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Determining developments in pesticide use: an application to the Netherlands

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Abstract

This paper analyses different causes of changes in pesticide use, with the situation in the Netherlands as background for empirical illustrations. The general methodology assumes a large inventory study on pesticide use. This inventory study may contain a number of errors or rest upon incomplete information. During a certain period indicators of pesticide use are often more aggregate. Moreover, the introduction of new pesticides, the abolishing of some old ones and the fluctuation in pesticide use because of changes in weather and disease patterns make it very difficult to measure developments in pesticide use. This is, however, an important element in the targeting of the reduction of emissions.

We present a methodology to introduce stepwise new information within a large database to provide decision makers with relevant information. The methodology classifies different causes, such as (1) inconsistency between different data sets, (2) changes in the area of different crops, (3) introduction of new and abolishing of old pesticides, (4) developments in pesticide use and (5) fluctuations in pesticide use. Because of the importance of the first, third and fifth category, it is difficult to give a clear indication of the development in pesticide use and therefore the fulfilment of environmental targeting in volume of active ingredient.

Keywords: pesticide use, the Netherlands, methodology linking different sources

Introduction

Many countries plan that future levels of pesticide use meet pre-determined targets. Different bases have been used to formulate those targets: Denmark and Sweden target the volume and the number of treatments (Dubgaard, 1990; Anonymous, 1992d); in the Netherlands attention has been focused on a volume reduction (Anonymous, 1991a, p. 101) while Germany gives most attention to the reduction in the number of pesticides that are used. For some targets it is difficult to determine whether they have been reached, although the number of pesticides that are allowed is a clear exception. In future policy decision-making clear insight will be useful to check policy aims.

The main purpose of this paper is to develop a flexible methodology to determine and analyse changes in pesticide use, relative to the targets, in a situation of imperfect information. This methodology is applied to the Netherlands, where an extensive inventory study has formed the basis of future targeting. It might be expected that such an extensive inventory study will not be repeated in the short term. Moreover, even if the study were to be repeated, different methods would be used and the resulting information would not be homogenous.

We start with a short overview of the main indicators of pesticide use in the Netherlands and the most relevant sources of information. We will then develop a methodology derived from a comprehensive database to investigate subsequent changes in pesticide use. This methodology will be applied to analyse – as an example – recent developments in the Netherlands, with different sources of information. Moreover, a classification will be developed, together with a methodology, to determine the importance of different factors for pesticide use. We will then examine annual fluctuations relative to systematic changes, using only one database. A short discussion on the present situation in the Netherlands will be followed by our conclusions.

A short overview of pesticide use in the Netherlands 1986-1988

During the eighties pesticides became an environmental problem in the Netherlands. The government made an extensive inventory of pesticide application and developed a Long-term Crop Protection Plan (LCPP). This plan develops a strategy to reduce pesticide use by at least 50% in 2000. Progress will be controlled every two years, starting in 1993. The data from the LCPP reflect the situation during 1986-1988. In addition, data of the Dutch Organization of Agrochemical Industries (NEFYTO) are available for 1984 and later years. These two data sets, however, differ considerably in detail.

The inventory of pesticide use of the LCPP depends heavily on the inventory compiled by Berends (1988). Berends's report contained the best information available at that time. He gives information on the intensity of pesticide use in 1987 for 37 crops, and per crop for up to 7 regions (for sugar beet). He asked crop protection experts of the extension service to estimate the actual pesticide use in their own region (expert judgement). The cooperation of these experts was especially important in assessing the likelihood of application (the part of the area treated), the period of application (months) and the application frequency (number of treatments per year). Drawing on this expertise Berends was able to make a valuable inventory of the potential load for surface water. This procedure is no longer possible, because of reorganisation of the extension service.

The LCPP gives, in addition to Berends's report, information on the intensity of pesticide use in terms of active ingredients for nine sectors of agriculture and for the use in public parks and gardens. In general, the same method is followed.

From the data of the LCPP a database on the use of pesticides has been composed. This database furnishes the means to calculate totals in kg active ingredient, in kg formulated pesticides and in guilders and to trace the compound(s) which are used as active ingredient for each pesticide (Oskam et al., 1992). This procedure yields slightly lower estimates of total active ingredient than the LCPP. With the database totals can be calculated at sectoral and crop level and main category, chemical group and compound level. Here we concentrate on the compound level and on the crop level.

NEFYTO has supplied information about pesticide consumption in the Netherlands since 1984. LCPP and NEFYTO both cover the period 1986-1988. NEFYTO data refer to quantities of pesticides in different categories of compounds, primarily used in, or sold to, agriculture. Totals are calculated for five main categories (for example, fungicides) from 37 chemical groups of pesticides (for example, dicarboximide compounds). Those last groups are aggregates of 385 pesticides/compounds in total. The extent of each group varies from 1 to 24 compound(s). From these data pesticide use is known for about thirty, mostly older, pesticides. Table 1 gives figures for ten of them which have been used most in 1986. The other ten pesticides have been added to be used as illustration further on. These twenty compounds represent about 50% of the total pesticide use (in weight).

We can compare the estimate of the LCPP with the estimate of NEFYTO. In the LCPP similar calculations have been made. The LCPP gives an impression of the reliability of the LCPP estimate by comparing some totals of it with totals of the NEFYTO figures of 1984 to 1988. We registered a difference of –1.4% for the total, after multiplying NEFYTO figures with the factor 1.07 because not all sellers are members of NEFYTO. Table 1 shows the differences between our database based on the LCPP and the NEFYTO data. Here, NEFYTO data have not been multiplied by the factor 1.07, because this factor could be quite different for each compound. The differences between the two estimates are quite large for several pesticides. We conclude that two different sources during the reference period of the LCPP show important differences at the compound level.

How can these differences be explained? A difference between +5% and +10% does not present a problem because not all sellers are members of NEFYTO. Changes in stocks is another possible explanation, but this is less likely as we considered a three-year period. Since there are no clear reasons for extensive buying of approved pesticides in foreign countries, we assume that negative and large positive differences are caused by errors in the data of the LCPP, which are often based on guesses of experts. Moreover, different years have been used in the LCPP as reference for the application of pesticides in different parts of agriculture. Dalapon, parathion and zineb are clear examples where the LCPP data should be wrong (Table 1). In case of captafol, DNOC and captan we have to be careful with conclusions, because banning is involved. Unless other external information is available a recalculation of the LCPP data on the basis of NEFYTO data is permissible.

Methodology to determine developments in pesticide use and their causes

Here we start from a situation in which a large inventory study has been made. Moreover, annual data on pesticide use are available at a more aggregate level. The

Table 1. Pesticide use per compound (in 10^3 kg active ingredient) in the period 1986-1988 according to NEFYTO and the LCPP and the difference between them (in per cent).

Compound	NEFYTO				LCPP	Difference[1]
	1986	1987	1988	1986/88	1986/88	
Atrazin	204	203	188	198	141	–29
Azinphos-methyl	7	8	6	7	2	–71
Captafol	2	17	21	13	0	–100
Captan	284	367	398	350	227	–35
Carbendazim	43	51	58	51	32	–37
Chlormequat	36	51	54	47	64	36
Chlorprofam	35	34	44	38	43	14
Dalapon	130	99	90	106	26	–75
Dichlorvos	10	31	41	27	18	–33
Dimethoate	31	25	53	36	20	–44
Dinoseb	446	452	560	486	568	17
DNOC	60	51	24	45	1	–98
Lindane	34	24	24	27	26	4
Maneb	1604	1786	1748	1713	1387	–19
MCPA	183	204	182	190	172	–9
Mecoprop	448	482	261	397	328	–17
Metam-sodium	6467	5112	5372	5650	5472	–3
Parathion	64	64	78	69	101	46
Sulphur	107	52	54	71	88	24
Zineb	169	177	184	177	311	76
Total[2]	21510	17977	18057	19181	20258	6

[1] Difference between estimated use LCPP and estimated use NEFYTO (the mean over 1986, 1987 and 1988) in percentage of estimated use NEFYTO.
[2] Total is inclusive of mineral oil, but exclusive of other additives.

interest is focused on quantifying different changes in the application of pesticides. This characterizes the situation in the Netherlands.

Assume that the inventory study has been made in period 0 (average over the period 1986-88) with a complete database of pesticides used in agriculture. In the Netherlands this database consists of:
- 296 different pesticides; several are only identical compounds but in various concentrations or mixes;
- 85 different subdivisions of agriculture; several are only identical crops but grown for various purposes.

This complete set of data will be called matrix A with a row for each pesticide and a column for each crop.

For all main pesticides prices are available. This gives the opportunity to calculate the price of the other pesticides, based on the price per unit of active ingredient. Quantities, prices and expenditures are thus available for different compounds and crops and also for any more aggregate figures (see Oskam et al., 1992, Chapter 2 and appendix II).

The actual application of pesticides, say, the application in period t, differs from the information contained in the database for several reasons:

1. Outside data have indicated that the quantity of pesticides sold by NEFYTO has changed over the years. The information provided by NEFYTO, however, is more aggregated than the information in the database. Let us call the array (or vector) quantities of pesticides in active ingredient: z_t. This change of z_t, compared with the same vector in the base year (say z_0) has been caused by several reasons (see 2, 3, 4 and 5).
2. The area of the different crops changes gradually over the years. If we assume that every crop has a specific quantity of typical pesticides that are used, the application of pesticides varies in quantity and composition because of area changes. Of course, changes in rotation scheme might mean that such changes are not proportional to changes in area. The vector with areas per crop (or size of the subsector) is h_t.
3. Owing to changes in regulations the application of particular pesticides might be abruptly adjusted to new levels. This could be either a reduction to zero or an increase. Moreover, particular pesticides could be added to the list of products that are allowed while others could be removed from that list. Below, we specify a method to incorporate such changes in the application of pesticides.
4. Changes in technology may cause adjustments in the application of pesticides to new levels. This could be either a reduction or increase, but given the present policies a gradual reduction will be expected.
5. Special circumstances such as weather and disease patterns might have a large influence on the actual use of pesticides in a particular year. This belongs to the category of 'random' factors.

Starting from the total set of data on the use of pesticides, say the matrix A_0, which consist of m = 296 rows and n = 85 columns, we might try to calculate matrix A_t from matrix A_0, using the vectors z_t, z_0 and h_t, h_0. Here z-vectors are of length k and h-vectors of length n. A_t is of importance in judging the policy target.

Let us first define matrix M, which consists of k rows (the number of compounds distinguished in the data set of NEFYTO) and with m columns. Most elements of matrix M are equal to zero, except the elements of row i and column j, for which holds that pesticide j belongs to the compound i of vector z. Those elements are equal to 1. Moreover, we define the column vector ι, which consists of elements equal to 1. Here holds:

$$MA_0\iota = w_0 \tag{1}$$

Equation (1) states in a formal way that the pesticides are distributed over the compounds distinguished by NEFYTO and added over all crops. If the data set is to be consistent in the base period, the vector w_0 would be equal to z_0. It has been already illustrated (Table 1) that the data sets are inconsistent. If $w_0 = 0$ for a certain pesticide (for example, captafol), a correction of A_0 must be made. After this and in all other cases a diagonal adjustment matrix (say C) can be used to make the two data sets consistent:

$$MCA_0\iota = z_0 \qquad (2)$$

Observe that the diagonal matrix consist of m non-zero elements, while at most n elements differ between w_0 and z_0. This implies that numerous C-matrices could be used to establish the equality in equation (2). If no additional external information is available, a maximum of n different elements of the diagonal matrix C can establish this equality, and this matrix will be used. Now, for atrazin the elements will be 198/141, for captan 350/227, for dalapon 106/26, for captafol after correction 13/13, etc. (Table 1).

Matrix A_t that matches exactly the z-vector in the period t can be derived in a similar way. We multiply each particular row of the A_0-matrix by the a factor, derived from a particular element of the z-vector, say, element i. If we define $f_i = z_{t,i}/z_{0,i}$ and compose the diagonal matrix F, with for each row of A the relevant f_i on the diagonal, then:

$$MFCA_0\iota = MA_t\iota = z_t \qquad (3)$$

Before we apply this to the situation in the Netherlands we must give some information about pesticide use in the period following 1988. See Table 2 for the same compounds as those of Table 1. Mecoprop-p, a substitute for mecoprop, has also been included. Captan and DNOC replace captafol and dinoseb, respectively, which have been abolished.

If we are interested in pesticide use in 1989, for atrazin the elements of the diagonal matrix F will be 170/198, for captan 370/350, for dalapon 72/106, etc. (Table 1 and Table 2).

This method, however, did not incorporate information on the change in area or adjustments for bans and permissions of pesticides (#2 and #3). Therefore, we will first start to incorporate those changes before the final adjustment starts to reach z_t.

This could be done in the following way. Define a vector g where each of the elements, say element i (i = 1,...,n), is defined as: $g_i = h_{t,i}/h_{0,i}$. Place this vector g within the diagonal matrix G and define the matrix A_0G, which gives the new level of pesticide application, after correction for the change in area. Placing this result within the previous framework, defined in equation (2), gives:

$$MCA_0G\iota = u_t \qquad (4)$$

The effect of a change in the application of pesticides due to the change in area is equal to $MCA_0(G\text{-}I)\iota \equiv \Delta z$. Here I is equal to the unit matrix of order n.

Applying this to the situation in the Netherlands requires some additonal information. Table 3 gives areas for some important crops per sector (Anonymous 1989a,b; 1992a,b).

Suppose we are especially interested in effects of area change on the use of captan in 1991. We have seen previously in Table 1 that the elements of C are 350/227. In 1986/88 (A_0) captan is used on 20 crops of which apple, pear and tulip are most important (95, 59 and 36 while 227 * 10^3 kg a.i. (= w_0) totally). The corresponding

Table 2. Pesticide use per compound (in 10^3 kg active ingredient) in the period 1989-1991 according to NEFYTO.

Compound	1989	1990	1991
Atrazin	170	172	189
Azinphos-methyl	6	4	3
Captafol	5	0	0
Captan	370	370	402
Carbendazim	61	61	67
Chlormequat	71	84	62
Chlorprofam	46	47	28
Dalapon	72	40	30
Dichlorvos	44	38	33
Dimethoate	83	79	55
Dinoseb	193	0	0
DNOC	24	298	243
Lindane	22	19	21
Maneb	1425	1383	1241
MCPA	212	249	250
Mecoprop	213	10	0
Mecoprop-p	0	0	275
Metham-sodium	6425	5969	5179
Parathion	103	107	90
Sulphur	73	58	54
Zineb	171	154	138
Total[1]	19044	18741	17119

[1] Total inclusive of mineral oil, but exclusive of other additives

Table 3. Area per crop (in 10^3 ha); inclusive the area in the LCPP estimate and the average of the area based on the statistics in the same period.

Crop	CBS							LCPP
	1986	1987	1988	1989	1990	1991	1986/88	1986/88
Maize	196.3	197.5	194.7	202.7	201.8	202.1	196.2	197.5
Sugar beet	137.7	127.7	123.4	123.8	125.0	123.4	129.6	127.7
Wheat	110.6	103.2	104.2	130.7	135.1	115.2	106.0	103.2
Ware potatoes	72.1	75.6	72.0	71.3	76.9	77.8	73.2	75.4
Starch potatoes	60.0	58.3	56.7	60.2	62.8	63.1	58.3	58.3
Seed potatoes	35.0	34.5	32.1	33.5	35.6	39.2	33.9	34.5
Tulip	6.8	7.1	7.1	7.0	6.8	6.9	7.0	7.3
Rose	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8
Apple	15.0	15.1	15.4	15.9	16.3	16.7	15.2	15.2
Pear	5.3	5.2	5.1	5.0	5.1	5.3	5.2	5.2
Sweet pepper	0.3	0.4	0.4	0.5	0.7	0.7	0.4	0.4
Pasture	1142.0	1124.5	1114.0	1098.8	1096.5	1079.9	1126.8	1150.0
Carrots	4.7	3.9	5.1	5.9	6.3	7.5	4.6	5.1

change in area (g_i) is: 16.7/15.2, 5.3/5.2 and 6.9/7.3, respectively. In this example we neglect changes in area for the other crops (mostly bulbs). So $u_{t;1991}$ (equation 4) will be:

$$350/227*(95*16.7/15.2+59*5.3/5.2+36*6.9/7.3+37)= 363*10^3 \text{ kg.}$$

We conclude that in 1991 the use of captan increased from 350 to $402*10^3$ kg. A quantity of 13 tons of this increase of 52 tons is because of changes in area.

The third type of information belongs to external information that will necessitate adjusting matrix A. Modifications could occur when new information on the application of a particular pesticide or the application to a specific crop comes available, and this information belongs either to the period 0 or to the period t and can be at the level of a particular pesticide or at crop and pesticide level. We assume that consistency will be required, and therefore z_0 will remain unchanged. This implies an adjustment by a diagonal F-matrix of corrections on matrix A_0.

Table 4 gives a systematic overview, if adjustments are included in a b-vector or B-matrix. This gives a rather wide range of opportunities to adjust matrix A and to maintain consistency with the total use of pesticides in the base period. Here v_t is the vector of pesticides used in the period t (after correction).

The introduction of a new (or the ban of an old) type of pesticide in the period t can also be handled by this method if a row with zeros is added to matrix A. The new quantities are included in the vector b_t or matrix B_t. Bans on old types can be handled in such a way that after the correction in b_t or B_t, the use of this particular pesticide is just equal to zero.

The difference between the vector z_t and v_t can be considered as 'other causes' in the change of pesticide use. We have previously mentioned that changes in technology and circumstances such as weather and disease patterns might be of importance. These differences could be incorporated in a consistent way in matrix A_t by the following operations:

$$MFD(CA_0G\iota+b_0+b_t) = MA_t\iota = z_t \quad (5a)$$

$$MFD(CA_0G\iota+B_0+B_t) = MA_t\iota = z_t \quad (5b)$$

Observe that matrix D bridges the differences between the vectors v_t and z_t.

Table 4. A systematic overview.

Period	Pesticide		Crop/pesticide	
	Adjustments	F-matrix/v_t vector derived from:	Adjustments	F-matrix/v_t vector derived from:
0	b_0	$MF(CA_0G\iota + b_0) = z_0$	B_0	$MF(CA_0G + B_0)\iota = z_0$
t	b_t	$MF(CA_0G\iota + b_t) = v_t$	B_t	$MF(CA_0G + B_0 + B_t)\iota = v_t$

We give one example of new external information. Vernooy (1992) gives figures of pesticide (insecticide and fungicide) use of sweet pepper for 1988/1989. Table 5 shows the relevant part of the database and some results of calculations of this new information. Vernooy gives totals of the lowest and the highest quintile and percentages of (groups of) pesticides.

Suppose we are especially interested in the use of dichlorvos in the corrected LCPP estimate. The elements in C will be 27/18 (Table 1). If $w_{t;1986/1988}$ is corrected with the information in Table 5, its value will be 20692 kg a.i: 21 ton. The elements in F will be therefore 18/21. (In this case the elements of G are equal to 1.)

We give one example of a ban of an old type of pesticide, dinoseb and its replacement by DNOC in January 1990 (Anonymous, 1991b; 1992c) (also Figure 1). We assume that all use of dinoseb, inclusive its use as weed killer, is replaced by DNOC. Table 6 gives the calculated adjustment. Because the use in the database is very low, the elements in C are high: 45 (Table 1). Therefore, after correction in B_t, use of DNOC in the database remains low: 298/45 ton a.i. (Table 2). In the correction we used areas of the crops mentioned in Table 6. Notice that this is a simple example: the ban of one pesticide is replaced by another and a few crops on which they are used. Mostly more pesticides and crops are involved.

Table 5. Use of fungicides and insecticides (in kg active ingredient) of sweet pepper in the database (A_0) and according to Vernooy (1988/89; mean of lowest and highest quintile).

	Database (LCPP)	Vernooy (LEI-DLO)	Adjustment use (b_0)
Area (in ha)	440	440	
Amitraz 190 g/l	334	291	–43
Dichlorvos 500 g/l	3300	5759	2459
Fenarimol 120 g/l	29	19	–10
Fenbutatin oxide 50%	616	193	–423
Pirimicarb 50%	616	1103	487
Propamocarb 750 g/l	858	929	71
Calciumcyanide 80%	0[1]	338	338

[1] Not in A_0, because no figures were available

Table 6. The ban of dinoseb and its replacement by DNOC (kg active ingredient) in January 1990.

Crops	Database		After ban		Adjustment use (B_t)	
	dinoseb	DNOC	dinoseb	DNOC	dinoseb	DNOC
Ware potatoes	252100	0	0	2702	–252100	2702
Peas	25690	0	0	82	–25690	82
Starch potatoes	104969	0	0	1188	–104969	1188
Seed potatoes	182000	0	0	1973	–182000	1973
Field beans	3402	0	0	11	–3402	11
Gladiolus	0	773	0	666	0	–107
Total	568161	773	0	6622	–568161	5849

Notice once again that all manipulations have been given at the level of quantities of pesticides. Multiplying quantities with prices would give total expenditure figures. Those expenditure figures could give another check if such data are available, either at crop or subsector level or at the level of total expenditure. Differences, however, could be either due to quantities or to prices.

Classifying different causes

In the above section different causes for changes in the application of pesticides have been given:

a) Inconsistency between the two databases, represented by the difference between z_0 and w_0. In fact this has nothing to do with changes in the application, but merely gives an impression of the differences if one starts from different sources of information.
b) Change in the crop areas, represented by the difference between u_t and z_0.
c) A ban on compounds and/or the introduction of new compounds, represented by the difference between v_t and u_t.
d) The resulting change in the use of pesticides, after incorporation of the aforementioned causes. This is represented by the difference between z_t and v_t.

It could be useful to give a single measure which determines the importance of each of those four changes. Notice that the difference between w_0 and z_0 is partly because of difference in area. This will be neglected. Also, the change due to banning old/introducing new compounds is more incidental and more specific for certain pesticides than the other three.

The differences between causes of change in pesticide use or in data sets will be classified according to mean absolute percentage differences. All differences are related to the quantities in a base period of the continuous data set.

$$MAP_{a,i} = S_i * 100* |z_{o,i}-w_{o,i}|/z_{o,i} \quad (6)$$

$$MAP_{b,i} = S_i * 100* |u_{t,i}-z_{o,i}|/z_{o,i} \quad (7)$$

$$MAP_{c,i} = S_i * 100* |v_{t,i}-u_{t,i}|/z_{o,i} \quad (8)$$

$$MAP_{d,i} = S_i * 100* |z_{t,i}-v_{t,i}|/z_{o,i} \quad (9)$$

where, S_i = share of the particular pesticide in total pesticide use (active ingredient) in the base period, i = type of pesticide (compound) administrated by NEFYTO.

A comparison of those differences can give a clear indication of which is most important. Moreover, comparing $MAP_{a,i} + MAP_{b,i} + MAP_{c,i} + MAP_{d,i}$ with the following measure:

$$MAP_{total,i} = S_i * 100* |z_{t,i} - w_{o,i}|/z_{o,i} \quad (10)$$

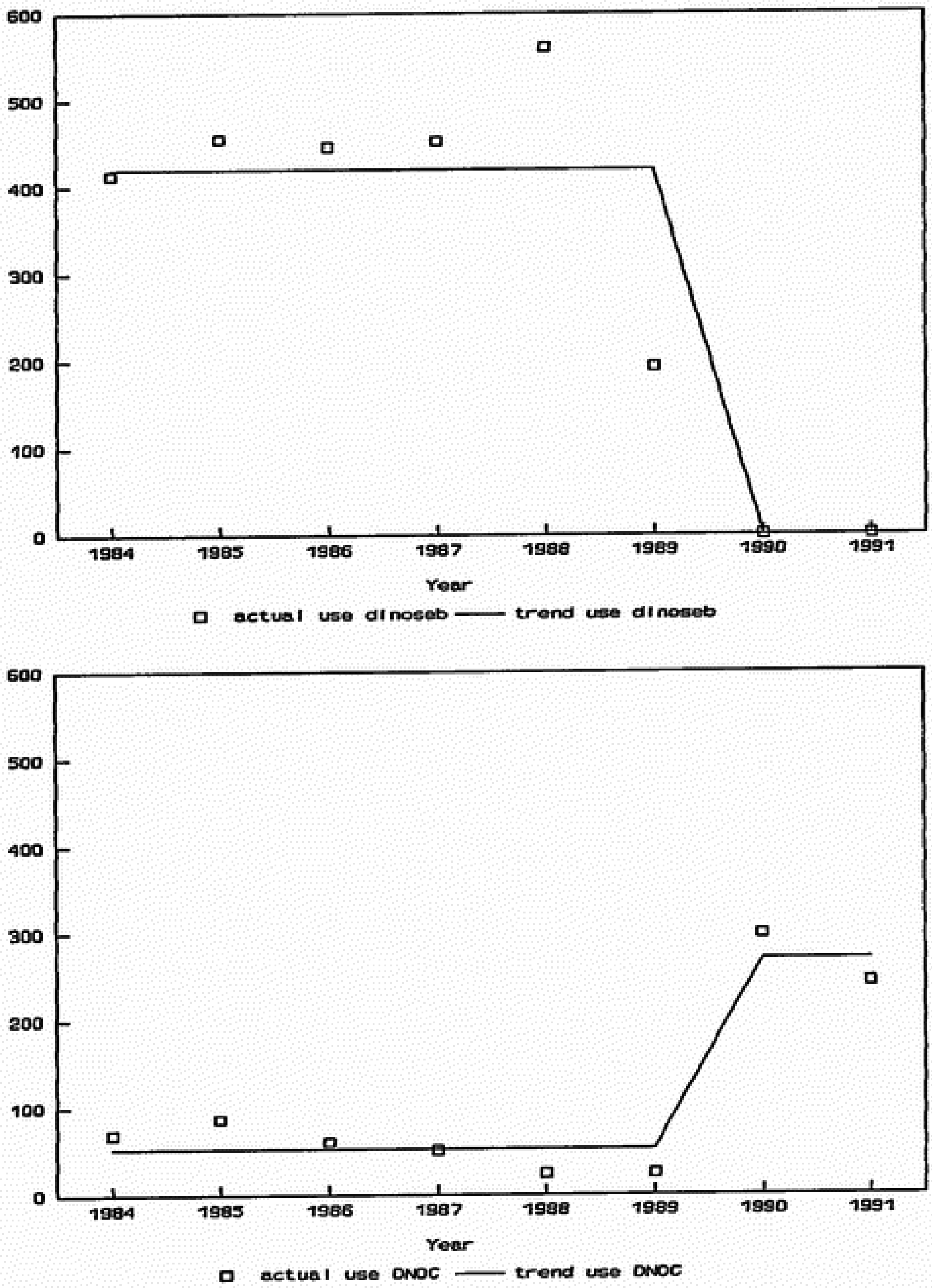


Figure 1. Pesticide use (in tonnes active ingredient per year) in the period 1984-1991. The ban of dinoseb in 1990 and its replacement by DNOC. The use of dinoseb is estimated by

$v_{t,\,dinoseb} = 419.83 - 419.83{*}D$, (90.74)

the use of DNOC by $v_{t,\,DNOC} = 52.33 + 218.17{*}D$. (22.58)

Where D=0 before banning/introducing and D=1 after banning/introducing.

Table 7. Mean absolute percentage differences (MAP) for 1991 with base period 1986/88 for 20 compounds.

Compound	$MAP_{a,i}$	$MAP_{b,i}$	$MAP_{c,i}$	$MAP_{d,i}$	$TOTAL_i$	$MAP_{tot,i}$
Atrazin	0.30	0.02	0.00	0.07	0.39	0.25
Azinphos-methyl	0.02	0.00	0.00	0.03	0.06	0.00
Captafol	0.06	0.00	0.03	0.04	0.14	0.01
Captan	0.64	0.10	0.01	0.19	0.94	0.91
Carbendazim	0.10	0.11	0.00	0.20	0.41	0.18
Chlormequat	0.09	0.02	0.00	0.05	0.16	0.01
Chlorprofam	0.03	0.00	0.00	0.02	0.05	0.08
Dalapon	0.42	0.00	0.00	0.40	0.82	0.02
Dichlorvos	0.05	0.04	0.00	0.01	0.09	0.08
Dimethoate	0.09	0.02	0.00	0.08	0.18	0.18
Dinoseb	0.43	0.08	2.62	0.00	3.13	2.96
DNOC	0.23	0.01	1.23	0.15	1.62	1.26
Lindane	0.01	0.00	0.00	0.03	0.04	0.02
Maneb	1.70	0.30	0.00	2.01	4.01	0.76
MCPA	0.09	0.05	0.00	0.36	0.50	0.41
Mecoprop	0.36	0.09	1.79	0.03	2.27	1.71
Metham-sodium	0.93	1.69	0.00	3.99	6.61	1.53
Parathion	0.17	0.09	0.00	0.20	0.46	0.06
Sulphur	0.09	0.03	0.00	0.11	0.22	0.18
Zineb	0.70	0.06	0.00	0.09	0.85	0.90
MAP (Σi)	6.49	2.72	5.68	8.06	22.95	11.51

gives an indication whether opposite effects cancel out partly.

If we choose for instance 1986 as base period, we cannot calculate MAPs for newly introduced compounds. If we choose for instance 1991 as base period, we cannot calculate MAPs for abolished compounds. Thus, S_i has clearly a strong influence on the MAP.

MAPs have been calculated to determine the importance of the differences for the compounds mentioned in Tables 1 and 2. The use after banning/introducing compounds is estimated by: $v_{t,i} = \alpha + \gamma D$ (Figure 1 and further on). Since we are especially interested in changes in use compared with those from 1986-1988, this last period is our base period. Table 7 shows the results of our calculations for 1991. The MAPs for mecoprop-p cannot be calculated. S_i differs per compound, therefore MAPs can best be interpreted for all compounds together (Σi). Table 8 shows the results if we divide by S_i and do not take absolute differences. Table 8 gives more detailed information, but this is not easy to interpret because $z_{0,i}$ differs per compound.

In Table 7 we first consider the last row, where total effects for twenty compounds are shown. As mentioned before, these compounds form about fifty per cent of total pesticide use, measured in kg active ingredient. If all the other pesticides would show a similar pattern, the numbers of the last row would double but would not affect the relative importance of each of the columns. From Table 7 we conclude that 'area change' (MAP_b) is the least important category and the 'resulting change' (MAP_d) is the most important one. Observe that for these categories and – nearly by definition – for 'banning/introducing compounds' (MAP_c) differences are highly

Table 8. Mean percentage differences per compound for 1991, related to the use in the base period 1986/88.

Compound	S_i	$MAP_{a,i}/S_i$	$MAP_{b,i}/S_i$	$MAP_{c,i}/S_i$	$MAP_{d,i}/S_i$
Atrazin	0.0103	29	2	0	–7
Azinphos-methyl	0.0004	66	10	0	–86
Captafol	0.0007	92	2	–38	–62
Captan	0.0182	35	6	1	11
Carbendazim	0.0027	37	–42	0	75
Chlormequat	0.0025	–36	9	0	21
Chlorprofam	0.0020	–13	1	0	8
Dalapon	0.0055	76	0	0	–72
Dichlorvos	0.0014	33	25	0	–7
Dimethoate	0.0019	45	9	0	44
Dinoseb	0.0253	–17	3	–103	0
DNOC	0.0023	98	–5	524	–62
Lindane	0.0014	7	1	0	–22
Maneb	0.0893	19	3	0	–23
MCPA	0.0099	10	–5	0	36
Mecoprop	0.0207	17	–4	–87	–1
Metham-sodium	0.2946	3	6	0	–14
Parathion	0.0036	–47	–25	0	55
Sulphur	0.0037	–23	7	0	–31
Zineb	0.0092	–76	–6	0	–10

concentrated at particular compounds. It is also quite clear from the last row of Table 7 that the sum of the different causes, represented by TOTAL, cancels out for nearly fifty per cent, because these differences go into different directions, which is illustrated in Table 8. Clear examples are azinphos-methyl, captafol, chormequat, dalapon, maneb, metham-sodium and parathion.

Table 8 presents results whereby the share of a compound in the total quantity of active ingredient plays no role. Here, mean absolute percentage differences are relative to initial quantities from the NEFYTO source.

Several conclusions can be derived from Table 8:

- use of atrazin, azinphos-methyl, dichlorvos, metham-sodium and sulphur increases because of area change but decreases because of resulting changes;
- use of carbendazim, chlorprofam, MCPA and parathion decreases because of area change but increases because of resulting changes;
- use of maneb and zineb decreases because of area change and resulting changes.

It would not be difficult to increase this list. But the most important message from the Tables 7 and 8 is that rather important differences exist between different information sources and periods. The 'resulting change' is most important (highest MAP for these twenty compounds). Therefore this category warrants closer examination.

Systematic changes versus incidental changes in pesticide use

We have tried thus far to determine the importance of several causes in the change and determination of pesticide use. One of the important elements in the application of pesticides, however, is the annual fluctuation due to weather, diseases, plagues, and the like. It would be interesting to see whether annual fluctuations are large relative to systematic changes. Here the measure 'the mean absolute percentage variation' can be used:

$$MAPV_i = 100*(1/DF)* \Sigma_t |z_{t,i}-\bar{z}_{t,i}|/\bar{z}_{t,i} \tag{10}$$

where, DF = degrees of freedom,

t = year = 1984,...,1991 = 1,...,8

$\bar{z}_{t,i}$ = trend value of the use of the particular pesticide i in year t.

The trend value is estimated by the following general model, where annual trend and a change due to banning/introducing pesticides have been included:

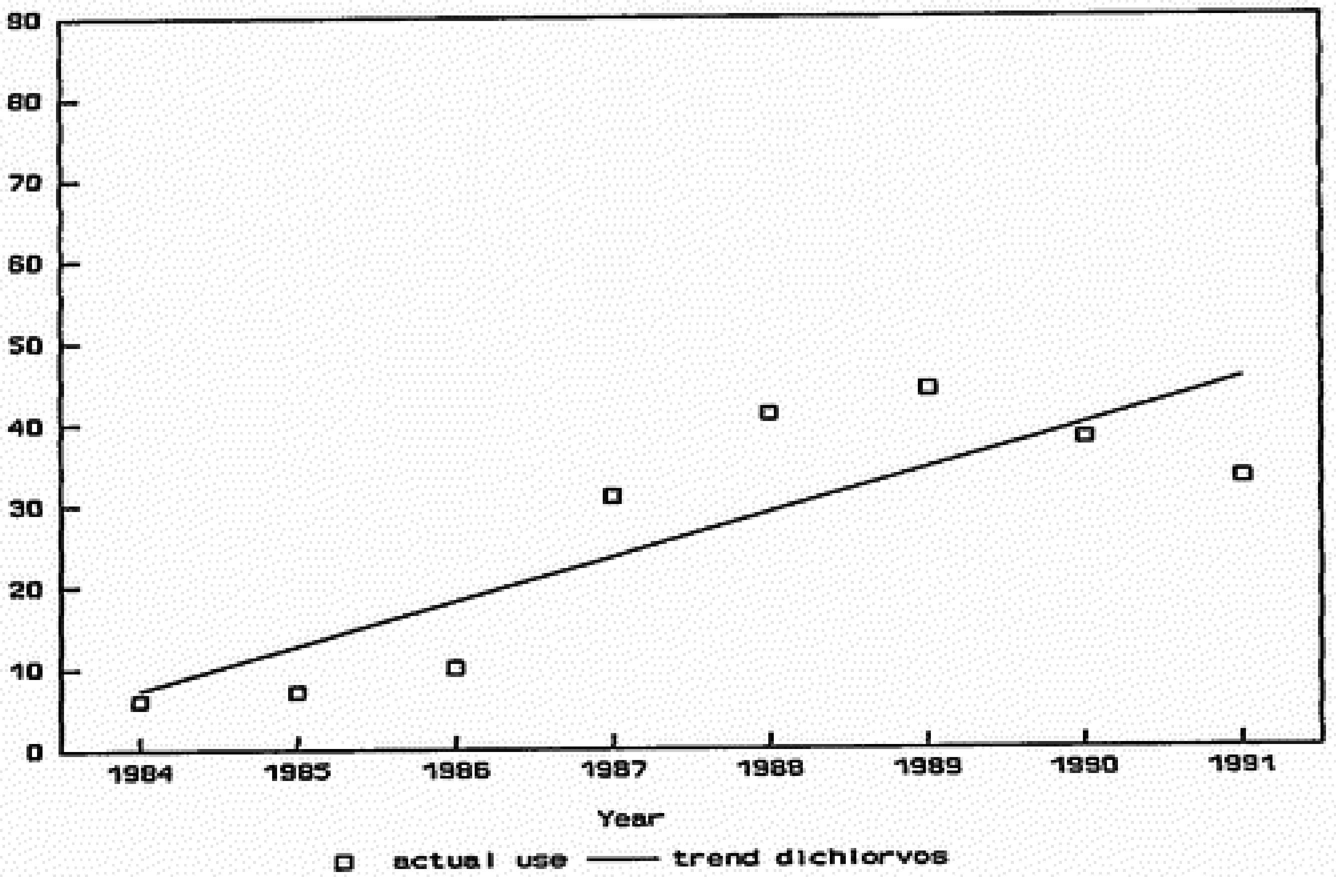
$$\bar{z}_{t,i} = \alpha + \beta_1 * T + \beta_2 * DT + \gamma * D \tag{11}$$

where:
- α = constant
- D = dummy variable; 0 before banning/introducing and 1 after banning/introducing
- γ = shift parameter (t-value between parenthesis)
- DT = dummy-trend; 0 before trend rupture, 1 in first period after trend rupture, 2 in second period, etc.
- β_2 = dummy-trend parameter (t-value between parenthesis)
- T = trend variable; 1 in first period, 2 in second period, etc.
- β_1 = trend parameter (t-value between parenthesis)

Table 9. MAPV (in %) for the period 1984-1991 for fifteen compounds based on NEFYTO statistics; also data of trend calculation (and reliability) are mentioned.

	MAPVi	Trend (β_1)	St. error coeff.	Reliability β_1[1]	R^2
Atrazin	6	–3.50	1.65	*	0.43
Azinphos-methyl	15	–0.77	0.14	****	0.84
Carbendazim	6	5.21	0.45	****	0.96
Chlormequat	25	2.39	2.25		0.16
Chlorprofam	21	–1.36	1.22		0.17
Dalapon	23	–12.71	2.77	****	0.78
Dichlorvos	40	5.43	1.47	***	0.69
Dimethoate	29	7.24	2.47	**	0.59
Lindane	11	–1.52	0.51	***	0.59
Maneb	9	–89.20	21.46	****	0.74
MCPA	10	8.58	3.20	**	0.54
Metham-sodium	14	164.37	121.67		0.23
Parathion	24	0.63	3.10		0.01
Sulphur	19	–6.52	2.49	**	0.53
Zineb	6	–5.90	1.64	***	0.68
Total	5	–511.18	163.16	***	0.62

[1] * = 90%, ** = 95%, *** = 97.5% and **** = 99%



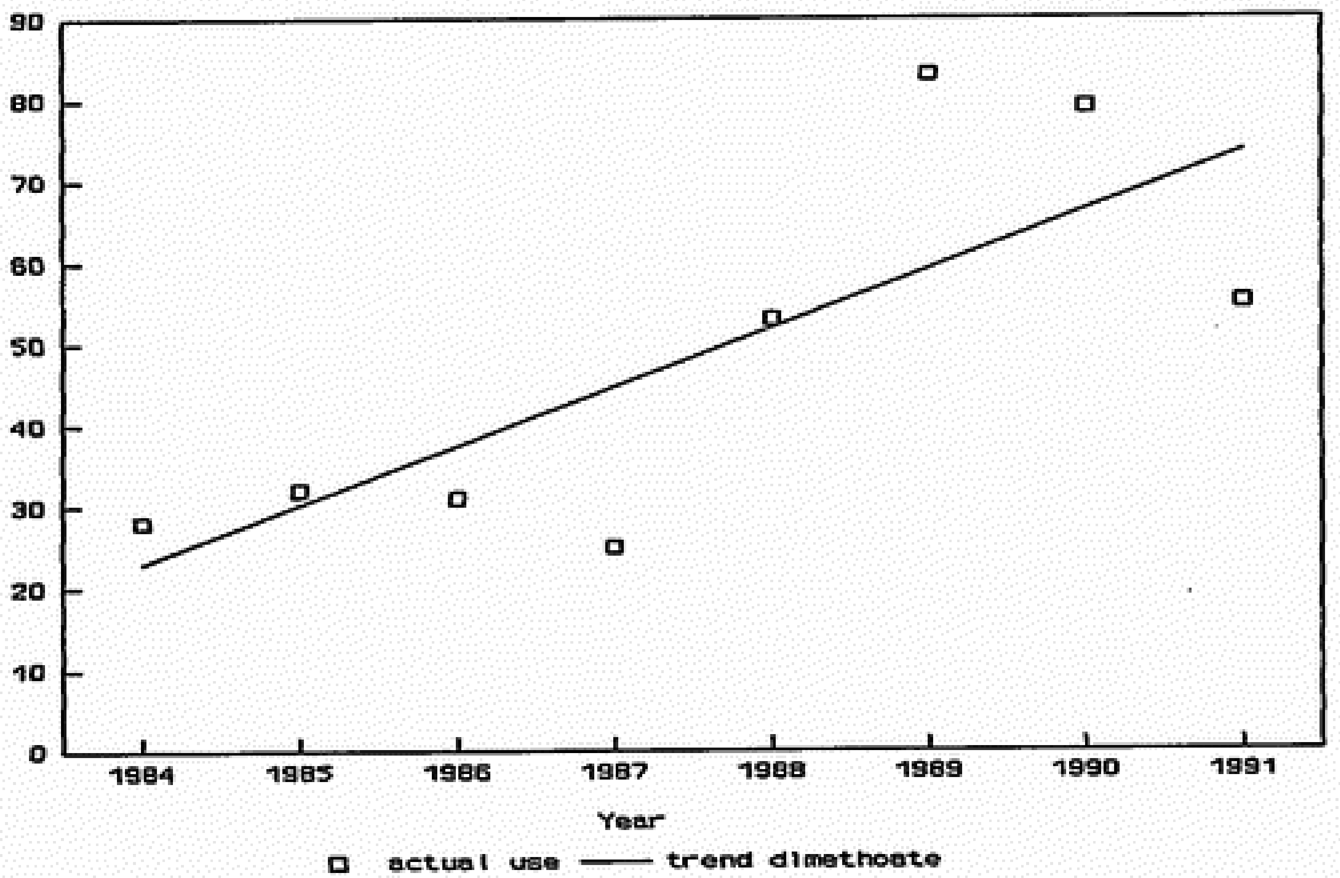


Figure 2. Use of dichlorvos and dimethoate (in tonnes active ingredient per year) in the period 1984-1991.

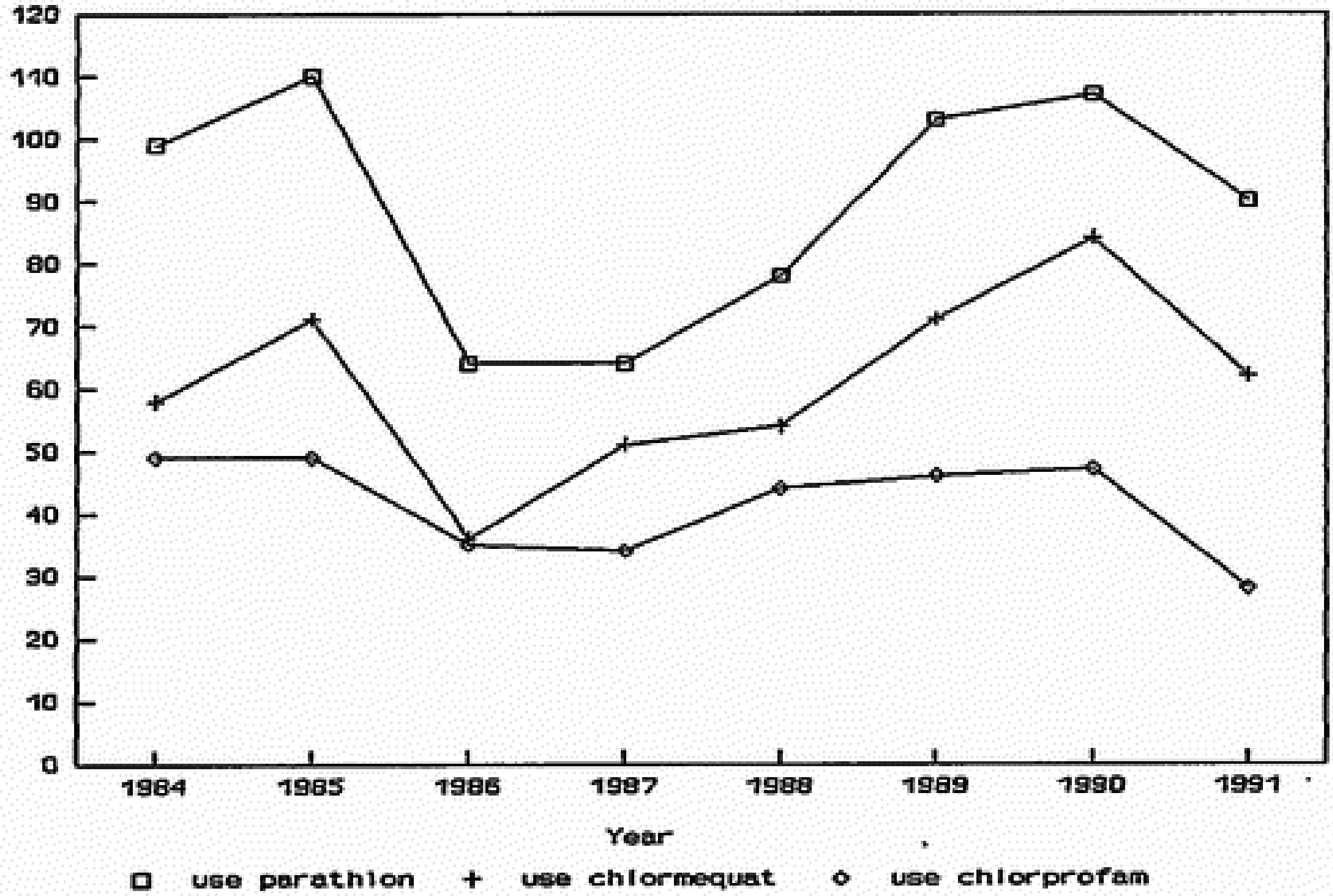


Figure 3. Some pesticides which show no trend in use in the period *1984-1991*. Pesticide use in tonnes active ingredient per year.

Because of the short estimation period, the general model could often not be used under the condition of a ban or introduction of a pesticide (Figure 1). Results of estimates for all compounds for which data are available in the NEFYTO statistics do not fall within the scope of this article. An appendix with all figures and equations is available upon request. Table 9 shows trend parameters and MAPVs for fifteen pesticides/compounds. Those compounds of which trend ruptures could be determined are dropped, because we are now especially interested in trends and annual fluctuations. Not only the MAPV is presented, but also some results of regression analysis like R^2 (the coefficient of determination), the trend-coefficient β_1 and its standard error.

We will first give attention to the MAPV. Insecticides like dichlorvos, dimethoate, parathion show a high MAPV. Figure 2 shows the development in the use of dichlorvos and dimethoate. Dichlorvos is mainly used on greenhouse crops while dimethoate on field crops. The use of dimethoate might be influenced by the restricted use of endosulphan since January 1987. The growth regulator chlormequat had a rather high MAPV. The same hold for herbicides such as dalapon and chlorprofam. We found a low MAPV for all fungicides, except sulphur. For the insecticides lindane and the herbicides atrazin and MCPA the MAPV was also small.

Regression analysis indicated important trends for compounds like carbendazim, azinphos-methyl, dalapon and maneb. We found negative (total, maneb, dalapon), but also positive relations (carbendazim, MCPA, dimethoate) between pesticide use and time. Figure 3 shows some compounds which show no trend (a very low R^2). In this case, there was no clear change in pesticide use during the period 1984 - 1991.

We might try to draw conclusions from Tables 8 and 9. Caution is neccessary since in Table 8 we see developments of pesticide use in 1991 compared with the period 1986-1988, while in Table 9 we searched for trends in the period 1984-1991. In Figure 2 different trends in different periods of time are clearly detectable. If we compare the size of $MAPV_i$ and direction and magnitude of the trend-coefficient in $MAPV_i$ (Table 9) with direction and size of $MAP_{b,i}/S_i$ and $MAP_{d,i}/S_i$ (Table 8) we derive the following:

- use of atrazin declines because of technological change, while annual fluctuations are not important;
- use of azinphos-methyl declines because of technological change, while changes because of area and annual fluctuations are of some importance;
- use of carbendazim increases because of technological change, while changes due to area go in the opposite direction, and annual fluctuations are not important;
- use of chlormequat increases because of technological and area changes, while annual fluctuations are important.

We could continue with similar conclusions. Most important, however, is that the annual fluctuation of total pesticide use is 5%. For compounds the range is between 6 and 40%. This implies that it is very difficult to give a clear indication of changes in pesticide use on the basis of data for a particular year.

Present situation in the Netherlands

Since June 1992 producers, importers and traders of pesticides are required to register their stocks and their received and sold pesticides. The use of pesticides will also be followed by the DLO Agricultural Economics Research Institute (LEI-DLO), the Netherlands Central Bureau of Statistics (CBS) and by way of regulation of soil fumigants. Registration of pesticide use is standardized. In this way the government receives more information of use per sector, region, crop and group of pesticides. In 1993 the progress of the LCPP is evaluated for the first time by using the figures of NEFYTO (Anonymous, 1993). It is concluded that the targets can be reached, but the reduction of fungicide and insecticide use remains a problem.

Discussion and conclusions

We have attended to pesticide use on compound level. A method was developed (equations 1 to 5) and applied to different sources of information on use in the Netherlands.

Some information is unusable (for example, Mulder & Poppe, 1993) because it is too aggregated. The database, based on the LCPP, is on a pesticide/crop level and therefore corrections can only be made if the new information is detailed enough (for example, Tables 4.30, 4.31, Kavelaars & Poppe, 1993, or more detailed information).

From two databases for 1991 versus the period 1986-1988 (LCPP period) we could classify different causes of change in pesticide use by calculating the mean absolute differences (equations 6 to 10). Applying this to twenty compounds/pesticides, area change is of less importance compared with banning/introducing compounds and changes in technology and weather. All these changes, however, might be assumed to increase if there is a longer time period between the two different data sources. Different changes, however, appear to cancel out partly.

The aforementioned method has been developed to measure systematic changes versus incidental changes (equations 11 and 12). Changes in crop area and changes in technology may be examples of a systematic change. Banning is an example of an incidental change. If banning is neglected, it might result in a high MAPV of one or more compounds. Using one database for the period 1984-1991 and only those compounds for which no trend rupture is known, we derive 'mean absolute percentage variations' (MAPVs) between 6 and 40% at the compound level. Incidental changes are of importance for insecticides but less important for fungicides.

The results of the trend coefficient in the regression equation (12) indicate many positive coefficients, but the total is strongly negative. We must conclude that changes in the use of the other pesticides are responsible for this decline. Notice once again that the pesticides mentioned in Table 1 (twenty out of a total of about three hundred) cover only half of the total use in kg active ingredient. It would be helpful if NEFYTO would give more information on compound level, for example, use from 1984 on of (cis-)dichloropropene, of endosulfan and other compounds which have been banned recently and of mevinphos and other compounds which threaten surface water quality (De Vries & Swaager, 1993). In this case in our method specified above (equations 1 to 5) matrix M should be corrected. In the same time MAP_b, MAP_c and MAP_d would become larger and more reliable.

Pesticide use on compound/crop and on the national scale level is of importance to check policy aims and to understand whether or not targets are reached. If uncertainties and differences between information sources play an important role, it will be difficult to conclude on policy targets. Here we have shown that unambigous measures of pesticide use are very difficult to obtain. Moreover, fluctuations in the application of pesticides cannot be neglected.

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