think that there is a lack of information, via extension agents and other sources, on these practices.

Among the farmers who have used these methods, about 60% are satisfied (Table 12).

Table 12: Satisfaction level with alternative methods

Satisfaction level	*% farmers*
Very satisfied	11
Satisfied	50
Little satisfied	33
Not satisfied	6
Total	100

About 65% of the farmers who cultivate maize reduce the amount of the herbicide atrazine applied on their crop. This reduction varies between 20 and 75%.

5.3. Use of decision support systems

Although about 90% of the farmers know about the decision support systems for field crops, few actually use them (sugar beet 57%, potato 33%); of the farmers who grow wheat, however, 70% use the decision support systems) (Table 13).

The farmers consult the decision support systems published in newspapers or available by fax or on the Internet (depending on the crop).

Table 13: Farmers' use of decision support systems, by crop

	Cereals	***Sugar beet***	***Potatoes***
Use of the decision support systems	70	57	33

It is interesting to note that only 33% of the potato growers regularly use the decision support system. According to some farmers, the usefulness of the system is restricted because the time to carry out the treatment is too short. However, 77% of the farmers consult it up to 5 times per season. They use it only as an information source, and do not follow it strictly during the cultivation season.

The use of decision support systems for winter wheat and sugar beet is related to the type of training a farmer has had (agricultural / not agricultural). If the farmers have had agricultural training they is more likely to use the decision support systems.

5.4. Spraying

5.4.1. Elements considered when farmers decide to spray

The principal element considered when farmers decide to spray their crops is the product price (Table 14). For 45% of farmers price is the first criterion in their choice of a crop protection product. Other product characteristics considered include: the mixture guidelines, the spectrum of activity, the time of action and the effectiveness of the product. It is interesting to note that when the farmers choose a product, they do not consider user toxicity, environmental impact, pre-harvest interval or the control of the resistance occurrence. In short, they tend to consider the economic factors rather than environmental and health factors.

Table 14: Elements considered when farmers choose the pesticide

Characteristics / % farmers	*TOTAL*	*1st choice*	*2nd choice*	*3rd choice*
Price	**28**	45	20	19
Toxicity for the user	5	5	7	2
Mixture guidelines	**12**	7	17	12
Phytotoxicity	6	5	5	8
Environmental impact	4	2	3	8
Spectrum of activity	**14**	14	15	12
Effectiveness	**12**	14	12	11
Pre-harvest interval	3	0	5	4
Control of resistance occurrence	3	1	0	7
Action timing	**10**	6	12	13
Formulation	1	0	1	2
Other	3	1	4	4
No response	2	1	2	2
TOTAL	**100**	**100**	**100**	**100**

5.4.2. Spraying equipment and protective accessories

Spraying equipment has an impact on the environment and on farmers' health.

5.4.2.1. Spraying equipment

The spraying equipment of the surveyed farms is good, with 70% having a wash can, an annex tank and a hopper. However, although most sprayers are equipped with an annex tank, 16% of the farmers admit to dropping the residue that accumulates at the bottom of the tank onto a dirt road or at the filling site (Table 16).

Statistical analysis shows a significant link between the spraying equipment and the treatment of the tank bottom residue. Of the farmers who have an annex tank on their sprayer, 91% dilute and redistribute the residue on the field. This is of primary importance for future sensitisation policies.

The condition of the spraying equipment on the surveyed farms is good and is not a hazard. It is important to note that in Belgium the technical condition of the sprayer is controlled by law (23 August 2001).

5.4.2.2. Protection accessories

Individual protective equipment reduces the risk of intoxication orally and via the skin. Skin penetration may be reduced by wearing gloves, overalls and boots, while masks reduce oral penetration.

Half of the farmers do not wear any protective accessories when they handle pesticides. Of those farmers who do use individual protective devices, all wear gloves as the minimum (Table 15) and some also wear other protection (mask or overalls).

Of those who use gloves, only 12% replace them regularly (five utilisations maximum).

After pesticide application, 13% of the farmers do not wash their hands and about 80% do not wash their bodies.

Table 15: Protection accessories

Protection accessories	*% farmers*
Boots	6
Overalls	17
Gloves	49
Mask	20
Goggles	10

It is important to note that 27% of the farmers reported that they felt unwell before they sprayed. Most of these complained of stomach problems and headaches. In most cases, this can be explained by the fact that the farmers do not put masks on when they prepare the mixture.

Most of the farmers who do not use any protective accessories say it is a habit (34%), while others say it is due to a lack of time (17%). It is important to note that 12% say it is not necessary to use protective accessories.

5.5. The treatment of the tank bottom residue

The inappropriate treatment of the tank bottom residue when the spraying is completed is the most important source of point pollution. Good crop protection practice would involve diluting the residue and redistributing it on the treated field. This practice, which is beneficial for the environment, requires the farmers to have an annex tank on their sprayers or to come back to the farm.

After the treatment of the crop, 80% of the farmers dilute the tank bottom reside (Table 16), notably via the annex tank on the sprayer (70% of the farmers have a sprayer equipped with an annex tank) and redistribute it on the treated crop.

Table 16: Treatment of the tank bottom residue

Treatment	*% farmers*
Dilute and redistribute on the field	**80**
Redistribute elsewhere	1
Released on a dirt road	9
Released at the filling site	7
Slurry pit	1
"Phytobac"	2
Total	100

5.6. Agri-environmental measures

In Wallonia, the agri-environmental programme specifies 11 measures to promote production methods that are compatible with two principal environmental objectives: reducing agricultural pollution and preserving biodiversity and the landscape.

According to the survey, all the farmers know about these agri-environmental measures. Among them, 55% have signed a contract for one or more measures (Table 17). In Wallonia, about 20% of the farmers comply with at least one agri-environmental measure. The survey results may appear distorted because they show that double that number of farmers adhere to one measure, but the sample is not, at this level, representative of the Walloon area. The sample does not include farms of less than 20 hectares, nor does it include farmers older than 60 years without a successor. These two populations are less sensitive to environmental problems.

One of the most practical agri-environmental measures is covering the soil during the winter before the spring sowing (measure 8). On average, 46% of the area intended for sugar beet crops (1860 ha) is covered during the winter. However, 15% of these farmers do not ask for the agri-environmental soil cover premium. The main reason for this is the requirement to plough the soil before 1 January and the obligation to repeat the measure for 5 years.

Another measure is the establishment of headland sown with grass (measure 2). This headland constitutes a buffer area between an ecosystem that needs to be protected and the crop. The survey shows that 34% of the farmers carry out this measure.

Table 17: Farmers use of agri-environmental measures

N°	*Environmental measure*	*% Farmers*
1	***Late cutting***	4
2	***Headland***	34
3	***Hedges, old orchards***	15
4	***Small stocking of livestock***	0
5	***Local races***	1
6	***Reductions in cereal crops***	4
7	***Mechanical weed control***	2
8	***Soil covering during the interval***	35
9	***Very late cutting***	0
10	***Wet area conservation***	0
11	***Orchards plantation with old varieties***	4

Many reasons are given to justify the non-adherence to the agri-environmental measures. The main ones are:

- A 5-year contractual obligation leads to a loss of independence
- The administration and income constraints are too demanding
- The premium is not attractive enough to support the demands of these practices.

6. Farmers' environmental concerns

Table 18 summarizes the environmental concerns of the surveyed farmers. It shows that river pollution by pesticides is one of the most important concerns, followed by nitrate pollution.

Table 18: Environmental concerns of the farmers

Aspects	*No concern*	*Average concern*	*Very concerned*
Nitrate pollution	22	57	21
Loss in quality of the landscape	32	40	28
Damage to animals and plant species	37	26	37
River pollution by pesticides	11	19	70

It is interesting to note that the majority (63%) of the farmers are aware that their actions may generate risks for the environment (Table 19). However, they must be paid to accept the inconvenience. About 94% think there are more important examples and causes of environmental pollution elsewhere.

Table 19: Environmental attitudes of the farmers

Attitudes	*Strongly disagree*	*Do not agree*	*Neutral*	*Agree*	*Strongly agree*
In your agricultural practices:					
Your activities may cause risks for the environment	15	12	10	47	16
We go on at you about the environment but there are more important environmental problems elsewhere	0	1	5	31	**63**
Environmental measures are inconvenient and you must be paid	1	4	7	28	**60**
To reduce the risk of agricultural pollution:					
We can have confidence in the farmers	0	14	21	42	23
There are less intrusive systems but there is a problem with their technical management	3	16	23	43	15
There are solutions but society must pay for it	5	9	8	30	48
You accept income loss because of the need for environment protection	**55**	20	14	10	1
You make phytosanitary treatments because:					
You are aware of the economic necessity to apply these treatments	0	2	1	23	**74**
You do not want to take any risks	3	9	14	41	33
The company encourages you to apply treatments	53	28	8	9	2
To protect your crops:					
You apply treatments systematically	22	22	10	32	14
You use broad-spectrum products	4	18	12	38	28

7. Farmers' suggestions for better use of crop protection products

During the face-to-face interviews, the farmers were asked if they had any solutions or suggestions to help solve the problems linked to pesticide utilisation. This question allowed the farmers to give their ideas.

Some farmers proposed a regulation requiring farmers to have an annex tank, hopper and a can cleaner on all the sprayers. This solution would reduce the occasional losses and would encourage farmers to dilute and redistribute the tank bottom residue on the treated field. But 70% of the sprayers already have this equipment.

Some farmers said that there are not enough instructions on the labels and that they have difficulty reading the information.

The standardisation of the product cans cause problems: the farmer can make mistakes and the consequences can be important for the crop. If the cans had different colours for the different types of pesticide (one colour for fungicides, one for insecticides, one for herbicides, etc.) it would be easier for the farmers. It was also suggested that the shape of the product cans should be changed for easier disposal.

Another suggestion was that the sale to individuals of some products should be forbidden or better regulated.

8. Conclusions

The socio-economic situation of the farmers is very diverse and this makes it difficult to classify them.

The management and information sources of the farmers are important and diverse, but two are particularly notable: the company representative and the decision support systems. These sources would be effective for raising farmers' awareness with regard to the environment and their health.

Despite their ability to read and understand the indications on the product labels, the farmers have poor knowledge of the danger pictograms.

The sprayers are well equipped. It is important to note that tank bottom treatment is linked to the annex tank equipment.

The farmers do not protect themselves with protective accessories. Despite being worried about their health, they do not take all the measures necessary to preserve it.

It appears that the improvement of phytosanitary practices must be integrated in a global plan of training and information. The fact that 27% of the farmers suffered illness could be useful in the development of general awareness of the risks linked to pesticide use.

Although the farmers are aware that there are risks to the health of the applicators and farm workers, only 50% use protection during spraying. It would be valuable to encourage initiatives that promote good practice in pesticide handling.

Annex 3

Multi-compartmental assessment of pesticides risks with POCER-2

Vincent Van Bol (1), Philippe Debongnie (1), Sara Claeys (2), Jean Marot (3), Walter Steurbaut (2), Henri Maraite (3), Luc Pussemier (1)
(1) Veterinary and Agrochemical Research Centre (VAR). FPS Health, Food Chain Safety and Environment. Leuvensesteenweg, 17. B-3080 Tervuren. Web site: http://www.var.fgov.be/index.php
(2) Crop Protection Chemistry Laboratory, Faculty of Agricultural and Applied Biological Sciences, Ghent University, Coupure links 653, B-9000 Ghent. Website: http://allserv.ugent.be/~hvanbost/labo/index.htm
(3) Phytopathology Unit, Catholic University of Louvain, Croix du Sud, 2 bte 3, B-1348 Louvain-la-Neuve. Web site: http://www.fymy.ucl.ac.be

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Abstract
POCER-2 has been developed to assess the risks of pesticide use in 14 areas (compartments) related to humans, the economy and the environment. Compared to POCER-1, the tool offers several innovative approaches in the translation of relative risk values into absolute values defined according to legal norms or the subjective ranking of the importance of the various compartments. The aggregation of the risks from several pesticides at the spatial and temporal levels was addressed using a procedure based on the frequency distribution of risks and resulting in the calculation of a **F**requency and **E**xcess **A**ggregation of **R**isk (FEAR) index.
The Risk Indicators System POCER-2 is presented here in detail and illustrated with an comparison of five pesticide application scenarios on winter wheat.

Key-words: pesticide risk indicator; risk indicator system; risk aggregation; risk scoring; membership function.

1. Introduction

Pesticides are used in agriculture within the context of the demand for goods and the competition for their production at the lowest price.
Clearly, people are concerned about the possible negative impact of pesticide use on their health and on natural resources. Many of these fears stem from well-documented problems, such as those with organochlorinated (e.g. DDT) or organophosphorus (e.g. parathion) compounds.
Public authorities have passed strict and complex legislation to reduce the risks linked to pesticides use. In the EU, this legislation is mainly preventive, with registration procedures for every **a**ctive **s**ubstance (a.s.) requiring the pesticide industry to test and report on numerous possible impacts on human health and environment. Once registered in Annex 1 of the 91/414/EC directive, a.s. can be mixed with several kinds of additives (e.g. wetting agents) to develop a **P**lant **P**rotection **P**roduct (PPP). The PPP is submitted for registration at national level for a specified crop and under specific use conditions.

Only these PPPs are allowed to be used. Residues of pesticides are monitored in food, feed and surface- and ground-water to ensure that everything is under control.
The ‘Thematic Strategy on the Sustainable Use of Pesticides’ was initiated by the EU Commission in 2002 through a broad consultation of European institutions and stakeholders in order to achieve a European plan for the sustainable use of pesticides. The problem was also addressed at federal level in Belgium (Plan for Reduction of Pesticides; Law of 28/3/2003 - MB / BS 11/05/2003) and at a regional level in Flanders (MIRA-T). All the plans include a procedure to assess the impact of pesticides on human health and on the environment, using indicators. There are plans to conduct a risk assessment on an annual basis.

There are already many indicators relevant to pesticide risk assessment. Currently, a literature review will reveal about a hundred of these indicators. Half of them assess risk for only one environmental compartment. A third of them address the problem of risk assessment for two or three compartments, with water organisms risk indicators dominating. The other indicators relate to between four and nine compartments. POCER-1 (Vercruysse and Steurbaut, 2002), which was developed in Belgium at Ghent University, assesses the risk for eight compartments. This article describes the development of POCER-2.

2. Material and methods for designing and testing POCER-2

Iterative prototyping

POCER-2 was developed on the basis of POCER-1, keeping the multi-compartmental approach to risk and many of its risk indicators. POCER-2 was progressively designed, with several prototypes being tested on pesticide applications where the impact on human health and the environment was already well documented. The prototype results were analysed in depth and modifications were made when needed.

Selection of compartments

Prior to any indicator development, compartments were selected so as to obtain risk information for the sustainability of pesticide use. This concept was based on three pillars: human health, natural resources and agriculture interest.

Selection of compartmental indicators

A specific **P**esticide **R**isk **I**ndicator (PRI) was allocated to each compartment. The PRIs were selected from the literature when available. Otherwise, it was developed on the basis of expert judgements.

Expert judgement

Although prototypes were analysed in the light of the well-documented impact of several pesticide applications, most of the validation process was performed on the basis of expert judgements.

Software development

POCER-2 was developed using Excel® spreadsheets and **V**isual **B**asic for **A**pplication® (VBA) routines. The software was built in a single Excel® file containing several worksheets: Input interface; Risks calculator; Databases for calculation (pesticide characteristics, parameters for exposure calculation, default coefficients, expert system); Module of VBA programme.

Database of chemical, physical and (eco)toxicological characteristics of a.s.

The database of chemical, physical and (eco)toxicological characteristics of a.s. (+/- 500 a.s.) was developed by Ghent University within the framework of POCER-1. It has been updated with the most recent data available for use in the POCER-2 project.
Each a.s. of the database was indexed with a CAS number in order to avoid any confusion arising from the molecule names in various languages.
Several data sources were used (in order of priority): European authorization report (http://europa.eu.int/comm/food/plant); active substance data from companies; CTB database (http://www.ctb-wageningen.nl); Pandora’s box (Linders *et al.*, 1994); Pesticide manual (Tomlin, 2000); Extoxnet (http://extoxnet.orst.edu); Toxnet (http://toxnet.nlm.nih.gov); and other scientific literature.
Due to the confidentiality agreement between Ghent University and the pesticide industry, some of the data used in calculations cannot be made public.

Aggregation levels of risk

Risk assessment has to be considered differently when applied to the following situations:

- risk assessment for one compartment with the application of a single a.s. at one location;
- risk assessment for multiple compartments with several a.s. applications at several locations and on several occasions.

The risk assessment in the first situation is performed with a combination of specific hazard and exposure parameters. For the second situation, the risk assessment also depends on the way the risks are combined between compartments, locations and periods. When risks are combined, it is necessary to adapt an aggregation procedure to the level of aggregation. The concept of aggregation level was developed on the basis of the literature review.

POCER-2 was designed to assess the risk at various aggregation levels: no aggregation; multiple a.s.; multiple times; multiple locations; and multiple compartments.

POCER-2 designed for future adaptations

The software was built using independent modular calculation procedures so to allow every calculation procedure to be modified without any major difficulty.

Concept definition

In order to facilitate the prototype development and the communication skills between researchers, some concepts (see definitions below) were drawn from the literature. New concepts were also developed. Risk indicators were characterised and classified.

3. Description of the POCER-2 Risk Indicators System

Conceptual definitions

Aggregation level: gradation of risk aggregation from the lowest level (risk for a single application) to the highest level (risk for multiple a.s., locations, times and compartments).

Aggregation procedure: procedure used to combine risk assessment.

Compartment: human or environmental area affected by pesticide use.

(Eco)**Tox**icological endpoint (Tox): a concentration or a dose at which a definite hazard (or the absence of any observable hazard) occurs.

Event: the application of one specified a.s., on one specified field at one specified time.

Exposure (Exp): the quantity of a.s. to which a compartment is exposed, or the concentration of a.s. in this compartment.

Hazard: the potential to cause harm (e.g. carcinogenicity) where no preventive action is possible (Lauwerys, 1999).

PRI: Pesticide Risk Indicator; a combination of Tox and Exp for one event and one compartment

RIS: Risk Indicators System; a combination of PRIs.

Risk aggregation: combination of risks from several events or several compartments.

Risk: the likelihood of harm where preventive action is possible (Lauwerys, 1999); a combination of hazard and exposure.

Selection of compartments

POCER-2 is an RIS based on risk assessments for 14 compartments: consumers; applicators (of pesticide); farm-workers; bystanders (in a field where pesticides are applied); beneficial arthropods; bees; birds; water organisms (fish, algae, crustaceans); earthworms; soil quality; air quality; ground-water quality; resistance induction (for target organisms); and farm cost.

Selection of Pesticide Risk Indicators

PRIs for applicators, farm-workers, bystanders, beneficials, bees, birds, earthworms, ground-water and soil were taken from POCER-1 (Vercruysse and Steurbaut, 2002). PRIs for water organisms and ground-water were adapted from the SyPEP model (Pussemier, 1999). PRIs for consumers, air quality, resistance induction and farm cost were developed within the framework of this research.

Each PRI is associated with a threshold value named '**K**ey **v**alue' (Kv) to make it possible to evaluate the relevance of the indices. The indices are then divided into two classes: excessive risk for the indices that exceed Kv; and accepted risk for the indices below Kv. When available, Kv is based on official norms.

The 14 indicators are described below.

$RI_{ground\text{-}water}$: Risk Index for ground water = $\frac{APEBOD}{Tox}$; Kv = 1 (Equation 1)

Where Tox = 0.1 µg/l: ground water max. pesticide a.s. concentration (EC 80/778; EC98/83); APEBOD (**A**mount **P**otentially **E**xportable **B**elow **O**ne meter **D**epth; µg/l) = (CSPER1 * actual dose / reference dose) * soil correction factor *1000 / 2600; CSPER1 (g/ha.year) is the amount of pesticide able to leach under 1 m depth according to the Dutch standard scenario (negligible when GUS < 2.96) = 0.00004 * $(GUSVar)^{8.228}$; soil correction factor is a function of soil type and annual rainfall; GUS (**G**round **U**biquity **S**core) = log DT_{50} * (4 - log Koc) (Gustafson, 1989).
Note that in this particular case, the Tox value is actually the European norm for drinking water, which is much more severe than the real toxicological MPC of authorized pesticides.

$RI_{water\ organisms}$: Risk Index for water organisms = $\frac{PCOW * (1 - BFI)}{Tox}$; Kv = 1 (EC 91/414)(Equation 2)

Where Tox = 10 * MPC (10: safety factor considering MPC is generally used form long-term toxicity); MPC (**M**aximum **P**ermissible **C**oncentration) (Crommentuijn *et al.*, 2000) = a selection of NOEC and L(C)D50 for fish, algae, daphnia; PCOW (**P**redicted **C**oncentration in **O**utflowing **W**ater; g/l) = (APESUW / rainfall * SPR) with rainfall in mm per fortnight; APESUW (**A**mount **P**otentially **E**xportable to **SU**rface **W**ater) = direct losses + CRR(drift + runoff + interflow & drainage); direct losses = 0.005 * AR (**A**pplied **R**ate; g/ha); drift = AR * dc (**d**rift **c**oefficient = 0.0001 for downwards spraying and 0.0005 for upwards spraying); runoff and erosion = 0.004 * DRS (**D**ose **R**eaching the **S**oil) = AR- direct losses - drift - Plant Interception (f(crop and date)); interflow (hypodermic flow) & drainage = DRS * dh (**d**rainage and **h**ypodermic flow = 0.01% when GUS < 3, 0.1% when 3 < GUS < 4, 1% when 4 < GUS < 4.5, and 10% when GUS > 4.5); CRR: **C**rop and **R**iver **R**atio = 0.01 for Belgium; SPR: **S**tandard **P**ercentage **R**unoff = 0.333 in Belgian conditions

RI_{soil}: Risk Index for soil = DT_{50}; Kv = 90 days (Equation 3)

$RI_{farm\text{-}workers}$: Risk Index for farm-workers = $\frac{DE * Ab_{de}}{AOEL}$; Kv = 1 (Equation 4)

Where DE (**D**ermal **E**xposure; mg/day) = 0.01 * (AR / LAI) * TF * f(D) * T * P; AR (**A**pplied **R**ate; kg a.s./ha); LAI (**L**eaf **A**rea **I**ndex; m^2/m^2); TF (**T**ransfer **F**actor; cm^2/person/hour); f(D) (**D**issipation **f**actor); T (**T**ime of re-entry; hour) P (**P**enetration factor for clothing); Ab_{de} (**de**rmal **Ab**sorption factor); AOEL (**A**cceptable **O**perator **E**xposure **L**evel; mg/kg) following tables

$RI_{earthworms}$: Risk Index for earthworms = $\frac{10 * PEC_{initial}}{LC_{50\,earthworms}}$; Kv = 0.1 (EC 91/414) (Equation 5)

Where $PEC_{initial}$ = [(mAR * f * 100) / (d * ρ)] (Boesten *et al.*, 1997); mAR (**m**ax. **A**pplied **R**ate; kg a.s./ha); f (fraction of applied a.s. on the soil); d (**d**epth; m)) with default value = 0.05; ρ (soil density; kg/m³)

$RI_{bystanders}$: Risk Index for bystanders = $\frac{DE * Ab_{de} + I * Ab_{i}}{AOEL}$; Kv = 1 (Equation 6)

Where DE (**D**ermal **E**xposure; mg/day) = AR * drift * opp; AR (**A**pplied **R**ate; kg a.s./ha); drift = % out of Ganzelmeier tables; opp (exposed skin surface; m^2/person/day); Ab_{de} (**de**rmal **Ab**sorption factor); Ab_i (**i**nspiration **Ab**sorption factor); I (respiratory exposure) = I_a * WR * AR where I_a (respiratory exposure for the **a**pplicator); and WR (**W**orking **R**ate; ha/day)

RI_{bees}: Risk Index for bees = $\frac{mAR}{50 * LD_{50}}$; Kv = 50 (EC 91/414) (Equation 7)

Where mAR = **m**ax. **A**pplied **R**ate (kg a.s./ha); LD_{50} (**L**ethal **D**ose for **50** % of the population; µg a.s. / bee)

RI_{birds}: Risk Index for birds = $\frac{10 * PEC}{LD_{50} * BW}$; Kv = 0.1 (EC 91/414) (Equation 8)

Where PEC = daily amount intake of a.i (mg/day) = max Exp of three routes: $Exp_{bird\ eating\ treated\ plant}$, $Exp_{bird\ eating\ treated\ seed}$, $Exp_{bird\ eating\ granule}$; $Exp_{bird\ eating\ treated\ plant}$ = 31 * AR * BW * 0.3; 31 = coef. based on (Hoerger and Kenaga, 1972); AR

(**A**pplied **R**ate; kg a.s./ha); BW (**B**ody **W**eight) with default value = 0.01 k g; 0.3: based on a DFI equal to 30% of a small bird body weight (Kenaga, 1973); $Exp_{bird\ eating\ treated\ seed} = AR * BW * 0.3$; $Exp_{bird\ eating\ granule} = 20\ GW * A$; 20: a daily consumption of 20 granules; GW (**G**ranule **W**eight; mg) whith default value = 2; A: fraction of a.s. in the granule

$RI_{applicators}$: Risk Index for applicators = $\frac{IE_{applicator}}{AOEL}$; Kv = 1 (Equation 9)

Where $IE_{applicator}$ (**I**nternal **E**xposure; mg/kg) issued from dietary exposure simulations EUROPOEM I

$RI_{beneficial}$: Risk Index for beneficial arthropods = RC; Kv = 30 (EC 91/414) (Equation 10)

Where RC (**R**eduction of beneficial **C**apacity; %) following the IOBC Working Group

$RI_{consumers}$: Risk Index for consumers = $\frac{MRL * EDI}{ADI} * \frac{AR}{RD}$; Kv = 1 (Equation 11)

Where MRL (**M**aximum **R**esidue **L**imit; mg a.s. / kg food); EDI (**E**stimated **D**aily **I**ntake; kg food/kg b.w./day); ADI (**A**cceptable **D**aily **I**ntake; mg a.s. / kg b.w./day); AR (**A**pplied **R**ate; kg a.s./ha); RD (**R**eference **D**ose; kg a.s./ha)

RI_{air}: Risk Index for air = $\frac{AC}{TLV}$; Kv = 1 (Equation 12)

Where AC (**A**ir **C**oncentration; g a.s. / m³ air) is calculated with the EQC model (Mackay *et al.*, 1996) at a fugacity level I; TLV (**T**hreshold **L**imit **V**alue; g a.s./m³) is the maximum concentration of a chemical in the air in the workspace of a worker, sometimes known as the Maximum Allowable Concentration of the pesticide in air normally permitted in industrial environments

$RI_{resistance\ induction}$: Risk Index for resistance induction = FRAC score; Kv = 1 (Equation 13)

Where FRAC (**F**ungicide **R**esistance **A**ction **C**ommittee) score = 0; 1; 2 or 3 for respectively a resistance induction level qualified as 'nil', 'low', 'medium' or 'high' in the FRAC listing of a.s. (FRAC, 2003). When no information is provided on the resistance induction level, the score is noted '/' which sign is used to disable the RI calculation. Insecticides and herbicides are scored '/' as no difference between a.s. is specified in the HRAC (**H**erbicide **RAC**) and IRAC (**I**nsecticide **RAC**) listings (HRAC, 1998; IRAC, 2003).

$RI_{farm\ cost}$: Risk Index for farm cost = $\frac{P}{Qs}$; Kv = $\frac{\overline{X}_P}{\overline{X}_{Qs}}$ (Equation 14)

Where Qs = **Q**uality **s**core is an evaluation of the adequacy of the pesticide selection to control the pest/disease; P (**P**rice) of the pesticide

Rem: <u>sensu stricto</u> $RI_{farm\ cost}$, $RI_{resistance\ induction}$ and RI_{soil} should not be considered as PRIs as long as they are not based on a combination of Tox and Exp; they are included as indicators of sustainability of the agricultural practices considered.

<u>Interpretation of the Risk Indices outputs</u>

In the context of the pesticide risk evaluation it makes sense to modulate the level of relevance of the indices according to their distance to Kv. The fuzzy logic methodology (Zadeh, 1968a; b) was used to address this problem. With this approach, the membership of an index in a class is progressively modified when the value gets closer to the limit. Membership values are then multiplied by 10 to obtain **R**isk **S**cores (RS) (Equation 15).

$$\forall \mathrm{RI} > \mathrm{Kv}; \mathrm{RS} = 10 * \left[1 - \left(\frac{\mathrm{Kv}}{\mathrm{RI}}\right)^k\right]; \ \forall \mathrm{RI} \leq \mathrm{Kv}; \mathrm{RS} = 10 * \left[\left(\frac{\mathrm{RI}}{\mathrm{Kv}}\right)^k - 1\right]$$ (Equation 15)

Where RI = **R**isk **I**ndex; Kv (**K**ey **v**alue); k = scoring coefficient depending of the output range specific to each compartment : k = 1 if (Kv/Max) ≥ 0.05 and k = $\log_{(Kv/Max)}(0.05)$, if(Kv/Max) < 0.05 where Max is the **Max**imal value of the RI outputs range (Figure 1)

Depending on the compartment assessed, outputs ranges vary greatly (e.g. outputs of RI_{birds} vary from [0 up to ∞[while those of $RI_{beneficials}$ vary from 0 up to 100). It was necessary to adapt the membership functions (Equation 15) to these various situations in order to avoid bias (Table 1).

For $RI_{farm\ cost}$ (Equation 14), Kv and k values vary as a function of the range of inputs (i.e. effectiveness and price) for the applications tested.

Except for RI_{cost}, all the other scoring functions not mentioned in Figure 1 have a shape similar to that of RI_{bees} but with a specific intercept relative to their Kv.

Multiple event situations

For any multiple event situation (e.g. several a.s. applications on a crop), a distribution frequency diagram of RSs is developed for each RI (Figure 2). This enables one to visualise the proportion of risk scores that are above zero (i.e. that are considered unacceptable).

Time, space, and active substance aggregation of Risk Scores

An a.s. aggregation procedure would need to be based on a theory of risk combination that does not currently exist. Are the risks additives, synergists or antagonists?
The resulting risk after a period would probably be reduced as a function of time proportionally to DT_{50}. In this situation, there is always a period after which no acute risk is relevant.
A space aggregation procedure would be based on a GIS approach *via* the definition of interpolation models specific to each compartment.

The development of such procedures will certainly be helpful to any further development of RIS. However, at present we are limited to working with the assessment of the frequency and the excess of individual risk. These aspects are integrated into a **F**requency and **E**xcess **A**ggregation of **R**isk (FEAR) index. This is calculated for each compartment as follows:

$$\forall \mathrm{RS}_j > 0; \mathrm{FEAR} = \left(\sum_{j=1}^{n} (\mathrm{RS}_j)^2\right)^{0.5}$$ (Equation 16)

Where FEAR = **F**requency and **E**xcess **A**ggregation of **R**isk; j = the event number; n = the number of events

This approach puts the emphasis only on RS positive values, and highlights the highest values compared to the lowest.

Compartmental aggregation of Risk Scores

A compartmental aggregation has been proposed for POCER-2 to obtain a risk assessment for each of the factors in the sustainable use of pesticides: human health, natural resources and the agricultural sector. The combination of risks between compartments depends on the relative importance given to each compartment, which is necessarily arbitrary. The aggregation procedure is based on the subjective ranking of compartments selected by the POCER-2 user. Such an aggregation procedure was also described by Mendoza et al. as a weighted linear combination (Mendoza and Prabhu, 2003).

A 'neutral' ranking of compartments is used as the standard for the compartment aggregation procedure (Table 2).

This standard ranking gives the same weight to all compartments. Some compartments are relevant for two centres of interest. Depending on the POCER-2 user, another compartment ranking could be chosen. This issue is, in fact, more of a political question than a scientific one and should therefore be addressed in the relevant forum.

A FEAR index is calculated, for each centre of interest, on RSs weighted by the compartments ranking grid.

$$\forall RS_j > 0; FEAR = \left(\sum_{i=1}^{14} \sum_{j=1}^{n} \left(Wf_{ij} * RS_{ij} \right)^2 \right)^{0.5} \quad \text{(Equation 17)}$$

Where FEAR = the **F**requency and **E**xcess **A**ggregation of **R**isk; j = the event number; n = the number of events; i = the compartment number; m = the number of aggregated compartments; Wf (**W**eighting **f**actor); RS (**R**isk **S**core).

Equation 17 is a more of a general equation for a FEAR calculation than the previous one (Equation 16), which was restricted to cases where the number of aggregated compartments is equal to 1.

Software development

The POCER-2 software was developed for risk assessment in a defined scenario. A scenario includes one or several events. When there are several events, they are assessed separately or grouped. Groups consist of every combination of a.s. that are applied in the same place or/and at the same time (e.g. commercial product; field treatment scheme of several applications).
The scenario is defined by the user completing the Input Sheet. For each event, 25 data are required (Table 3).
In a further development of the software, the input data registration should be done using a specific interface.

Each run of POCER-2 results in the creation of a report in a separate workbook that includes six chapters (Table 4).

Expert system

RI calculations are based on exposure models adapted to general application conditions. However, in some specific situations and for some RIs, an expert judgment is needed to avoid systematic bias. For example, drift does not occur when pesticides are applied as granules. In this particular situation the calculation of exposure due to drift should be cancelled.

The following event parameters were checked for their impact on RIs:

crop species;
crop type (field crop, orchard, greenhouse crop);
application type (seed dressing, spraying, pouring, granule, soil injection);
treatment date;
flowering period.

Important situations where the risk calculation is not relevant were checked and summarized in a worksheet included in the POCER-2 workbook. When such situations are detected by the expert system the risk calculation is cancelled. RS is then fixed at '-10', and a 'NR' (Not Relevant) notation appears in the report.

4. POCER-2 assessment example

The scenario tested is a comparison of five treatment schemes for winter wheat. The scenario had already been tested in the CAPER research (Reus *et al.*, 1999).
The calculation coefficients common to all events of a scenario are summarized in the 'Introduction'. This easy check of the calculation parameters helps make POCER-2 more transparent for the user. The content of the introduction report is presented below (Table 6).

The 'Active Substance' chapter (Figure 3) includes a risk assessment for each event separately, i.e. for the 62 molecules in the CAPER winter wheat scenario. Each event is referenced with a number, which is also used in the other chapters of the report. Characteristics specific to the event are mentioned below the a.s. name. A graph shows the risk assessment for each compartment. The values are expressed in Risk Scores (i.e. from –10 to +10). When data are lacking for calculation, no result is given and a '/' sign is noted. When the expert system cancels a risk calculation, the score becomes '-10' and an 'NR' (Non Relevant) notation appears to the right of the compartment name.

In these examples, excessive risks are highlighted for resistance induction in both events and for applicators and soil in Event 22. Due to the lack of data, no calculation was performed for the air and farm cost compartments. All the other risk scores were negative (risk considered as negligible).

The frequency distributions of risk scores are presented, for each treatment scheme, in the 'Group' chapter (Figure 4). The results are presented in a graph for each compartment.

The scores on the right of the vertical dashed line are those considered as excessive. The more numerous these are, the more they will appear on the right side of the figure and the more important FEAR is. It is worth noting that FEAR is not calculated when the % of available results is too low (i.e. when less than 75% of the group results are available).

In the treatment scheme 'Worst case', FEAR is greater than zero for six compartments out of 14. FEAR is not calculated for four compartments and an excessive risk is noted for four compartments. Figures analyse is supported by the information provided in the 'Active substance' chapter. For example, the excessive risk shown for applicators is due to *isoproturon* (RS = 10) and *mecoprop-p* (RS = 5).
Compartment aggregation is performed in the 'Global risk' chapter. There, RSs are combined for several compartments following a subjective ranking of the compartments' importance. In this example, five RIs represent the 'Human health' focus, seven RIs represent the 'Natural resources' focus and six RIs focus on 'Agriculture' (Table 7). Each selected compartment is equivalent in importance to the others.
The FEAR index is calculated ((Equation 17) following this (subjective) grid for each a.s. separately and for each treatment scheme.

Results represented by '/' mean that, due to a lack of data, the FEAR index could not be calculated. The FEAR index for treatment schemes increases from the best case to the worst case.

The POCER-2 report has been completed by a technical annex where events characteristics and RIs are presented (Table 8) in columns. The characteristics common to every event have been presented in the 'Introduction' chapter.

5. Discussion

One would expect that, in general, no pesticide registered for agricultural use would present an unacceptable risk for human health and the environment under normal application conditions. The registration of pesticides is meant to prevent this. The risk assessment of pesticide applications within a regular framework should thus never show any excessive risk for the compartments concerned in the registration procedure. Nevertheless, POCER-2 does show some excessive risks. This stems from the RIs and the Kv definitions.

RIs are based on a first tier approach, i.e. worst case for exposure is taken into account. This means that when the risk is considered to be acceptable in a first tier approach, we expect that this would always be true in real application conditions. In contrast, when a risk is considered to be excessive with a first tier approach, this means that we have to verify whether this occurs in real application conditions. The expert system used in POCER-2 by-passes the risk determination for some usual application conditions for which the risk is considered to be negligible (e.g. risks of surface-water contamination with seed treatments). But there are still numerous other situations where pesticides are rejected at a first tier risk assessment. The case of paraquat is a good illustration of a pesticide rejected at a first tier risk assessment. This cationic molecule is potentially hazardous for aquatic organisms in a first tier approach. But, in the rivers, this is almost not bio-available because of its specific physico-chemical properties, and consequently does not present any risk for aquatic organisms. For such situations, a second and sometimes a third tier risk assessments are necessary. Normally, such detailed assessments are provided within the framework of pesticide registration. Nevertheless, a first tier approach with indicators can still be used to identify which products and applications might be avoided to minimize the impact of pesticides on human health and the environment.

The Kv selection is of major importance for the FEAR calculation. FEAR is based only on positive RSs, which are, in fact, the RI outputs that overstep the Kv. Reducing every Kv would result in a general increase of the FEAR values, and *vice-versa*.

Another problem linked to the RI definition is their time-scale heterogeneity. Seven RIs in POCER-2 have been developed using a long-term risk approach. One is based on a medium-term risk approach, while the six others are based on a short-term risk approach.

Even if the risk is accepted for a single event, it is not currently possible to assess the risk for a situation with multiple events of accepted risks. Aggregation procedures are to be developed to solve this problem.
Temporarily, the solution proposed in POCER-2 is to develop a FEAR index calculation and a graph of RS frequency distribution. The FEAR calculation is *de facto* a risk aggregation based on an additive hypothesis of risks, with the emphasis put on higher values.
The frequency distribution graph of RSs is perhaps more interesting for further development. If one could define for each compartment a representative distribution curve, it should be feasible to calculate the excessive risk probability. This concept would be certainly be easier to combine with the caution principle as the basis for the sustainable use of pesticides.

The compartmental aggregation procedure deals with sociological, economic and political concerns grouped under the 'subjective' compartment ranking concept. This has the advantage of reserving the compartment ranking considerations for any assembly (e.g. consumer groups, country representatives) that is adequate from the point of view of the POCER-2 user. (It worth noting that some subjectivity on the risk assessment may already exist at the stage of the membership functions used for scoring RIs outputs. The translation of relative values of RIs into absolute values of RSs depend in fact on Kv which is ultimately a political issue)

6. Conclusions

POCER-2 is not just yet another pesticide risk indicator system adapted to local conditions. Compared to POCER-1, it brings some progress in the following areas:

- a wide multi-compartmental risk assessment for 14 compartments;
- a specific compartmental aggregation procedure where the relative importance of compartment ranking is clearly related to the appreciation of the stakeholders in the 'pesticide question';

- a spatial, temporal and a.s. risk aggregation procedure based on the distribution frequency of risks;
- a FEAR index which is based only on risks considered to be excessive and which puts more emphasis on higher risks than lower ones.

Scoring functions based on membership functions to classes (excessive risk or not excessive risk) are, in POCER-2, of major importance for the risk assessment. Any modification of their parameters (Kv) should allow the tool to be adapted based on a fairly stringent approach to safety.

In risk management, there is always room for both objective and subjective considerations. Risk assessment follows this rule as long as there is a need to compare a relative risk (RI) with a risk which is subjectively considered to be acceptable. POCER-2 has the advantage of clearly delimiting the influence of this subjectivity in the scoring functions and the compartment ranking.

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Table 1 - Membership function parameters

RI	eq n°	Kv	Source	Outputs range	k
Ground-water	1	1	EC 80/778; EC 98/83	[0; + ∞[	1.0
water organisms	2	1	EC 91/414	[0; + ∞[	1.0
soil	3	90	EC 91/414	[0; 3650]	1.0
farm-workers	4	1		[0; + ∞[	1.0
earthworms	5	0.1	EC 91/414	[0; + ∞[	1.0
bystanders	6	1		[0; + ∞[	1.0
bees	7	50	EC 91/414	[0; + ∞[	1.0
birds	8	0.1	EC 91/414	[0; + ∞[	1.0
applicators	9	1	EC 91/414	[0; + ∞[	1.0
beneficials	10	30	EC 91/414	[0; 100]	2.5
consumers	11	1	EC 91/414	[0; + ∞[	1.0
air	12	1		[0; + ∞[	1.0
resistance induction	13	1		[0; 3]	2.7
farm cost	14	variable		[0; max]	variable

Table 2 - 'Neutral' ranking of compartments used as the standard for compartmental aggregation

Compartments \ Centres of interest	Human health	Natural resources	Agriculture
consumers	100%		
applicators	100%		100%
farm-workers	100%		100%
bystanders	100%		
birds		100%	
bees		100%	100%
beneficials		100%	100%
water organisms		100%	
earthworms		100%	100%
air	100%	100%	
soil		100%	100%
ground water	100%	100%	
resistance induction			100%
farm cost			100%

Table 3 - Required data characteristic to each event in POCER-2

	Parameters	Format options
(1)	Scenario name	free name
(1)	Active substance number in scenario	integer number
(1)	Active substance name	registered CAS name
	Plant Protection Product (PPP) name	free name
	Active substance concentration in PPP	number
	Unit of concentration	g/l; % volume
(1)	PPP formulation	symbol from a specific list
(1)	Date of application	day and month
(1)	Flowering period	yes; no
(1)	Crop name	name from a specific list
(1)	Dose rate	number (g/ha)
	Pest or disease	targeted organism name
(1)	Application technique	spraying; pouring; seed dressing; granule; soil injection
(1)	Application type 1	mechanical; manual
(1)	Application type 2	indoors; outdoors
(1)	Application direction	upwards; downwards
(1)	Personal Protection Equipment (PPE) of applicator	yes; no
(1)	PPP of farm-worker	yes; no
(1)	Region name(2)	name from a specific list
(1)	Region soil type(2)	name from a specific list
(1)	Compartment ranking type	name from a specific list
	Product price	€/ha
	Effectiveness of the pesticide against target	numerical range for quality, e.g.: 1-10
(1)	Direct losses cautions	yes; no
	Group name (common name of events that are to be grouped)	free name

Legend: (1)Mandatory input; (2)These parameters are required to select calculation coefficients specific to a region (e.g. the Crop and River Ratio in $RI_{water\ organisms}$). The choice of options for these parameters is limited to available regional coefficients.

Table 4 - POCER-2 report table of contents

Chapter I - Introduction (Common characteristics) - Database references (version & date) - File name of the report - Name of the person conducting the assessment - Name of the scenario tested - General comments - Common characteristics of the scenario tested - Common characteristics of a.s. tested in the scenario
Chapter II - Active substance - Active substance risk assessment ° Specific characteristic of the application ° Risk scores for every compartments ° Risk figure
Chapter III - Commercial product (optional; if tested in the scenario) - Commercial product risk assessment ° Commercial product name ° Commercial product composition and references of every a.s. risk assessment in the chapter 'Active substance' ° Frequency distribution of RSs for every compartment ° FEAR for each compartment
Chapter VI - Group (optional; if tested in the scenario) - Group risk assessment ° Group name ° Group composition and references of every a.s. risk assessment in the chapter 'Active substance' ° Frequency distribution of RSs for every compartment ° FEAR for each compartment
Chapter V - Global risk - Subjective ranking of compartment selected for the risk assessment - Human health, natural resources and agriculture focussed risk assessment with FEAR values ° Active substance(s) ° Commercial product(s) ° Group(s)
Annex (Risk Indices and specific characteristics of events) - Calculation references - (Eco)toxicological and physical parameters used - Calculation coefficients - RIs values before any scoring and aggregating process

Table 5 - Scenario for comparing treatment schemes

Treatment scheme reference	Date	Pest/disease	Active ingredient	Dose rate (g/ha)	Application type
I - best case	1w Nov		fludioxonyl	15	seed treatment
			anthraquinone	150	seed treatment
	4w March	weeds	fenoxaprop-p-ethyl	100	field spray
			metsulfuron methyl	4	field spray
	2w May	diseases	epoxyconazole	105	field spray
II - second best case	1w Nov		fludioxonyl	15	seed treatment
			anthraquinone	150	seed treatment
	3w Nov	weeds	isoproturon	750	field spray
			diflufenican	150	field spray
	3w April	diseases	prochloraz	300	field spray
			cyproconazole	80	field spray
	3w May	diseases	epoxiconazole	125	field spray
			kresoxim-methyl	125	field spray
	3w June	aphids	pirimicarb	125	field spray
III - normal	1w Nov		fludioxonyl	15	seed treatment
			anthraquinone	150	seed treatment
			tefluthrin	60	seed treatment
	2w March	weeds	mecoprop-p	250	field spray
			isoproturon	1000	field spray
	1w April	growth regulation	chlormequat	800	field spray
	2w April	weeds	fluroxypyr	200	field spray
	3w April	diseases	prochloraz	300	field spray
			cyproconazole	80	field spray
	3w May	diseases	kresoxim-methyl	105	field spray
			epoxyconazole	105	field spray
	2w June	aphids	esfenvalerate	5	field spray

Treatment scheme reference	Date	Pest/disease	Active ingredient	Dose rate (g/ha)	Application type
IV - almost worst case	1w Oct		fludioxonyl	20	seed treatment
			anthraquinone	200	seed treatment
			tefluthrin	80	seed treatment
	1w Nov	weeds	isoproturon	1500	field spray
			diflufenican	188	field spray
	2w April	weeds	MCPA	800	field spray
		weeds	fluroxypyr	200	field spray
		growth regulation	chlormequat	800	field spray
	3w April	diseases	prochloraz	450	field spray
			carbendazim	200	field spray
	2w June	diseases	kresoxim-methyl	105	field spray
			fenpropimorph	750	field spray
	3w June	diseases	epoxyconazole	105	field spray
			chlorothalonil	1080	field spray
	3w June	aphids	pirimicarb	125	field spray
	3w July	aphids	esfenvalerate	5	field spray
V - worst case	1w Oct	various	imidacloprid	105	seed treatment
			bitertanol	23	seed treatment
			anthraquinone	75	seed treatment
	1w March	weeds	isoproturon	1000	field spray
			bifenox	300	field spray
			ioxynil	92	field spray
			mecoprop-p	260	field spray
			amidosulfuron	15	field spray
	1w April	growth regulation	chlormequat chloride	920	field spray
	2w April	growth regulation	chlormequat chloride	690	field spray
	2w April	diseases	cyprodinil	600	field spray
			cyproconazole	43	field spray
	4w April	weeds	metsulfuron methyl	4	field spray
	2w May	diseases	epoxiconazole	100	field spray
			fenpropimorph	400	field spray
	1w June	diseases	metconazole	90	field spray
			chlorothalonil	750	field spray
	1w June	insects	esfenvalerate	5	field spray
			oxydemeton-methyl	125	field spray
	1w August		glyphosate	1000	field spray

Table 6 - Scenario parameters that are common to all events

Common characteristics of the scenario
Product Name(/): /
Crop Name (/): Winter wheat
Human Food Crop : Yes
PPP Formulation: SL
Crop Name: Winter wheat
Application Type: Mechanical
Indoor/Outdoor: Outdoors
Application Direction: Downwards
PPE of Applicator: no
PPE of Farm-Worker: no
Regional Reference: Belgium
Soil Type: Loam
Compartment Ranking Type: Neutral
Common calculation coefficients
$\mathbf{RI_{applicators}}$, $\mathbf{RI_{farm\text{-}workers}}$, $\mathbf{RI_{bystanders}}$
Mixing and Loading Inhal. Coef. (mg/kg a.s.): 0.005
Mixing and Loading Dermal Coef. (mg/kg a.s.): 20
Applicator Inhalation Coefficient (mg/kg a.s.): 0.008
Applicator Hand Coefficient. (mg/kg a.s.): 2
Applicator Dermal Coefficient (mg/kg a.s.): 0.6
Daily Area Treated (ha/day): 10
Transfer Factor (cm^2/hour): 5000
Inhalation Coefficient (cm^2/hour): 1
Body Weight (kg): 70
Exposure With PPE (%): 0.1
Default Dermal Hand Absorption Coefficient (/): 0.1
Default Dermal Body Absorption Coefficient (/): 0.1
Duration of Re Entry (h): 8
Body Exposed Area (m^2/person/day): 0.4225
Mixing Loading Class (/): Liquid
Leaf Area Index (foliar m^2/soil m^2): 1
$\mathbf{RI_{water\ organisms}}$
Standard Percentage Run-Off (/): 0.333
Basis Flow Index (/): 0.5
Drift Coefficient (/): 0.01
Application Direct Losses (/): 0.005
Bystander Drift (/): 0.005
Crop And River Ratio (/): 0.01
Ground Water Annual Recharge (mm): 2600
Averaged Monthly Rainfall (mm): 32.5
$\mathbf{RI_{birds}}$
Default Bird Weight (kg): 0.01
Default Granule Weight (mg): 2
$\mathbf{RI_{earthworms}}$
Soil Impregnation Depth (m): 0.05
Soil Density (kg/m^3): 1430
Soil Correction Factor (/): 0.14

NB: for compartment ranking type 'Neutral' see Table 2

Table 7 - Global risk report

a) Subjective ranking of the compartments’ importance

Compartments	Focus Human health	Natural resources	Agriculture
consumers	100%		
applicators	100%		100%
farm-workers	100%		100%
bystanders	100%		
birds		100%	
bees		100%	100%
beneficials		100%	100%
water organisms		100%	
earthworms		100%	100%
air			
soil		100%	100%
ground water	100%	100%	
resistance induction			
farm cost			

b) FEAR* values related to the above subjective ranking

	Human health	Natural resources	Agriculture
Active substance level			
1. fludioxonyl	0.0	0.0	0.0
2. anthraquinone	/	0.0	/
3. fenoxaprop-p-ethyl	6.9	0.0	6.9
4. metsulfuron methyl	/	0.0	0.0
…			
60. esfenvalerate	0.0	10.2	10.1
61. oxydemeton-methyl	/	12.8	/
62. glyphosate	0.0	0.0	0.0
Group level			
1. I - best case	6.9	0.0	6.9
2. II - second best case	/	11.2	13.7
3. III - normal	20.6	18.7	16.8
4. IV - almost worst case	20.6	19.3	17.5
5. V - worst case	/	26.9	20.5

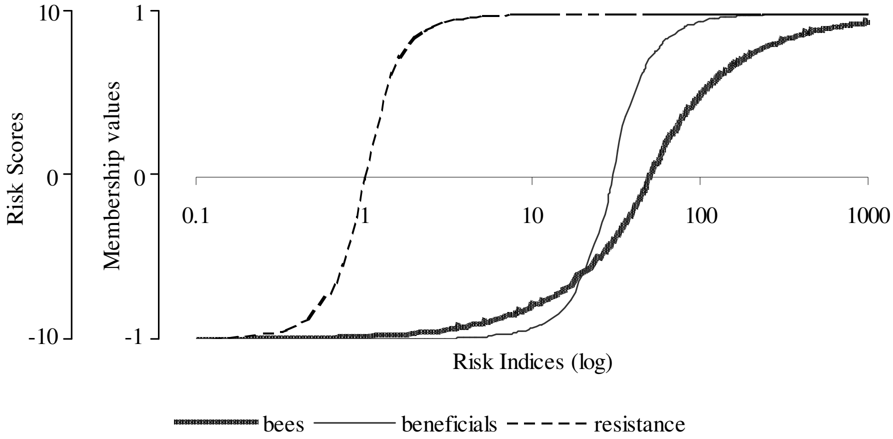
* FEAR (Frequency and Excess Aggregation of Risk) is defined as the square root of the sum of squares of positive Risk Scores.

Table 8 - Technical annex

Calculation Reference	1	…	62
Calculation parameters			
Active Substance Name	fludioxonyl	…	glyphosate
CAS N° (/)	131341-86-1	…	1071-83-6
Koc (l/kg)	*	…	884
DT50 Soil (day)	*	…	12
GUS (/)	*	…	1.14
Pesticide Type (/)	Fungicide	…	Herbicide
MRL (mg a.s./kg food)	/	…	5
AOEL (mg/kg/day)	0.25	…	0.2
Acceptable Daily Intake (mg a.s./kg b.w.)	0.033	…	0.3
Dermal Absorption (%)	10	…	3
TLV (g/m³)	/	…	/
LC50 Earthworms (mg/kg soil)	*	…	480
LD50 Bees (µg/bee)	*	…	100
LD50 Birds (mg/kg b.w.)	*	…	2000
Min. Aquatic Tox. (mg/l)	*	…	72.9
Coefficient Predation Reduction (%)	23.6535	…	12.5
Mode Of Action	FRAC-12	…	HRAC-G
Resistance Status	2	…	/
Air Concentration (g/m³)	0.000	…	0.000
Crop Interception (/)	0	…	0.8
Fortnight (/)	nov-1	…	aug-1
Drainage Correction Factor (/)	0.0001	…	0.0001
DAC (Dermal Absorption Coefficient; /)	0.1	…	0.03
Risk Index outputs			
consumers	NR	…	0.0
applicators	0.0	…	0.5
farm-workers	NR	…	NR
bystanders	NR	…	0.0
birds	0.0	…	0.0
bees	NR	…	NR
beneficials	NR	…	12.5
water organisms	0.0	…	0.0
earthworms	*	…	0.0
air	/	…	/
soil	*	…	12.0
ground water	0.0	…	0.0
resistance induction	2.0	…	/
farm cost	/	…	/

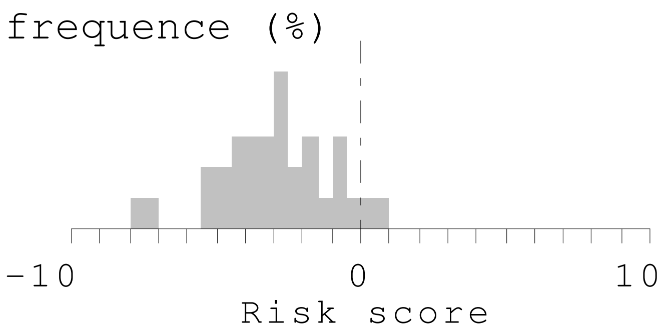
Legend: NR = risk assessment is ***N****ot* ***R****elevant; (*) for confidential values.*

Figure 1 - Scoring functions for Risk Indices



Legend: scoring functions are shaped specifically to the RIs outputs range; the intercept of functions corresponds to the Kv for each compartment.

Figure 2 - Frequency distribution of risk scores for a single-compartment, multiple-events situation



Legend: risk scores above 0 are considered unacceptable

Figure 3 - Active Substance Report - example with two outputs

1. fludioxonyl
Date of Application: 1w November
Flowering Period: No
Dose Rate: 15 g/ha
Pest or Disease: various
Application Technique: Seed Dressing
Group Name: I - best case

Compartments	Score
consumer	-10
applicator	7
farm-worker (NR)	-10
bystander	-10
birds	-10
bees (NR)	-10
beneficials	-7
water organisms	-9
earthworms	-10
air	/
soil	1
ground water	-10
resistance induction	9
farm cost	/

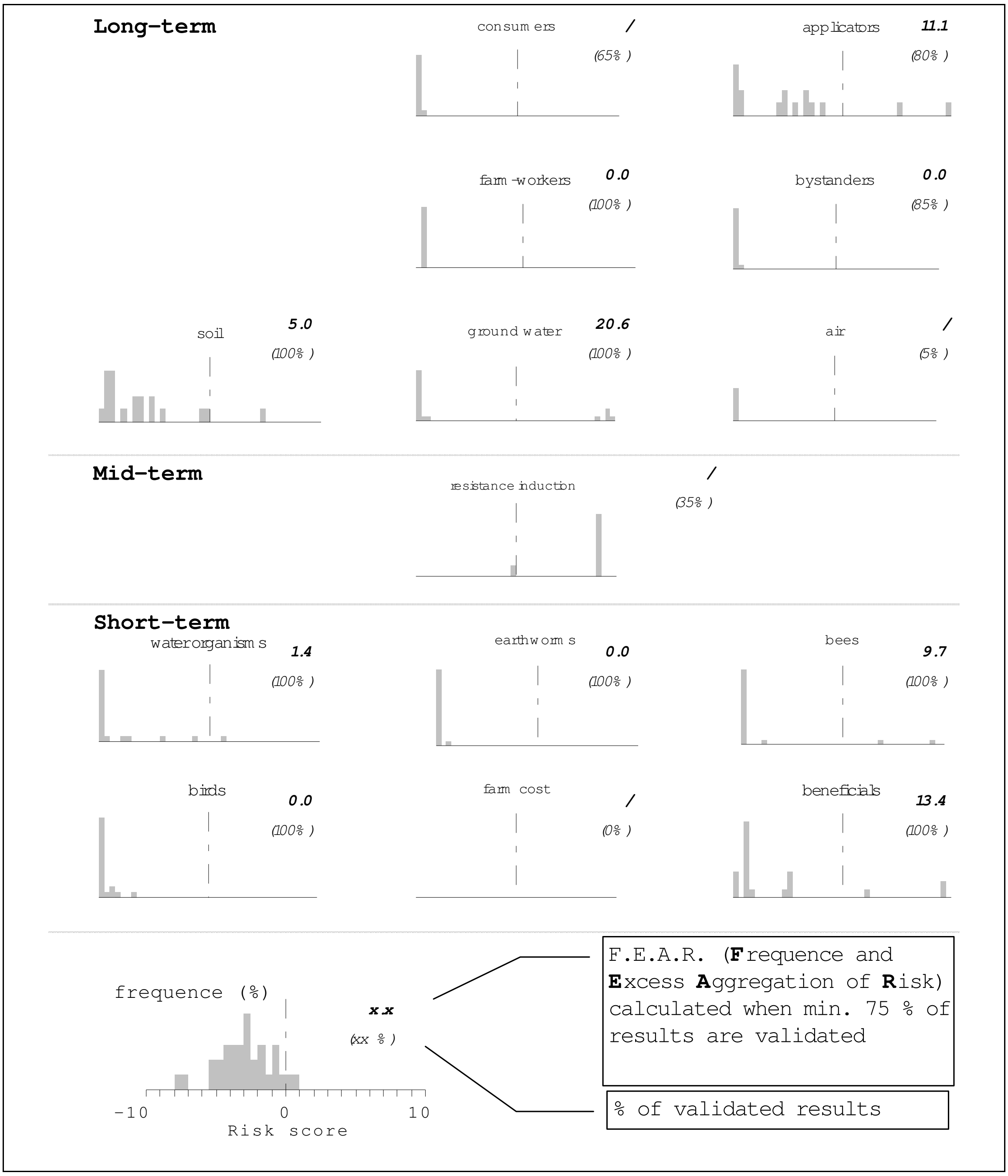
...

22. prochloraz
Date of Application: 3w April
Flowering Period: No
Dose Rate: 300 g/ha
Pest or Disease: diseases
Application Technique: Spraying
Group Name: III - normal

Compartments	Score
consumers	-10
applicators	7
farm-workers (NR)	-10
bystanders	-10
birds	-10
bees (NR)	-10
beneficials	-7
water organisms	-9
earthworms	-10
air	/
soil	1
ground water	-10
resistance induction	9
farm cost	/

...

Figure 4 - Frequency distribution of risk for the treatment scheme 'Worst case'



Annex 4

Comparison of pesticide indicators for Belgium

Vincent Van Bol [a], Philippe Debongnie [a], Sara Claeys [b], Jean Marot [c], Walter Steurbaut [b], Henri Maraite [c], Luc Pussemier [a]

Abstract

Belgian pesticide sales statistics are analysed on a period from 1982 to 2002. Risk indicators are calculated in order to compare the effect of pesticides used in agriculture for terrestrial and aquatic organisms. These indicators are also compared to the Frequency of Application indicator. In general, with herbicides and fungicides, risk for living organisms was increased during the first decade and more constant during the second decade. With insecticides, the risks were generally reduced except for bees where, depending the exposure hypothesis, the risk pattern is increased or relatively constant over the two decades. It shown very clearly that the risk patterns are very much influenced by some few active substances. Single risk indicators generally provide divergent analysis of the statistics. The comparison of pesticide sales and the Frequency of Application indicator shows that the reference dose (max. dose allowed for each application) was about 50 % reduced over the analysed period.

Key-words

Pesticide risk analysis, risk indicator, Belgium, Frequency of Application, SEQ, Index of Load, Norwegian Terrestrial Indicator.

Introduction

A pesticide indicator comparison is made in the framework of the OECD TERI (TERrestrial Indicators) workgroup activities where participants were asked to test indicators: Frequency of Application (FA) from Denmark; Index of Load from Denmark, calculated for birds, bees and earthworms; Norwegian Terrestrial Indicator. In order to obtain a comparison for aquatic organisms, the Belgian Spread Equivalent indicator is also calculated.

Material and methods

For each pesticide, the total amounts of pesticide used in agriculture are derived from the Belgian official statistics on total sales of pesticide active substances (a. s.) from 1982 to 2002. The available information on non-agricultural uses of pesticides (e.g. road weeding, garden plant protection, Christmas tree production) is scarce. In the present study, the risk indicator was calculated for agricultural uses only, and these were evaluated at less than 100% of total sales for the following a. s. : *atrazine:* 83%, *glyphosate:* 81%, *2,4-D:* 46%, *amitrol:* 30%, *dichlobenil:* 9%,

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[a] Veterinary and Agrochemical Research Centre. FPS Health, Food Chain Safety and Environment. Leuvensesteenweg, 17. B-3080 Tervuren. Website: http://www.var.fgov.be/index.php

Corresponding author : Dr. V. Van Bol, VAR; tel.: +32 (2) 769 22 42; fax: +32(2) 769 23 05; e-mail: vivan@var.fgov.be

[b] Crop Protection Chemistry Laboratory, Faculty of Agricultural and Applied Biological Sciences, Ghent University, Coupure links 653, B-9000 Ghent. Website: http://allserv.ugent.be/~hvanbost/labo/index.htm

[c] Phytopathology Unit, Catholic University of Louvain, Croix du Sud, 2 bte 3, B-1348 Louvain-la-Neuve. Website: http://www.fymy.ucl.ac.be

diuron: 8%, *simazine:* 8% (Beernaerts and Pussemier, 1997). Besides, it is assumed that *sodium chlorate* and *iron sulfate* are not used in agriculture.
When different doses of the same a. s. are authorized for different crops, the reference dose is taken as the highest of these values.
Indicators are calculated as follows.
Frequency of Application (Gravesen, 2000)

$$\frac{1000 \times \sum_i \frac{SQ_i}{RD_i}}{A} \text{ (Ha-dose)} \qquad \text{(equation 1)}$$

where SQ: **S**old **Q**uantity (kg a.s.); RD = **R**eference application **D**ose per hectare cultivated (kg/ha); A: total arable **A**rea (ha);i = counter for a.s.

Bees risk, Birds risk and Earthworms risk based on Index of Load (Gravesen, 2000)

$$\frac{\sum_i \frac{SQ_i}{TOX_i}}{A} * 1000 \qquad \text{(equation 2)}$$

where A: total arable **A**rea (ha); SQ: **S**old **Q**uantity (tones/year); i is a counter for a.s.; TOX_i is one of the eighteen toxicity (or fate) parameters such as mammals, acute oral toxicity, LD50 (mg/kg bodyweight), birds, reproduction toxicity, NOEC (mg/kg feed), etc.

Terrestrial organism risk based on Norwegian Terrestrial Indicator (Spikkerud, 2002)

$$\sum_i E_i \times IAF_i \qquad \text{(equation 3)}$$

where E_i: **E**nvironmental Risk Index; IAF: **I**ndividual **A**pplication **F**requency; i = counter for a.s

$$E = (T_{bee} + T_{bird} + T_{ew} + Per + Bioac)3 \qquad \text{(equation 4)}$$

where T_{bee}: **T**errestrial effects on **bee**s; T_{bird}: **T**errestrial effects on **bird**s; T_{ew}: **T**errestrial effects on **e**arth**w**orms; Per: **P**ersistance; BioAc: **Bio-ac**cumulation

$$T_{bee} = \text{Score (AR/Tox)} \qquad \text{(equation 5)}$$

where AR: **A**pplied **R**ate (g/ha); Tox = $LD_{50\ oral}$ for oral exposure and $LD_{50\ dermal}$ for dermal exposure (µg/bee); score is based on an expert judgment.

$$T_{bird} = \text{Score (Tox/}Exp_{bird}\text{)} \qquad \text{(equation 6)}$$

where Tox =dietary LC_{50} (mg/kg food) or acute oral LC_{50} (mg/kg body weight) or LD_{50}; score is based on an expert judgment.

For birds eating leaves, insects, corn & weed seeds

$$Exp_{bird} = AR \times K \qquad \text{(equation 7)}$$

Where AR: **A**pplied **R**ate (kg/ha); K: constant based on measurements to estimate the concentration of pesticide residues in food stuffs which comprise a bird's diet (Hoerger and Kenaga, 1972) .K = 30 in this calculation. If Tox values are based on LD50, then Exp_{bird} is calculated on the base of the DI[d]: Daily Intake (mg/kg body weight) = AR × 9 for small birds and AR × 3 for large birds .

For treated seeds and granules, Exp is directly based on their concentration

T_{ew} = Score (Tox/PIEC) (equation 8)

Where Tox = 14 day LC50; PIEC: **P**redicted **I**nitial **E**nvironmental **C**oncentration; score is based on an expert judgment.

PIEC = rate × (1 - f_{int}) / (100 × depth × BD) for single application (equation 9)

where f_{int}: **f**raction **int**ercepted by crop canopy (from 0 to 0.5), depth = mixing depth (cm; 5 for surface application; 20 for incorporation) and BD: **B**ulk **D**ensity (g/m³; default = 1.5) (Boesten et al., 1997).

Per = Score (RD; DT_{50}) (equation 10)

Where score is based on an expert scoring.

BioAc = Score (log Pow) × Score (DT_{50}) × Score (purification DT_{50})[e] (equation 11)

Where scores are defined on the base of an expert judgement.

$$IAF = \frac{SQ}{RD}$$ (equation 12)

Where SQ: **S**old **Q**uantity (kg a.s.); RD = **R**eference application **D**ose per hectare cultivated (kg/ha).

Aquatic organism risk based on Spread Equivalent global **(Buyck and Coelus, 1996)**

$$\sum_i SEQ_i \times A_i \quad (10^6 \text{ litres})$$ (equation 13)

where SEQ: **S**pread **Eq**uivalent; A: proportion of the **A**rea concerned with pesticide application (%); i = counter for a.s.

$$SEQ = \frac{SQ \times T}{MPC}$$ (equation 14)

where SQ: **S**old **Q**uantity (kg a.s./year); T: half-time live = DT_{50} (year); MPC: **M**aximum **P**ermissible **C**oncentration (mg/l).

The most relevant a.s. according to each indicator are identidied (min 5 % impact on indicator output, on average, for the 20 years period). Among these molecules, only those that are significantly correlated ($\alpha = 0.05$) to the general trend of the value of an indicator are considered as partly responsible for this indicator's evolution.

For each analysis, results are presented both in a table and in a figure. The table contains the rough indicators values while the figure illustrates the results in percentage of the 1982 values, which is used as reference year.

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[d] in this calculation DI is based on small birds

[e] This aspect is not include in this risk assessment

Results and discussion

The indicators were calculated separately for the 3 sub-groups herbicides, fungicides and "insecticides" (including in this group all other a. s. used against animal pests : acaricides, nematicides, etc) as well as for the total of all pesticides.

For herbicides (Table 1), sales start at c. 2700 tons in 1982, peak at c. 2900 tons in 1998, and are down to c. 2300 tons in 2002. During this period, AF starts at 0.9 in 1982, also peak in 1998 (at 1.5), but afterwards does not decrease as much as total sales, and is higher in 2002 (1.2) than in 1982. Birds and Earthworms risk indicators remain practically constant throughout the period (Figure 1). The Bees risk indicator decreases more than ten-fold between 1982 and 1993, and remains stable since. This decrease corresponds to the banning of *dinoterb* (Table 2), due precisely to its toxicity for bees. The Terrestrial organisms risk indicator starts at 11.8, peaks at 17.3 in 1995, then decreases every year except in 1998, down to 8.6 in 2002. The Aquatic organisms risk indicator starts around 12, increases to >15 for most of 1988-1995, then decreases to <13, and is down at 8.6 in 2002. *Paraquat* accounts for 54% of the value of this indicator, and for most of its variations in time.

> The increase of FA and Sales is distributed on a large number of molecules. This is also true for Birds risk indicator. Nevertheless, we have to keep in mind that FA is calculated, for each a.s., on a reference dose based on the maximum dose agreed in Belgium for agricultural crops. Due to the fact that the real doses are probably lower than these values, the FA indication might be an underestimation.
> *Dinoterb* was used as anti-dicot in annual crops. This pesticide is recognized to be toxic for bees (LD_{50} 0.1 µg/bee) and was no longer authorized after 1992.
>
> A major limitation in these risk assessment approaches is the exposure parameter, which is only based on the pesticide dose independently of the context of application. This implies that pesticides effects are considered as equivalent everywhere, in every time and, especially for FA, for every not-targeted organism. The case of *paraquat* is a good illustration of the caution that must be taken with these indicators. This cationic molecule, which influences 54 % of Aquatic risk indicator, is quasi non-bio-available due to its specific physico-chemical properties and consequently does not present any risk for aquatic organisms in the environment.

Concerning fungicides (table 3), sales increase steadily from c. 1800 tons in 1982 to c. 3300 tons in 1992, then fluctuate around 2700 tons. *Mancozeb* alone amounts to 33% of the total sales (figure 2). AF increases even more (x 3) than sales (x 1.5). From 0.9 in 1982 (for c. 1800 tons sold), it reaches 2.1 in 1992 (for 3300 tons) and keeps increasing after that, up to 2.8 in 2002, despite the lower sales (c. 2600 tons).
The Bees risk increases at first from 0.020 in 1982 to 0.028 in 1992, 0.024-0.028 throughout 1988-2000, but decreases back to 0.022-0.021 in 2001-2002. The Bird and the Earthworm risk indicators follow trends similar to that of total sales. *Thiram* (6% of sales) accounts for 25% of the Birds risk, *carbendazim* (<5% of sales) for 32% of Earthworm risk. The most important variation is observed for the Terrestrial organisms risk indicator with a 5-fold increase between 1982 and 2002 . The Aquatic organisms risk indicator decreases slightly from 1.1-1.2 in the 1980s to 0.8-1.0 since 1996. This indicator presents a brutal decrease in 1991 followed by a large

increase in 1992 that is partly explained by the use of *fentin acetate* (Table 3). *Mancozeb* is a major contributor to all indicators (Table 4).

> The values observed for Terrestrial organisms risk indicator are linked to the a.s. use quantity, the application rate, but mainly to a particular way to express and combine the risk and toxicity parameters. This mode of calculation, which is based on scores, has the advantage to be less sensitive to extreme values (and so more constant) than with unscored calculation methods. Following previous studies (OECD Bilthoven meeting), the indicator is strongly influenced by the scores for persistence and bioaccumulation, which account for more than 75 % of the variance in the risk indices.

The large increase observed (Figure 2) in FA is logically linked to the increase of fungicide sales figures (e.g. *mancozeb*), but moreover, it means also that molecules with lower reference dose are increasingly used. This is the case for *hymexazol* which is used as seed dressing fungicide in sugar beet against *Pythium sp.* and *Aphanomyces cochlioïdes.*

> The large variations observed during the years 1988 – 1993 in Aquatic risk indicator is mainly due to variations in the sales of *fentin acetate* which is used in potato crop against *Phytophthora infestans* and *Alternaria sp*. These annual variations in sales could, for example, result from annual variations of potato late blight importance in the fields.
> The substantial increase in potato acreages and yields during the analysed period (+ 68% of area and + 81 % of production) accounts for most of the increase in fungicide amounts used. This is well illustrated by the contribution to the results of *maneb* and *mancozeb*, which are applied for 95 % on potatoes.
> Birds risk is greatly influenced by *thiram* and *captan*. These molecules are mainly applied on pomes fruit crops.
> Earthworms risk is largely influenced by *carbendazim*, which is mainly applied on sugar beet (28 %) and winter wheat (24 %). *Carbendazim*, belonging to the *benzimidazol* group, is known to be very harmful for earthworms.

Indicators for insecticides (Table 5) are much more divergent than for the two other former pesticide categories. While the sale indicator presents a clear decrease over the two decades (from c. 2100 to c. 750 tons), FA start from 0.6 in 1982, peak to 1.0 in 1996 and decrease to 0.5 in 2002 (Figure 3). Concerning risk assessment, Aquatic organisms risk, Birds risk and Earthworms risk are reduced by a factor of about 4 while Bees risk is increased about 2-fold. The risk indices down from 0.08 to 0.02 for birds; from 0.023 to 0.006 for earthworms; from 195 to 59 for terrestrial organisms; and from 43 to 10.4 for aquatic organisms. All these variations are quite well explained by the use of only few molecules (Table 6): *lindane* for Aquatic organisms risk; *aldicarb* for Earthworms and Birds risk; *imidacloprid* for Bees risk.

> *Lindane* and *parathion* where no longer admitted for sale in 2002, which explains this general large decrease of indicators.
> The large increase of the Bees risk indicator is due to *imidacloprid* use since 1992. Due to the very simple exposure concept of the Bees risk indicator (exposure = applied dose), all the *imidacloprid* sold is taken into account. Nevertheless, in Belgium, *imidacloprid* is bought for seed dressing by the seed industry and for direct application on apple trees by pomes fruit producers. Unfortunately, we have no information on the quantity of *imidacloprid* corresponding to treated seeds leaving the country not either on imported treated seeds. In 2002, *imidacloprid* was used as seed dressing in beet (78 000 ha), winter barley (12 000 ha) and maize (6 000 ha). The pesticide was also directly

applied (spray) on about 10 000 ha of apple trees. For bees, the question of the impact of *imidacloprid* when used as a seed dressing is still pending. The Bees risk indicator is calculated here for all crops independently of the application method. This can be considered as a worst-case scenario. The exposure would be largely lowered if one considers that flowering crops only endanger bees, which doesn't include beet. It is interesting to notice that, if the no-effect hypothesis of seed dressing application is assumed, only about 5 % of the *imidacloprid* sales (direct application on crop) should be taken into account. The Bees risk indicator would then become very constant with a slight decrease between 1982 and 2002 and a low standard deviation of only 11 %. This rises the question of the relevance of these quite oversimplified indicators: the increase trend observed for insecticides is (only) due to the *imidacloprid* use while it can reasonably be assumed that the application in seed dressing is harmless to the bees.

The global analysis on all pesticide categories (Table 7) is the sum of the three previous exercises. Sales and Terrestrial organisms indicators are quite constant while FA and Bees risk increase. Birds risk, Earthworms risk and Aquatic organisms risk indicators show a decrease during the same period (Figure 4). Risk indicators variations are partly explained by the use of only a few molecules such as *lindane* for Aquatic organisms risk, *aldicarb* for Birds risk and *imidacloprid* for Bees risk (Table 8).

The average reference dose in 1982 is 2.7 kg/ha and 1.4 kg/ha in 2002. This explains why FA increases although sales are constant.
For birds, bees and earthworms, the most influent pesticides dominate the indicator evolution in term of absolute value (i.e. *imidacloprid* on Bees, *aldicarb* on birds and *lindane* on aquatic's).

The influence of pesticide type (i.e. herbicide, fungicide, insecticide) on final output widely vary among indicators (Figure 5). The discrepancy between the impact of insecticides on risk indicators (i.e. Bees, Birds, Earthworms, Terrestrial org., and Aquatic org. risk) and on the two others indicators is obvious. On the reverse, fungicides that are major contributors to Sales and FA are of minor importance considering all the risk indicators with the exception of earthworms. The impact of *imidacloprid* on Bees risk and *lindane* on Aquatic org. risk appears here very well.

It is interesting to notice that a reduction in pesticide sales and/or in FA would be preferentially achieved with a lower fungicide use that would have a significant impact Earthworms risk only.
On the contrary, a general reduction of insecticides use, by the way of various tools (e.g. biological control), would have potentially an important impact on every living organism.

The analyse of differences between indicators for 2002 and 1982 for the three types of pesticides (Figure 6) shows that major risk modifications are due to pesticides. A relatively large increase is observed for Bees risk while a large decrease is observed for Birds, Earthworms, Terrestrial org. , and Aquatic org. risks. Sales indicator shows a reduction for herbicides and insecticides and an increase for fungicides. AF indicator increases for fungicide and shows a relative *staus quo* for the two other type of pesticides.

The figure shows well that even the sales of each pesticide types fluctuate during the studied period, the major modifications in risk are due to insecticides. This is linked both to a use reduction and to variations of the a.s. choice. Insecticides were less used in term of quantity but not in term of application frequency. It can be concluded that insecticides were used as frequently in 2002 than in 1982 but with lower dose and with less dangerous a.s. for birds, earthworms and aquatic organisms, but not for bees.
Fungicides were applied more frequently, but their impact on bees, earthworms, birds and aquatic organisms is assessed unchanged.

It seems that when compared scenarios are very contrasted in term of pesticide pattern, dose and quantity used, significance of AF is not any more reliable to any risk consideration.

Conclusions

Large divergences exist between various approaches. None of them is sufficient alone to understand the situation. All indicators have limitations due to the oversimplification of the exposure model, the calculation procedure or the indicator foundation. Nevertheless, all indicators are commonly limited by the relevance of the a.s. databases on use, physico-chemical and (eco)toxicological properties. It appears very clearly that AF and Sales indicators are not related to any specific risk indicator, in particular when there are used to compare very contrasted scenarios. About sales data, an improvement would be to work on pluri-annual (2 or 3 years) averages in place of the annual data. A decisive improvement would be to work with real use data instead of sales data.

Exposure approaches in such “global” indicators are very simple and could be improved by an expert judgment in order to avoid some big overestimations of the risk as it can be the case for *paraquat* and *imidacloprid*.

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Table 1 - Indicators results for herbicides in Belgium over the period 1982-2002

years	Sales for agriculture (t)	Freq. of Application (R.D./ha)	Bees risk (T.U./ha)	Birds risk (T.U./ha)	Earthworms risk (T.U./ha)	Terrestrial org. risk (score/ha)	Aquatic org. risk (m^3)
1982	2727	0.9	0.52	0.002	0.005	21	11.8
1985	2593	1.0	0.42	0.002	0.005	21	13.1
1988	2704	1.1	0.28	0.003	0.006	41	16.3
1991	2715	1.3	0.20	0.003	0.007	51	15.0
1992	2437	1.2	0.17	0.003	0.007	39	16.4
1993	2505	1.3	0.04	0.003	0.006	42	15.7
1994	2724	1.3	0.04	0.003	0.007	42	13.3
1995	2820	1.5	0.04	0.003	0.007	47	17.3
1996	2857	1.4	0.04	0.003	0.007	53	12.7
1997	2667	1.4	0.04	0.003	0.007	50	12.4
1998	2938	1.5	0.04	0.003	0.007	52	13.8
1999	2319	1.3	0.03	0.002	0.006	40	11.2
2000	2597	1.3	0.03	0.003	0.006	48	11.8
2001	2391	1.2	0.03	0.002	0.006	46	10.7
2002	2283	1.2	0.03	0.002	0.005	46	8.6

Legend : R.D. is **R**eference **D**ose; T.U. is **T**oxic **U**nit

Table 2 – Major contributors to herbicides indicators

Sales for agriculture		Frequency of Application		Bees risk	
9%	glyphosate	7%	atrazine	71%	dinoterb (+)
8%	isoproturon (+)	6%	isoproturon		
7%	atrazine				
7%	metamitron				
6%	chloridazon				
6%	prosulfocarb				

Birds risk		Earthworms risk		Aquatic org. risk	
18%	paraquat	27%	atrazine	54%	paraquat (+)
13%	diquat	13%	prosulfocarb (+)	10%	lenacil (+)
9%	mcpa	6%	mcpa	7%	aclonifen
		6%	glyphosate	6%	monolinuron (+)
		5%	ethofumesate	5%	chlorotoluron
				5%	diuron

Legend: contributions that are significantly and positively correlated (P < 0.05) are indicated with (+)

Table 3 - Indicators results fungicides in Belgium over the period 1982-2002

years	Sales for agriculture (t)	Freq. of Application (R.D./ha)	Bees risk (T.U./ha)	Birds risk (T.U./ha)	Earthworms risk (T.U./ha)	Terrestrial org. risk (score/ha)	Aquatic org. risk (m^3)
1982	1761	0.9	0.02	0.003	0.009	16	1.1
1985	2128	1.4	0.02	0.003	0.011	37	1.1
1988	2642	1.8	0.02	0.004	0.013	54	1.2
1991	2844	2.1	0.03	0.005	0.016	73	0.7
1992	3295	2.1	0.03	0.006	0.018	79	1.7
1993	2845	2.2	0.03	0.005	0.015	76	1.0
1994	2286	2.0	0.02	0.004	0.014	63	0.9
1995	2663	2.3	0.03	0.005	0.018	75	1.1
1996	2405	2.1	0.02	0.004	0.013	70	1.0
1997	2588	2.4	0.02	0.004	0.013	73	0.9
1998	2666	2.0	0.03	0.005	0.013	82	1.0
1999	2992	2.9	0.03	0.005	0.013	78	1.0
2000	3040	2.7	0.03	0.006	0.013	82	0.9
2001	2287	2.5	0.02	0.004	0.011	78	0.8
2002	2590	2.8	0.02	0.005	0.011	85	0.8

Legend : R.D. is **R**eference **D**ose; T.U. is **T**oxic **U**nit

Table 4 – Major contributors to fungicides indicators

Sales for agriculture		Frequency of Application		Bees risk	
33%	mancozeb	22%	hymexazol (+)	13%	mancozeb
15%	maneb	9%	mancozeb (+)	11%	maneb
10%	sulphur	8%	fentin hydroxyde (+)	9%	pyrazophos
6%	thiram (+)			8%	sulphur
				5%	dodine
				5%	zineb

Birds risk		Earthworms risk		Aquatic org. risk	
25%	thiram (+)	32%	carbendazim (+)	41%	fentin acetate (+)
19%	mancozeb (+)	14%	sulphur	26%	dodine
19%	captan (+)	12%	fentin hydroxyde	9%	fentin hydroxyde
14%	fentin hydroxyde (+)	10%	mancozeb	5%	mancozeb
		9%	thiram		
		6%	thiophanate-methyl		

Legend: contributions that are significantly and positively correlated ($P < 0.05$) are indicated with (+)

Table 5 - Indicators results for insect ides, acaricides, nematicides, rodenticides and molluscicides in Belgium over the period 1982-2002

years	Sales for agriculture (t)	Freq. of Application (R.D./ha)	Bees risk (T.U./ha)	Birds risk (T.U./ha)	Earthworms risk (T.U./ha)	Terrestrial org. risk (score/ha)	Aquatic org. risk (m³)
1982	2115	0.6	2.09	0.085	0.023	195	43.0
1985	1746	0.6	2.45	0.075	0.019	210	44.2
1988	1667	0.5	2.05	0.057	0.014	161	36.9
1991	1510	0.7	2.06	0.060	0.017	174	34.0
1992	1667	0.8	3.52	0.063	0.016	180	32.0
1993	1460	0.7	4.02	0.047	0.015	164	29.3
1994	1028	0.6	3.25	0.036	0.012	129	21.9
1995	1352	0.8	3.97	0.037	0.012	157	22.4
1996	1569	1.0	5.08	0.040	0.014	202	27.5
1997	1298	0.9	6.46	0.033	0.013	195	29.3
1998	1333	0.9	6.36	0.034	0.012	190	34.8
1999	1003	0.9	5.40	0.031	0.009	145	27.2
2000	896	0.7	6.06	0.027	0.008	114	26.5
2001	853	0.7	5.72	0.027	0.007	119	27.6
2002	768	0.5	4.22	0.020	0.006	59	10.4

Legend : R.D. is **R**eference **D**ose; T.U. is **T**oxic **U**nit

Table 6 – Major contributors to insecticides indicators

Sales for agriculture		Frequency of Application		Bees risk	
23%	1,3-dichloropropene	13%	thiometon (+)	52%	imidacloprid (+)
16%	methyl bromide (+)	8%	parathion	9%	parathion
15%	mineral oil (+)	7%	permethrin	7%	cyfluthrin
12%	metam-sodium	6%	imidacloprid		
		6%	chlorpyrifos-methyl (+)		

Birds risk		Earthworms risk		Aquatic org. risk	
28%	aldicarb (+)	30%	aldicarb (+)	66%	lindane (+)
16%	parathion	21%	endosulfan	9%	parathion (+)
12%	carbofuran (+)	8%	dnoc (+)	6%	chlorpyrifos
6%	dnoc (+)	6%	imidacloprid		
		5%	methidathion (+)		
		5%	lindane (+)		

Legend: contributions that are significantly and positively correlated ($P < 0.05$) are indicated with (+)

Table 7 - Indicators results for all pesticides in Belgium over the period 1982-2002

years	Sales for agriculture (t)	Freq. of Application (R.D./ha)	Bees risk (T.U./ha)	Birds risk (T.U./ha)	Earthworms risk (T.U./ha)	Terrestrial org. risk (score/ha)	Aquatic org. risk (m^3)
1982	6603	2.4	2.63	0.090	0.037	232	55.9
1985	6467	3.0	2.89	0.081	0.035	267	58.4
1988	7013	3.4	2.35	0.064	0.033	256	54.4
1991	7069	4.1	2.29	0.068	0.039	297	49.7
1992	7399	4.2	3.72	0.072	0.040	291	50.1
1993	6810	4.2	4.09	0.054	0.036	270	46.0
1994	6038	3.9	3.31	0.043	0.033	224	36.1
1995	6835	4.6	4.04	0.045	0.036	268	40.8
1996	6832	4.5	5.14	0.047	0.035	310	41.2
1997	6553	4.7	6.52	0.040	0.033	291	42.5
1998	6937	4.4	6.42	0.042	0.031	300	49.6
1999	6313	5.1	5.46	0.039	0.028	263	39.4
2000	6532	4.7	6.12	0.035	0.027	244	39.1
2001	5532	4.4	5.77	0.034	0.023	244	39.1
2002	5641	4.6	4.27	0.028	0.021	189	19.8

Legend : R.D. is **R**eference **D**ose; T.U. is **T**oxic **U**nit

Table 8 – Major contributors to all pesticides indicators

Sales for agriculture		Frequency of Application		Bees risk	
13%	mancozeb	12%	hymexazol (+)	50%	imidacloprid (+)
6%	maneb (+)			9%	parathion
				7%	cyfluthrin

Birds risk		Earthworms risk		Aquatic org. risk	
24%	aldicarb (+)	13%	carbendazim	44%	lindane (+)
14%	parathion (+)	12%	aldicarb (+)	16%	paraquat
10%	carbofuran	9%	endosulfan	6%	parathion (+)
5%	dnoc (+)	6%	sulphur (+)		

Legend: contributions that are significantly and positively correlated ($P < 0.05$) are indicated with (+)

Figure 1 - Relative evolutions of risk, sales and frequency of application for herbicides

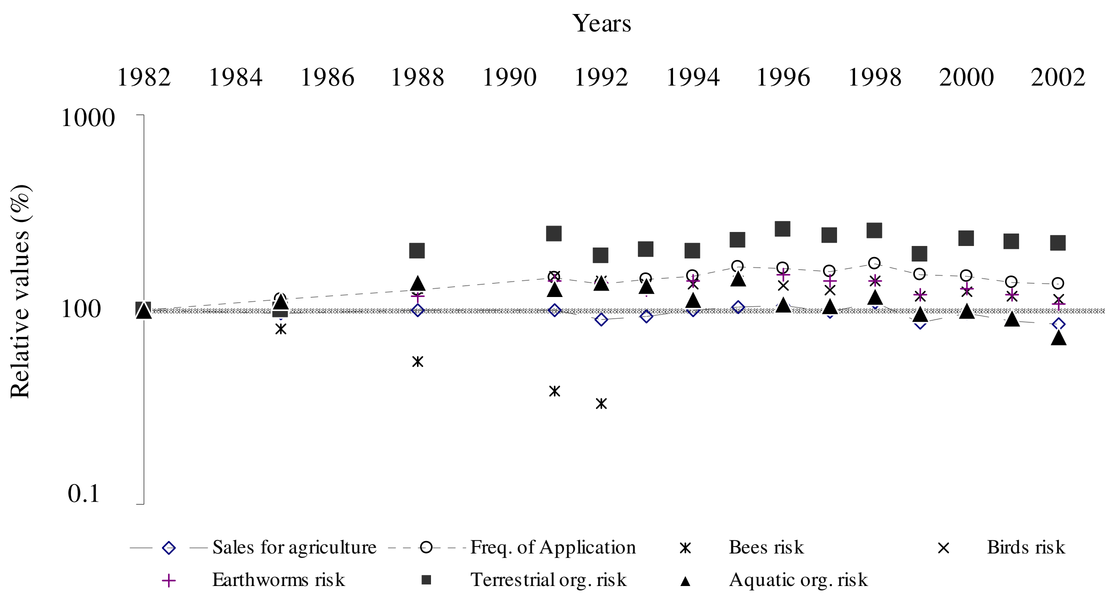


Figure 2 - Relative evolutions of risk, sales and frequency of application for fungicides

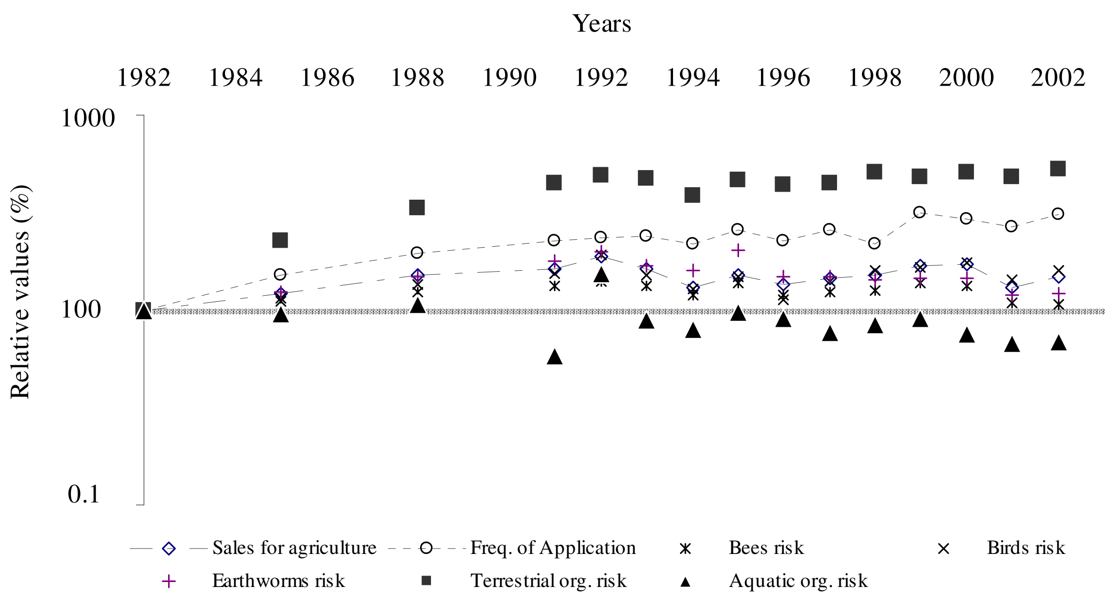


Figure 3 - Relative evolutions of risk, sales and frequency of application for insecticides

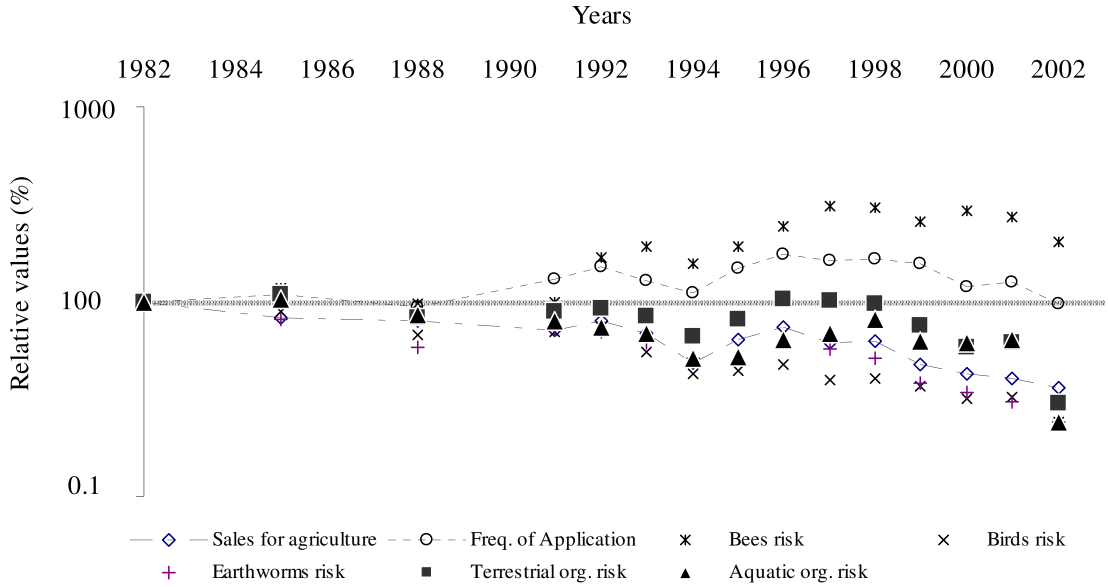


Figure 4 - Relative evolutions of risk, sales and frequency of application for all pesticides

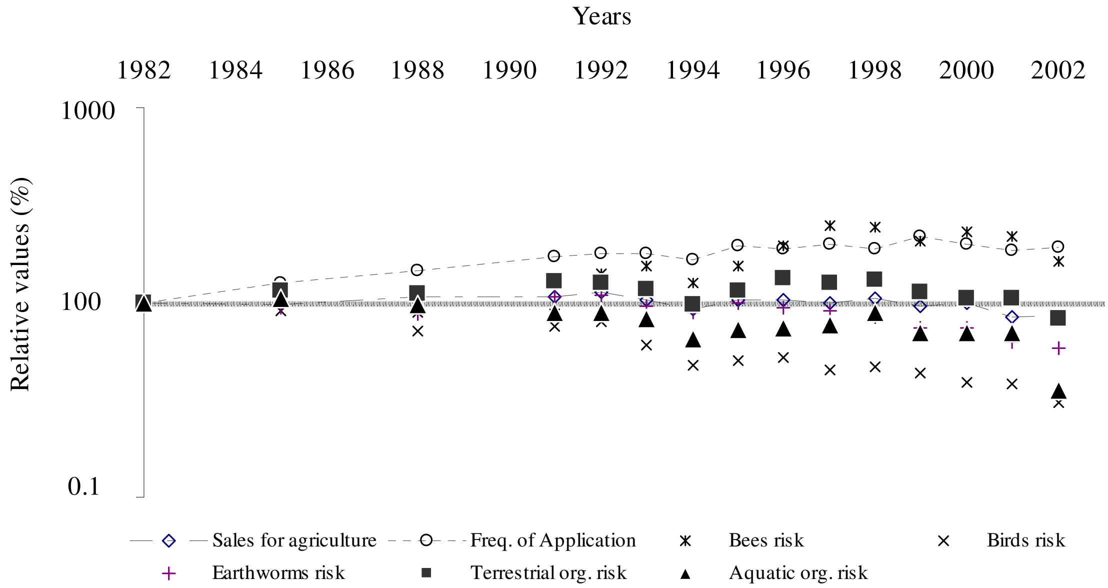


Figure 5 – Relative importance of pesticide type according to indicators (average for the period 1982-2002)

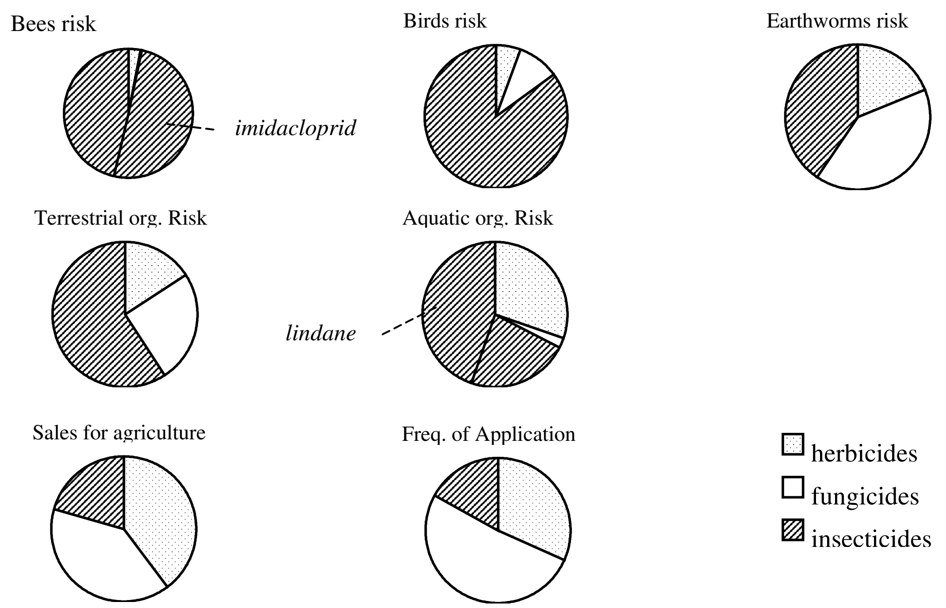
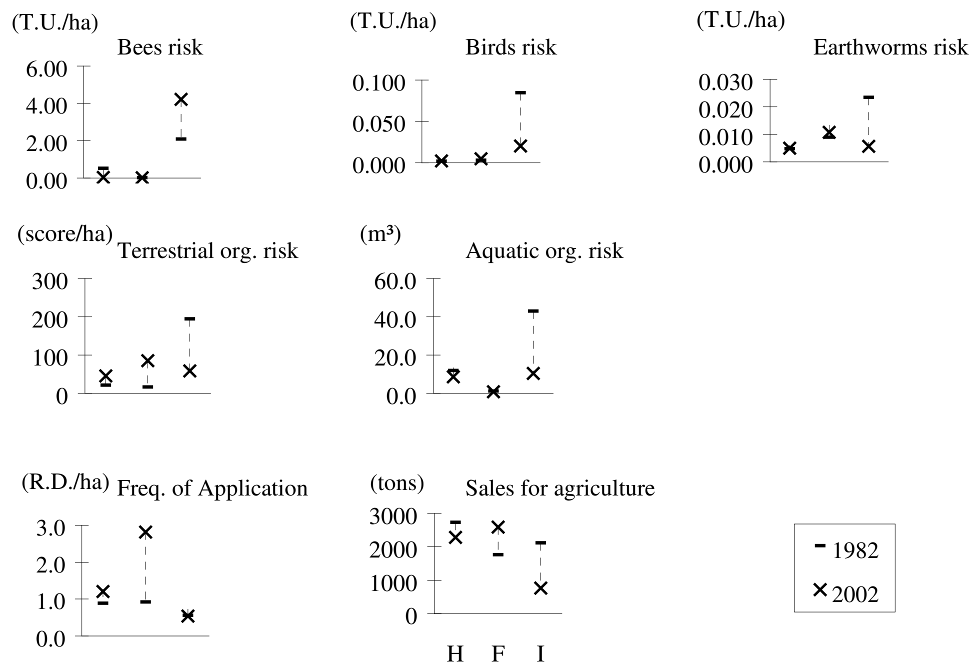


Figure 6 - Difference between indicators results for 2002 and 1982 for the three type of pesticide



Legend : R.D. is **R**eference **D**ose; T.U. is **T**oxic **U**nit

Annex 5

Pesticide indicators

Vincent Van Bol [1], Sara Claeys [2], Philippe Debongnie [1], Jordan Godfriaux [3], Luc Pussemier [1], Walter Steurbaut [2], Henri Maraite [3]

Introduction

In its communication No. 349 (1 July 2002), the European Commission put forward a proposal for a thematic strategy on the sustainable use of pesticides. The proposal focuses on reducing the risk associated with pesticide use and the amounts used. It was expected that a decrease in pesticide use will reduce the risk to human health and the environment.

Numerous indicators reflect pesticides characteristics, including chemical and physical properties, toxicological effects, hazard categories, effectiveness, importance in use, etc. Among the available indicators, a major distinction is to be made between two different types :

- Pesticide Use Indicators (PUIs): total amounts of pesticide used or total number of sprayings ;
- Pesticide Risk Indicators (PRIs): a combination of hazard and exposure characteristics for one or several environmental compartments (e.g. farm worker, air, birds, earthworms) that are assessed separately.

About 100 different indicators have been developped untill now (Van Bol *et al.*, 2002).

Pesticide Use Indicators (PUIs)

The first indicators used by public authorities were PUIs, where the annual sales of pesticides give an indication of the amount of chemicals released into the environment (Table 1). However, a PUI based only on sales data does not distinguish between high-toxicity and low-toxicity pesticides. It gives an undue weight to relatively harmless herbicides (e.g., glyphosate), compared with highly toxic insecticides (e.g., some carbamate or organophosphorous insecticides).

In theory, annual sales comparisons could be correlated to the risk for humans and the environment if there are no important modifications in either the pesticide characteristics or the exposed environment. The environment will probably not change significantly over the next decade, but the pesticide characteristics certainly will, as a result both of scientific progress and of the re-registration process imposed by the EU Directive 91/414. Even if it can be assumed that the future pesticide use will be based on less toxic and more selective active substances, this does not necessary imply that the amount required to control pests will be reduced.

In order to better control pesticide use, Danish authorities have developed the concept of Frequency of Application (FA) (Gravesen, 2000), also known as Pesticide Treatment Frequency (PTF), Treatment Frequency (TF) or Treatment Frequency Index (TFI). This indicator is regarded as an indicator of the spraying intensity as well as an overall indicator of the environmental impact of pesticides. It is assumed that there is a link between dose rates (and therefore the effects on target organisms) and the effects on non-target organisms, but this is not always true.

[1] Veterinary and Agrochemical Research Centre. FPS Health, Food Chain Safety and Environment. Leuvensesteenweg, 17. B-3080 Tervuren. Website: http://www.var.fgov.be/index.php
[2] Crop Protection Chemistry Laboratory, Faculty of Agricultural and Applied Biological Sciences, Ghent University, Coupure links 653, B-9000 Ghent. Website: http://allserv.ugent.be/~hvanbost/labo/index.htm
[3] Phytopathology Unit, Catholic University of Louvain, Croix du Sud, 2 bte 3, B-1348 Louvain-la-Neuve. Website: http://www.fymy.ucl.ac.be

These facts are illustrated in Table 2, where the potencies and toxicities of 15 active substances are compared (a low dose rate implies a high potency, just as a low MPC, LD50 or LC50 value means a high toxicity). In general, fungicides and herbicides are, as could be expected, much less toxic than insecticides. Even within each of these categories, increased potency does not necessarily mean increased risk for non-targets (for example, compare the insecticide pirimicarb with esfenvalerate, much more potent but much less toxic for non-target organisms). The FA approach therefore leads to a misinterpretaion of the situation by considering the unwanted side-effect of any two treatments as equivalent, whatever the nature and toxicity of the a.s. used.

In order to compare all these 15 a.s. at a glance, we have plotted their relative potencies and toxicities (Figure 1) (the relative potency of a.s. "*i*" was defined as dose rate $_{esfenvalerate}$ / dose rate $_{i}$, and the relative toxicity of "i" e.g.for mammals was define as LD50 $_{pirimicarb}$/LD50 $_{i}$). The FA assumption that the effects on target and non-target organisms are proportional to each other would be verified only if there was a clear positive correlation between potency and toxicity, and this is obviously not the case.

In addition, the objective of reducing pesticide use in terms of risk to humans and the environment can not be assessed by the former indicators in the following situations:

1. comparison of regions where the pesticides dosage is different due to different registration status ;
2. comparison of regions where the pesticides use pattern is different because the major crops differ ;
3. comparison of regions where the major crops are similar but where the environment is not comparable in terms of sensitivity to pesticides ;
4. when, for socio-economic reasons, pesticides are stockpiled by end-users.

Hence PUIs are inappropriate for assessing risk reduction, mainly because the recommended dose does not correlate with the (eco)toxicity profiles of the active substances. PUIs are also inappropriate for risk comparisons between countries and regions where the environment and/or the use pattern are not similar. Inter-annual comparisons of pesticide use in a same region can produce some gross information on the risk evolution provided that there is no major modification in the environment or in the pesticides characteristics. This situation is not likely to occur in Europe over the next decade due to the rapid changes in the list of authorized a.s.

Pesticide Risk Indicators (PRIs)

Numerous risk indicators have been developed throughout the world. Eleven of the most commonly used PRIs are listed in Table 3, ranked by order of complexity.

Indicators increase considerably in complexity when the risk assessment is applied to multiple environmental compartments in multiple contexts and with multiple pesticide applications. The number of required parameters then may be so large that it becomes difficult to manage them all. This is the reason why risk assessment at global level is usually based on assessement of a limited number of "representative" compartments that vary in function of the environmental context, for example:

Non-target animal impacts

- Acute Aquatic Risk Index (Netherlands) – fish, crustaceans and algae
- Acute Toxicity Equivalent (Sweden) – honeybees, fish, crustaceans, algae and earthworms
- Index of Load (Denmark) – mammals, birds, earthworms, fish, crustaceans and algae
- SYNOPS-1 (Germany) – earthworms, algae, crustaceans and fish
- Collective Environmental Risk Indicator (Norway) – earthworms, honeybees, birds, fish, crustaceans and algae
- POCER-1 (Belgium) – fish, crustaceans, algae, birds, bees and beneficial arthropods

Human impacts
- Acute Toxicity Equivalent (Sweden) - Risk phrases on product labels (that concern *de facto* the pesticide applicators, the farm workers and the bystanders)
- Acute/Chronic Toxicity Persistence Units (USA) – mammal toxicity parameters multiplied by a safety factor

PRIs complexity is also linked to the way the risk is aggregated from a particular to a general context both in term of time scale than in term of surface scale. Aggregation procedures vary from a single sum of risks to very sophisticated GIS approach coupled with fugacity model including degradation kinetic of pesticides.

An idea of the range of complexities involved is given by the comparison of the relatively simple indicator ATE with the more complex SYNOPS-1.

- ATE : *Acute Toxicity Equivalent* (Ekstrom *et al.*, 1996)

$$1000 * \sum_i \frac{SQ_i}{LD_{50\ oral\ mam.i}}$$

SQ = sold quantity, Σ_i = summ over *i* a.s.

- SYNOPS-1 : *SYNOPtisches Bewertungsmodell für PlanzenSchutzmittel* (Gutsche and Rossberg, 1999)

  Graphical representation of short- and long-term risk for earthworms, algae, crustaceans and fish

  Short term PRI = ABR for each taxa; ABR: Acute Biological Risk index = Exp/Tox

  Exp = PEC_{st}: PEC short term

  for soil : $PEC_{st} = VDT_{soil}$. AR .d

  for surface water : $PEC_{st} = VDT_{drift}$. AR . d

  VDT_{drift}: Value from Distribution Table (%) according to the crop and its growth stage

  AR: Applied Rate

  d: dilution factor depending the context

  Tox = LC_{50}

  Long-term PRI are obtained from calculations based on exposure diminution related to DT50 and long-term toxicity values (NOEC, NOEL, etc.)

  For an assessment at national level, SYNOPS-1 values are weighted by the application probability and the national sales data

The challenge for a good pesticide risk assessment is to work with indicators that are “easy” to calculate with a small number parameters and precise enough to obtain information on the risk to human health and the environment. The input data required by ATE are relatively easy to obtain, but critical differencies between use patterns and envirenmental fates of different a.s. are overlooked. SYNOPS-1 takes more account of theses aspects, but requires far more input data which increases the difficulties and uncertainties. This has proved a real problem, for example, in the case of the Danish “Index of Load” and the Norwegian “Collective Environmental Risk Indicator”.

Proposal for an adequate pesticide risk outlook

Obviously the adequacy of a PRI for a global assessment increases in proportion to the reduction of its adequacy for a specific assessment. Consequently, for a pesticide risk assessment at regional level, it could be interesting to work with both a “global” indicator, for the over-all impact, and a “specific” indicator for the most relevant combinations of a.s., use pattern, and environmental compartment.

The “global” indicator would have the following characteristics:

- it would include parameters only on the amount of active substances used (based on active substances sales), persistence and chronic toxicity (e.g., the American CTPU or the Belgian SEQ_{global} (Spread EQuivalent), (De Smet and Steurbaut, 2002) ;
- it would be used at regional level for inter-annual and inter-regional comparisons, mainly for policy purposes ;
- precautions would be taken to avoid using this indicator at local level (farm, field), as is unfortunately the case for the FA indicator in Denmark.

The “specific” indicator would have the following characteristics:

- it would be based on several (10–15) pesticide risk indicators specific for particular aspects (farm worker risk, consumer risk, water organisms, resistance induction of target organisms, etc.), as in the case of the Danish IL, the Norwegian CERI or the Belgian POCER-1 indicators ;
- risk assessment of the particular aspects should be aggregated in a traceable procedure in order to determine the implications for human health, farmer interest and environment, as in the case of POCER-2 developed in Belgium (Maraite, 2002) ;
- it would be used mainly at farm or field level to support any IPM improvement for sustainable development or quality label evaluation purposes.

Of course, one of the problems encountered in the use of all pesticide indicators is the large number of pesticide active substances and the even larger number of pesticide formulations. It is anticipated that these numbers will be significantly reduced by the on-going re-registration process in the framework of EU Directive 91/414.

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Table 1: Pesticide use indicators used by public authorities

Use indicators	Country	Survey period
OECD pesticide use indicator (OECD, 1999)	OECD	1985–
Frequency of application (Gravesen, 2000)	Denmark, Sweden	1986–
Hectare doses	Denmark, Sweden	1991–

Table 2: Recommended rate of application and toxicity data for 15 active substances used in European agriculture

	Active substance	Dose rate	Aquatic organisms (MPC)	Mammals ($LD_{50\ oral}$)	Birds (LD_{50})	Bees (LD_{50})	Earthworms (LC_{50})
		g.ha⁻¹ → $g.ha^{-1}$	$mg.l^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$\mu g.bee^{-1}$	$mg.kg_{soil}^{-1}$
Fungicides	epoxiconazole	125	1.0E-03	5000	2000	100	1000
	kresoxim-methyl	125	3.0E-04	5000	2150	20	937
	tolylfluanid	750	5.0E-05	250	5000	43	1780
	chlorothalonil	1500	7.0E-05	1000	4640	181	1000
	mancozeb	1500	1.6E-04	3420	700	193	455
Herbicides	rimsulfuron	13	6.3E-02	5000	2000	100	1000
	metribuzin	750	3.6E-05	250	168	35	332
	MCPA	800	1.0E+00	650	377	100	234
	isoproturon	1500	3.2E-04	2000	3042	50	1000
	glyphosate	2200	1.3E-01	2000	2000	100	360
Insecticides	esfenvalerate	**5**	1.0E-06	89	381	0.02	**11**
	imidacloprid	60	3.6E-02	131	31	**0.0037**	**11**
	diflubenzuron	100	**8.0E-07**	4640	2000	30	367
	dimethoate	200	3.2E-03	30	15	0.12	18
	pirimicarb	400	3.8E-04	**25**	**8**	51	60

Note: active substances, recommended dosage and aquatic organisms MPC (Maximum Permissible Concentration) were obtained from the CAPER database (Reus et al., 1999). Mammals toxicity was based on AGRITOX (Mercier, 2001). Toxicity parameters for birds, bees and earthworms were obtained from the POCER-1 database (Vercruysse and Steurbaut, 2002). Minimum values (i.e. maximum potencies and toxicities) are indicated in bold.

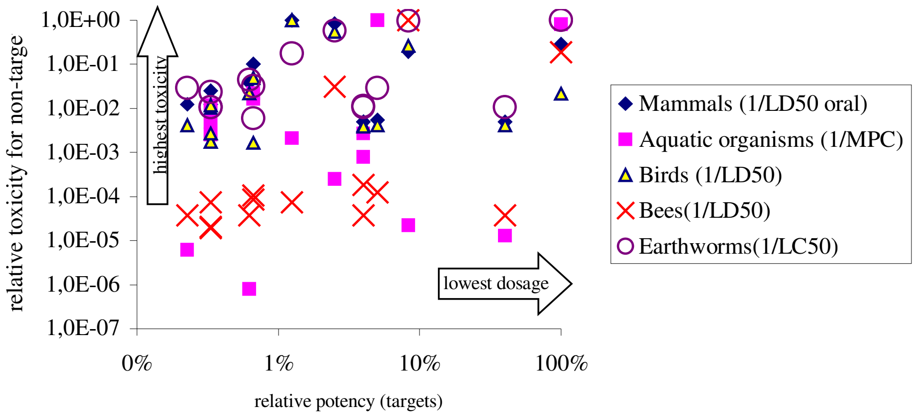
Table 3: Pesticide risk indicators used by public authorities

Risk indicator	Level of cmplexity	Country	Survey period
Acute Aquatic Risk Index – NL (Luttik, 2000)	*	The Netherlands	1984–
Acute Toxicity Equivalent (Ekstrom *et al.*, 1996)	*	Sweden	1981–1985, 1991–1995
Acute Toxicity Persistence Units (Barnard, 2000)	*	USA	1964, 1966, 1971, 1992
Chronic Toxicity Persistence Units (Barnard, 2000)	*	USA	1964, 1966, 1971, 1992
Collective Health Risk Indicator (Spikkerud, 2000)	*	Norway	1990–1994, 1998–
Swedish Environmental Risk Indicator (Ekstrom *et al.*, 1996)	*	Sweden	1986–2001
Swedish Human Health Risk Indicator (Ekstrom *et al.*, 1996)	*	Sweden	1986–2001
Collective Environmental Risk Indicator	**	Norway	1990–1994,

Risk indicator	Level of cmplexity	Country	Survey period
(Spikkerud, 2000) Index of Load (Gravesen, 2000)	**	Denmark	1998– 1986–
POCER-1 (Vercruysse and Steurbaut, 2002)	***	Belgium	2002
SYNOPS-1 (Gutsche and Rossberg, 1999)	***	Germany	1987, 1995

*Note:. complexity range is defined by the function of the number of parameters required for the calculation, ≤ 5, 6-20, ≥ 21 is represented by *, **, ***, respectively.*

Figure 1:Toxicity parameters of a selection of 15 active substances: target effect *versus* non-target effect



Short description of the authors activities

The authors of the article are engaged in a research at the Belgian level aiming to develop a pesticide risk indicator to help public authorities, extensionists and farmers to manage the pesticide use in a more sustainable manner.

Dr Vincent Van Bol, Dr Philippe Debongnie and Dr Luc Pussemier (Head of the Department of Quality and Safety) work at the Veterinary and Agrochemical Research centre (VAR) on various pesticide topics such as pesticide (eco)toxicology, residue analyses, pesticide indicators. Concerning this last aspect, it worth to mention the participation of VAR to the CAPER European research (Reus *et al.*, 2002) with SyPEP (System for Predicting the Environmental impact of Pesticides) and the development of the SEPTWA model (System for the Evaluation of Pesticides Transport to Surface Waters).

Prof Dr Henri Maraite, head of the Phytopathology Unit at Université catholique de Louvain (UCL) since 1985, supervises research teams working on the development of crop protection strategies aiming to high quality and yield while respecting the environment. He is the chairman of “Comité regional PHYTO”, a service of the Walloon region for advice on environmental responsible use of pesticides.
Ir Jordan Godfriaux (Agronomist) is a researcher at the UCL Phytopathology Unit. He is currently president of the “Fédération des Jeunes Agriculteurs” in Belgium.

Prof Dr Walter Steurbaut, head of the Faculty of Agricultural and Applied Biological Sciences, Department of Crop Protection at Ghent University supervises studies on pesticide residues, formulation techniques and environmental impact assessment.

Ir. Sara Claeys is working as researcher in this Department. She is Bio-Engineer in Environmental Technology (Ghent University, 2002). She is engaged on PhD-thesis on the pesticide impact on environment.