

## **OECD Survey of National Pesticide Risk Indicators, 1999-2000**

### **Country, Ministry**

Germany

Federal Biological Research Centre for Agriculture and Forestry (BBA)

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### **Indicator Name**

Synoptisches Bewertungsmodell für Pflanzenschutzmittel (SYNOPS)

### **When and why was the indicator developed?**

In Germany, the amendment of the Plant Protection Act of 1986 focused attention on environmental protection for the registration of pesticides. SYNOPS was developed to meet the needs of the government to be able to monitor the effectiveness of policies which promote sustainable agriculture. SYNOPS does this by assessing and comparing the risk potential to the environment of active ingredients in plant protection products. SYNOPS only recognizes pesticide application by spraying equipment.

Two versions of SYNOPS, SYNOPS\_1 and SYNOPS\_2, have been developed.

**SYNOPS\_1** considers each potential application of all active ingredients involved in the comparison singularly (i.e., with no balance of environmental concentration in case of repeated applications). Each potential application derived from the "Register of Authorized Plant Protection Products" is assigned a series of discrete exposure and biological risk indices. Based on this, SYNOPS\_1 calculates a weighted mean value for each index. The weights are related to the application probability, to the national crop area, and to the national sales data.

The purpose of **SYNOPS\_2** is to assess the environmental risk potential of a plant protection strategy in a region and to compare different strategies using different plant protection agents. For each chosen strategy, the chemicals which are intended for application have to be fixed.

### **How have the indicators been used?**

## SYNOPS\_1:

- In general, to evaluate progress toward pesticide risk reduction goals on a national/regional level. To find out whether the risk potentials of pesticides in the environment have decreased since the amendment of the German Plant Protection Act in 1986. For this purpose, only arable farming and insecticides were considered.
- Specifically, to investigate the risk trend of pesticides to the environment, on a national level in Germany, based on information for the ten herbicides, fungicides, and insecticides with the highest recorded sales in 1987 and 1995.
- A comparison of the risk potential of organophosphates versus pyrethroids.

## SYNOPS\_2:

- In general, to compare different plant protection management strategies according to their environmental risk potential.
- To include pesticide risk indicators in the definition of regional goals of sustainable farming.

### Description of the indicator:

The following list of steps outlines the approach of the SYNOPS indicators to estimate risk trends on a national level.

#### PROCEDURES INVOLVED:

- (1) Determination of the groups of active ingredients (a.i.) to be compared. For example, determination of the top ten herbicides, fungicides, and insecticides most used in arable crops in 1987 and 1997 according to their estimated application area. In Germany, a first version of a procedure is available outlining how to estimate the application area based on national sales data (include reference).
- (2) Determination of all potential applications in arable crops of each a.i. considered.
- (3) Calculation of loads of soil, surface water and the air caused by each potential application of each a.i. considered.
- (4) Calculation of all exposure indices (7) and all hazard indices (8) for each possible application of each a.i. based on load results calculated in

#### DATA REQUIRED:

- (a) National sales data for all relevant a.i. used in 1987 and 1995.
- (b) Area of the different crop systems (arable crops, vegetables, orchards, vineyards, others) Rough estimation of the application frequency of herbicides, fungicides and insecticides in the different crop systems.
- (c) Annually publications of the registration authority which indicates, for example, pests and crops, application rates of pesticides, content of a.i. in pesticide products, etc.
- (d) see above
- (e) Theoretical time table of all possible applications.
- (d) see above
- (f) Interception table, spraydrift table.
- (g) Data base of characteristics of a.i. of pesticides.  
Data base on (default) environmental

- Procedure (3). (Indices are defined below)
- (5) First aggregation of the results (over all potential applications of one a.i.): Calculation of a weighted mean value for each index; the weightings are related to the relative crop area and, optionally, to the probability of each potential application. Therefore, each a.i. is characterized by a set of 15 indices which are weighted mean values.
- (6) Second aggregation of the results (over the a.i. within one group): Calculation of a weighted mean value of each index; the weightings are related to the estimated relative application area of each a.i. within the group considered. So each pesticide group (e.g., top ten herbicides in 1987, top ten herbicides in 1997,...) is characterized by a set of 15 indices which are weighted mean values corresponding (indirectly) to the sales data.
- (7) Visualisation of the risk potential of each group (measured by the values of the 15 indices) by means of risk graphs. Comparison of the risk graphs and calculation of simple index ratios are used to detect the trend between 1987 and 1997.
- (h) conditions.
- (i) Area of the different arable crops.
- (j) (Optional) Table of the application probabilities.
- (k) Estimated application area of each a.i. as a result of Step 1.

### **Types of risk**

aquatic, terrestrial

### **Routes of Exposure**

spray drift

### **Variables Included**

- chemical-physical parameters of active ingredient:
  - DT50<sub>soil</sub> (mandatory), DT90<sub>soil</sub>
  - DT50<sub>water</sub> (mandatory; only for the water body), DT90<sub>water</sub>
  - log K<sub>ow</sub> (logarithmic partition coefficient n-octanol-water; mandatory)
  - DT50 photolysis (only if air compartment is considered)
  - DT50 hydrolysis (only if air compartment is considered)
  - vapour pressure (VP; only if air compartment is considered)
  - molecular weight (MOLW; only if air compartment is considered)
  - solubility (SOL)
- toxicity of active ingredient:
  - LC50, NOEC earthworm
  - LC50, NOEC *Daphnia*
  - EC50, NOEC algae

- LC50, NOEC fish
- $t_{exp}$  (experimental duration of the NOEC experiments)

- application data:
  - rate of application (g ai/hectare)
  - timing of application (day)
  - frequency of application
  - probability of application (optional)
  - application technique
  - type of crop
  - crop stage on the day of application (BBCH-code define?)
- environmental conditions:
  - daily average temperature during growing season
  - daily sum of precipitation during growing season
  - soil type and organic content (OC) of soil
  - slope (of the field considered or as an average of the region or as default value on national level)
  - water index
- other:
  - National sales data for all relevant active ingredients
  - Area of different crop systems

NOTE: For the water index, if a single field is considered, then it is only necessary to answer the question of whether the field borders on a surface water body. If a region is considered, then the model has to be provided with the bank length of the surface water body that borders on arable fields measured in meter per hectare. In this case, the percentage of fields in the region that are next to surface water bodies can serve as a first approximation.

For using the model on a national level, the water index has to be set to a default value. Then all the results are related to the surface water conditions that are assumed by the default values (for example, regions with few ditches, rivers, lakes, etc. versus regions with a high number of surface water elements).

## **I. Methods or formulae for combining: SYNOPS\_1**

SYNOPS\_1 consists of five main steps:

### ***Step 1: Assessment of the application pattern of pesticides and calculation of loads (correspondes to Procedure (3) above):***

First, the application pattern is defined as “the total number of possible applications against a certain pest on a certain crop at a certain growth stage of this crop”, as set out in the registered application conditions. In the case of repeated applications, the maximum number given in the registration (e.g., registered label) is used. According to the “normal” infestation situation in

Germany, each potential application is considered to have an application probability (is there a reference for this?).

Second, when a pesticide is applied, not only the target (e.g., the leaves of the crop) is “loaded”, but also other compartments (plant, soil, surface water). To calculate the load in different compartments, a simple table is used which contains the percentage distribution of the applied volume to the plants, soil and drift (is there a reference for this table? For the decimal codes?).

Table 1. Example of a distribution table for estimating loading of compartments.

Crop	From DC <sup>a</sup>	To DC	Plant (%)	Soil (%)	Drift (%)
Sugar beet	0	9	0	99	1
Sugar beet	10	14	14	85	1
Sugar beet	15	30	49	50	1
Sugar beet	31	40	79	20	1
Sugar beet	41	49	94	5	1
Hop	0	9	0	96	4
Hop	10	39	51	45	4
Hop	40	99	86	10	4
Cereal	0	9	0	99	1
Cereal	10	20	14	85	1

<sup>a</sup> Decimal code for growth stages of crops.

The load for **soil** is estimated by

$$S = VDT_{\text{soil}} (AR/100)$$

and (if we assume a relationship between agricultural area and water area of 10:1) the load of **surface water** is estimated by

$$W = VDT_{\text{drift}} 0.1 (AR/100)$$

where:

AR = the rate of the application considered (g ai per hectare)

VDT = the value (%) from the the distribution table (Table 1) according to the crop and its developmental stage

S = soil load

W = surface water load

**Step 2: Calculation of indices of environmental exposure (corresponds to Procedure (4) above):** the short-term predicted environmental concentration (sPEC) and the long-

term predicted environmental concentration (IPEC) of the substance in soil, surface water and in the air

The sPEC reflects the amount of chemical entering soil, water and air compartments immediately after application. The IPEC predicts the environmental concentrations after the compound has decomposed with time, due to chemical-physical reactions and microbial processes. An adsorbent index (A) is used to represent the proportion of the chemical that is adsorbed to soil or sediment and, therefore, not available for decomposition. An IPEC for air is calculated without consideration of the decomposition of the substance.

The following formula are used to calculate the seven (7) exposure indices:

$$sPEC_{soil} = S/375$$

$$IPEC_{soil} = S/4500 \int_0^t (C_{soil}^{(t)} dt/100)$$

$$sPEC_{water} = W/3$$

$$IPEC_{water} = W/3 \int_0^t (C_{water}^{(t)} dt/100)$$

$$IPEC_{air} = AR_{min} (DT50_{hyd}, DT50_{pho}) K_{henry}$$

$$A_{soil} = Kd_{soil} [(S/4500)/(Kd_{soil} + 1)]$$

$$A_{w.sediment} = Kd_{w.sediment} [(W/3)/(Kd_{w.sediment} + 1)]$$

where:

$$\log K_{oc} = 1.029 \log K_{ow} - 0.18 \text{ (Bonazountas and Wagner, 1984)}$$

$$K_{oc} = 0.66060 K_{ow}^{1.029}$$

$$Kd_{soil} = \%OC_{soil}/100K_{oc}$$

$$Kd_{w.sediment} = \%OC_{w.sediment}/100K_{oc}$$

$$K_{henry} = VP \times MOLW/(R \times SOL \times T)$$

C(t) = the relative concentration of ai (%) as function of time, approximately calculated by means of the input parameters DT50 and DT90.

$$R = \text{gas constant} = 8.314 \text{ Pa}\cdot\text{m}^3\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$$

T = temperature (default = 20°C = 293 K)

For other definitions, see above in the section, “Variables included”.

These formulas are subject to the following assumptions:

- Soil density is 1.5 g cm<sup>-3</sup>
- Soil depth for calculation of sPEC is 2.5 cm
- Soil depth for calculation of IPEC is 30 cm
- Water depth is 30 cm

- Organic carbon content of soil,  $OC_{\text{soil}}$ , is 2%
- Organic carbon content of surface water sediment,  $OC_{\text{s.water}}$ , is 5%

**Step 3: Calculation of indices of related biological risk:** acute biological risk (abr) and chronic biological risk (cbr)

This index is calculated for acute (abr) and chronic (cbr) biological risk for earthworms, aquatic invertebrates, algae and fish. The acute biological risk is calculated as the ratio of the short-term predicted environmental concentration (sPEC) to the median lethal concentration (LC50). The chronic biological risk is calculated at the ratio of the long-term predicted environmental (IPEC) concentration to the no observed effect concentration (NOEC). To account for the risk that a substance can accumulate in fatty tissue of an organism, the bioconcentration factor (BCF) is determined for earthworms and fish as another indices of biological risk.

The following formula are used to calculate the eight (8) hazard indices:

$$\cdot abr_{\text{earthworm}} = \text{sPEC}_{\text{soil}} / \text{LC50}_{\text{earthworm}}$$

$$\cdot cbr_{\text{earthworm}} = \text{IPEC}_{\text{soil}} / (\text{NOEC}_{\text{earthworm}} \times t)$$

$$\cdot abr_{\text{daphnid}} = \text{sPEC}_{\text{water}} / \text{LC50}_{\text{daphnid}}$$

$$\cdot cbr_{\text{daphnid}} = \text{IPEC}_{\text{water}} / (\text{NOEC}_{\text{daphnid}} \times t_{\text{exp}})$$

$$\cdot abr_{\text{algae}} = \text{sPEC}_{\text{water}} / \text{EC50}_{\text{algae}}$$

$$\cdot cbr_{\text{algae}} = \text{IPEC}_{\text{water}} / (\text{NOEC}_{\text{algae}} \times t_{\text{exp}})$$

$$\cdot abr_{\text{fish}} = \text{sPEC}_{\text{water}} / \text{LC50}_{\text{fish}}$$

$$\cdot cbr_{\text{fish}} = \text{IPEC}_{\text{water}} / (\text{NOEC}_{\text{fish}} \times t_{\text{exp}})$$

where:

$t_{\text{exp}}$  = experimental duration relevant to the chronic studies (NOEC values)

As bioconcentration factors (BCF) are not often available, SYNOPS uses quantitative structure-activity relationships (QSARs) to estimate the BCF.

For fish, the worst case curve from Nendza (1991) is applied:

$$\cdot \log BCF_{\text{fish}} = 0.99 \log K_{\text{ow}} - 1.47 \log (4.97 \times 10^{-8} \times K_{\text{ow}} + 1) + 0.0135$$

For earthworms, QSAR estimation of Pflugmacher (1992) is used:

$$\cdot \log BCF_{\text{earthworm}} = 1.098 \log K_{\text{ow}} - 2.2917$$

**Step 4: Aggregation of the calculated indices (corresponds to Procedure (6) above):** the indices that were calculated in steps 1-3 (for each possible application) are aggregated.

Two options are offered:

· Calculation of a weighted mean for each index. The weightings are related to the relative crop area for each application. (Needs more explanation or an equation; does this mean that each index is calculated for each active for a particular year, each index is multiplied by the relative crop area, a decimal fraction of which all add to one; is this the same as proportion?; and then the mean taken for all actives in that year? )

· The probability of the application (related to pest infestation probability) is additionally taken into consideration, i.e., the weighting related to the crop area is additionally multiplied by the application probability.

**Step 5: Visualization of the risk potentials.**

A risk graph is used, which is a circle divided into segments corresponding to the individual aggregated indices. The value of each index determines the length of the radius of the corresponding segment such that large risk graphs suggest a high risk potential of the chemical and small risk graphs suggest a lower risk potential.

## II. Methods or formulae for combining: SYNOPS\_2

SYNOPS\_2 also consists of five main steps:

**Step 1: Determination of the crop and different pest management strategies to be compared.**

Each pest management strategy is characterized by a number of active ingredients, the rates of application, and application times related to the developmental stage of the crop (BBCH-code). Table X gives an example of a strategy (for demonstration only).

Table 1. Hypothetical pest management strategy for potatoes.

Application number	Active ingredient	Application time		Dose rate (g/hectare)
		Day number	BBCH	
1	glufosinate	120	0	549
2	bentazon	140	20	960
3	mancozeb	166	40	1440
4	mancozeb	176	47	1440
5	methamidophos	180	51	720
6	mancozeb	186	55	1440
7	mancozeb	196	65	1440
8	mancozeb	206	75	1440
9	mancozeb	216	85	1440

The following steps (2-4) are carried out for each strategy.

**Step 2: Calculation of environmental concentrations (loads) for each a.i.**

For each a.i. in the strategy table, its environmental concentration is calculated in the following manner.

(a) Calculation of direct loads (for each application)

$$\text{DRIFT} = \text{DOSE RATE} \times \text{VGT (distance, crop)}/100 \text{ (g/hectare) (1)}$$

$$\text{SOIL LOAD} = (\text{DOSE RATE} - \text{DRIFT}) \times \text{VDT(crop)}/100 \text{ (g/hectare) (2)}$$

$$\text{WATER LOAD} = \text{DRIFT} \times \text{WATER INDEX} \text{ (g/hectare) (3)}$$

where:

VGT(distance, crop) = spray drift value (%) from the Ganzelmeier table (Ganzelmeier, 1997) depending on the crop and the distance between spraying device and the surface water body

VDT (crop) = value (%) from a table which describes the distribution of the remaining application (dose) rate between the plant surface and the soil surface depending on the developmental stage of the crop

WATERINDEX = bank length of surface water body that borders on fields in the region per 100 meter site length of the fields in the region in percentage. If these data are not available, the percentage of fields in the region, which neighbour surface water, can serve as a first approximation. (Can also be set to default values.)

(b) Calculation of the concentration in soil for each a.i. as a function of time:

In case of repeated applications of the same a.i., each application is separately considered at first. The time,  $t$ , is measured in days, and the time period for calculation is one year (365 days). First order kinetics is assumed for degradation of the substance in soil.

$$y(t) = y_0 \cdot \exp(-\lambda \cdot t) \quad (4)$$

$$\text{with } \lambda = \ln 2 / \text{DT50}_{\text{soil}} \quad (5)$$

where:

DT50<sub>soil</sub> = 50% disappearance time in soil from the standard laboratory experiments

The dependence of  $\lambda$  on the organic content of soil is not explicitly reflected in the model. It can implicitly be done by modifying the DT50 value, if information is available. But the influence of temperature on degradation is considered as follows:

$$\lambda^*(t) = (\exp(0.08 \cdot \text{Temp}(t) - 20)) \cdot \lambda \quad (6)$$

So, concentration in soil as a function of time,  $CS(t)$ , measured in mg/kg soil, is calculated by the following recurrent formula:

$$CS(0) = y_0 \quad (7)$$

$$t^* = 1 \quad (8)$$

$$t = 1 \quad (9)$$

$$dy = y_0 (\exp(-\lambda^*(t) \cdot (t^*-1)) - \exp(-\lambda^*(t) \cdot t^*)) \quad (10)$$

$$CS(t) = CS(t-1) - dy \quad (11)$$

$$t^* = -\ln (CS(t)/(y_0 \cdot \lambda)) \quad (12)$$

$$t = t + 1 \quad (13)$$

goto (10)

where:

$y_0$  = initial concentration in soil caused by the soil loading (mg/kg soil)

$y_0 = \text{SOILLOAD}/375$  (14)

The formula is subject to the assumptions:

Soil density is  $1.5 \text{ g/cm}^3$ .

Soil depth is 2.5 cm.

In the case of repeated applications, the concentration of the considered a.i. is obtained by summing up the concentrations of the single applications:

$$CS(t) = \sum_{I=1}^{napp} CS(t, i)$$

where:

$napp$  = number of applications of the a.i. under consideration

(c) Calculation of the concentration in surface water for each a.i. as a function of time

All calculations are carried out similarly for soil concentration (using equations 4-15) with the following changes:

$DT50_{\text{water}} =$  50% disappearance time for water (only water body) from standard laboratory experiments

$CW(t) =$  concentration in water (mg/L)

$y_0 =$  WATERLOAD/3000 (14a; assumes a depth of water of 30 cm)

Additional to the concentration in water caused by spraydrift, a concentration peak caused by a default run-off event 3 days after application is taken into consideration. The amount of the peak (RUN) is calculated by submodel (I) (see Annex I). So for  $t = 3$ , the formula (11) has to be modified to

$$CW(t) = CW(t-1) - dy + RUN \quad (11a)$$

**Step 3: Calculation of environmental exposure indices for each a.i.** Four mandatory indices and three optional indices.

Used in SYNOPSIS I and SYNOPSIS II:	<b>For compartments soil and surface water:</b>	
Exposure indices for each active ingredient (a.i.)	time depending concentration $C(t)$	adsorbent index $A = Kd \cdot sPEC / (Kd + 1)$
	short term exposure index	long term exposure index
	$sPEC = \max_{t=1}^{365} C(t)$	$IPEC = \frac{365}{\sum_{t=1} C(t)}$
	<b>For compartment air:</b>	
	air exposure index $Air = DOSERATE \cdot \min(DT50_{hydr.}, DT50_{phot.}) \cdot K_{henry}$	
Used in SYNOPSIS I and SYNOPSIS II:	<b>For earthworms, daphnia, algae and fish:</b>	
Biological risk indices for each a.i.	acute biological risk index $abr = sPEC / LC50$	chronic biological risk index $cbr = IPEC / (NOEC \cdot t_{exp})$
Only used in SYNOPSIS II:	<b>For earthworms, daphnia, algae and fish:</b>	
	acute biological risk index $abr = \max_{a.i.} (sPEC / LC50)$	
Biological risk indices for a pest management strategy including m a.i.'s	time depending subchronic risk index $scr(t) = \sum_{a.i.=1}^m \sum_{j=t}^{t+t_{exp}} C(j) / (NOEC \cdot t_{exp})$	
	total subchronic risk index $tscr = \max_{t=1}^{365} scr(t)$	

- exposure variables
- toxicity variables: In the majority of cases, for each input parameter, several data are available because, for example, tests were carried out for different species of a group. Therefore, a rule base was developed of how to aggregate the data into a relevant single input parameter (geometric mean value, 10<sup>th</sup> percentile, etc.).
- toxicity and exposure

- risk and use

### **Use of Scoring**

There is no use of scoring in either SYNOPSIS\_1 or SYNOPSIS\_2.

### **Treatment of Missing Data**

### **Aggregation of pesticides and crops**

**How are the results of the indicator presented?** (give examples)

### **Lessons learned from working with indicators: obstacles to overcome, successful approaches, benefits and limitations of indicators**

A high quality database on pesticide characteristics (chemical-physico data and ecotoxicological data) is essential for a proper indicator usage.

Clear rules should be defined how to manage data gaps in the pesticide database.

A detailed sensitivity analysis has to be required to understand the model results.

Pesticide usage data reflecting the predominant plant protection management of the farmers should be used as primary information.

Using sales data is only the second best way to get realistic input data for the indicator.

For regional approaches the indicator should respond on the most important environmental conditions.

A good visualisation of the indicator results is necessary.

### **Important References**

Bonazountas and Wagner, 1984

Ganzelmeier, 1997

Gutsche, V. and D. Rossberg. 1997. SYNOPSIS 1.1: a model to assess and to compare the environmental risk potential of active ingredients in plant protection products. *Agriculture, Ecosystems and Environment* 64:181-188.

Nendza, M. 1991. QSARs of Bioconcentration: Validity Assessment log Pow/log BCF Correlations. In: Nagel, R., Loskill, R. (Eds.), *Bioaccumulation in Aquatic Systems*. VCH, Weinheim, pp. 43-66.

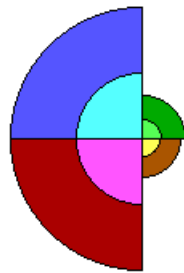
Pflugmacher, J. 1992. Struktur-Aktivitätsbeziehungen zwischen der Biokonzentration von Pflanzenschutzmitteln und dem Oktanol-Wasser-Koeffizienten. *Zeitschrift für Umweltchemie und Ökotoxikologie* 4(2), 77-81.

## Visualisation of the risk potentials by means of risk circles

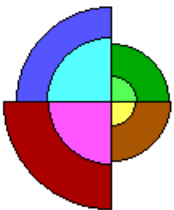
Biological risk potential of the 5 pesticide strategies in potatoes used in the CAPER\* project



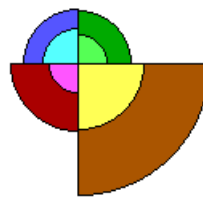
Strategy 1



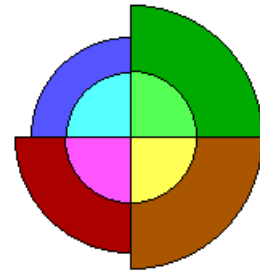
Strategy 2



Strategy 3

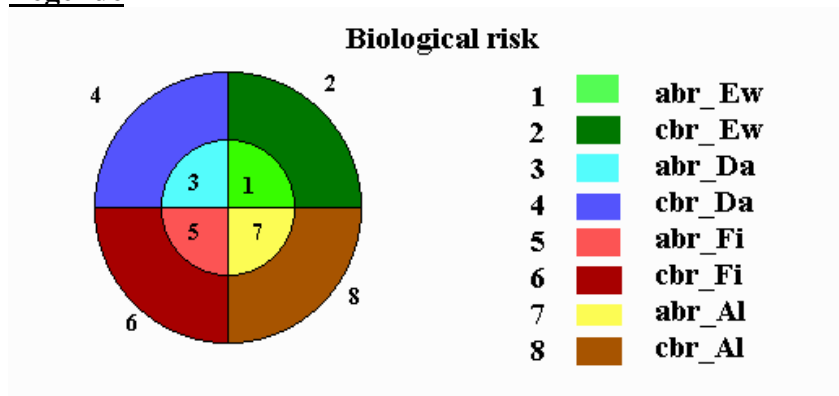


Strategy 4



Strategy 5

## Legende



\* Concerted Action on Pesticide Environmental Risk Indicators, EU contract CT97-3510