The Bichel Committee 1999

Report from the Sub-comittee on the environment and health

Miljøstyrelsen
Miljø- og Energiministeriet

Preface

The Sub-committee for Environment and Health, which is part of the Bichel Committee, was appointed in autumn 1997 to assess the consequences for the environment and public health of phasing out the use of pesticides. This report is a result of those assessments and is one of five technical background reports that form the basis for the Bichel Committee's final report to the Minister of Environment and Energy.

The other background reports cover the consequences for agriculture, the consequences for the economy and employment and, lastly, the legal possibilities of phasing out the use of pesticides. The last-mentioned report also covers the overall consequences of total restructuring for organic farming.

This is the first time in Denmark - and probably also internationally - that such an extensive interdisciplinary analysis has been conducted of the consequences for agriculture of a total or partial phase-out of pesticide use and of total restructuring for organic production.

The Sub-committee for Environment and Health found a wide range of health and environmental impacts from pesticides that are now banned. On this basis, the sub-committee also found that our knowledge about impacts is constantly increasing, so substances that are at present regarded as safe may be viewed differently in the future. Experience to date thus confirms that pesticides should only be used with great caution.

The sub-committee also ascertained a number of impacts from the use of pesticides on both the terrestrial and the aquatic environment, but did not find any health effects on the population in general from currently authorised pesticides. The sub-committee identified various lacunae in our knowledge that make it difficult to calculate the consequences of phasing out the use of pesticides. The sub-committee therefore had to limit the actual analysis of consequences to the few impacts about which there was sufficient background information.

The sub-committee also considered how the environment and health could be protected still further and, in that connection, indicated various areas for action.

The sub-committee based its report on a number of consultants' reports. The consultants, the members of the sub-committee and the secretariat all made a major contribution to the creation of the report, and we take this opportunity to thank everyone concerned for their good work.

Henrik Sandbech
Chairman of the Sub-committee for Environment and Health

1 Introduction

On 15 May 1997 the Folketing (the Danish Parliament) unanimously passed a parliamentary resolution urging the government to appoint a committee with independent expertise to analyse all the consequences of totally or partially phasing out the use of pesticides in agriculture and to examine alternative methods of preventing and controlling plant diseases, pests and weeds.

The committee was to assess the consequences for production, the economy, legislation, health and the environment, and employment. In continuation of its mandate (see chapter 2), the Sub-committee for Environment and Health looked at issues relating to the precautionary principle (see chapter 8) and the relationship between the pesticide load and the load from other chemical impacts in agriculture (see chapter 7).

The results of the committee’s work were to be used in the coming work on a new pesticide action plan.

In the mandate of 4 July 1998, the Minister of Environment and Energy stipulated that a main committee be appointed with expert members from the research world, the agricultural industries, the “green” organisations, consumer organisations, the foodstuffs and agrochemical industries, the trade unions and relevant ministries. Its members were to cover the specialist areas of agricultural production, economics, legislation, employment, health, the environment and ecology.

In addition, four sub-committees were appointed. Their task was to facilitate the main committee's final reporting by drafting specialist background reports.

The main committee had the task of coordinating and discussing the sub-committees' work and of preparing the final report for the Minister.

The sub-committees were to cover the following areas:

1. Agriculture
2. Production, economics and employment
3. Environment and health
4. Legislation

As points of reference for their work, the sub-committees were to use both the optimum production from the standpoint of operating economy and the production achieved to date by the agricultural industries – farming, market gardening and forestry. They were to assess the consequences for production, the economy, legislation, health, employment and the environment.

In their work, the sub-committees were to evaluate scenarios for total and partial phasing out of pesticides and examine the consequences of restructuring for organic farming, taking into account activities already in progress concerning such restructuring.

2 The sub-committee’s mandate and composition

2.1 The sub-committee’s mandate and scenarios for phasing out pesticides

According to its mandate, the Sub-committee on Environment and Health, working on the basis of the above-mentioned cultivation systems, was to evaluate the environmental consequences of a total or partial phase-out of pesticides. In its evaluation, the sub-committee was to consider the effects on groundwater as a resource for the population and the natural environment, surface water as a resource for flora and fauna, and the terrestrial ecosystems in agriculture and forestry as a resource for flora and fauna.

In its evaluation of the health consequences, the sub-committee was to include the effects of pesticides on the people using them and the effects of using the proposed cultivation systems. On the other hand, the sub-committee was not required to consider the health and environmental aspects of the industrial production of pesticides.

In its work, the sub-committee was to analyse the following scenarios in relation to present production practice:

- A total phase-out of pesticides (the 0-scenario). This scenario is described as a reference situation, and the environmental and health consequences of a total phase-out were to be compared with the present situation.

- Use of pesticides only for pests covered by the quarantine laws (the 0+scenario). In this scenario, pesticides would be used to comply with specific requirements concerning purity or for controlling pests defined in orders from the Plant Department.

- Use of pesticides in crops with serious losses (the +scenario). In this scenario, pesticides would only be used for limited areas in which large yield losses could be expected or where production of specific crops could not be maintained. The scenario also covers the 0+scenario’s areas.

- Reduction of pesticide consumption to a level without yield losses (the ++scenario). In this scenario, use would be made of all available technical and cultivation methods that reduce the use of pesticides without significant economic losses. The scenario covers the areas of the 0+scenario and the +scenario and is based in part on the principle of integrated prevention and control.

2.2 Composition of the sub-committee

The sub-committee had the following members:

The President	Henrik Sandbech, Director General, National Environmental Research Institute (DMU)
Members	Professor Poul Bjerregård, Odense University Dr. Hans Løkke, Director of Research Department, National Environmental Research Institute (DMU) Dr. Agro. Arne Helweg, Danish Institute of Agricultural Sciences (DIAS) Dr. Erik Thomsen, Government Geologist, Geological Survey of Denmark and Greenland Dr. Ib Knudsen, Executive Director, Veterinary and Food Administration (VFA) Dr. Ole Ladefoged, veterinarian, VFA Dr. Lars Ovesen, Head of Division, VFA Professor Finn Bro-Rasmussen, Technical University of Denmark (DTU) Dr. Ib Johnsen, Institute of Botany, Organic Department, University of Copenhagen Dr. Peter Jantzen, The National Board of Health (retired from the sub-committee in January 1998) Elle Laursen, Deputy Superintendent, The National Board of Health (joined the sub-committee in January 1998) Sonja Plough Jensen, Principal, Danish Working Environment Authority (WEA) (retired from the sub-committee in January 1998) Kjeld Mann Nielsen, Special Consultant, WEA (joined the sub-committee in January 1998, retired in December 1998) Bent Horn Andersen, Special Consultant, WEA (joined the sub-committee in December 1998)

In addition, Claus Vangsgård, M.Sc., Association of Danish Waterworks, participated in some of the sub-committee’s meetings.

The secretariat comprised Dr. Kaj Juhl Madsen, Danish Environmental Protection Agency, Lise Nistrup Jørgensen, Senior Scientist, Danish Institute of Agricultural Sciences, and Anne Marie Linderstrøm, Head of Section, Danish Environmental Protection Agency.

The sub-committee’s report was edited by Hans Løkke, Director of Research Department, National Environmental Research Institute, and Birgit Nygaard Sørensen, Executive Secretary, National Environmental Research Institute, took care of the layout and writing of the report.

3 Definition of the work

With a view to evaluating the consequences of a total or partial phase-out of pesticides, the sub-committee first gathered together the existing information on the known environmental and health effects of the use of pesticides as a reference frame for analysing the various cultivation systems set up by the Sub-committee on Agriculture.

Definition of pesticides

In its work, the sub-committee used the definition of pesticides proposed by the Sub-Committee on Legislation. That definition is reproduced below:

“The expressions pesticides, plant protection products and active ingredients appear frequently in the following. For the sake of clarity, they and some other terms are therefore explained here.

Pesticides is an inclusive term for plant protection products and biocides.

Plant protection products (or spraying products) are the products used in the agricultural industries (farming, forestry, market gardening and fruit production) for prevention and control of weeds, pests and fungal diseases and for regulating growth (including straw shortening). Plant protection products can also – where permitted by law – be used in private gardens and similar, including uncultivated and public land.

Biocides include wood protection products, rat poisons and slimicides for use in paper pulp etc.

A pesticide consists of one or more active ingredients and some coformulants. The active ingredient is the substance that is specifically aimed at pests etc. The coformulants are substances that are added to enhance the intended effect.”

The sub-committee knew that the Committee on Drinking Water appointed by the Danish Environmental Protection Agency in March 1996 had presented its report on 17 December 1997. The report showed that the committee had examined the existing regulation of pesticides and the risk of contamination of drinking water with pesticides. Therefore, where relevant, the Sub-committee on Environment and Health used this report as background material.

The sub-committee examined the existing body of knowledge to determine the general level of knowledge in this area and to ascertain how any lack of knowledge affected the possibility of evaluating the consequences of a total or partial phase-out of pesticides.

At the request of the main committee, the sub-committee also assessed the possibility of identifying the most harmful of the pesticides authorised for use today.

In that connection, the sub-committee considered how the precautionary principle could be operationalised in the case of pesticides and examined the pesticide problem in relation to other chemical compounds used in agriculture.

The sub-committee did not carry out a systematic evaluation of the present authorisation scheme, partly because this lay outside its mandate and partly because an expert evaluation had already been carried out in the case of groundwater protection in the spring and summer of 1997. Readers are also referred to a brief review in Annex 1 of the data required for authorisation of pesticides and to Annex 2 concerning the general rules for risk assessment of environmental impacts and classification of health impacts.

Consultants' reports

Pesticides detected in the groundwater: *Walter Brüsch, Bo Lindhardt, Martin Hansen, GEUS*

Exposure and effect of pesticides on harmful insects in cultivated and terrestrial ecosystems: *Lars Monrad Hansen, DIAS*

Effects on flora in cultivated and uncultivated ecosystems: *Gösta Kjellsson, DMU, Kathrine Hauge Madsen, KVL*

Pesticides detected in precipitation, contribution of precipitation to soil and groundwater and international contribution to the pesticide load: *Gitte Felding, DIAS*

Pesticides detected in drain water and soil water: *Niels Henrik Spliid, DIAS*

Reduction potential at filling and washing yards: *Niels Henrik Spliid, DIAS*

Exposure and effects of pesticide usage on useful fauna and other lower and higher fauna in arable land: *Niels Elmegård, DMU*

Pesticides in soil: *Inge S. Fomsgaard, DIAS*

Effects on flora and fauna in fresh water: *Nikolaj Friberg, DMU*

Pesticides found in watercourses and lakes, together with surface run-off: *Betty Bügel Mogensen, DMU*

Ingestion of pesticides through diet: *Arne Büchert, VFA*

Effect of pesticides on public health: *Lars Rauff Skadhauge, The National Board of Health*

Analysis/description of the consequences for health and safety of phasing out pesticides within the agricultural industries: Karen Gertrud Bjørn, Occupational Health Service (OHS) Greater Copenhagen, Leif Rothmann, OHS Funen

Interaction between pesticides and production of toxins in food products: *Susanne Elmholt, DIAS*

Input concerning: Nitrate leaching during different forms of soil treatment: Elly Møller Hansen, Jørgen Djurhuus, DIAS

Change in consumption of fossil energy with restructuring for 0-pesticide agriculture: *Tommy Dalgaard*

Synthesis of the known effects of pesticides on the agro-ecosystem's organisms and modelling of effects on bird populations on arable land in connection with a total or partial phase-out of pesticides: *Bo Svenning Petersen, Flemming Pagh Jensen, Ornis Consult*

Pesticide scenarios: Effects on lower fauna: *Niels Elmegård, Jørgen A. Axelsen, DMU*

Analysis of the environmental impact of pesticide use in private forestry: *Morten Strandberg, DMU*

Effect of pesticides on the aquatic environment with different treatment frequency indices: *Flemming Møhlenberg, Kim Gustavson, DHI Water & Environment*

Technical background report on identification of the most harmful pesticides authorised for use today: *Bo Lindhardt, GEUS, Peter B. Sørensen, DMU, Niels Elmegård, DMU, Inge S. Fomsgård, DIAS, Else Nielsen, VFA, Jim Hart, VFA, Lene Gravesen, Danish Environmental Protection Agency (DEPA), Lerke Ambo Nielsen, DEPA, Lene Lorenzen, DEPA, Kaj Juhl Madsen, DEPA.*

Comments received from individuals/institutions that were not members of the sub-committee

Novartis, Ole Jensen: Midway Conference in the Bichel Committee

Novartis/Mads Kristensen: Comments and questions to the Pesticide Committee

Bayer, Frank Rothweiler: Follow-up on the Midway Conference in the Bichel Committee

Cheminova, Lars-Erik K. Pedersen: Comments to the Committee following the Midway Conference in the Bichel Committee

Hans Sanderson, Comments to the Sub-committee for Environment and Health

Peter Højer: Questions to the Pesticide Committee

Jens Husby: Questions to the Bichel Committee

Institute for Product Development, Technical University of Denmark, Bente Mortensen

Comments to Henrik Sandbech’s paper at the Midway Conference in the Bichel Committee

Helga Moos, MP (Liberals): Comments to the Midway Conference
Zeneca Agro, Freddy Kjøng Pedersen: The Midway Conference on 21 September 1998

Erik Faurholt: Questions to the Pesticide Committee.

4 Occurrence of pesticides in the environment

Pesticides are distributed in the environment through spraying, spreading as granulate, with dressed seed, through swabbing, etc. During spraying, the pesticides can be carried by the wind over both short and long distances. Some chemicals can also evaporate from the surface of plants or soil. Atmospheric transport can be of considerable magnitude and is often far-reaching and transboundary. Pesticides can also be washed out from the atmosphere with rainwater or be deposited on surfaces by so-called dry deposition. Pesticides can spread with rainwater to the aquatic environment, where they occur in soil water, run-off water, drain water, watercourses and lakes. Lastly, pesticides can be conveyed to the environment by accident or through unlawful use.

This section describes the occurrence of pesticides in the different compartments, as shown in table 4.1. This table also shows the types of organism that are exposed to pesticides. Section 4.1.6 also describes how pesticides can be distributed in the environment and thus contribute to exposure of people and the environment. The possible effects of pesticides are described in section 4.2. The main effects occur in connection with the treatment with pesticides, when organisms are directly affected, but there are also indirect effects as a consequence of the impact on food chains. The report does not cover bioaccumulation of pesticides in organisms and possible concentration in food chains. The Danish Environmental Protection Agency's assessment of the bioaccumulability of pesticides is certain to lead to such pesticides not being authorised in Denmark.

Table 4.1
Compartments in which pesticides occur and the types of organisms exposed to them. The table also shows the sections of the report in which the occurrence is described and the sections in which the potential effects of pesticides in the different compartments are described.

Compartment	See section:	Exposed organisms	Effects, see section:
Ground water	4.1	The population, flora and fauna in watercourses, lakes	6, 5.3
and coastal waters	4.2	Flora and fauna in watercourses	5.3
Watercourses,	4.3	Flora and fauna in lakes, ponds and watercourses	5.3
ponds	4.4	Soil fauna and terrestrial flora, together with flora and fauna in watercourses, lakes, ponds and coastal waters	5.1
Rainwater	4.5	Terrestrial flora	5.2

Systematic data are not available on the occurrence of pesticides in lakes and coastal waters, so the report does not include data from these compartments.

4.1 Pesticides in groundwater

Denmark’s water supply system is based on pure groundwater, which can be supplied to the consumers without treatment. In the last few decades, groundwater has been found to be contaminated with industrial chemicals, leachate from landfills, nitrate, heavy metals and, lately, pesticides. In 1994, contamination of the groundwater in Ejstrupholm with the herbicide atrazine led to splash headlines in the media. At the same time, countrywide analyses showed that pesticides were commonly found in the groundwater. New research results also show that even in clayey soil, fissures and cracks from the Ice Age enable pesticides to leach down to the groundwater relatively quickly.

Groundwater quality is one of the main elements of Denmark’s environmental legislation. For pesticides, Denmark uses the EU’s limit values of 0.1 microgramme per litre water for every substance and 0.5 microgramme per litre water for the sum of pesticides, irrespective of the nature of the substance. Since groundwater is regarded as a basic resource that must be kept free of pollution, these limit values have been set as ”hygienic limit values”. This is further supported by the fact that the groundwater used as drinking water forms over long periods of time. This means that by the time pollution can be measured in the aquifer itself, it is too late to avert it or control the extent of it.

Database

In Denmark, groundwater is analysed for pesticides and, in some cases, for degradation products in different contexts:

- The Aquatic Environment Plan’s National Groundwater Monitoring Programme, GRUMO
- The Aquatic Environment Plan’s Nationwide Monitoring Programme for Agricultural Catchments, LOOP
- The water companies’ raw-water monitoring system
- Expanded analytical programmes carried out for example by county authorities and water companies.

Groundwater monitoring programme GRUMO

The groundwater monitoring programme (GRUMO) covers 67 monitoring areas spread around the country. The areas have been chosen with a view to providing a representative picture of Denmark’s aquifers. In most cases, the monitoring areas are situated in regions in which land is predominantly used for farming. Most of the areas include an extraction well to a waterworks and 10-20 specially established monitoring wells that characterise the main flow pattern of the groundwater (Figure 4.1).

The samples of water are extracted from well screens. A ”well screen” should be understood to mean a closed pipe placed at the lower end of the groundwater well shaft. The well screen is equipped with slots or similar openings, which, in interaction with a screen pack of filter gravel around the well screen, are intended to retain the fine particles in the soil. The length of the well screen can vary so that the pumped up water comes from the depth interval in which the well screen is placed. Three types of well screen are used in the groundwater monitoring programme:

point, line and volume monitoring screens. The last-mentioned type is often a waterworks well. In the point-monitoring and line-monitoring screens, the water samples represent the chemistry of the water samples at a specific point at a specific time in the aquifers examined. The volume-monitoring screens, on the other hand, represent mixed water, cf. the section on raw-water monitoring.

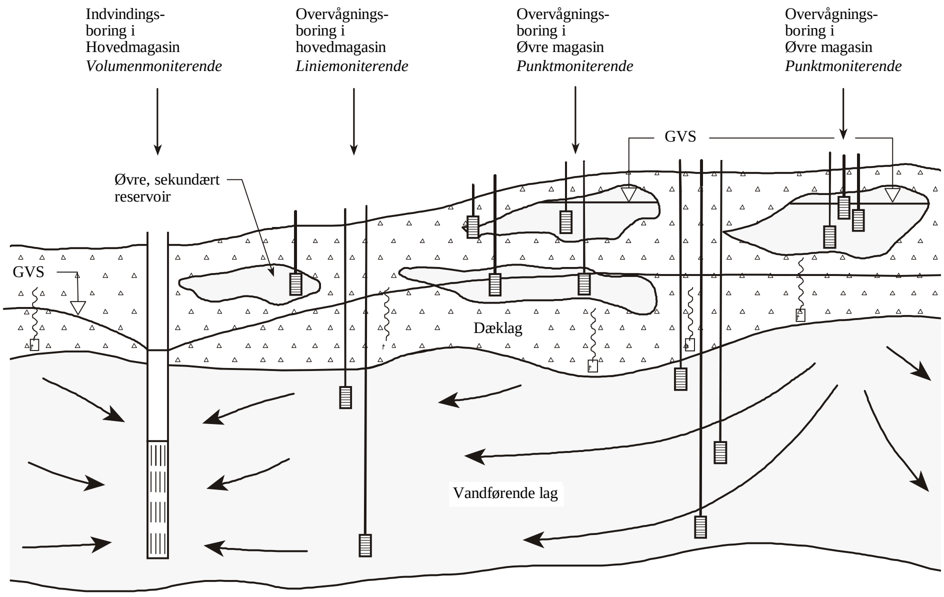


Figure 4.1
Types of monitoring in the monitoring programme. GVS = groundwater table

(Figure text:
Indvindingsboring i hovedmagasin *Volumenmoniterende* = Extraction well in main aquifer *Volume monitoring*
Overvågningsboring i hovedmagasin *Liniemoniterende* = Monitoring well in main aquifer *Line monitoring*
Overvågningsboring i øvre magasin *Punktmoniterende* = Monitoring well in upper aquifer near the limit of the catchment area *Point monitoring*
Øvre sekundært reservoir = Upper aquifer
GVS = Groundwater table
Dæklag = Overburden
Vandførende lag = saturated sediments

The Nationwide Monitoring Programme for Agricultural Catchments (LOOP)

The Nationwide Monitoring Programme for Agricultural Catchments (LOOP) is carried out in five well-defined run-off catchment areas in agricultural regions where farming practice is known. Among other things, groundwater near the surface is monitored, so it is possible to relate leached substances to the use of the land. However, there are only limited data concerning pesticides from LOOP.

The water companies' raw water monitoring system

The raw water monitoring system includes monitoring the water from the water companies' extraction wells. In many cases, the interval in the wells from which water is extracted is of considerable length, and the water can be extracted from several separate saturated sediments. A water sample from the raw water monitoring system is therefore often a "mixed sample" of different types of water of different age and containing different substances. Since a number of water companies have extraction wells near towns, pesticides detected in the raw water monitoring system often bear signs of non-agricultural use.

In its yearly reporting of the results from the groundwater monitoring programme, GEUS gives the results from GRUMO, LOOP and the water companies' raw water monitoring system separately because they concern different types of water sample.

Detection of a pesticide, or a metabolite, is defined as detection of the substance in question above the current detection limit. The laboratories use different detection limits. For example, DMU specifies a detection limit of 0.005 microgramme per litre for some substances, while other laboratories specify a detection limit of 0.01 microgramme per litre for the same substances. The detected substances are then divided into two groups: one over the detection limit and one over or equal to the limit value (i.e. the latter is a subset of the first group).

Pesticides have been found in groundwater all over the country with the exception of some areas north of the Limfjord and in North Zealand. Table 4.3 shows the pesticides detected in the raw water monitoring system.

The groundwater monitoring programme, GRUMO

The national groundwater monitoring programme gives a complete picture of the state of the groundwater, including the situation with respect to pesticides (GEUS 1998). Under the groundwater monitoring programme, analyses were carried out for eight pesticides in 1,014 well screens in the period 1990-1997. The programme covers two triazines (atrazine, simazine), four phenoxyacetic acids (dichlorprop, mechlorprop, MCPA, 2,4-D) and two nitrophenols (dinoseb, DNOC). Of the eight GRUMO pesticides, three (atrazine, dinoseb and DNOC) are now banned, while five of the others are subject to restrictions with respect to dosage, crops, etc. In all, 4,230 analyses of water samples have been carried out for these eight substances. As a consequence of the county authorities' expanded analytical programmes, data were reported in 1998 from 594 well screens in the monitoring system from which water samples were analysed for more pesticides and their degradation products.

One or more of the eight GRUMO pesticides were detected one or more times in 121 well screens. The screens came from 101 wells, in 16 of which pesticides were found in two or three screens. The 121 screens correspond to just over 12% of the screens analysed, while the limit value for drinking water (0.1 microgramme per litre) was exceeded in 35 screens, corresponding to just under 3.5%, see table 4.2. There is often an interval of three years between sampling, and as pesticides normally occur in pulses, they are often not detected again in subsequent samples.

In the 594 screens in which some of the county authorities have carried out expanded analytical programmes, pesticides or degradation products have been detected in 21% and the limit value has been exceeded in 13%, see table 4.2. However, data have usually only been reported on one set of water samples from the 594 screens.

Counties analyse samples from sensitive wells for BAM

In the case of 2,6-dichlorobenzamide (BAM), which has been detected in about 14% of the screens analysed, the data must be treated with caution because the county authorities selected sensitive screens for testing for this compound. Sensitive screens should be understood to mean screens in young groundwater near the surface or screens close to potential sources of pollution. BAM is a degradation product, the parent compound of which is dichlobenil. Dichlobenil has not been used for agricultural purposes and is no longer permitted in Denmark.

The triazine degradation products desethylatrazine, desisopropyl-atrazine and hydroxyatrazine have been detected in 6.6%, 5% and 2.8%, respectively. However, hydroxyatrazine has been analysed for in only a few screens, and experience from other countries does not normally reveal high detection percentages for this substance.

Table 4.2
Detection of pesticides related to the number of analysed screens in the groundwater monitoring programme (GEUS 1998).

Groundwater monitoring	Analysed screens	Detections above the detection limit (often 0.01 µg/L)	in %	Detections above or equal to the limit value (0,1 µg/L)	in %
8 GRUMO pesticides	1014	121	12	35	3.5
Analysis for other pesticides than the 8 GRUMO pesticides	594	126	21	76	13

µg/L = microgramme per litre

The extension of the monitoring programme in 1998 to approx. 50 pesticides and degradation products may reveal possible further occurrence of pesticides in groundwater, particularly as only a few of the 594 screens have been analysed for all 50 substances.

The depth distribution of the pesticides shows that the eight GRUMO pesticides occur in 22% of the high-lying and youngest groundwater in the interval 0-10 metres below ground level and that the frequency decreases with the depth. Where screens have been analysed for more than eight substances in the monitoring programme, pesticides have been detected in 34% of the groundwater samples in the interval 0-10 metres below ground level, see figure 4.2. Of these, 23% of the detections were over or equal to 0.1 microgramme per litre.

It can thus be concluded that pesticides and their degradation products occur particularly in young groundwater. This may be due partly to the fact that the substances are gradually degraded while being transported down through the aquifers and partly to the fact that they are transported horizontally with the groundwater to watercourses, lakes and groundwater wells. It is also possible that the pesticides are transported towards the groundwater so slowly that the increased occurrence and rising concentrations of the substances found today in young ground water will be found in the lower aquifers in the future. It will only be possible to assess this when there are longer time series in the monitoring programmes, dating of groundwater with CFC and results from research projects that are being carried out to elucidate this.

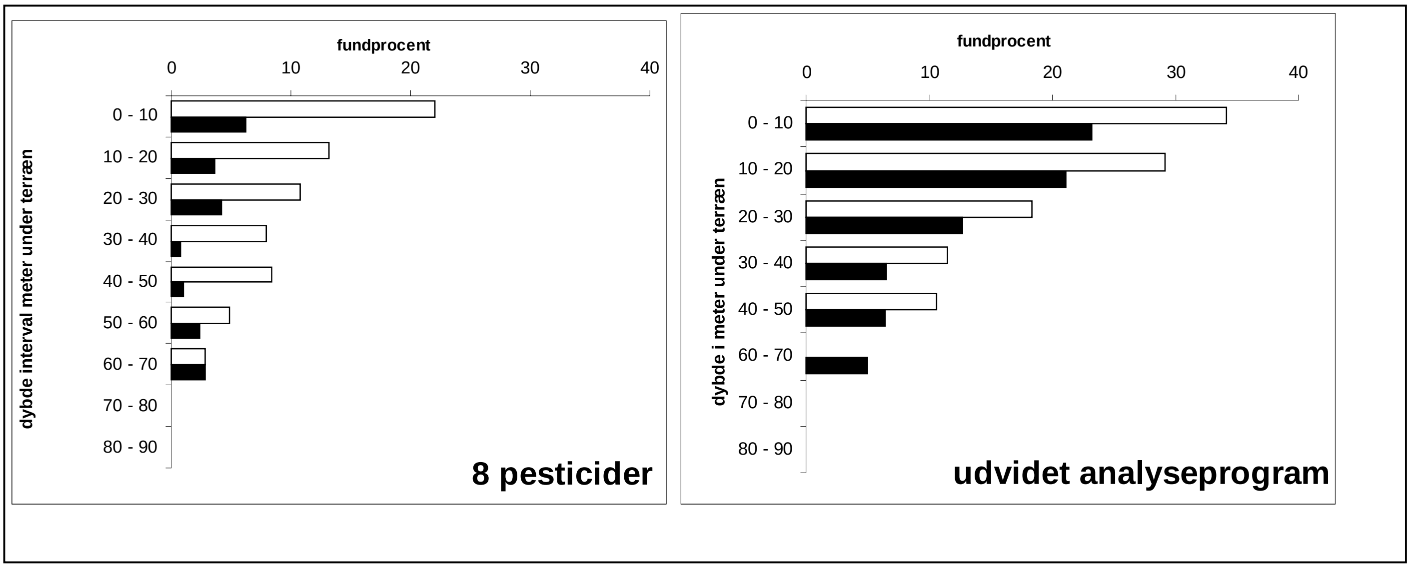


Figure 4.2
Detections of pesticides in % against depth in metres below ground level are shown as white bars. The youngest groundwater is presumably most often found in the interval 0-10 metres below ground level. In analyses for eight GRUMO pesticides in the depth interval 0-10 metres below ground level, pesticides have been detected in 22% of the screens. The detection percentage rises to 34% when analysing for more than eight pesticides. In the bar chart, the black, horizontal bars show the detection percentage for the number of detections over or equal to 0.1 microgramme per litre (GEUS).

(Figure texts:
fundprocent = detection percentage
dybde interval i meter under terræn = depth in metres below ground level
pesticider = pesticides
dybde i meter under terræn = depth in metres below ground level
udvidet analyseprogram = expanded analytical programme

The water companies' raw water monitoring system

In the water companies' raw water monitoring system, pesticides have been detected in 17% of 4,209 wells, and the limit value has been exceeded in 6%. These wells have mainly been analysed for the eight GRUMO pesticides.

The most frequently analysed substances are shown in table 4.3. The number of analyses does not reflect the number of analysed wells; for example, dichlorprop has been analysed in 5,714 water samples from 3,998 wells. Of the eight GRUMO pesticides, dichlorprop, mechlorprop and atrazine have been detected most frequently, while, in percentage terms, degradation products from triazines have been detected more frequently in the water samples than, for example, atrazine. The relatively frequent occurrence of hexazinone is surprising because this substance has only been detected in samples from groundwater monitoring wells even though it has been used frequently in forestry. One explanation could be that hexazinone has been used for treating urban areas.

The distribution of finds of pesticides in the water companies' wells is very reminiscent of the distribution in the groundwater monitoring system. However, the analysed pesticides occur in 26% of the water samples taken from wells with “top screen” in the interval from 10 to 20 metres below ground level, compared with 13% in the groundwater monitoring programme. This may be because the water companies in some areas extract groundwater from high-lying, fractured limestone, where the groundwater is presumably younger and more affected by the use of pesticides on the surface of the earth.

As a consequence of the many detections of the degradation product BAM (2.6-dichlorobenzamide) in the last few years, some water companies have analysed for this substance in their routine monitoring. The water companies have carried out 2,310 BAM analyses of water samples from 1,656 wells and have detected BAM in 448 of them, corresponding to around 30%. The limit value for drinking water was exceeded in 187 wells, corresponding to about 11% of the analysed wells. Most of the detections of BAM in waterworks wells were made from ground level to a depth of 0-30 metres, where the highest concentrations were also measured. BAM’s parent compound is a herbicide, dichlobenil, which has primarily been used in urban areas. Because of the earlier widespread use of the now prohibited parent compound dichlobenil, BAM can thus be expected to occur both under built-up areas and under farmyards, gravel roads and other areas kept free of vegetation.

Expanded analytical programmes

In recent years, the county authorities, the water companies and DMU have carried out a number of expanded analytical programmes for groundwater and waterworks water. Results covering 108 pesticides and metabolites are available. Of these 108 substances, around 40 have been detected in Danish groundwater, 29 of them in concentrations above the limit value for drinking water, see table 4.4. DMU's expanded analytical programmes comprise mainly analyses of groundwater from the LOOP regions. The data in the table are from analyses carried out in 1997, from older analyses that were not reported to the groundwater database at GEUS, and from analyses that were partly or totally reported to the groundwater database at GEUS, e.g. analytical programmes carried out in LOOP and a few groundwater monitoring areas. The table does not include data from the general monitoring of the groundwater monitoring areas. Twenty of the pesticides detected in groundwater were in use in Denmark in 1996, but some of them have since had restrictions imposed on their use or have been banned. However, a few substances, e.g. the degradation product ETU, was found in both soil water and groundwater in a research project by Fladerne Bæk (river) and in an analysis carried out by Copenhagen County Council in 1997, in which ETU was detected in piezometric wells close to a landfill site.

Table 4.3 *Detections of pesticides analysed in connection with the water companies’ raw water monitoring system (Brüsch et al. 1998). Ranked by falling number of analyses. Consumption data from Bekæmpelsesmiddelstatistik (Pesticide Statistics) 1997 (Danish Environmental Protection Agency 1998a).*

Pesticide/metabolite	Analyses number	Analysed wells number	Wells with finds number	Wells with finds ≥0.1 µg/L number	Consumption in 1997 in kg a.i.
Atrazine	5759	4015	148	31	B
Desethylatrazine[M]	1335	1169	50	6	MB
Hydroxyatrazine[M]	594	562	3		MB
Desisopropylatrazine[M]	1290	1133	33	3	MB
Dichlorprop[a]	5714	3998	88	19	4560

Simazine[a]	5708	4007	82	7	20270
Mechlorprop[a]	5677	3985	77	15	14586
MCPA[a]	5629	3989	24	4	79512
DNOC	5605	3980	1		B
Dinoseb	5599	3979	3		B
2,4-D[a]	5055	3732	10		677
2,4-dichlorophenol[M]	2256	1554	8	6	
4-chloro-, 2-methylphenol[M]	2241	1544	9	5	
Pentachlorphenol	2058	1455	6	2	B
2,6-dichlorophenol[M]	2025	1421	5	1	
Hexazinone	1438	1253	19	6	B
Bentazon[a]	1353	1160	31	6	79317
Isoproturon	1236	1089	2	1	541365
Pendimethalin	1042	953	4		357928
Metamitron	932	854	1	1	207298
Diuron[a]	631	574	3	2	22695
Propiconazole	484	431	1		86355
Ioxynil[a]	476	430	1		92130
2-(4-chlorophenoxy)-propionic acid[M] (4-CPP)	371	332	10	2	
Metribuzin[a]	364	326	1		12389
2-(2,6-dichlorophenoxy)-propionic acid [M] (DCPP, 2,6-)	345	322	1		
2,6-dichlorobenzamide (BAM)[M]	2310	1656	448	187	MB
Dichlobenil	1480	1325	13		B
Terbuthylazine	1230	1103	3		62636
Hydroxyterbuthylazin[M]	57	54	1		
Dinoterb	46	42	1		B
Chlorpyriphos-methyl[M]	43	34	1		
Ethylene thiourea (ETU) [M]	39	39	2	1	

a.i. = active ingredient

µg/L = microgramme per litre

[a] = Substance reviewed or permitted with restricted/very restricted use or authorised on certain conditions

Bold text = one of the 8 GRUMO substances

[M] = Metabolite/degradation product

B = Banned/withdrawn; MB = metabolite from banned/withdrawn pesticide

[u] = Possible impurity in pesticide

Table 4.4

Pesticides detected in groundwater in county authorities, water companies and DMU's expanded analytical programmes. The situation in March 1998 from GEUS (Brüsch et al. 1998). Consumption data from Bekæmpelsesmiddelstatistik (Pesticide Statistics) 1997 (Danish Environmental Protection Agency 1998a).

Pesticide/metabolite	Number of analyses, total	Number of detections > 0.01 µg per litre	Number of detections ≥ 0.1 µg per litre	Consumption in 1997 in kg a.i.
4.1.1.1.1 **Atrazine**	1287	93	10	B
Desisopropylatrazine[M]	957	139	32	MB

Desethylatrazine[M]	941	110	22	MB
Hydroxyatrazine[M]	270	31	13	MB
2,4-D[a]	1281	10	0	677
MCPA[a]	1280	33	7	79512
Mechlorprop[a]	1276	68	6	14586
Simazine[a]	1275	101	6	20270
Dichlorprop[a]	1265	73	5	4560
Dinoseb	1254	16	2	
DNOC	1254	19	0	B
Bentazon[a]	953	115	10	79317
Hexazinone	948	14	5	B
Cyanazine	942	9	1	B
Carbofuran[a]	861	6	0	6896
Hydroxycarbofuran[M]	182	1	1	
Terbuthylazine	856	10	1	62636
Desethylterbuthylazine[M]	223	2	1	
Hydroxyterbuthylazin[M]	182	10	0	
Isoproturon	853	13	3	541365 B
Dimethoate	773	3	0	34927
2,6 Dichlorobenzamide (BAM)[M]	753	260	125	MB
Metamitron	691	24	2	207298
Pirimicarb[a]	415	2	0	7190
Propiconazole	415	2	1	86355
Ioxynil[a]	414	2	1	92130
Diuron[a]	401	3	1	22695
Metazachlor	392	4	0	B
2,4-dichlorophenol[M]	367	3	2	
Dichlobenil	354	6	0	B
Metribuzin[a]	291	2	1	12389
Pendimethalin	190	4	0	357928
Benazolin	182	1	0	B
Fluazifop	182	1	0	10704
4-chloro-, 2-methylphenol [M]	152	15	12	
Ethylene thiourea (ETU) [M]	116	10	5	
2-(2,6-dichlorophenoxy)-propionic acid[M] (DCPP, 2,6-)	104	1	0	
2-(4-chlorophenoxy)-propionic acid[M/u] (CPP, 4-)	104	2	1	
Sebutylazine*	26	1	0	B*

a.i. = active ingredient
[a] = *Substance reviewed or permitted with limited use or authorised on certain conditions*
* = *the substance has not been permitted in Denmark*
***Bold** text = the 8 GRUMO substances*
[M] = *Metabolite/degradation product*
[u] = *Possible impurity in pesticide*
B = Banned/withdrawn
MB = metabolite from banned/withdrawn pesticide.

In connection with a search of the literature for analytical data from foreign monitoring programmes for pesticides in groundwater, a search was made for 544 pesticides and metabolites that have been or still are used in Denmark. Of these substances, data were gathered on 281 that have been analysed abroad, 159 of which have been found mainly in groundwater. About 55 of these were used in Denmark in 1996. However, for many of these substances, there have been only a few finds in groundwater.

Finds of pesticides under different types of area

Finds of pesticides in deep aquifers cannot be definitely related to specific fields or other areas within the individual catchment area boundaries.

Prompted by a dialogue with the Agricultural Advisory Centre, GEUS has calculated the impact of pesticides on groundwater close to the surface of the ground in rural areas (including forests, wetlands, etc.) on the basis of data from the groundwater monitoring programme. The data treatment is conducted in relation to permitted and banned pesticides and in relation to agricultural and non-agricultural pesticides. Hydroxy-terbuthylazine was not included in the calculation owing to too little data. All data from the City of Copenhagen, Frederiksberg Municipality and Copenhagen County were omitted. Only screens placed in the interval 0-10 metres below ground level were included because it is estimated that groundwater near the surface is often the youngest groundwater. However, the age of this groundwater can vary.

Tables 4.5-4.7 show that pesticides found in the groundwater monitoring programme in rural areas in groundwater close to the surface are equally distributed between agricultural and non-agricultural substances. Most of the substances found are now banned or regulated with restrictions on their use.

Table 4.5
Permitted and banned pesticides. Of the 4 phenoxy acids, only MCPA is included as permitted on account of a large consumption, while the other 3 are included as banned substances even though they are still sold in small quantities. Desisopropylatrazine is included with 50% in each group because the metabolite can come from pesticides permitted today.

GRUMO screens less than 10 metres below ground level	Banned pesticides Relative %	Permitted pesticides Relative %
0,01-0,1 μg/L	52.7	16.6
≥ 0,1μg/L	24.4	6.7

μg/L = microgramme per litre

Table 4.6
Agricultural/non-agricultural pesticides. All triazines are equally distributed between agricultural and non-agricultural because these substances have also been used in both forestry and fruit growing and in urban areas. However, simazine and hexazinone have not been included as agricultural substances. In this calculation, GEUS has not differentiated between permitted and banned substances.

GRUMO screens less than 10 metres below ground level	Non-agricultural pesticides Relative %	Agricultural pesticides Relative %
0,01-0,1 μg/L	33.6	35.2
≥ 0,1 μg/L	17.1	14.1

μg/L = microgramme per litre

Table 4.7
Background data, groundwater close to ground level. Groundwater monitoring data. Urban areas omitted. Only screens 0-10 metres below ground level are included. P = permitted; R = permitted with restricted use or authorised with conditions; B = banned; A = agricultural use; NA = non-agricultural use; Fr = fruit, berries, forest, plantation, etc. "Number of screens ≥ 0.1 μg/L" is a sub-set of "number of screens with finds" (μg/L = microgramme per litre).

Groundwater monitoring programme, 1990-1997, urban areas omitted

Substance	Permitted/ banned agric./urban	Number of analyses	Number of analyses with finds	Number of screens analysed	Number of screens with finds	Number of screens ≥ 0.1 µg/L	Finds % > detec.	Finds % ≥ 0,1 µg/L
Dichlobenil	B / NA	67	1	48	1	0	2.1	
BAM	B / NA	154	34	78	13	6	16.7	7.7
Atrazine	B / ANA	710	44	138	14	5	10.1	3.6
Desethylatrazine	B / ANA	135	26	75	11	3	14.7	4.0
Desisopropylatrazine	PB / ANA	133	14	75	10	3	13.3	4.0
Hydroxyatrazine	B / ANA	39	2	37	2	1	5.4	2.7
Chloridazon	P / A	30	0	21	0	0		
Hexazinone	B / NA	128	1	74	1	0	1.4	
Metamitron	P / A	67	0	53	0	0		
Metribuzin	P / A	30	0	21	0	0		
Terbuthylazine	P / A	124	1	75	1	0	1.3	
Hydroxy-terbuthylazine	P / A	9	1	9	1	0	11.1	
Dichloroprop	R / A	719	19	138	7	2	5.1	1.4
MCPA	R / A	714	5	138	5	1	3.6	0.7
Mechlorprop	R / A	715	16	138	6	1	4.3	0.7
DNOC	B / A	713	1	137	1	0	0.7	
Dinoseb	B / A	713	1	138	1	0	0.7	
Simazine	P / A Fr	707	6	138	6	1	4.3	0.7
2,4-D	R / A	509	3	127	3	0	2.4	0.7
Bentazone	P / A	133	12	76	3	2	3.9	2.6
Isoproturon	P / A	131	1	76	1	0	1.3	
All substances		765	113	141	48	15	34.0	10.6

Table 4.8

*Pesticides and metabolites found in ground water in the five nationwide monitoring catchment areas during the period 1990-1997. The median value has been calculated on the basis of median values at screen level. GRUMO pesticides are in **bold** (GEUS 1998) (µg/L = microgramme per litre).*

Ground-water monitoring, LOOP	Analyses	Filters with analyses	Filters containing findings		Screens with finds ≥0.1 µg/L		Median values	Max conc.
Pesticides	Number	Number	Number	%	Number	%	µg/L	µg/L
Atrazine	471	105	7	6.7	1	1.0	0.01	0.12
Desethylatrazine	173	59	13	22.0	1	1.7	0.02	0.22
Desisopropylatrazine	150	53	15	28.3	5	9.4	0.02	0.24
Hydroxyatrazine	46	37	2	5.4	0			0.02
2,4-D	386	94	4	4.3	1	1.1	0.04	0.12
Bentazone	223	62	14	22.6	0		0.01	0.05
Cyanazine	173	59	2	3.4	0			0.02
Dichloroprop	466	104	7	6.7	0		0.02	0.04
Dinoseb	467	105	4	3.8	1	1.0	0.01	0.12
DNOC	467	105	5	4.8	1	1.0	0.02	0.10
Isoproturon	236	62	5	8.1	0		0.02	0.05
MCPA	467	105	10	9.5	0		0.02	0.07
Mechlorprop	463	105	12	11.4	0		0.02	0.08
Metamitron	143	57	3	5.3	0			0.01
Pirimicarb	23	11	2	18.2	0			0.01
Propyzamide	18	9	1	11.1	1	11.1		0.11
Simazine	461	105	3	2.9	0		0.04	0.05

Triazines (including atrazine) and their metabolites are included in the calculation as equally distributed between use in agriculture and in urban areas. However, since agricultural land predominates in the groundwater monitoring programme, these substances should presumably be weighted higher as agricultural use. This is supported by the available data on pesticide finds in groundwater near ground level in the LOOP areas, where only agricultural land with known cultivation practice is monitored. There, high find percentages are found, particularly in the case of triazines' metabolites (Table 4.8).

4.1.2 Conclusions

In Denmark, extensive data are available on the distribution and occurrence of the 8 GRUMO pesticides in Danish groundwater. A smaller database covers other pesticides and metabolites. Together, these data show that pesticides and metabolites occur particularly in the uppermost and youngest aquifers. In these aquifers, pesticides have been found in 34% of analysed screens in an expanded analytical programme in the interval 0-10 metres below ground level. A planned future expansion of the monitoring system and the water companies' expanded analytical programme (covering more substances) will show the extent to which groundwater near the surface contains pesticides and metabolites. The frequency of finds of metabolites from the now banned substances atrazine and dichlobenil is high both in the groundwater monitoring system and in the water companies' raw-water monitoring. It should be noted that the water companies' raw water often comes from wells in areas near towns, so the finds are characterised by non-agricultural use of pesticides.

The following specific conclusions can be drawn:

- One or more of the 8 GRUMO pesticides (dichlorprop, mechlorprop, MCPA, 2,4-D, dinoseb, DNOC, atrazine and simazine), have been found in just over 12% of the analysed 1,014 screens in the groundwater monitoring areas. The limit value is exceeded in 3.5%. In 42 screens, a pesticide has been found more than once, corresponding to just over 4% of the analysed screens.

- In 594 GRUMO screens analysed with expanded analytical programmes, pesticides or metabolites have been found in 21% and the limit value has been exceeded in 13%. With BAM omitted, pesticides have been found in approx. 16% of 551 screens analysed for more than the 8 GRUMO pesticides.

- The depth distribution in the groundwater monitoring areas shows that the 8 GRUMO pesticides occur in 22% of the groundwater near the surface and that the frequency decreases with the depth. Where screens have been analysed for more substances than the 8 GRUMO pesticides, pesticides have been found in 34% of the groundwater near the surface. Of these finds, 23% are equal to or greater than 0.1 microgramme per litre.

- In a number of expanded analytical programmes, about 40 pesticides and metabolites are at present found in groundwater, with 29 of them in concentrations above the limit value. In foreign monitoring programmes, 159 substances that have been or are still being used in Denmark have been detected.

- In the water companies' raw water monitoring, pesticides have been found in 17% of the wells tested, with the limit value exceeded in 6%.

The distribution of finds of pesticides in the water companies' wells is very reminiscent of the distribution in the groundwater monitoring system.

- The water companies have found BAM, (2,6-dichlorobenzamide), in approx. 30% of 1,656 tested wells, with the limit value exceeded in around 11%.

- In the groundwater monitoring areas it is not possible to relate finds of pesticides in aquifers to specific land use in fields and other areas.

- A report on pesticides detected in groundwater near the surface in rural groundwater monitoring areas shows an equal distribution of agricultural and non-agricultural pesticides. Most of the substances found are now banned or regulated.

- In the pesticide finds in groundwater, the limit value of 0.1 microgramme per litre for drinking water is exceeded in up to 13% of the samples. The metabolite BAM from the universal herbicide dichlobenil has been detected in 30% of the water companies' wells, but a wide range of substances used by farmers for treating crops are also present in a relatively large number of wells. Larger amounts of pesticides were detected in drain water and soil water than in groundwater, and this may reflect concentrations that may similarly later move towards the groundwater, during which they may undergo degradation and possible formation of metabolites. In both watercourses and ponds, a number of pesticides have been detected in higher concentrations than the concentrations that have effected aquatic organisms in the laboratory.

4.2 Occurrence of pesticides in watercourses

In the following, the occurrence of pesticides in watercourses is described. The effects of their occurrence are described in section 5.3. These data have also been used in calibrating the models for calculating the consequences of a partial phase-out of pesticides.

Pesticides can reach watercourses through:

- spray drift
- spraying too close to watercourses
- deposition from the air through long-distance atmospheric transport
- leaching from treated fields and transport to watercourses via drainage pipes or groundwater
- surface run-off
- pollution from point sources, e.g. machine-washing sites.

The sources with the biggest implications for watercourses, quantitatively, are run-off from land treated with pesticides and leaching with transport in drain water. Direct spraying and leaching from washing sites are unlawful pollution events that imply a considerable risk of harmful effects in watercourses. Surface run-off from sloping fields can lead both water-soluble substances and substances that bind to particles of soil out into a watercourse. Particle-borne transport occurs during heavy run-off of rainwater or melt water and soil erosion.

Up to and including 1996, 32 different pesticides were detected in Danish watercourses, corresponding to approx. 30% of the pesticides tested for (see table 4.9). Several different pesticides can be found simultaneously in the individual watercourses. Pesticides are found in watercourses in all seasons, but most frequently in the spraying season and during increased run-off after rain. The frequency of pesticide finds and the concentration of pesticides are generally highest in agricultural catchment areas with clayey soil. Some of the pesticides are found in only a few per cent of the samples, while others are found in up to 64% of them.

The detection frequency is highest in the spraying periods and in connection with precipitation with increased run-off in watercourses. The highest value in the analyses up to and including 1996 was 10 microgramme per litre (bentazon). 12 of the pesticides were found in concentrations above 1 microgramme per litre and 31 substances were found in concentrations above 0.1 microgramme per litre. Glyphosate was tested for in 6 samples and found in all of them in concentrations from 0.02 to 0.21 microgramme per litre (Funen County 1997, Kronvang 1998; Spliid, Mogensen 1995).

Analyses of surface water in Funen County 1997

Since 1996 there have as yet been only a few reports from counties and municipalities. Funen County Council has published the results of analyses of 6 watercourses, 4 springs and 11 drains in agricultural areas (Funen County 1999). Samples were tested for 94 active ingredients and 5 metabolites. Of these, 33 different substances were found in concentrations up to 10 microgrammes per litre (the herbicide bentazon). Of these, 26 are authorised for use today. It should be noted that one of the substances found, metazachlor has never been authorised in Denmark. Most of the substances were found in concentrations above 0.1 microgramme per litre. Up to 18 different pesticides were found in individual watercourses within the same day. The substances found most frequently in 33 samples from watercourses in concentration of or over 0.1 microgramme per litre were the metabolite AMPA from glyphosate (79%), the metabolite BAM from the banned herbicide dichlobenil (48%), isoproturon (36%), glyphosate (31%), the banned herbicide hexazinone (30%), and diuron (24%). The substances and concentrations found largely correspond to earlier finds.

The study indicates that many of the pesticides occurring in the watercourses are transported to them via drains, particularly in the spraying season. It has also been established that there is some transport of pesticides via urban wastewater. Drift does not seem to be of any great significance to the occurrence of pesticides in the watercourses tested. On the basis of observations over a 10-year period, Funen County Council estimates that more than 200 km of watercourse, corresponding to around 20% of the watercourses tested, have been exposed to acute damage, since large numbers of crustaceans and aquatic insects have been killed.

Analyses of water from a watercourse in Kolding Municipality in 1998

In May-June 1998, Kolding Municipal Council tested 14 water samples from Dalby Møllebæk (a mill brook), situated in an agricultural catchment area consisting mainly of moraine clay (Kolding Municipality 1998). The analysis covered 33 pesticides or metabolites, of which 21 were found in concentrations of up to 11 microgramme per litre (simazine). Of these 21 pesticides, 14 are authorised for use today, while 5 are subject to restrictions. The 3 most frequently found substances were BAM, isoproturon and simazine, all of which were found in all the analysed water samples. Also found in at least half of the samples were the substances MCPA, mechlorprop, atrazine, bentazon, desisopropylatrazine, ethofumesate, metamitron, terbuthylazine, bromoxynil, propiconazole, dichlobenil, dichlorprop and ioxynil. The highest concentrations were found in connection with precipitation events. The frequent occurrence of atrazine (79% of the samples) and atrazine's metabolites indicates that the occurrence came from use of the substance before it was banned in 1994 and thus from the groundwater.

The figures from Funen County for 1997 and those from Kolding Municipality for 1998 will be included in the overall survey for the years in question when the finds are reported. They therefore do not appear in the tables in this chapter as the data supplied are incomplete seen from a countrywide perspective.

Table 4.9
Occurrence of pesticides in Danish watercourses with indication of number of positive finds in relation to number of samples. H = herbicide, F = fungicide, I = insecticide. The samples were collected in the period 1989-1996 (Mogensen 1998).

Active ingredient	Concentration µg/L	Finds (%)	Number of samples
Atrazine (H)	0.005 – 1	27	305
Bentazon[a] (H)	0.01 – 10	27	155
Bromoxynil (H)	0.01 – 0.5	8	102
Clopyralid (H)	0.1 – 0.4	2	101
Cyanazine (H)	0.09 – 0.3	2	97
2,4-D[a] (H)	0.02 – 6.6	15	139
Diazinon (H)	0.05	20	5
Dichlobenil (H)	0.01 – 1.7	33	156
Dichlorprop[a] (H)	0.01 – 2.8	12	290
Dimethoate (I)	0.08 – 0.6	4	140
Dinoseb (H)	0.01 – 0.12	5	98
Diuron[a] (H)	0.02 – 2	35	106
DNOC (H)	0.01 – 0.7	14	199
Esfenvalerate (I)	0.03 – 0.2	9	43
Ethofumesate (H)	0.03 – 0.6	20	105
Fenpropimorph (F)	0.02 – 0.4	13	97
Glyphosate (H)	0.02 – 0.21	100	6
Hexazinone (H)	0.04 – 4	39	132
Ioxynil[a] (H)	0.01 – 0.3	10	120
Isoproturon (H)	0.01 – 3	23	280
Linuron (H)	0.05 – 0.6	10	42
MCPA[a] (H)	0.005 – 7	19	303
Mechlorprop[a] (H)	0.01 – 7	31	313
Metamitron (H)	1 – 7	8	25
Methabenzthiazurone (H)	0.3	20	5
Pendimethalin (H)	0.1	20	10
Pirimicarb (I)	0.06 – 0.6	17	126
Propiconazole (F)	0.03 – 0.8	6	142
Propyzamide (H)	0.01 – 0.8	6	120
Simazine[a] (H)	0.01 – 4	16	307
Terbuthylazine (H)	0.01 – 0.1	20	164
Tribenuron-methyl (H)	0.008 – 0.03	4	48

Substances in italics are banned.
[a] = permitted with restricted use/or authorised on special conditions
µg/L = microgramme per litre

Table 4.10 *Occurrence of pesticides in watercourses, with a breakdown in types of catchment area. The table shows the number of finds out of the total number of samples and the concentration range in microgramme per litre. The first study was carried out by DMU in 1989-1991. In 1994-1996 a major study was carried out in Funen County. In 1996, the table includes data from several counties (Mogensen 1998).*

Active ingredient/ Type of catchment area	Urban area	Mixed catchment area, clay	Mixed catchment area	Clayey agric. catchment area	Sandy agric. catchment area	Sandy/clayey catchment area	Forest watercourse	Uncultivated catchment area	Springs
2,4-D (H)	1/5; 0.02	6/58; 0.05-0.1	n.d./5	16/78; 0.03-7	5/86; 0.02-0.3	n.d./10	n.d./25	n.d./5	n.d./12
atrazin (H)	5/5; 0.04-0.2	14/57; 0.005-0.4	n.d./5	59/151; 0.01-1	7/86; 0.01-0.08	n.d./10	1/25; 0.07	n.d./5	n.d./12
bentazon (H)	n.d./5	7/58; 0.05-0.3	n.d./5	25/72; 0.01-10	10/25; 0.02-0.2	n.d./10	n.d./25	n.d./5	n.d./12
bromoxynil (H)	n.a.	n.d./58	n.a.	6/47; 0.01-0.5	2/55; 0.02-0.03	n.a.	n.a.	n.a.	n.d./12
clopyralid (H)	n.a.	n.d./58	n.a.	2/101; 0.1-0.4	n.d./10	n.a.	n.d./25	n.d./5	n.d./12
cyanazine (H)	n.d./5	n.d./55	n.d./5	2/97; 0.09-0.3	n.d./25	n.d./10	n.d./25	n.d./5	n.d./12
diazinon (I)	n.d./5	n.d./58	n.d./5	1/5; 0.05	n.d./25	n.d./10	n.d./25	n.d./5	n.d./12
dichlobenil (H)	5/5; 0.02-0.3	15/54; 0.04-0.2	1/5; 0.01	25/62; 0.01-2	2/5; 0.06-0.1	4/10; 0.04-0.06	n.d./25	n.d./5	n.d./12
dichlorprop (H)	3/5; 0.02-0.2	11/58; 0.1-0.2	n.d./5	12/141; 0.01-3	8/76; 0.01-0.6	n.d./10	n.d./25	n.d./5	n.d./12
dimethoate (I)	n.d./5	1/53; 0.1	n.d./5	4/62; 0.08-0.6	n.d./25	n.d./10	1/25; 0.1	n.d./5	n.d./12
dinoseb (H)	n.d./5	n.a.	n.d./5	5/98; 0.01-0.1	n.d./15	n.d./10	n.a.	n.d./5	n.a.
diuron (H)	n.a.	24/54; 0.07-1	n.a.	13/52; 0.02-2	n.d./10	n.a.	n.d./25	n.a.	n.d./12
DNOC (H)	3/5; 0.2-0.7	n.a.	2/5; 0.04-0.2	16/98; 0.01-0.6	3/76; 0.01-0.07	1/10; 0.03	n.a.	1/5; 0.01	n.a.
esfenvalerate (I)	n.d./5	n.d./58	n.d./5	4/43; 0.03-0.2	n.d./25	n.d./10	n.d./25	n.d./5	n.d./12
ethofumesate (H)	n.a.	7/55; 0.03-0.1	n.a.	14/50; 0.03-0.6	n.d./10	n.a.	n.d./25	n.a.	n.d./12
fenpropimorph (F)	2/5; 0.1-0.3	n.d./58	n.d./5	9/67; 0.02-0.4	1/25; 0.05	1/10; 0.1	n.d./25	n.d./5	n.d./12
glyphosate (H)	n.a.	5/5; 0.02-0.2	n.a.	1/1; 0.2	n.a.	n.a.	n.a.	n.a.	n.a.
hexazinone (H)	n.d./5	17/54; 0.04-0.08	n.d./5	17/42; 0.04-4	n.d./25	n.d./10	16/25; 0.07-0.3	n.d./5	2/12; 3
ioxynil (H)	n.d./3	n.d./58	n.d./3	10/64; 0.01-0.3	2/56; 0.01-0.05	n.d./6	n.d./25	n.d./5	n.d./12
isoproturon (H)	2/5; 0.02-0.04	16/54; 0.08-1	n.d./5	38/139; 0.02-3	6/75; 0.01-0.2	2/10; 0.01-0.02	n.d./25	n.d./5	2/12; 0.06-0.2
linuron (H)	n.a.	n.d./58	n.a.	4/42; 0.05-0.6	n.d./10	n.a.	n.d./25	n.a.	n.d./12
MCPA (H)	3/5; 0.03-0.09	13/58; 0.07-0.2	n.d./5	33/149; 0.01-7	8/81; 0.005-0.2	n.d./10	n.d./25	n.d./5	n.d./12
mechlorprop (H)p	3/5; 0.05-4	24/58; 0.08-0.4	2/5; 0.01-0.03	55/149; 0.01-7	9/81; 0.05-0.2	2/10; 0.02-0.07	n.d./25	1/5; 0.02	n.d./12
metamitron (H)	n.d./5	n.d./58	n.d./5	2/53; 1-7	n.d./25	n.d./10	n.d./25	n.d./5	n.d./12
methabenzthiazurone (H)	n.a.	n.d./58	n.a.	1/53; 0.3	n.d./10	n.a.	n.d./25	n.a.	n.d./12
pendimethalin (H)	n.a.	n.d./58	n.a.	2/50; 0.1	n.d./10	n.a.	n.d./25	n.a.	n.d./12
pirimicarb (I)	n.d./5	15/54; 0.03-0.08	n.d./5	6/62; 0.03-0.6	n.d./25	n.d./10	n.d./25	n.d./5	n.d./12
propiconazole (F)	n.d./5	1/53; 0.08	n.d./5	6/64; 0.033-0.8	1/25; 0.03	n.d./10	n.d./25	n.d./5	n.d./12
propyzamide (H)	n.a.	2/54; 0.5-0.8	n.a.	5/66; 0.01-0.2	n.d./10	n.a.	n.d./25	n.a.	n.d./12
simazine (H)	5/5; 0.05-4	10/54; 0.09-0.3	n.d./5	23/145; 0.01-0.03	10/88; 0.01-0.2	n.d./10	n.d./25	n.d./5	n.d./12
terbuthylazine (H)	3/5; 0.01-0.02	16/54; 0.03-0.1	n.d./5	11/67; 0.01-0.1	n.d./25	1/25; 0.01	n.d./25	n.d./5	1/13; 0.4

Active ingredient/ Type of catchment area	Urban area	Mixed catchment area, clay	Mixed catchment area	Clayey agric. catchment area	Sandy agric. catchment area	Sandy/clayey catchment area	Forest watercourse	Uncultivated catchment area	Springs
tribenuron-methyl (H)	n.a.	2/48; 0.008-0.03	n.a.	n.d./53	n.d./10	n.a.	n.d./25	n.a.	n.d./12

n.a. = not analysed; n.d. = not detected. H = herbicide, F = fungicide, I = insecticide.

It will be seen from table 4.10 that the frequency of pesticide finds and the concentration of the pesticides are generally highest in agricultural catchment areas with clayey soils. That is presumably due to the fact that farmers on rich soil often farm more intensively and thus spray more often and to the fact that pesticides are quickly transported to watercourses via drains through cracks in the clayey soil. The fact that pesticides have been detected in springs indicates specifically that pesticides can be led to watercourses via groundwater. Fewer different pesticides have been found in forest watercourses, but the herbicides that are used in forests frequently occur in the watercourses. That applies particularly to hexazinone. Many different pesticides have been detected in urban watercourses, which cover both “urban watercourses” and “mixed catchment areas”. Agricultural pesticides therefore also occur. Dichlobenil, which is used as a universal herbicide and particularly its metabolite, BAM (2,6-dichlorobenzamide), occur very frequently, both in urban areas, agricultural areas and forest watercourses, see table 4.11. Concerning BAM, readers are referred to section 4.1, where a similar frequency in groundwater is described.

In most of the watercourses, many different pesticides are found at the same time, which is of significance in the assessment of the effects on flora and fauna in the aquatic environment, see section 5.3.

Table 4.11
Occurrence of metabolites (of a dichlobenil, b glyphosate, c atrazine) of pesticides in watercourses, with a breakdown by type of catchment area. The table shows the number of finds out of the total number of samples and the concentration range in microgramme per litre. Dichlobenil and atrazine may no longer be used in Denmark. The first studies were carried out by DMU in 1989-1991. In 1994-1996, a major study was carried out in Funen County. In 1996, the table includes data from several counties (Mogensen 1998).

Type of catchment area/Metabolite	2,6-dichlorobenzamide (BAM)[a]	AMPA*,[b]	desethyl-atrazine[c]	desisopropyl-atrazine[c]
Urban area	5/5; 0.03-0.4	n.a.	3/5; 0.01-0.03	4/5; 0.01-0.1
Mixed catchment area, clay	46/54; 0.05-0.2	5/5; 0.1-0.5	n.d./57	n.d./57
Mixed catchment area	5/5; 0.04-0.07	n.a.	n.d./5	n.d./5
Clayey agric. catchment area	63/72; 0.03-0.4	1/1; 0.5	6/72; 0.01-0.1	8/72; 0.01-0.2
Sandy agric. catchment area	12/25; 0.01-0.01	n.a.	n.d./25	n.d./25
Sandy/clayey catchment area	8/10; 0.01-0.009	n.a.	n.d./10	1/10; 0.02
Forest watercourse	4/25; 0.08-0.5	n.a.	n.d./25	n.d./25
Uncultivated catchment area	n.d./5	n.a.	n.d./5	n.d./5
Springs	3/12; 0.1-0.5	n.a.	n.d./12	n.d./12

* = AMPA has been detected in the same samples as the parent compound glyphosate. It is therefore likely that the metabolite comes from glyphosate, but other sources cannot be excluded.
n.a. = not analysed
n.d. = not detected

4.2.1 Conclusions

32 different pesticides have been detected in Danish watercourses, corresponding to about 30% of the substances tested for, together with 4 metabolites. The frequency of finds is greatest in the spraying periods and in connection with precipitation events with increased run-off. The highest value of 10 microgrammes per litre was found for bentazon. 12 of the pesticides were found in concentrations above 1 microgramme per litre and 31 substances were found in concentrations above 0.1 microgramme per litre. Glyphosate was tested for in 6 samples and found in all of them in concentrations from 0.02 to 0.21 microgramme per litre (Funen County 1997, Kronvang 1998; Spliid, Mogensen 1995). The pesticides occur in all types of watercourse, but mostly in clayey agricultural catchment areas. Pesticides can be transported to lakes and watercourses with surface run-off. That applies both to water-soluble substances and to substances that bind to particles of soil and that are only transported with heavy run-off, which causes soil erosion. Therefore, both substances that are banned because of their mobility in soil (e.g. atrazine, dichlorprop and hexazinone) and substances that, as far as is known today, are only transported to the groundwater with leaching rainwater under extreme conditions (e.g. glyphosate, esfenvalerate and pirimicarb) have been detected. Also detected is DNOC, which can come from transboundary atmospheric transport and be synthesised from car emissions through atmospheric, chemical processes (see section 4.5).

The studies of watercourses are representative of Denmark

The first study was carried out in the period 1989-91, and the others in the period 1994-97. There are big differences in the sampling intensity and strategy in the various analyses. In some cases, sampling was done on predesignated dates; in some, it was concentrated in the spraying season, and in some, sampling extended over the whole year. Some sampling was done in connection with increased water flow in the watercourse. The analyses did not include samples taken because of suspected pollution from, for example, point sources. The watercourses analysed cover a number of counties and different types of catchment area and types of soil, and must generally be regarded as representative of Denmark. There are not as yet any long time series of measurements of pesticides in watercourses, but monitoring programmes in progress in the counties and countrywide studies will in time result in the necessary database for determining the development.

The following specific conclusions can be drawn:

- 32 pesticides have been detected in watercourses, corresponding to 30% of the substances tested for.

- In many watercourses, several pesticides have been detected at the same time.

- Detection of pesticides in springs indicates that pesticides can be carried to watercourses via groundwater.

- The frequency of detection is highest in spraying periods and in connection with heavy precipitation, but pesticides have also been detected in watercourses outside the spraying periods.

- The frequency of detection is highest in agricultural catchment areas with clayey soils.

- There are not many different pesticides in forest watercourses, but pesticides that are or have been used in forests occur frequently (atrazine, hexazinone and dimethoate).

- There are many different pesticides in urban watercourses.

- The distance requirements made in connection with authorisation of pesticides are expected to reduce the frequency of detection in the future.

4.3 Pesticides in lakes and ponds

Pesticides enter lakes, coastal waters and ponds via watercourses, surface run-off from adjacent land, groundwater and atmospheric deposition, including spray drift. The effects of pesticides in stagnant water are described in section 5.3. There are as yet no systematic data on the occurrence of pesticides in Danish lakes and coastal waters. Data from these compartments are therefore not included in the report. In connection with Aquatic Environment Plan II, a measuring programme is being initiated, but results for lakes cannot be expected in the coming year.

The studies from stagnant water cover results from two projects. One includes samples from four ponds in the Køge district (Spliid, Mogensen 1995), while the other includes a number of ponds in South Funen and Avernakø (Briggs in press). In both districts, the ponds are in fields with clayey soil. Many field ponds have neither inflow nor outflow. It must therefore be expected that pesticides remain in them longer than in watercourses and that the risk to the aquatic organisms in them is greater. The results of these studies are given in table 4.12.

The concentration interval in the table indicates the lowest and highest concentration in the samples in which the pesticide in question was detected. Column 3 shows the number of samples analysed for the pesticide in question and the number of samples in which the substance was detected. All the substances for which the samples were analysed were detected, with the exception of bromoxynil and simazine. The highest concentration for an individual substance was 11 microgrammes per litre.

Table 4.12
Pesticides detected in ponds in Danish farmland in studies carried out by DMU in 1989-1991 and by Amphiconsult in 1994-1995 (Mogensen, Spliid 1997)

Active ingredient	Concentration µg/L	Number of detections/ Number of samples
Atrazine	0.01-0.2	2/24
Bromoxynil	-	0/13
2,4-D	0.1-0.4	3/25
Dichloroprop	0.01-0.3	11/40
Dimethoate (I)	0.13	1/20
Dinoseb	0.04	2/25
DNOC	0.07-0.6	4/25
Ethofumesate	0.1-0.2	2/2
Fenpropimorph (F)	0.1-7	6/10
Fenvalerate (I)	0.12	1/3
Ioxynil	0.02-1	3/16
Isoproturon	0.08	1/13
MCPA	0.009-1	9/40
Mechlorprop	0.01-11	18/41
Pirimicarb (I)	0.13	1/2
Propiconazole (F)	0.1-3	4/6
Simazine	-	0/25

µg/L = microgramme per litre

4.3.1 Conclusions

There have been only a few analyses of stagnant water, and then only of ponds. Mechlorprop has been detected in concentrations up to 11 microgrammes per litre. In the case of 5 substances, the concentrations exceeded 1.0 microgramme per litre and in the case of 13 of the 15 substances tested for, the concentrations exceeded 0.1 microgramme per litre.

The ponds tested include several in the Køge region and on the island of Avernakø. The analyses were carried out at the beginning of the 1990s. Most of the sampling took place in the spraying season. The analyses of ponds were less extensive than those in watercourses and cannot be regarded as representative of Denmark as a whole.

The following specific conclusions can be drawn:

- 15 pesticides have been detected in ponds.
- Danish analyses of pesticide concentrations in lakes and coastal waters are being initiated in connection with Aquatic Environment Plan II.
- Only a few analyses of pesticide concentrations in lakes and seawater have been carried out in Denmark.

4.4 Pesticides in drain and soil water

Soil water can be defined as water that is present in the uppermost part of the soil stratum. Soil water can be collected by installing ceramic or teflon suction cups in the soil to suck water out of the soil matrix. Drain water is water that runs freely through the soil to drainage pipes, which are typically placed at a depth of about 1 metre. Pesticides in drain water can thus, if mobile pesticides are used in periods with a lot of precipitation, have a retention time in the soil of just a few days or weeks. For pesticides that are bound in the soil or that are used in periods without downward movement of water in the soil, the retention time can be months or years.

Soil water samples containing pesticides generally indicate use of the pesticides in question on the surface of the ground directly over the sampling site or transport with rainwater. Pesticides spilled on the surface of the soil or pesticide waste buried near the sampling site can be detected in soil water or drain water, but if several suction cups are established under the same field, a point source occurrence near one of them can be detected.

Drain water samples represent water from the entire catchment area that is drained by the drainage system in question. The catchment area can include many fields with different uses, backfilled marlpits, buried waste, sites for filling and washing of spraying equipment, greenhouses, etc. To be able to interpret the result of a drain water sample it is important to know which catchment area the sample in question represents. By placing vertical drainpipes with screens at a depth of 1 metre one can extract drain water samples that represent the local area around the screen when the soil is saturated.

We have analyses of pesticides in soil and drain water from 10 different localities in Denmark. The samples analysed include samples from Højvands Rende and Bolbro Bæk, which are part of LOOP in Aquatic Environment Plan I. A number of samples have also been taken in special studies and research projects in the last 10 years. However, there have been no systematic analyses of pesticides in soil water and drain water of the kind carried out in groundwater.

The results of all analyses of pesticides and their metabolites in soil and drain water are shown in tables 4.13 and 4.14. Table 4.13 shows the occurrences in fields with sandy soil, and table 4.14 the occurrences in fields with clayey soil. These analyses do not include analyses of drain water from filling and washing sites, greenhouses, and other point sources, where high concentrations of pesticides have been found in special analyses.

The analyses cover 27 pesticides and metabolites. The number of analyses carried out is shown in the tables. The results are given as detections of less than 0.1 microgramme per litre, detections greater than 0.1 microgramme per litre and the highest concentration detected. It will be seen directly from a comparison of tables 4.13 and 4.14 that both the concentration levels and the frequency of detections are highest in localities with clayey soil. The substances detected in the highest concentrations are atrazine (7.8 microgrammes per litre), hexazinone (4.3 microgrammes per litre), dichlorprop (1.4 microgramme per litre) and 2,4-D (1.2 microgramme per litre). Concentrations greater than 0.1 microgramme per litre have also been found for the pesticides isoproturon, bentazon, MCPA, and mechlorprop, and for the degradation products desisopropylatrazine, 2,4-dichlorophenol and ETU.

Some of these detections can be correlated with pesticides used on experimental areas or stated to have been used on the land in question. For example, relatively high concentrations of both atrazine and hexazinone (herbicides) were detected under a Christmas tree plantation, where the substances had previously been used (Felding 1992). In some cases, low concentrations of pesticides have been detected in places where these substances have not been used for years. This could indicate that the retention time for the pesticides in question in the soil has been long in these cases. In a special analysis of the chlorophenoxy acids MCPA, dichlorprop, 2,4-D and mechlorprop, all the substances were detected after 3 years in soil water at a depth of one metre in concentrations that were in several cases greater than 0.1 microgramme per litre (Felding 1993). The detections of ETU are from a trial area treated many times with dithiocarbamate fungicides, which break down into ETU (Spliid 1998a).

As a test system between full-scale field analyses and simple laboratory analyses, lysimeter analyses with undisturbed columns of soil can be used to predict whether a pesticide or its degradation products can leach from a column of soil. Such lysimeter analyses now form part of the documentation material used as the basis for approving new pesticides. A lysimeter can consist of a block of soil sampled at the site in a steel frame without being disturbed. The lysimeter is moved to the test locality, where crops are grown in it and it is treated with the pesticide in the ordinary way. The naturally or artificially supplied water passing the block of soil is collected. Using a radioactively labelled pesticide, one can determine whether there is any breakthrough of radioactivity and thus of pesticide or degradation products. Where possible, the substances passing the soil column are identified by means of chromatographic methods and by comparison with reference substances. A lysimeter analysis is typically carried out several years after the pesticide has been applied. It can be used to determine the risk of a pesticide leaching in different types of soil, with different cultivation conditions and in different precipitation situations, with a surface area from 0.25 to 1 m^2.

To determine the mobility in columns of soil in the deeper soil layers, columns with a surface area of, for example, 0.25 m^2 can be sampled in a steel cylinder and taken to the laboratory, where the temperature and the groundwater's movements can be simulated and controlled.

Table 4.13
Pesticides and metabolites detected in fields with sandy soil (Spliid 1998a)

Component	Soil water and drain water analyses Localities with sandy soil			
	Detections < 0.1 µg/l	Detections > 0.1 µg/l	Highest value (µg/l)	Number of analyses
Atrazine	10	1	0.11	98
Cyanazine	n.d.	n.d.	n.d.	21
Desethylatrazine^M	n.d.	n.d.	n.d.	21
Desisopropylatrazine^M	1	1	0.11	21
Dimethoate	n.d.	n.d.	n.d.	21
Hexazinone	1	n.d.	0.02	21
Hydroxy-carbofuran^M	n.d.	n.d.	n.d.	21
Isoproturon	4	1	0.29	75
Metamitron	4	n.d.	0.01	21
Simazine	8	n.d.	0.09	82
Terbuthylazine	n.d.	n.d.	n.d.	21
2,4-D	2	3	1.2	82
2,4-dichlorophenol^M	7	5	0.22	54
2,6-dichlorophenol^M	1	n.d.	0.05	54
4-chloro-, 2-methylphenol^M	n.d.	n.d.	n.d.	54
Bentazone	3	2	0.1	21

Bromoxynil	3	n.d.	0.04	54
DNOC	4	n.d.	0.02	82
Dichloroprop	2	2	1.4	82
Dinoseb	1	n.d.	0.01	82
Ioxynil	n.d.	n.d.	n.d.	54
MCPA	4	3	0.17	82
Mechlorprop	3	3	0.17	82
Metazachlor	n.d.	n.d.	n.d.	21
Alachlor	n.d.	n.d.	n.d.	21
Ethylene thiourea[M] (ETU)	n.d.	2	0.34	28

n.d. = not detected
[M] = metabolites
Italics = substances authorised in 1998, possibly with dispensation
μg/L = microgramme per litre

Table 4.14
Pesticides and metabolites detected in fields with clayey soil (Spliid 1998a)

Component	Soil water and drain water analyses Localities with clayey soil			
	Detections < 0.1 μg/l	Detections > 0.1 μg/l	Highest value (μg/l)	Number of analyses
Atrazine	8	34	7.8	160
Hexazinone	3	37	4.3	41
Isoproturon	n.d.	2	0.15	68
Simazine	1	n.d.	0.04	119
2,4-D	10	4	0.24	184
2,4-dichlorophenol[M]	3	4	0.29	68
2,6-dichlorophenol[M]	6	n.d.	0.08	68
4-chloro-, 2-methylphenol[M]	1	n.d.	0.01	68
Bromoxynil	3	n.d.	0.03	68
DNOC	1	n.d.	0.005	119
Dichloroprop	20	11	0.30	184
Dinoseb	n.d.	n.d.	n.d.	119
Ioxynil	1	n.d.	0.09	68
MCPA	22	8	0.29	184
Mechlorprop	15	11	0.34	184

n.d. = not detected
[M] = metabolites
Italics = substances authorised in 1998, possibly with dispensation
μg/L = microgramme per litre

4.4.1 Conclusions

In a number of analyses, pesticides have been detected in soil water and drain water from fields that have been treated with pesticides. In the analyses described, there is information concerning the use of pesticides on the fields in several projects, while for a few localities, the figures cover the catchment area in general, and it is not possible to demonstrate a relationship between dosage and detections for the individual field. With the available data it is not deemed warranted to draw conclusions concerning relationships between dosage and concentration of pesticides in the water samples analysed.

The following specific conclusions can be drawn:

- The pesticides detected in soil and drain water are often the same as are detected in the aquifers, see section 4.1.

- The concentrations of pesticides detected in soil and drain water exceed the limit value for drinking water more frequently than in the groundwater analyses. Many of the pesticides detected are now banned in Denmark, but were permitted at the time of the analyses.

- Owing to limited data, it is not deemed warranted to draw conclusions concerning relationships between dosage in the field and concentration of pesticides in drain and soil water.

- Assuming that the extent of the catchment area is known and that the pesticides used in the area are known, a drain water analysis gives an idea of whether used pesticides or their degradation products can reach the groundwater. However, the results depend on the local conditions and the weather, and it is not possible to carry out a mass flow analysis that describes the fate of the pesticides in time and space.

- Lysimeter studies and laboratory analyses of radioactively labelled pesticides and degradation products in undisturbed columns of soil can be suitable tools for judging the risk of leaching in connection with the use of pesticides in different soils.

- Both the level of concentration and the frequency of detections are highest in clayey soils. However, the data are limited and can be improved with supplementary studies.

4.5 Pesticides in rainwater

As found by Felding (1998a), there have been relatively few studies in Denmark. In a cooperative project under the auspices of the Nordic Council of Ministers, rainwater samples were collected from 2 localities in Denmark – Ulfborg Plantation 10 km from the west coast of Jutland, and Gadevang near Gribskov, a forest in North Zealand – from 1992 to 1994. The analyses covered 10 pesticides: propiconazole, prochloraz, lambda-cyhalothrin, cypermethrin, esfenvalerate, deltamethrin, atrazine, mechlorprop, dichlorprop and MCPA. Only the phenoxy acids were detected, and the highest concentrations found were just under 0.4 microgramme per litre (Kirknel et al. 1997). The concentrations found were very small in relation to the dosage in field spraying. The effects of pesticides in rainwater are assessed in section 5.2.

In a current project, samples of precipitation are being collected from three Zealand localities: Gadevang, Gisselfeld and Lorup. The samples are analysed for the phenoxy acids: MCPA, mechlorprop and dichlorprop, and for the herbicide isoproturon. The highest concentrations found so far are just over 0.6 microgramme per litre for the phenoxy acids and just under 0.4 microgramme per litre for isoproturon. In most cases, the time when the herbicides were detected in the precipitation coincided with the time of use (Felding 1998a).

In autumn 1997, 13 mixed samples extracted from the above-mentioned 3 localities from September 1996 to November 1997 were analysed for 44 pesticide chemicals. Table 4.15 shows the content of the 13 samples. In all, 8 pesticide chemicals were detected: isoproturon, metamitron, DNOC, mechlorprop, methabenzthiazuron, 2-hydroxyterbuthylazine, terbuthylazine and 2,4-D. DNOC was found to be present during the entire period in a relatively high concentration range from 0.3 to 4.5 microgramme per litre. This substance has not been used in Denmark for the last 10 years. The substance can also be formed by atmospheric, chemical reactions, see section 4.5. There may thus be transboundary air pollution. DNOC has also been detected in groundwater near the surface and in watercourses (Spliid et al. 1996), see sections 4.1.1 and 4.1.2.

In 1990-1991, DMU measured the content of α-HCH and γ-HCH (lindane) in rainwater in 2 localities in Denmark: Husby and Ulfborg in West Jutland. In 1992, analyses were carried out of samples from 3 localities: Ulborg, Bagenkorp and Anholt. The maximum concentration was found to be 0.1 microgramme per litre. The analysis indicated that the occurrence of lindane came from use in countries south and west of Denmark (Cleemann et al. 1995).

Table 4.15
*Pesticides and degradation products in rainwater samples collected in the period September 1996 to November 1997. In all, 13 samples were collected over a period of 2-3 weeks in Lorup, Gisselfeld and Gadevang on Zealand. DMU analysed the samples for 36 active ingredients and 8 metabolites. The concentrations are given in microgramme per litre. It will be seen that for isoproturon and DNOC, the concentration exceeds the drinking water limit of 0.1 microgramme per litre (marked in **bold**) (Felding 1998a).*

Extracted	Isoproturon[a]	Metamitron	DNOC[b]	Mechlorprop[c]	Methabenzthiazuron	2-hydroxyterbuthylazine[M]	Terbuthylazine[M]	2,4-D[c]
Sept. 96	0.007	n.d.	**0.61**	0.005	n.d.	n.d.	n.d.	n.d.
Oct. 96	**0.20**	0.019	**4,5**	**0.23**	n.d.	n.d.	n.d.	n.d.
Oct. 96	0.054	0.039	**0.69**	0.07	n.d.	n.d.	n.d.	n.d.
Nov. 96	0.017	0.038	**0.89**	0.07	n.d.	n.d.	n.d.	n.d.
Nov. 96	n.d.	n.d.	**0.77**	0.030	0.013	n.d.	n.d.	n.d.
April 97	n.d.	n.d.	**0.82**	0.016	0.008	0.096	n.d.	n.d.
May 97	n.d.	n.d.	**0.31**	0.015	n.d.	0.098	0.008	n.d.
June 97	n.d.	n.d.	**0.57**	0.012	n.d.	n.d.	0.009	n.d.
Aug. 97	n.d.	0.024	**1.6**	n.d.	n.d.	n.d.	n.d.	n.d.
Sept. 97	n.d.	n.d.	**0.38**	0.005	n.d.	n.d.	n.d.	0.046
Sept. 97	**0.17**	0.088	**1.3**	0.068	n.d.	0.015	0.008	0.059
Oct. 97	**n.d.**	n.d.	**0.44**	0.016	n.d.	n.d.	n.d.	0.013
Oct. 97	**0.29**	n.d.	**0.47**	0.076	n.d.	n.d.	n.d.	n.d.

n.d. = not detected; [a] = ban recommended in 1998
[b] = banned; [c] = banned with dispensation in 1997
[M] = metabolite (of atrazine)

Table 4.16

Pesticides and degradation products in rainwater samples from Zealand. The table shows the figures from table 4.15 for the deposition of pesticides, calculated as g per hectare (Felding 1998a). The analysis covers 36 active ingredients and 8 metabolites.

Extracted	Isoproturon[a]	Metamitron	DNOC[b]	Mechlorprop[c]	Methabenzthiazuron	2-hydroxyterbuthylazine[M]	Terbuthylazine[M]	2,4-D[c]
Sept. 96	0.007	n.d.	0.63	0.005	n.d.	n.d.	n.d.	n.d.
Oct. 96	0.050	0.005	1.13	0.058	n.d.	n.d.	n.d.	n.d.
Oct. 96	0.053	0.038	0.68	0.069	n.d.	n.d.	n.d.	n.d.
Nov. 96	0.018	0.040	0.94	0.074	n.d.	n.d.	n.d.	n.d.
Nov. 96	n.d.	n.d.	0.66	0.026	0.011	n.d.	n.d.	n.d.
April 97	n.d.	n.d.	0.64	0.012	0.006	0.075	n.d.	n.d.
May 97	n.d.	n.d.	0.27	0.013	n.d.	0.086	0.007	n.d.
June 97	n.d.	n.d.	0.36	0.007	n.d.	n.d.	0.006	n.d.
Aug. 97	n.d.	0.014	0.92		n.d.	n.d.	n.d.	n.d.
Sept. 97	n.d.	n.d.	0.08	0.001	n.d.	n.d.	n.d.	0.009
Sept. 97	0.072	0.037	0.55	0.029	n.d.	0.006	0.003	0.025
Oct. 97	n.d.	n.d.	0.45	0.017	n.d.	n.d.	n.d.	0.013
Oct. 97	0.116	n.d.	0.19	0.030	n.d.	n.d.	n.d.	n.d.
Total	0.32	0.13	7,5	0.34	0.017	0.17	0.016	0.048

Sum of the detections of the pesticide chemicals analysed for	8.5 g/ha

n.d. = not detected; [a] = ban recommended in 1998
[b] = banned; [c] = banned with dispensation in 1997
[M] = metabolite (of atrazine).

In table 4.16, the measured concentration of pesticide chemicals from table 4.15 is converted from microgramme per litre to gramme per ha. In this analysis, which does not cover all volatile pesticides, DNOC (4,6-dinitro-2-methylphenol) constitutes just under 90% of the total quantity of pesticide chemicals in the atmospheric deposition with rainwater. The distribution of phenols and nitrophenols in clouds and the occurrence and formation of phenols in the atmosphere have been described by Lüttke and Levsen (1997) and Lüttke et al. (1997). It is concluded in these studies that DNOC occurs mainly in gaseous form rather than in liquid form in the atmosphere. Dinitrophenols are mainly formed through reactions in the atmosphere, unlike mononitrophenols, which are primarily formed in connection with exhaust fumes from cars.

4.5.1 Conclusions

Pesticide chemicals have been detected in precipitation collected in Denmark. The study was limited and covered only a few substances and not those with the highest potential for volatilisation. In most cases, there was a relationship between the spraying season and the time of detection. However, pesticides that are no longer used in Denmark were also detected. These substances were presumably transported here over long distances or originated from other sources than treatment with pesticides in agriculture. The prohibited substances found in the precipitation included DNOC, which was found in rainwater throughout the year and in by far the highest concentrations among the substances analysed for. It is therefore highly likely that its presence is due primarily to the formation of nitrophenols in the atmosphere. The international literature describes the formation of nitrophenols in the atmosphere as a reaction between benzene, toluene and NO_x. The exhaust fumes from cars contain mononitrophenols and other nitrophenols, which contribute to the atmosphere's content of these substances. However, the use of DNOC as a pesticide outside Denmark may also contribute to the content of nitrophenol in the atmosphere.

The following specific conclusions can be drawn:

- The insecticide lindane has been detected as an example of a presumed transboundary atmospheric transport of pesticides.

- The existing national monitoring of the content of pesticide chemicals in precipitation is limited and there is a lack of data that can be combined with the meteorological data.

- There are no Danish in situ measurements of the content of pesticide chemicals in the air in connection with spraying.

4.6 Exposure pathways

Exposure of both people and the environment can occur during handling of pesticides, during and immediately after treatment and as a consequence of dispersal in the environment. The extent to which pesticides are dispersed depends on their physical and chemical properties, environmental conditions, and the way they are used. A pesticide's persistence should be understood to mean its durability in the environment: substances with a long degradation time are said to have high persistence. The environmental effects of pesticides are discussed in chapter 5. Human exposure from intake of pesticide residues is described in section 6.2. Exposure of the users of pesticides is dealt with in section 6.1. In the following we discuss the dispersal in the environment, which is of fundamental importance both for the environment and for the exposure of people. The following processes and dispersal pathways are described:

- surface run-off
- spray drift
- volatilisation
- degradation and leaching of pesticides
- filling and washing sites

4.6.1 Surface run-off

Pesticides can be transported with water running on the surface of the ground. Surface run-off from sloping fields can carry both water-soluble substances and substances that are adsorbed to particles of soil out into watercourses and lakes. Particle-borne transport occurs during heavy run-off of rainwater or melt water and soil erosion.

In a project in the Danish Environmental Protection Agency's Pesticide Research Programme (Felding et al. 1997), the surface run-off of two relatively water-soluble herbicides (mechlorprop and dichlorprop) and a sparingly water-soluble insecticide (alfacypermethrin) was studied during two growth seasons (1992-1993). The field had an average gradient of 12% and was used for winter wheat in both years.

Table 4.17 shows the quantities of pesticide transported with surface run-off in the years mentioned. For both years, the quantities, stated in parts per thousand of the sprayed pesticide, were 0.08 for mechlorprop, 0.002 for dichlorprop and 0.001 for alphacypermethrin.

Mechlorprop and dichlorprop were detected particularly in the aqueous phase of the surface run-off, while alphacypermethrin was only detected in samples of water containing particles of soil, which accords with the fact that this substance adsorbs strongly to soil particles. It will be seen that the biggest run-off was of substances applied in the autumn.

Table 4.17
Spraying of pesticides on the trial field and pesticides detected in surface run-off (Felding et al. 1997). The substances in question were authorised at the time of spraying.

Spraying date	Pesticide	Dose, kg a.i. per ha	Concentration in samples (microgramme per litre)	Total quantity in run-off (milligramme)	Period in which pesticide occurred after spraying
21-11-1991	mechlorprop	0.584	0.05-3.5 0.29-15	8	28/11-91 to 10/11-92
14-05-1992	dichlorprop	3.00	0.04-4.6	4	26/07-92 to 22/2-93
02-07-1992	alphacypermethrin	0.0125	not detected	-	-
13-11-1992	mechlorprop	0.584	0.13-6.2 0.11-7.2	42	20/11-92 to 02/08-93
28-04-1993	dichlorprop	3.00	0.21-0.39	1	28/6-93 to 31/8-93
30-06-1993	alphacypermethrin	0.0125	0.01-0.21	0.009	25/07-93 to 11/09-93

a.i. = active ingredient

Events with run-off occur only, and momentarily, when the precipitation within 24 hours exceeds 10 mm (DMU 1995); Groenendijk et al. 1994; Liess et al. 1999; Møhlenberg, Gustavson 1999). On average, this occurs three times a year in Denmark (Funen County, South Jutland County). During precipitation events of more than 10 mm, the surface run-off of pesticides make up 0.2 % of the pesticide pool from the nearest 2 ha in the field, which, according to Groenendijk et al 1994, is a good estimate in countryside with slight gradients. Swedish studies from 1990-1996 (Kreuger 1998; Kreuger, Tornqvist 1998) estimate correspondingly that 0.1-0.3% of the pesticide spread on fields in the catchment area are lost to the aquatic environment. Recent German studies carried out near Braunschweig, which has the same type of soil and field topography as Eastern Denmark, has shown that the run-off of fenvalerate, among other pesticides, occurred in pulses and was clearly associated with precipitation events of more than 10 mm per day (Liess et al. 1999). The total transport to a watercourse was calculated at between 0.012% and 0.068% of the total amount applied to a 9 ha field. Converting to a run-off area of 2 ha and taking account of the degradation as used in the model in section 10.3.3, that corresponds to a loss of 0.05-0.03% with surface run-off (Møhlenberg, Gustavson 1999). Møhlenberg, Gustavson use a loss of 0.2% from 2 ha as a conservative estimate in the model calculations in section 10.3.3.

The main measure used to try to prevent pollution of watercourses and lakes is the establishment of buffer zones along watercourses and lakes within which cultivation is not allowed. The buffer zone acts as a filter and reduces the amount of surface run-off.

4.6.2 Conclusions

The following specific conclusions can be drawn:

- Pesticides can be transported to watercourses and lakes via surface run-off.

- Surface run-off of pesticides occurs only in connection with precipitation events of more than 10 mm per day. The magnitude of the run-off depends on the run-off area and its gradient. In the scenario analyses in section 10.3.3, the run-off is estimated to be 0.2% of the amount of pesticide applied on the nearest 2 ha.

- This applies both to water-soluble substances and to substances that adsorb to particles of soil.

- Surface run-off is greatest for pesticides applied in the autumn.

- The amount of pesticide that reaches watercourses and lakes can be reduced by establishing grass buffer zones between the field and the recipient.

4.6.3 Spray drift

"Spray drift" should be understood to mean the amount of pesticide that is not deposited on the field being sprayed. Pesticides can be transported via the atmosphere to land outside the sprayed area in the following two ways:

1. The actual drift, i.e. the amount that is deposited in droplets on surfaces outside the area being treated.

2. Deposition further away from the area treated. Drift models normally deal only with the former aspect.

During field spraying, the spray liquid is relatively finely atomised in order to achieve a uniform distribution on the area and good deposition of the spray liquid on the crop and pests. During the droplets' transport to the crop and its pests, loss can occur through the droplets being carried out of the sprayed area in particulate form as drift or in the form of vapour. The loss can occur both on the droplet's way to the target and from the target of the spraying for a period after spraying. Drift, together with volatilisation of pesticides, explains why pesticides are detected in precipitation, surface water and on unsprayed areas. Drift is the reason why, with very low vapour pressure, pesticides can be measured in the atmosphere and in precipitation, because these substances can be transported as small particles that form from drops of spray fluid that are borne and dried in the air.

Several factors affect the extent of drift. Numerous measurements have shown that most of the spray liquid reaches the target in calm weather. In conditions with more wind or atmospheric instability, some of the spray liquid is transported out of the sprayed area. The proportion transported out of the area depends on the following factors (Jensen et al. 1998):

- the wind velocity and relative humidity
- the average droplet size and droplet size distribution, which depend on the type of and size of the nozzle, the hydraulic pressure and the surface tension and viscosity of the spray liquid
- the distance between the nozzle mouth and the spray target (boom height)
- the spraying equipment used (conventional, air-assisted, screening, size and design of the spraying equipment, electric charging of the drops, etc.).

The spraying techniques that can be used to reduce spray drift are discussed in section 9.6. In field spraying, for example, the farmer can influence the drift through his choice of spraying equipment and its setting, while the actual drift is heavily affected by the climatic conditions - particularly the wind. Also drift is far greater when spraying on bare soil or on soil with a low crop than when spraying in the later stages of the crop, when the crop is dense.

Droplet size, volatilisation and relative humidity

Volatilisation from such small droplets simply reduces the size of the droplets still further and produces very small droplets that are transported with wind over long distances. Droplets with a diameter of less than 50 micrometres have a critical size because they remain suspended in the air for a relatively long time. If the relative humidity is low, large droplets can also become smaller, whereby the risk of drift increases considerably. It has thus been calculated that the proportion of air-borne droplets at a distance of 500 metres from the sprayed areas increases more than tenfold if the relative humidity falls from 100% to 50% at 20^{o}C (Thomson, Ley 1982).

Height of spraying boom above the ground

The height of the spraying boom has a considerable effect on drift. It is primarily the small droplets – 100 micrometres or less – that are affected by changes in the height of the boom. Drift thus doubles when the boom height is increased from 50 cm to 70 cm with a traditional flat-spray nozzle (Miller 1988).

As mentioned in section 9.6, spraying equipment is undergoing further development that could help to reduce drift.

4.6.4 Conclusions

Drift to the surrounding areas implies a risk of exposure of hedgerows, dykes, dry stone walls and small biotopes in farmland and of natural terrestrial and aquatic areas. Drift, together with volatilisation of pesticides, explains why pesticides are detected in precipitation, surface water and on unsprayed areas. Drift depends particularly on the droplet size and wind velocity. The droplet size depends on the spraying equipment and spraying technique used.

The following specific conclusions can be drawn:

- It is primarily droplets with a diameter of less than 100 micrometres that are transported with the wind.

- Small droplets are formed when larger droplets evaporate in dry air.

- Pesticides with a very low vapour pressure cannot be transported to the atmosphere by volatilisation. Even so, they are found in the atmosphere and in precipitation because they can be transported as small particles formed from droplets of spray liquid that are borne and dried in the air.

- A low boom height reduces the quantity of small droplets that form through volatilisation.

- In dry air, large droplets change into small droplets through volatilisation. Spraying in moist air reduces the volatilisation. The air is often moist and the wind velocity low in the morning hours, so the risk of drift is generally lowest then.

- Little is known about the magnitude of drift and the exposure of terrestrial and aquatic biotopes. In current practice, terrestrial biotopes are protected by means of spray-free zones and aquatic environments are protected by means of substance-specific distance requirements in the authorisation of pesticides.

4.6.5 Volatilisation

Pesticides evaporate both during and, especially, after spraying. Together with drift, see section 4.6.2, volatilisation conveys relatively large quantities of pesticides to the atmosphere, which is thus, quantitatively, the principal transport path for pesticides away from the sprayed area. Lastly, it should be noted that considerable quantities of pesticides can be transported by wind erosion – for example, if there is a storm after spraying of crops in the spring, when the plant density is low. The volatilisation depends on the properties of the substance and, particularly, on its vapour pressure. The temperature, water solubility and adsorption to the soil and plant surfaces, the humidity of the soil, atmospheric turbulence, and the concentration of the pesticide, including its degradation, also play an important part. It is difficult to measure the volatilisation because of its great natural variability (Løkke 1998).

Models for volatilisation

Volatilisation of pesticides depends on the aforementioned factors and can be calculated by means of mathematical models that include the main factors governing the volatilisation. Jansma and Linders (1995) calculated the volatilisation from the surface of the earth by means of the so-called “Dow method”, which takes account of the pesticides’ vapour pressure, water solubility and adsorption to soil as the factors governing the volatilisation. The method was validated by comparison with measured values. This method can thus be used for crops grown in rows, where the plant cover is small and most of the pesticides hit the surface of the earth. The calculated values generally lay within a factor of 7 from the measured values. However, this model has a tendency to overestimate the volatilisation. There are as yet no suitable models for estimating the volatilisation of pesticides that are mixed with the soil during harrowing and ploughing. It is also difficult to make a general model for the volatilisation of pesticides from the surface of the plants.

Volatilisation from soil

In the case of many pesticides, most of the pesticide that lands on the ground can in theory evaporate within a few days, depending on the climatic conditions. Volatilisation increases with rising temperature and wind velocity. If the relative humidity is low, the ground surface dries out, which reduces volatilisation.

Volatilisation from plants

Little is known about volatilisation of pesticides from plants. High relative humidity increases the volatilisation but can at the same time increase the absorption of a pesticide by the plant. Once the pesticide has penetrated the plant, 95% of it remains there. The volatilisation depends on the species of plant, the amount of foliage per unit of area and the nature of the surfaces of the plant. The spraying technique and the coformulants in the pesticide formulation also play a part. These substances are intended to ensure that pesticides are spread and attach to and penetrate the plant. The ancillary substances can thus help reduce volatilisation and thus increase the substances action time in and on the plant. Volatilisation is greatest from small droplets, which have the relatively largest surface, and least from large droplets, partly because absorption by the plant is greatest from large droplets. The Dutch authorities have estimated that about 20% of a sprayed pesticide evaporates from plant surfaces and is transported to the atmosphere (Ministerie van L.N.V. 1991).

Measurements of volatilisation in the laboratory and the field

There have been many foreign studies of the volatilisation of pesticides. Most of them were carried out more than 10 years ago with pesticides that are no longer used in Denmark. Jansma and Linders (1995) have reviewed data from the literature. It appears from their work that both the herbicide DNOC and the chlorinated insecticide lindane, which have been detected in rainwater in Denmark (see section 4.1.5), evaporate very quickly from plant surfaces. In German field tests with different crops, it was found, for example, that 45% of lindane evaporated from green beans within one hour of spraying, 50% from lettuce, 30% from kohlrabi and 25% from spring wheat (Boehncke et al.1990). After 3.1 days, 88% had evaporated from the spring wheat and more than 90% from the other crops. In several studies, measurements of the volatilisation of lindane from the ground showed a lower rate of volatilisation but still so much that most of the sprayed pesticide was transported to the atmosphere.

Measurements exist of the volatilisation of individual substances included in measurements of the content of pesticides in Danish rainwater. The substances include atrazine and simazine.

For atrazine, measurements in field studies in the USA have shown that up to 9% can evaporate from the ground surface in 35 days. In another study, 1.3% of simazine evaporated from the ground within 21 days. Measurements of volatilisation from the ground of substances now in use in Northern Europe, showed up to 49% of chlorpyrifos after 26 days, up to 52% of deltamethrin after 3.1 days and 90% of trifluralin after 2.5-7 days. Field tests in Germany of volatilisation of the insecticide deltamethrin after 3.1 days showed 72% from green beans, 34% from kohlrabi, 70% from lettuce and 24% from spring wheat (Boehncke et al. 1990). The same authors measured up to 100% volatilisation of mevinphos from plants after 3.1 days.

Calculation of the volatilisation from the surface of the ground

The simplest model for calculating volatilisation is a so-called 1st order model. In the “Dow model” it is assumed that the so-called rate constant for volatilisation is directly proportional to the vapour pressure and inversely proportional to the water solubility and the soil-adsorption constant (Jansma, Linders 1995). This model is used in the EU´s PC-based expert system for assessment of chemical substances, EUSES (EC 1996). The volatilisation according to this model is shown in table 4.18 for substances with high volatilisation that are also widely used. However, the model overestimates the volatilisation. Another model, developed recently in the Netherlands, includes the substances’ fate in the atmosphere, deposition and effects on plants. The results indicate that, with the pattern of use in the Netherlands in the period 1985-1995, in all 5.5% of the amount of *herbicides* applied evaporated. The atmospheric deposition corresponded to an average treatment frequency index on nature areas of 0.02 per year (Klepper et al. 1998).

Table 4.18
Calculated volatilisation of pesticides with potential volatilisation from ground surfaces (Jansma, Linders 1995; Løkke 1998).

Pesticide	Quantity sold in 1997 (1000 kg)	Percentage volatilisation after:	
		1 day	4 days
Chlorothalonil	39	1	6
Bentazone	79	7	24
Cypermethrin[m]	2	1	5
Dimethoate	35	1	6
Diuron	23	3	11
Fenpropimorph	278	11	38
Flamprop-M-isopropyl	13	1	6
Pendimethalin	358	99<	99<
Permethrin	2	31	77
Propyzamide	22	57	96
Prosulfocarb	75	26	69
Terbuthylazine	63	8	27

However, these calculations also showed that there is very little volatilisation from ground surfaces of most of the pesticides used in Denmark today. There is apparently considerable volatilisation of fenpropimorph, pendimethalin, permethrin, propyzamide and prosulfocarb. There is thus a risk of these substances being spread in the atmosphere and detected in rainwater and surface water. The fate and occurrence of these substances in the atmosphere over Denmark have not been investigated and are not covered by DMU’s analytical programme for rainwater (Løkke 1998).

4.6.6 Conclusions

Pesticides evaporate both during and, especially, after spraying. Together with drift, see section 4.6.2, and occasionally wind erosion of soil treated with pesticides, volatilisation transports relatively large quantities of pesticides to the atmosphere and is thus, quantitatively, the principal transport path for pesticides away from the sprayed area. The volatilisation depends on the properties of the substance and, particularly, on its vapour pressure. The temperature, water solubility and adsorption to the soil and plant surfaces, the humidity of the soil, atmospheric turbulence, and the concentration of the pesticide, including its degradation, also play an important part. It is possible to calculate the volatilisation from ground surfaces by means of simple mathematical models, whereas there are as yet no similar models for calculating the volatilisation from plant surfaces. According to model calculations, there can be considerable volatilisation from ground surfaces – theoretically right up to 100% within a few days in the case of some substances. In the Netherlands it is estimated that about 20% of the total amount placed of all types of pesticides evaporates.

Model calculations show that very little of most of the pesticides used in Denmark is transported from ground surfaces to the atmosphere through volatilisation, although some substances show a big potential for volatilisation.

The following specific conclusions can be drawn:

- Calculations indicate that, quantitatively, considerable volatilisation of the substances fenpropimorph, pendimethalin, permethrin, propyzamide, prosulfocarb and trifluralin can occur. There is thus a risk of these substances being spread in the atmosphere and detected in rainwater and surface water. The fate and occurrence of these substances in the atmosphere over Denmark have not been investigated.

- There is a need for studies of the actual volatilisation of the pesticides used in Denmark with a view to later modelling of the volatilisation.

- In order to be able to estimate the importance of atmospheric deposition of pesticides in Denmark in relation to other sources, knowledge is needed about the rate of removal from the atmosphere through dry and wet deposition.

- Knowledge is lacking about the fate of pesticides in the atmosphere – particularly their degradation, the rate of degradation and possible formation of environmentally xenobiotic reaction products.

4.6.7 Degradation and leaching of pesticides

Pesticides degrade in a stepwise process, often via the formation of metabolites, the chemical structure of which may be similar to the original pesticide. A pesticide’s metabolites can be more toxic and leach more easily than the original pesticides. This applies, for example, to the atrazine metabolites, deethylatrazine and desisopropylatrazine. It is therefore of great importance that studies of the persistence of pesticides in the soil and leaching from the soil include corresponding studies of metabolites (Fomsgaard 1998).

Degradation and sorption are key factors in the assessment of pesticides’ persistence in the soil. The time of application and the locality also affect the persistence of pesticides. The amount of organic matter in the soil can lead to greater sorption and thus slower degradation and slower leaching. Conversely, the organic matter can also increase the presence of microorganisms, which can in turn increase the rate of degradation.

Extreme soil environments, such as the surface on railway lines, paths and car parks, are such poor environments for biological activity that herbicides used on these areas are degraded very slowly. Furthermore since these types of soil bind pesticides poorly, they have a high potential for pollution of groundwater.

Processes that remove pesticides from the soil

A wide range of processes – surface run-off, volatilisation, uptake in plants, leaching and degradation – help to remove pesticide residues from the soil after spraying. Degradation and metabolism in plants differ from the other processes by transforming the substance or removing it permanently from the environment. Surface run-off and leaching can carry the substance into surface water or groundwater; volatilisation can lead to the occurrence of pesticide residues in rainwater; and uptake by plants can lead to contaminated food if the pesticide is not broken down after uptake. Pesticide residues can also be bound in the soil without being degraded.

Persistent pesticides

Pesticides are generally either degraded abiotically, e.g. by photodegradation, or biologically, primarily through biological conversion by microorganisms. A persistent pesticide is characterised by remaining intact in its active form if it is not sensitive to physical and chemical factors or if the microorganisms cannot degrade it. In addition, metabolites, degradation products or reaction products that can be similarly persistent can be formed. The pesticide and/or these metabolites can be inaccessible to degradation if they are adsorbed on humus or clay minerals. The distribution of pesticides between the soil's pore water and particles of soil is an equilibrium between free molecules and molecules bound to either dissolved organic matter or to attached soil particles. There is therefore a possibility that pesticides bound in the soil can later be released as a consequence of a change in the physical-chemical environment, e.g. acidification of the soil or degradation of humus or clay minerals.

Persistence analyses in the authorisation of pesticides

In connection with the authorisation of pesticides, laboratory tests are carried out as a basis for assessing the persistence. The active ingredient or its metabolites, degradation products or reaction products that are of environmental importance must not have a half-life of more than 3 months and not more than 10% of the amount applied must remain after one year. If only a small proportion of the active ingredient (i.e. less than 5% in 100 days) is completely broken down into CO_2, water and salts, there is a risk of it being bound unchanged in the soil. It is therefore a requirement that not more than 50% of the active ingredient may be bound in the soil after 30 days or max. 70% after 100 days. If these values are exceeded, an evaluation of the conditions for use is carried out and relevant field trials may also be included in the assessment. Active ingredients that have half-lives of more than 6 months and that imply a risk of exposure of the external environment are regarded as possessing unacceptable persistence. This means that the pesticide in question cannot be authorised.

In cases in which relatively large amounts of a persistent pesticide are bound in the soil after repeated application without being directly accessible, it is known that small amounts of the pesticide can be absorbed by plants, earthworms and microorganisms. With continuous accumulation of persistent pesticides in the soil, this absorption must be expected to increase. It is not known how such absorption will affect organisms in the soil in the longer term (the so-called chronic effects). In cases in which a pesticide is bound very strongly to the soil without breaking down, it will not be possible within the foreseeable future to carry out long-term trials to see whether the ingredient and its relevant metabolites, degradation products and reaction products are released and cause damage to the soil's ecosystem. In such cases, the authorities may decide that an active ingredient must not be authorised due to unacceptable persistence. This authorisation practice is used in Denmark and the Netherlands, and Denmark is seeking to get it implemented in the EU.

Soil treatment

Soil treatment affects the chemical, physical and biological factors in the soil and thus has a major indirect effect on the persistence and leaching of pesticides. In the international literature, the relationship between leaching and soil treatment has been studied by Hatfield (1996), Locke and Harper (1991) and Gaston et al. (1996). If soil treatment is increased, some of the macropores would be destroyed. That means that the pesticides' retention time would probably increase in the ploughing layer, where the potential for degradation is greatest, and leaching would be reduced. On the other hand, surface run-off might increase. If soil treatment were reduced or eliminated, transport in macropores would increase and thus also leaching of pesticides. Reduced soil treatment can also have the opposite effect, since volatilisation increases when the soil is not treated.

Metabolites

The degradation of a pesticide is a phased process that often proceeds via the formation of metabolites, the chemical structure of which is often similar to that of the original pesticide. Complete mineralisation leads to the formation of CO_2, salts and H_2O. Only some of the amount of pesticides that may end up in the soil after spraying will be fully mineralised (i.e. converted into water, CO_2 and salts). The rest of it will be leached or strongly bound or chemically incorporated in the soil's humus and/or biomass. Both mineralisation and strong adsorption (non-desorbable) or chemical incorporation in, for example, humus remove the environmentally harmful effects of the pesticide/metabolites. The metabolites formed by degradation of pesticides can be not only more toxic to the environment but also more water-soluble and often leach more easily than the original pesticide. If the metabolite is more toxic or leaches more easily, it can present a bigger problem than the original pesticide. The detection of metabolites of dichlobenil and atrazine in groundwater illustrates this.

In the national groundwater monitoring programme (GEUS 1997), analyses were carried out in many Danish counties in 1997 for the metabolite 2,6-dichlorobenzamide (BAM), which is the degradation product of the herbicide dichlobenil, and for atrazine's three primary degradation products deethylatrazine, desisopropylatrazine and hydroxyatrazine (see section 4.1). The occurrence in groundwater is an important indicator that future studies of the persistence of pesticides in the soil should include the persistence of metabolites with high water solubility and/or low sorption. The sorption can be expressed by the adsorption constant K_d. The value of K_d usually increases with the soil's content of organic matter. The adsorption constant and solubility of atrazine and the three primary metabolites are shown in table 4.19. Deethylatrazine and desisopropylatrazine are less adsorbable than atrazine.

Table 4.19
Water solubility and adsorption constants (K_d) for atrazine and primary atrazine metabolites. Atrazine is banned in Denmark.

	Water sol. mM (a)	K_d in soil with 14% organic matter (b)	K_d in soil with 4 % organic matter (b)	K_d in soil with 2,3 % organic matter (b)	K_d in soil with 1,0 % organic matter (b)
Atrazine	0.15	14	2.6	1.5	0.44
Deethylatrazine	2.0	6.5	0.96	0.58	0.24
Desisopropylatrazine	1.2	8.6	1.2	0.73	0.41
Hydroxyatrazine	0.24	82	4.1	3.7	1.7

(a): Erickson, Lee 1989
(b): Brouwer et al. 1990

DEPA has published a list of pesticides currently used in Denmark and the associated metabolites (DEPA 1997). Selected examples from this list are shown in table 4.20. It is just as important to determine the persistence of metabolites as the persistence of the pesticides themselves because, as mentioned, the metabolites are in some cases more toxic than the pesticides from which they are formed.

Table 4.20
Pesticides with associated metabolites. Selected from DEPA (1997).

Active ingredient	Metabolites
dichlorprop	2,4-dichlorophenol
	3,5-dichlorocatechol
glyphosate	aminomethylphosphonic acid (AMPA)
	formaldehyde
	glycine
	methylphosphonic acid
	sarcosin (N-methylglycine)
mancozeb	ethylene thiouram disulphide
	ethylene thiouram monosulphide
	ethylene thiourea
terbuthylazine	2-chloro-4-ethylamino-6-amino-1,3,5-triazine

Relationship between degradation and adsorption, transport, spraying time and locality

Most pesticides that are strongly bound in soil degrade slowly. This is because the adsorption reduces the contact between the pesticides and the microorganisms carrying out the degradation. The pesticides can be released again (desorbed). The rates of adsorption and desorption play an important role in leaching. The greater the adsorption and the slower the desorption, the lower the probability that the substances will be leached through the soil to the groundwater.

The presence of organic matter, on the other hand, can increase the rate of degradation if the organic matter supplies nutrition and thus growth for the microorganisms that break down the pesticide. This has been demonstrated by Mueller et al. (1992) for fluometuron, by Veeh et al. (1996) for 2,4-D and by Walker et al. (1983) for simazine. The amount of organic matter in the soil at the individual locality thus affects the rate of degradation, although it is not known exactly how.

The temperature can affect the metabolism of many herbicides. For example, on average, the rate of degradation is reduced 2.2 times with a temperature reduction from 20°C to 10°C (Walker et al. 1996). Metabolism of pesticides therefore takes place far more slowly in the wintertime. Application in the autumn with subsequent low temperatures and percolation of precipitation therefore has a much greater potential for pollution of groundwater than application of the same substance in the spring or summer.

4.6.8 Conclusions

The rate of degradation and the adsorption of pesticides are key factors in the assessment of the pesticides' persistence in the soil. The rate of degradation is affected by a number of environmental factors. The effect of the temperature, the depth of the soil and the water content are of particular interest. Lower temperature and greater depth of soil generally reduce the rate of degradation. A very low water content reduces the possibilities of contact between the pesticide and microorganisms. A very high water content often reduces the rate of degradation because the supply of oxygen can be reduced. In recent studies it has been found that many other factors also influence the degradation of pesticides. For example, the initial concentration of a pesticide greatly affects the rate of degradation. With a high concentration of a pesticide, the degradation process is very slow.

A pesticide's metabolites can be more toxic and leach more easily than the original pesticides. This applies, for example, to the atrazine metabolites, deethylatrazine and desisopropylatrazine. It is therefore very important for studies of the persistence of pesticides in the soil and leaching from the soil to include corresponding studies of metabolites.

Extreme soil environments, such as the surface on railway lines, paths and car parks, are such poor environments for biological activity that herbicides used on these areas are degraded very slowly. Furthermore since these types of soil bind pesticides poorly, they have a high potential for pollution of groundwater. For many substances, application in the autumn, with reduced temperature and bigger precipitation, can involve a higher risk of groundwater pollution than application in the summer and spring.

The following specific conclusions can be drawn:

- Lower temperature and increasing depth of soil generally reduce a pesticide's degradation rate.
- A very low and a very high water content also reduces the degradation rate.

- A wide range of other factors influence degradation, including the initial concentration.

4.6.9 Pollution from filling and washing sites

No data are available on the extent of washing and filling sites as point sources of pollution of groundwater and surface water. There is thus no documentation showing whether this is a real problem, although there are indications that point sources with pesticides do pollute. For example, pesticides are sometimes detected in groundwater or watercourses in such high concentrations that it is unlikely that the source is application on fields. Point-source pollution can thus explain some local instances found today of limit values having been exceeded in groundwater and wells.

In one of the few studies carried out, Jørgensen and Spliid (1993) examined a washing and filling site in an orchard and found a very large content of phenoxy acids in the analysed soil samples.

Other studies have shown that farmers' wells and boreholes can be seriously contaminated with pesticides (Anon 1995; Spliid 1998b) caused either by point sources or by use of herbicides on farmyard areas. Areas surfaced with gravel and stone present a special risk of leaching of pesticides compared with ordinary agricultural land. Areas of this type are found in farmyards (Jacobsen et al. 1998).
A German study by Fischer et al. (1996) showed that 98% of the considerable pollution of a watercourse was caused by discharge of isoproturon directly from yard areas via sewerage systems or drains.

Potential sources of pesticides in groundwater

Where pesticides are used and handled outside normal field spraying, there is a risk of pollution of the surrounding environment – of the groundwater, the farmer's own well or borehole and watercourses – via drainage systems from the farm yard. Table 4.21 shows the potential water pollution from filling and washing sites.

There are no data showing whether washing water or pesticide spills cause serious groundwater pollution, nor is it known whether buried packaging is a serious problem. Before 1980. the authorities recommended burying empty packaging.

In directions from the Pesticide Board of the former Ministry of Agriculture from 1966 it was stated in a section entitled "Disposal of residual stocks of pesticides" that small remnants of pesticides and up to approx. 1 kg should be emptied into an 0.5 metre deep hole and that the packaging should be destroyed. The hole had to be at least 50 m from any well, watercourse, lake or drainage pipes. In the case of larger quantities, it was stated that these should be buried at a tip after permission for this had been obtained from the local health inspector.

Table 4.21
Potential sources of water pollution from filling and washing sites (Jensen et al. 1998).

Risk areas	
• Spilling of concentrated pesticide during filling, e.g. 100 ml IPU	• Can pollute 500,000 m^3 water above the limit value
• Overflow from the sprayer tank during filling, e.g. 10 l Express spray liquid	• Can pollute 5,000 m^3 water above the limit value
• Washing the outside of spraying equipment	• The IPU UK Task Force has estimated that washing the outside of a sprayer can pollute

• Controlling weeds in farmyard areas • Storage and disposal of packaging and chemical waste • Emptying residual spray liquid onto topsoil or gravel-surfaced areas	2,500 m^3 water and that washing of gloves can pollute 100 m^3 water. • The area load is generally high and there is a big risk of pollution of groundwater and well water. • Just a few leaching ml can pollute large quantities of water. • (see table 4.22)

IPU = Isoproturon.

A number of factors mean that the areas mentioned can be particularly critical. Pesticides from buried packaging and from filling and washing sites can affect the surroundings in a very concentrated form. They can also impede microbial activity, bringing degradation more or less to a standstill. Washing and filling sites are used regularly for many years. That means a big area load, compared with use of the pesticide for field spraying. In addition, washing and filling sites are often unsuitably sited on areas surfaced with gravel and stone but without any organic topsoil. This significantly increases the risk of pollution. When topsoil, with its content of humus, is removed, so are the microorganisms on which biological degradation of spilled pesticides mainly depends. And the big potential for sorption and retention is removed as well. That results in a relatively high rate of transport of water and pesticides. For the same reason, the use of herbicides in farmyard areas and lanes puts well water and groundwater at risk.

Another reason why pollution from filling and washing sites is particularly problematical is that the pesticides are led to the ground with a relatively large quantity of water, which increases the risk of leaching. The yards may also be connected with drains, so the pesticides can be led to watercourses or lakes. In addition, spraying equipment is often washed and filled close to wells, so leaching can occur directly in them unless special measures are taken to prevent it.

Table 4.22
Examples of pesticides in water used to wash spraying equipment. As the examples show, emptying even the diluted washing water out onto the ground can present a risk. The spray-liquid tank should be washed out several times with even small amounts of water. As the examples show, diluting 10 litres twice to 100 litres gives 100 times dilution. If the 10 litres are diluted to 50 litres in four goes, the water consumption will be only 160 litres, but the dilution will now be 625 times greater (Jensen et al. 1998).

Assumptions: The pesticide is mixed with 150 l water per ha. After spraying, the tank contains remaining spray liquid – normally 5-50 l. If 10 l is left and is diluted up to 100 l with clean water twice, a dilution of 100 times will be achieved.		
	Active ingredient in spraying and washing water:	The limit of 0.1 µg/L can be exceeded in the following quantities of water:

Example 1: **IPU dosage 1000 g active ingredient per ha:** - 10 l remaining spray liquid - 100 times diluted	 67 g 0.7 g	 670,000 m^3 6,700 m^3
Example 2: **Express dosage 7.5 g active ingredient per ha:** - 10 l remaining spray liquid - 100 times diluted	 0.5 g 5 mg	 5,000 m^3 50 m^3

IPU = isoproturon.
µg/L = microgramme per litre

A model calculation by GEUS of the potential importance of point sources to groundwater pollution shows that only a minimal proportion of pesticide detections comes from point sources (GEUS 1996). The calculations are based on various assumptions – for example, that the size of the point source is only 0.3 x 0.3 m. Since washing sites and sprayed farmyard areas are usually much larger than that, the leaching could be much greater than calculated.

In an ongoing project in which DIAS, GEUS and DMU are participating, the extent of a pesticide plume from a washing and filling site is being studied. This will provide supplementary knowledge about the importance of point sources.

4.6.10 Conclusions

- The use of pesticides and cleaning of tractors and sprayers near wells and the use of herbicides on farmyard areas and similar can lead to pollution of water supplies.

- Filling and washing sites are serious but limited, potential sources of pollution because the concentration and area load are high.

- Serious pollution can occur if a sprayer is filled directly from the water supply and the tube is left in the spray tank, since water can pollute the well by back-siphoning into the pipe.

- It is assumed that point sources with pesticides pollute groundwater and surface water. In directions from 1966, farmers were advised to bury small remnants of pesticides, but despite later warnings and extensive information, pesticides are still sometimes detected in groundwater or watercourses in such high concentrations that the source is unlikely to be field application. It has not been proven that such point-source pollution is the cause of the cases found in which limit values are exceeded in groundwater and wells.

- There is as yet no complete evaluation of filling and washing sites as sources of pollution.

4.7 The sub-committee's conclusions and recommendations

1. There are studies of pesticides in the different compartments – groundwater, watercourses, drain water, soil water and rainwater. There are only a few measurements of pesticides in ponds and lakes. Only in the case of groundwater are there time series, but the

measuring programmes have not been going on long enough to enable a description of the trends.

2. In the expanded analyses in the groundwater monitoring programme, pesticides or degradation products were detected in 34% of the screens examined in the interval 0 to 10 metres below soil surface. The limit value was exceeded in 23% of the screens. The detection frequency decreases with the depth, which may indicate that remnants of the last 50 years' increasing use of pesticides are moving towards the deeper aquifers, with increasing future groundwater pollution as a consequence. Another possible explanation might be that degradation is taking place during the onward movement because the concentrations in the deeper soil strata have been exposed to biological and chemical degradation for a longer period of time than concentrations in the uppermost strata. Only when sufficiently long time series from the monitoring programmes are available – which means in 5 to 10 years time – will it be possible to test these hypotheses. The latest research indicates that the degradation of certain pesticides in the aquifers is very slow, while others show degradation.

3. In the expanded analyses in the groundwater monitoring programme, pesticides or degradation products were found in 21% of the screens examined. The limit value was exceeded in 13% of the screens. The degradation product BAM from the now banned herbicide dichlobenil was detected in about 30% of the wells analysed in connection with the water companies' raw water monitoring system. However, a wide range of substances that are used in agriculture for treating crops are also present in relatively many wells analysed in connection with the water companies' raw water monitoring system. Larger amounts of pesticides were detected in drain water and soil water than in groundwater, and this may reflect concentrations that may similarly later move towards the groundwater, during which they may undergo degradation and possible formation of metabolites. In both watercourses and ponds, a number of pesticides have been detected in higher concentrations than the concentrations that have effected aquatic organisms in the laboratory.

4. It is a condition of authorisation of pesticides that they degrade in the environment and are metabolised into water, carbon dioxide and salts or into harmless organic substances. However, the sub-committee has noted that, in the case of pesticides detected in the different compartments, it is often only a fraction of the quantities used that can be accounted for, apart from degradation. There is thus a lack of information concerning the total mass flows and the largest flows, including volatilisation and drift, and a lack of actual systematic measurements in the environment of degradation and metabolism as an element of the integrated mass flow analysis. It is thus not possible to make a real and complete description of the fate of the pesticides in relation to the environmental and health loads.

5. The detection of authorised pesticides above the limit value in both groundwater near the surface and in aquifers at greater depths indicates that the present authorisation scheme does not ensure

completely against future pollution of the groundwater. As a safety measure, a warning system for pesticides has been established with a view to enabling fast evaluation and, if necessary, removal of authorised pesticides that are a threat to the groundwater.

At present, authorisation of pesticides in Denmark and the EU is based on analyses of research results and assessment of the consequences for health and the environment. This means, in particular, that the fate of the pesticides is not subject to an analysis of the uncertainties and actual variations that form part of an integrated mass flow analysis – in part because such an analysis would require data concerning the actual use, dispersal and degradation under Danish conditions. The sub-committee recommends that an actual mass flow analysis be carried out when pesticides are being reviewed for renewal of their authorisation in pursuance of section 33(4) of the Act on Chemical Substances and Products. This analysis must include both average and "worst-case" scenarios based on measurements taken and experience gained in the period in which the substance in question has been used. If, in this mass flow analysis, knowledge is lacking concerning the individual flows, the sub-committee recommends that the precautionary principle be applied in the assessment of the substances in order to counteract or prevent any consequences of the dispersal of the pesticides and exposure of people and the environment.

The sub-committee recommends that the gross list drawn up with a view to reexamining leaching of pesticides be included in recommendations concerning substitution with less dangerous substances. The sub-committee also recommends that new substances be assessed in relation to the gross list and in relation to non-chemical, alternative methods.

The sub-committee also recommends that volatilisation and chemical reactions of pesticides in the atmosphere be taken into account in connection with authorisation of the pesticides.

5 Environmental impacts

This section describes the known direct and indirect impacts of pesticides on flora and fauna in terrestrial and aquatic ecosystems. The main impacts occur during the application of the pesticides, when organisms are directly hit. However, indirect impacts, which occur as a consequence of the effect on food chains, can also be substantial. Bioaccumulation of pesticides in organisms and possible concentration in food chains are not covered by this report because pesticides with bioaccumulability are not authorised in Denmark.

Table 5.1
Health and environmental topics in which the impact of pesticides has been described in this chapter.

Topic	See section:	Impacts:
Fauna in cultivated and uncultivated areas	5.1	Decrease in populations, changed biodiversity, change in the growing medium and regulation by natural pests, food-chain and indirect effects
Flora in cultivated and uncultivated areas	5.2	Effect on species' occurrence, changed biodiversity
Flora and fauna in aquatic systems	5.3	Changes in flora and fauna in lakes, ponds and watercourses

During spraying, there is spray drift to the surrounding areas. However, hedgerows, dikes, dry stone walls and other small biotopes are of such small width that they should in practice be included in the area that is affected by spray products. Spray drift can affect both terrestrial and aquatic ecosystems. Among the aquatic ecosystems, it is particularly ponds, watercourses and lakes near fields that could potentially be affected. Seen overall, it is not the individual field and its possible loss of wild flora that are the problem but, rather, the countrywide impact on the characteristic farmland flora. Putting it in popular terms, small, uncultivated biotopes like ponds, hedges, dikes and hedgerows can be regarded as small oases in large expanses of monocultures. Large distances between these oases reduce the dispersal and remigration of species and therefore increase the risk of local eradication. It has become more difficult for some bird species to find nesting places in the large, uniform fields. If there is too little food in one type of crop, it is often also too far to fly to the next. The impact of pesticides must thus also be seen in relation to the physical structure of cultivated land and other impact factors, such as fertilisation and crop rotations.

5.1 Impact of pesticides on the fauna in cultivated and uncultivated terrestrial ecosystems

The environmental impact from the use of pesticides, understood as the effect on flora and fauna in farmland and forests is closely connected with how the individual pesticide is used and how often it is applied, the pesticide's fate in the environment and its toxic properties. The impact on the individual plant or animal species depends on the species' dispersal in time and space, how sensitive the species is to a given pesticide (direct effects) and how affected it is by changes in the population of other species and other indirect effects. The effect of pesticides must also be seen in relation to other factors that affect farmland fauna – particularly fertilisation, soil treatment, crop rotation and other operational measures. In addition, reduced dosages, split dosages and product mixtures affect the pesticides' impact on the fauna directly or indirectly through their effect on the flora. The information in this section is amplified in Elmegaard (1998) and Strandberg (1998).

Exposure of field fauna through treatment with insecticides

The exposure of the fauna in cultivated fields depends in part on how the products are applied. There are three common methods in Denmark: spraying with a boom-spray, spreading on the soil as granulate and dressing of seed. Spraying is far and away the most common method. Insecticide applied with a boom-spray is normally placed in a developed crop with some degree of cover. The insecticide is deposited in small drops of water on the leaves and stems down through the crop, and the remainder lands on the ground. When cereal crops are sprayed with insecticide, 10-30% of the insecticide normally ends up on the ground. Deposition is greatest at the top of the crop, close to the nozzles, and decreases on the way down through the crop. For animals living up in the vegetation, exposure can also take place as they come and go on contaminated leaf surfaces (residual uptake) or via their food, which is either parts of plants or other arthropods.

For species that live on or in the soil, there can similarly be several exposure routes. The effect of the substance deposited on the ground depends on how strongly the substance adsorbs to organic matter and soil particles and thus also on the composition of the soil. Many insecticides adsorb strongly to clay or organic matter and therefore have low bioavailability in soil.

Direct effects on natural enemies of pests in fields treated with pesticides

Beneficial animals, meaning the natural enemies of pests, can be divided into two groups: general and specific predators. General predators live from many kinds of food and the most important species are to be found among ground beetles, rove beetles and spiders. The main species seek food on the surface of the ground and, in the case of some species of spider, by means of webs in the vegetation. The other group of beneficial animals is specific predators, which live mainly or only from a limited group of pests. In cereals, aphids are the main pests, and the specific predators are ladybirds, parasitic wasps, buzzing fly larvae and lacewing larvae.

In the case of boom spraying, direct toxic effects on field arthropods are caused mainly by insecticides, although herbicides and fungicides can also have direct toxic effects on some arthropods. The pest is often an insect living up in the crop, where it is exposed to large concentrations of the spray product. The specialised predators are also affected because they normally live in the same places as the pest. In cereals, ladybirds, buzzing flies, lacewings and parasitic wasps are therefore exposed when insecticides are applied.

The fauna on the ground can be seriously affected by insecticides in some cases, but not in others. Many of the general predators hide in cracks in the soil or under stones and similar in the daytime, when spraying is done, and are therefore hit less directly by the spray mist. The exposure occurs at night, when the animals leave their hides and wander round on treated soil and plant material (Unal, Jepson 1991).

Beneficial fauna also include bees, which, as pollinators, play an important economic role in some crops. Bees are active in the daytime and visit flowering crops to gather pollen and nectar. Daytime spraying of flowering crops with products that are dangerous for bees is therefore prohibited. This reduces the risk of direct exposure of the bees, but residual intake and intake via food cannot be avoided if the bees continue drawing on the treated crop. Some products have a repellent effect on bees, which means that the bees avoid the sprayed plants.

Effects on other non-target arthropods in farmland; general aspects

The length of time the spraying effect lasts depends on the biology of the species. Some flies and midges spend the larval stages of their life protected down in the soil or inside plants and are therefore only exposed in the short period in which they live in the open as adults. In addition, adult individuals hit by insecticides are followed by new individuals that hatch from puppae. However, for forms with larval stages on the outside of vegetation or similar and forms with lengthy adult stages, the effect can be considerable (Nielsen et al. 1996; Vickerman, Sunderland 1997).

Spiders

Spiders are often exposed to heavy effects from insecticides through direct exposure to the spray mist or through subsequent intake from the surroundings. Web-spinning spiders can gather a considerable amount of the spray product (Samu et al. 1992). Some species are very sensitive to pyrethroids (Wiles, Jepson 1992).

Springtails

The effect on springtails also depends on the form of life; species that live on the surface of the earth are more exposed to spraying with pesticides than species that live in the soil (Frampton 1988).

Effects of herbicides on the biology of the soil

By and large, herbicides have not been found to have any direct effects on the biology of the soil in laboratory tests in which field doses of herbicides have been used (Wardle 1995). However, bacteria have shown some sensitivity in around 40% of the tests. On the other hand, there are known, indirect effects on several groups of organisms. After application of a herbicide, dead organic material is added to the soil and, in the short term, stimulates microorganisms and the trophic levels that live off them. At the same time, there has been a reduction in the number of earthworms and ground beetles, which benefit from a weed-covered habitat that provides concealment and moisture. Herbicides have not been seen to have any clear effects on fungi, nematodes (but a tendency towards stimulation), mites and springtails in field tests with field-relevant doses (Wardle 1995). Lastly, the diversity of above soil level insects in a field depends on the amount of weed and therefore decreases where the weed is controlled (Wardle 1995).

There are insecticides, fungicides and herbicides that are poisonous to earthworms, but very few of them are sold in Denmark today. The carbamates are the only group of substances that is generally assumed to be poisonous to earthworms (Edwards, Bohlen 1992). Some of these substances are on the Danish market.

Leaf beetles

The knotgrass leaf beetle is a source of food for field birds. It is estimated that when a cereal is treated with the insecticide dimethoate, 7-40% of the population is exposed to a directly fatal dose of the insecticide (Kjær, Jepson 1995; Kjær et al. 1998). Practically no leaf beetles survive treatment with insecticides because the survivors eat leaves containing dimethoate (Elmegaard et al. 1998).

Direct effects of spray drift on arthropods in areas close to fields

When a field is sprayed, drift can occur to areas in the immediate vicinity of the sprayed area. The extent of this drift depends on both the spraying equipment and the climatic conditions – primarily the wind velocity (see section 4.1.6.2). A number of studies have been carried out of the effect of spray drift on the large cabbage white butterfly. These studies showed that the butterfly was affected by insecticides right up to 24 metres from the edge of the field. The effect naturally depended on the spray product used and varied between 2 and 24 metres (Davis et al. 1991, 1993, 1994; Sinha et al. 1990; de Jong, van der Nagel 1994). The long-term effect can be expected to be greater since the studies mentioned only monitored the butterflies for a short time after they had been exposed. Cilgi and Jepson (1995) thus found, for the same species, that exposed larvae continued to have excessive mortality 10 days after they had been removed from plant surfaces treated with the spray product deltamethrin.

Waysides

Waysides, like other small biotopes, have important ecological functions for plants' and animals' survival in the landscape. Wayside flora in Denmark comprises several hundred species and many different plant societies, ranging from totally dry to distinctly wet and from completely light and open to very shady. Studies of waysides at the end of the 1960s showed that perennial species covered about 90% of the wayside area, biennials 2%, and annuals 9%. Of these species, only the dandelion spreads seeds to annual crops. The dandelion is also favoured by the widespread mowing of waysides. Some local and county authorities still use chemical weed control in many places, over a width of about 30 cm along roads and under and around crash barriers and road signs (Bisschop-Larsen 1995). In addition, damage is often seen after herbicide treatment of fields, and in some cases the herbicide is sprayed directly out onto waysides. There is no systematic Danish registration of the effect of pesticides on wayside flora and fauna.

Direct effects on higher fauna

Direct poisoning of birds and mammals has been reported many times – also in Denmark. However, cases of individuals found dead after normal agricultural use of pesticides are rare. Many of the cases of poisoning observed and described are due to dressed seed or granulates that tempt mammals and birds. Dressed seed and granulate, lying accessible, make it possible for the animals to consume large quantities of pesticide in a short space of time. Since it can be difficult to find carrion after a case of poisoning and determine whether the death was due to poisoning, one must be cautious about rejecting such a risk because of lack of records. On the other hand, numerous field studies and laboratory tests indicate that the vast majority of pesticides used legally in Denmark do not have direct toxic effects in the concentrations in which they occur in the field. That also applies to most of the products used for seed dressing or as granulate, since products that constitute a serious threat to fauna are no longer sold on the Danish market.

Hormone-mimicking effects

Growing evidence has been found in the last few decades that man-made substances can mimic hormones or the regulation of hormones in animals and humans (Colborn et al. 1993). Such substances are often described as hormone-like substances. They can have a big effect on reproduction and the growth of organisms. Particular attention has been paid to substances that mimic or affect the sex hormones, the so-called oestrogenous and androgenous substances (Toppari et al. 1995). Manmade substances that affect the hormone systems have been known for more than 40 years and include previously and currently used pesticides and industrial chemicals. Most of the knowledge in this area concerns humans and fish, whereas little is known concerning terrestrial animals (Janssen et al. 1998). In the case of pesticides, hormone-like substances have been found among the now banned organochlorinated pesticides and organotin compounds. Alkylphenols and alkylphenolethoxylates, which have been used as coformulants in pesticide formulations, are examples of industrial chemicals that can affect the hormone systems in animal tissue (Györkös 1996; Janssen et al. 1998). Tests with these substances have been carried out primarily on rats, mice and a few bird species. However, the observed effects must be assumed also to apply to a large group of mammals and birds. According to Janssen et al. (1998), corresponding information is not available for other groups of animals. The pesticides authorised for use today are not deemed to constitute a risk to terrestrial fauna with respect to hormone-like effects. The amount of alkylphenols and alkylphenolethoxylates used as coformulants in pesticides represents less than 10% of the total use of this group of substances in Denmark. Pesticides are the only group of products for which a phase-out of these substances has been prescribed before the year 2000. The phase-out has largely been completed.

Indirect effects of pesticides on arthropods

The purpose of treating crops with herbicides, fungicides and insecticides is to remove the respective pests. Since the products generally have toxic effects beyond what is intended, plants, fungi and insects must be expected to be affected to a varying extent by spraying. This affects organisms that prey on the affected species. It has also been proven that herbivorous insects occur with much lower densities in areas treated with herbicides (Potts, Vickerman 1974; Hald et al. 1988; Hald et al. 1994; Reddersen et al. 1998) and that fungivorous insects are found in smaller numbers in plots treated with fungicides (Hald et al. 1994; Reddersen et al. 1998). In the case of predatory and parasitic insects, it can be difficult to distinguish the direct effect from the indirect effect of insecticides on their food. However, it has been found, for example, that the frequency of ground beetles with empty stomachs is higher in fields treated with insecticides than in untreated fields (Chiverton 1984).

There are thus numerous examples of pesticides affecting the density of prey, so that the predators lack food. If, on the other hand, the predators are the most sensitive to a given pesticide, the effect can be the opposite. Treatment can thereby reduce the density of predators, leading to an increased number of prey (Croft 1990). If the prey is primarily pests, there could thus be an unintended increase in the number of pests.
In several countries, including Denmark, a richer flora has been found in organically cultivated fields (Moreby et al. 1994; Hald, Reddersen 1990) and this – together with other factors that differentiate the two cultivation systems – has been followed by considerably richer insect fauna, with respect to both species and individuals, in organically cultivated fields (Reddersen 1998).

Several studies have shown a negative indirect effect on the insect fauna from herbicide spraying in addition to the effect on herbivorous insects. In particular, it is well documented that various general predators, such as ground and rove beetles, are more numerous in cereals with ground cover of wild plants (Speight, Lawton 1976; Powell et al. 1985; Chiverton, Sotherton 1991; Reddersen et al. 1998). Here, it is presumably the ground cover, which provides concealment and changes the microclimate in a favourable direction, that is the deciding factor. However, it does not appear that spiders are affected by the ground cover (Chiverton, Sotherton 1991; Reddersen et al. 1998). It has also been shown that a large number of other insect groups, including many beetles, flies and midges, are indirectly affected by herbicides via the quantity of weed. Serious and long-term indirect effects of herbicide treatment on the entire insect community in cereal fields have been observed, with greatly reduced total densities (20-85%) and also a consistently lower species diversity (Reddersen et al. 1998).

Indirect effects on mammals and birds

Indirect effects of the use of pesticides have also been found one step higher up the food chain. Common species of bird in farmland, such as partridge, pheasant, yellowhammer and skylark, breed less successfully in fields treated with pesticides than in unsprayed or organically cultivated fields, even though the substances used are not directly poisonous to birds in the dosages used (Potts 1986; Hill 1985; Petersen et al. 1995; Odderskær et al. 1997). Attention has therefore been directed towards effects on the birds' sources of food. In the breeding season, birds and, particularly, their young eat mainly insects from all trophic levels, e.g. herbivores, fungivores and insectivores.

The relationship between source of food and the birds' breeding success has been closely studied in Denmark in the case of the skylark (Odderskær et al. 1997). This study is one of the most detailed and statistically best designed studies with respect to clarifying the relationship between pesticides, source of food and the birds' breeding success.

The study showed that treatment with herbicides and insecticides impairs the skylarks' source of food, but the relationships are complex since other factors than use of pesticides affect the system. For example, the weather affects the amount of food and also affects the need for food and the time available to the parent birds to search for food, since the young cannot tolerate lying alone and unprotected in the nest in bad weather.

Theoretically, one can imagine an optimum year in which the use of pesticides has no effect on skylarks because they have ample food and a catastrophic year in which pesticide treatment reduces the skylarks' breeding success to zero. However, such extremes are likely to be very rare.

In the four years of the skylark study, the number of young leaving the nest fell on average by 38% on sprayed fields compared with fields that were not sprayed with herbicides and insecticides. The difference was due to the fact that the skylarks in treated fields had more unsuccessful attempts at breeding and largely abandoned the attempt after the insecticide treatment, whereas many pairs of skylarks continued breeding in untreated fields. For two weeks after treatment with insecticides, there was on average three times less insect food in the treated fields. Thereafter, the difference between treated and untreated fields decreased considerably. Barley fields are often treated with insecticides at the time the skylarks' breeding activity culminates. A considerable part of the nestlings' food consisted of ground beetles (42%), which occurred irrespective of the pesticide treatment of the fields. However, the amount of food is not necessarily the only critical variable; the quality of the food may also be of importance. An analysis of the nestlings' faeces revealed that the content differed considerably in treated and untreated fields. The proportion of ground beetles was greatest in sprayed fields, while butterfly larvae, plant bugs, leaf-beetle larvae and several other species were more frequent in unsprayed fields, where the diet was more varied. Precisely among butterflies, plant bugs and leaf-beetles, a large proportion of the species live from wild plants. Many of the herbivorous insect species occurred in greatly reduced numbers in treated fields because their conditions were considerably impaired by both herbicides and insecticides.

In British studies of the grey partridge, it has also been concluded that the fauna living on cereals are an important part of the bird's diet, both quantitatively and qualitatively (Potts 1986). In Britain, both partridges and pheasants have been found to have a higher survival rate in fields with unsprayed headlands (Rands 1985). The headlands are important for these gallinaceans because they often forage along the edges of fields. The edges of fields are the part of the field that is richest in species of both flora and fauna, while at the same time the crop yield is often reduced (Hald, Elmegaard 1989; Hald et al. 1994; Wilson, Aebischer 1995). The edge zone is therefore the part of the field where one gains most from not spraying.

In Denmark, the sizes of yellowhammer broods have been studied on organically and conventionally cultivated fields and found to be about 15% bigger on organically cultivated fields (Petersen et al. 1995). In this study, too, the effect is attributed to a larger, more varied and more stable food resource on organically cultivated fields, although the yellowhammer's food was not analysed. At the same time, higher densities of yellowhammer were recorded on organically cultivated fields in the wintertime, which may be due to the more abundant flora and the consequently larger seed pool (Petersen, Nøhr 1992).

Birds are particularly interesting because a breeding bird index is prepared each year on the basis of counts all over the country. Birds are thus the only group of organisms for which we have monitoring data that can be related to pesticide consumption over time. It is known that birds are affected by a number of other agronomic variables as well and also exhibit climatically determined population fluctuations. Some species are migratory birds, which are affected in the winter period by the conditions in other countries, including the use of pesticides. To summarise, the relationship between the breeding bird index and the use of pesticides is complicated, and the use of pesticides can be regarded as one of many factors in a multifactorial complex. That means that qualitative or quantitative changes in the use of pesticides are hardly likely to be directly reflected in the year's index but may be reflected in the trend over a number of years.

The population fluctuations of sixteen species of bird in the period 1976-1996 have been described by mathematical models as a function of a number of climatic variables, land use, treatment frequency for pesticides, size of population in the previous year and several other factors (Petersen, Jacobsen 1997). For three species – wood pigeon, sparrow and yellowhammer, the model indicated that the use of herbicides and/or insecticides had a negative impact on the population size. For these three species, a simulation of the effect of a reduced treatment frequency index (the action plan's goal) on population size was carried out. For wood pigeon and sparrow, the simulation indicated a considerably larger population, whereas the effect on the yellowhammer population was negligible. It is not certain how these results should be interpreted, firstly because the method is based on a number of assumptions and, secondly, because it is not clear how much importance should be attached to the size of the previous year's population. The breeding success of the skylark was thus seriously reduced by the use of pesticides in the individual year but no clear link to population development has yet been established.

Table 5.2 shows the bird species in farmland that are included in the scenario calculations in this report (see 10.3.1). The table gives the size of population and development of these species in the period from 1976 to 1996. The development has now stabilised and some farmland birds, such as the crow, have shown some progress. One of the most vulnerable and specialised farmland birds – the corn bunting – is not included because the available data are thought to be insufficient (Petersen, Jensen 1998).

Table 5.2
Characteristic farmland birds for which sufficient data are available for modelling the population development in the different scenarios. The table also shows the latest estimate of the size of each species population in Denmark and the population trend in Denmark from 1976 to 1996, using the following symbols: -: decline, +: increase, 0: unchanged (+/-20%), 1: 20-50% change, 2: >50% change (Based on Petersen, Jensen 1998).

Species	Number of breeding pairs in Denmark	Trend

Partridge	20,000 – 30,000	-1
Lapwing[a]	30,000 – 50,000	-2
Skylark	1,360,000	-1
Swallow	200,000 – 300,000	0/-1
Whitethroat	358,000	-1
Crow	21,000 – 220,000	+1
Starling	660,000	-1
Linnet	283,000	-1
Yellowhammer	567,000	0/-1

[a]Included in the Red/Yellow list of threatened species as "Requiring attention".

The many indirect impacts of pesticide use mean that species that are not directly affected by spraying still have changed conditions after a field has been sprayed. Depending on the products used and the situation in which they are used, the indirect effects will in many cases be the most extensive. Since the indirect effects are not due to toxic effects on the organisms considered, e.g. birds, one cannot protect the organisms by more stringent requirements concerning the toxicity of the products.

There is nothing to indicate that mammals are generally affected in the same way as birds by side effects of pesticide use. In studies of the hare's population dynamic, pesticides are not mentioned as a possible explanatory factor in the decline in population in the 1960s (Hansen 1991). Among mammals, there are not as many species that are dependent on insects and similar in cultivated fields. For the insectivorous species there are no studies throwing light on the problem.

Unsprayed headlands

Unsprayed headlands are established along fields normally sprayed with herbicides and other pesticides. Unsprayed headlands are in principle a one-year scheme that forms part of the crop rotation. Owing to problems with weeds, unsprayed headlands are not used in crop rotations with beets and potatoes. Placing the zones at the edges of fields, possibly against a hedgerow or other shady vegetation, is normally the least costly solution for the farmer because the yield is often lower along the edges of fields owing to shading and competition for nutrients and water. Unsprayed headlands provide wild plants in the zones with a better possibility of survival and growth. At the same time, they act as a buffer against spray drift to the adjacent small biotopes. After each winter, many of the insect species return to the field from uncultivated areas. Since reproductive capacity is high, spray-free conditions have a big and rapid effect. Insects therefore react with a big and rapid increase in number even though the buffer zones are only one-year zones and are placed differently from year to year. From Danish trials in cereals, we know the effect of unsprayed headlands at pesticide loads slightly below the national average. (Hald et al. 1994). Under these conditions, the total insect densities were just under 50% higher and the species diversity approx. 25% higher than in the sprayed field. The insects considered to be the preferred food of farmland birds were no less than 65% more numerous. These average figures cover a big variation within different insect groups. The effects were greater on larvae than on adult insects and greater on beetles, flies, parasitic wasps, plant bugs and plant hoppers than on other groups. The biggest effect was observed among the herbivores and fungivores. The last-mentioned effects are mainly indirect, since herbicides and fungicides remove the food eaten by these insect groups (Hald et al. 1994; Reddersen et al. 1998).

Importance of headland vegetation to the fauna

The absence of herbicides, in particular, plays a major ecological role in headlands because it results in a much richer flora, with the possibility of both flowering and seeding. The ground cover with different plant species is important as a food resource for herbivores, insects that visit flowers and seed-eaters, although the microclimate and the possibility of concealment also play a role (Reddersen et al. 1998). Buffer zones bordering on uncultivated small biotopes also mean that ground beetles and rove beetles can overwinter there and return to the field in the spring. Certain common insect groups occur in the field only in the buffer zone along uncultivated small biotopes, whether, as in the case of plant bugs and plant hoppers, they live there or, as in the case of harvest spiders, ants and woodlouse, they are simply guests from the boundary biotope.

Only a few species of bird and small mammal live in the cultivated field, while the many species living in uncultivated small biotopes often go on foraging excursions in the field edge: that applies, for example, to different species of mice and species of bird, such as yellowhammer, partridge and pheasant. Such species naturally potentially benefit from the ample food resources available to them in unsprayed headlands.

Effect of pattern of pesticide use on flora and fauna

Wild plants are an important and basic element in the agroecosystem's species diversity, see earlier sections. Use of reduced herbicide dosages could be expected on average to leave more weed in Danish fields. Surviving plants could form a food resource for herbivorous insects, among others, if the food quality of the host plants were adequate. This has been studied in the case of the knotgrass leaf beetle and the herbicide Glean (Elmegaard, Kjær 1995; Kjær, Elmegaard 1996).

There is generally reason to assume that sublethally treated plants can form a food resource for herbivorous animals. The treated plants do not always have the same quality as untreated plants, but for herbivorous animals and seed-eaters, insects visiting flowers, etc. a little food is better than none.

However, there has not been any clear tendency towards an increase in the amount of weed due to the widespread use of reduced dosages – at any rate not when the registration takes place at harvest time (Kristensen 1994). In other words, farmers have become better at spraying optimally and are achieving the same effect with reduced dosages. Studies have not been carried out of the development of weed throughout the season as a function of changes in the spraying pattern.

Reduced dosages of insecticides are not widely used, but are recommended in certain cases by the Agricultural Advisory Service.

For species with LD_{50} close to or above the corresponding field dose, repeated spraying will also increase the probability of the individual being hit and affected by an application. The advantage or disadvantage of split dosing (i.e. the full dose is distributed over several applications with reduced dose) for harmless organisms thus seems to depend on the species' sensitivity to the dosage used. It is therefore interesting to compare these considerations with observations in the field. Split dosing is at present of greatest relevance for fungicides. The side effects are particularly effects on harmless fungi and the derivative effects of reduced fungus densities.

In a study of the effect of split dosing of a leaf fungicide, the effect of 1/3 dose proved to be relatively high, and particularly the effect of the first two (beginning-end May) applications. Depending on the year, 3 x 1/3 dose often has a greater effect on both harmless and harmful fungi than a single full dose. (Reddersen et al. 1998). The results of such comparisons must be expected to depend on the year (the weather) and the actual and relative times when the individual applications are carried out. It is probable that the same applies to fungicides as to herbicides: the recommended dose is normally more than enough to achieve the desired effect. Placed optimally, the effect of 3 x 1/3 dose on sensitive fungi will therefore be more comparable to 3 x full dose than 1 x full dose.

Clear analyses of the importance of split dosing, reduced dosages, spraying time, and weather conditions require simulation models and sensitivity analyses. Such tools are only now being developed.

Since the beginning of the 1980s, farmers have traditionally sprayed winter cereals twice with fungicides. Ten years ago, they used two full doses. Today, optimisation of the application time and falling grain prices have made two applications of 1/3 of the dose the most economically optimum and, on average, that has replaced two applications of the full dose. Depending on the product, the reduced dosages produce a varying dosage response. Split dosing has not increased the risk of routine application of insecticides. However, when traditional spraying with fungicides is carried out around earing, many farmers are tempted to add an insecticide if they have seen a few aphids in order to avoid perhaps having to spray again one week later, when the damage threshold has been exceeded. All else being equal, the direct effects of pesticides will be less with use of reduced dosages.

Product mixtures in preparations and sprayer tanks

The effect of product mixtures is an unknown factor in the assessment of the effects on the pests and non-target organisms. That is because the substances can affect each other's toxicity. In many crops the usual thing is to apply several active ingredients in one go, either as finished preparations or by mixing them in the tank. In Denmark, the extent to which tank mixtures are used in practice has not been investigated. The substances can have an additive, intensifying or impeding effect. It is not possible to get a picture of which substances intensify each other's effect, partly because there are many possible combinations and partly because it depends on the species on which the mixture is tested, the dosages used, and the timing of the test. It has been proven that the effect of many insecticides is intensified by the presence of other substances with an entirely different toxic effect. The intensifying effect may be due to the fact that the substances act on the enzymatic degradation of the toxin, on the penetration of the substance or on the adsorption of the substance. In some cases, an up to 100 times increase in toxicity has been observed, which can radically change a substance's hazard classification. In 32% of the cases found, where an insecticide is involved, the effect on mammals increases by a factor of 10 or more.

An intensifying effect has also been demonstrated in the interaction with ergosterol-inhibiting (EBI) fungicides and pyrethroids. In the UK it has been found that the fungicide prochloraz increases the toxicity of the insecticide lambdacyhalothrin to honey bees 18 times at field dosages. EBI fungicides also affect the toxicity of the organophosphorous insecticides dimethoate and malathion to partridges when the birds have been exposed to an EBI product before being exposed to the insecticides. The effect is assumed to be due to activation of the enzymes that are responsible for the metabolism of the organophosphorous products into the active metabolite. Since the EBI product, together with dimethoate and the pyrethroids are, respectively, the most widely used fungicides and insecticides in Denmark, it is highly probable that intensifying effects occur and cause greater effects than expected on non-target organisms. This is also substantiated by the fact that, in the UK, greater effects than expected have been observed in bees from applications of product mixtures under normal conditions.

Effects of pesticides in forestry

Very few studies have been carried out specifically of the environmental impact from the use of pesticides in forestry. Such analyses of the environmental consequences of silvicultural use of pesticides as have been carried out are therefore to a very great extent based on experience from studies outside forests and on knowledge of how the forest ecosystem functions (Elmegaard et al. 1996; Strandberg 1998). In the case of the higher fauna, it is estimated that direct effects of pesticides are very low in forests, but that there is a direct effect on the lower fauna from pesticides used to prevent and control aphids and other harmful insects in connection with the production of Christmas trees and ornamental greenery. It is particularly the nordmann fir cultures that are treated with insecticides (Østergaard et al. 1998).

In the case of indirect effects, it is primarily the use of herbicides that has effects on both higher and lower fauna. It is principally in ornamental greenery and Christmas tree cultures that one sees indirect effects on fauna, but the use of herbicides in connection with clear cutting in wood-producing forestry also has an effect by removing a large part of the food resources for a time and by affecting the microclimate and the possibilities of finding concealment (MacKinnon, Freedman 1993). In forestry, one operates with long rotation times, determined by the generation length of the different species of tree, which can easily exceed 100 years. Since long-term effects on fauna cannot be excluded, the lack of such studies of pesticide use in forests is unfortunate.

5.1.1 Conclusions

The effect of the use of pesticides on fauna can be divided into direct toxic effects and indirect effects. The direct toxic effects are caused particularly by applications targeted on harmful species of fauna. Besides the harmful species, a wide range of related species are seriously affected, including the pests’ natural enemies and pollinating insects, depending on the species’ dispersal in time and space. Pesticides also affect fauna by removing their food resources through the effect of herbicides on flora, see section 5.2. The effects must also be seen in relation to other effects, including those of crop rotation and soil treatment.

The following specific conclusions can be drawn:

- The indirect effects of the use of pesticides are usually caused by changes in the species' food resources and are due to both insecticides, herbicides and fungicides etc., since the fauna's food resources are to be found among insects, plants, fungi, etc. This affects both harmful and beneficial species and species of higher fauna. The indirect effects in farmland and forests are generally thought to be considerably more extensive than the direct effects.

- Farmland bird life has been the subject of extensive studies, which have shown a significant decline in most of the species associated with farmland in the period 1976-1996. The decline is due to a number of factors, including the use of pesticides, crop rotation and the management of hedgerows and other small biotopes.

- Dressed seed and granulates present a risk to birds and mammals.

- There are very few amplifying studies of the effect of pesticides on organisms that live in the soil. Since the diversity and number of processes in the soil are great and exhibit a similarly big variation in sensitivity to pesticides, the long-term effect has not been adequately clarified.

- The way in which pesticides are used can affect the environmental load. For example, the use of reduced dosages can reduce the direct effects on fauna. In the case of herbicides, it is uncertain whether reduced dosages have been of much benefit to fauna because very effective control is achieved with low dosages.

- Split dosing of fungicides in cereals constitutes a great risk to fungal flora and the associated fauna. Insufficient information on spraying practice is available for analyses at national level.

- When pesticides are used in forests, it is the indirect effects that cause the main impact on fauna. The long-term effects on fauna cannot be judged owing to a lack of tools/knowledge.

- It has been documented that the use of product mixtures involves a risk of intensified effects, but the significance of this in the field is unclear and there is a lack of information on treatment practice.

- The sub-committee recommends that more consistent and systematic use than hitherto be made of permanent unsprayed headlands and protection borders. In this connection, it must be ensured that linked dispersal corridors are established. It is also recommended that the natural environment be reinstated by introducing animal species with a small dispersal potential.

5.2 Effect on the flora in cultivated and uncultivated terrestrial ecosystems

Repeated spraying changes the flora

Trials have shown that repeated and effective spraying of herbicides year after year reduces the number of wild plants in cultivated areas. In semi-cultivated areas, herbicides have been applied occasionally – usually in the form of products against dicotyledonous species with a view to promoting grass species and increasing the fodder value of grazing/hay production. Artificial fertiliser has also often been applied to increase fodder production on the area. This has also been done on land with section 3 status under the Nature Protection Act, which does not fully protect against adverse effects of the use of herbicides and fertilisers since the law simply "freezes" existing practice.

Spray drift

During spraying, there is spray drift to the surrounding areas, although this can be reduced with modern spraying equipment. 10-20 years ago, direct herbicide-spraying with an end nozzle on the spray boom was recommended and practised in many places. Spray drift in connection with normal use of herbicides is a particular problem for edge biotopes because of their relatively large edge area in relation to the total area. For the same reason, most of the small biotopes bordering on rotation fields are seriously affected by eutrophication, caused particularly by artificial fertiliser spread centrifugally on adjacent fields.

Herbicides and nutrients change the flora

As a result of the widespread load of herbicides and nutrients, the composition of the vegetation in these types of biotope has developed towards high-growing grass and herbaceous vegetation with low species content and completely dominated by such species as great nettle, wild chervil, common couch grass, cocksfoot grass, tall meadow oat, corn thistle, grey magwort and goosegrass. These species tolerate most herbicides relatively well and can use the ample supply of nutrients for rapid and high growth, thereby shading out most competitors. In such disturbed biotopes, one typically finds increased plant production and plant biomass per unit of area. In all, there are thus fewer species and less locally and regionally characteristic vegetation, while species with high nutritional requirements predominate.

Reestablishment of the flora is difficult

In work on reinstatement of the natural environment, it has been considered whether the original but lost natural values can be recreated by blocking the negative, direct and indirect input of herbicides and fertilisers. Experience with this is disappointing – in practice, there is substantial 'ecological inertia' acting against reversion to former types of vegetation, mainly due to two factors:

- A tendency towards long-term maintenance of the high-level nutrient status of the biotopes in almost every type of soil except the most sandy and dry. This maintains the competitive high-growing type of vegetation, which effectively prevents remigration of original species.

- The species' poor and often short-lived seed pool and poor dispersal abilities make reestablishment difficult. There are usually big distances, few and poor dispersal paths or actual barriers to dispersal, all working against remigration.

Effects on the seed pool and wild plants in the field

The occurrence of the most common plants in Danish fields generally became less frequent in the 20-year period from 1967-70 to 1987-89 (Andreasen et al. 1996). Weed control is practised with the precise intention of minimising some species (weeds) and favouring others (crops), and the fewer wild plants there are, the less need there is to spray the field in question. There has been a heavy decline in some species because of the intensive weed control with herbicides. In a 25-year period, from 1964 to 1989, increased use of herbicides reduced the average number of species in the seed pool from 12 to 5 per field (Jensen & Kjellsson 1995). In the same period, the total number of viable seeds in farmland halved.

With the object of investigating the relationship between the effects of herbicides on species of weed and the reduction in the number of viable seeds in farmland, a study was carried out to correlate effects at full dose of herbicide mixtures, which were frequently used in cereals in the 1970s and 1980s (effect figures from PC Plant Protection, Per Rydahl, personal communication), with the percentage decrease in the seed pool of individual species (Kjellsson & Madsen, 1998a). However, no clear relationship was found, possibly because other factors also influence the seed pool (e.g. crop rotation, soil treatment and level of fertilisation). A British study shows that the crop rotation plays a major role, affecting the size of the seed pool (Jones et al. 1997).

Spray-free buffer zones

Spray-free buffer zones are established along fields with annual crops, which are normally sprayed with herbicides and other pesticides as described in section 5.1. The wild flora generally reacts strongly and immediately to spray-free conditions because there is plenty of seed in the seed pool to ensure a high plant density. Many wild plants are characterised by a flexible and largely individual growth potential. One could in particular expect considerable quantitative changes and, only secondarily, a number of qualitative changes in the flora. For example, in buffer zones in winter wheat, the total biomass of wild plants was seen to increase 10 to 40 times within a year (Reddersen et al. 1998). The increased growth and seed production would also significantly increase the seed pool after 2-3 years (Hald et al. 1994; Kjellsson & Rasmussen 1995). Buffer zones in cereal crops would have a beneficial effect on common dicotyledonous plant species such as shepherd’s purse, corn pansy, forget-me-not, speedwell, chickweed, white goosefoot and dead nettle, together with a large number of less common species. At the same time, some grasses – particularly annual meadow grass – would decline somewhat. In the short term, one could thus primarily expect an increased total biomass of wild plants caused by the increase of a rather limited number of common species, while an improvement for the less common species would generally require more permanent buffer zones. Hald et al. (1994) thus did not observe any clear increase in the number of species in permanent buffer zones over 5-6 years.

Permanent unsprayed, fertiliser-free headlands

Like buffer zones, unsprayed headlands could help to protect well-preserved vegetation in small biotopes, where such vegetation still exists. In most places, however, the vegetation in small biotopes has been seriously affected by both herbicides and fertilisers in the last few decades. To ensure recolonisation, which normally takes place very slowly, it would be necessary to establish permanent spray-free and fertiliser-free edge zones.

Effect on seed production

It has been shown that sub-lethal doses of herbicides lead to a reduction in plants' seed production. The reduction is related to the dose, and this is probably directly related to a smaller biomass production (Rasmussen 1993; Andersson 1994). For example, a sub-lethal dose (1/2 the normal dose) of isoproturon resulted in a 50 per cent reduction in seed production in common pennycress (Hald 1993). In a Danish study it was shown that seed production in unsprayed field plots was 6-14 times higher than the seed production in sprayed plots (Kjellsson, Rasmussen 1995). At the same time, spraying with herbicides (dichlorprop + 2,4-D/MCPA in normal dosage) resulted in a smaller proportion of the surviving plants being able to propagate. It has been shown that some herbicides (tribenuron-methyl and, to a lesser extent, MCPA) can result in a smaller seed size in some species, such as black bindweed, goosegrass and common pennycress (Andersson 1994). With this knowledge and different scenarios for herbicide use (0 and 100%), it would be possible to model and estimate the effects on the seed pool in farmland and the consequences in the form of changes in the frequency and composition of the vegetation (Kjellsson, Rasmussen 1995; Madsen et al. 1996, 1997, 1999).

The wild flora in hedgerows and small biotopes

Herbicides are normally not used in hedgerows and small biotopes, so any impact on these areas is due to unintended effects from agricultural use of herbicides, e.g. through spray drift (see section 4.1.6.2). During a 5-year period, the flora in Danish field hedges showed a slight tendency to contain more species along unsprayed edges of fields than along sprayed ones (Hald et al. 1994). A 50% standard trial treatment with the herbicide fluroxypyr of a fallow field on sandy soil in the Netherlands reduced the content of species (Kleijn, Snoeijing 1997). Effects on survival at lower dosages (5 and 10 %) were only found for a few species in some years. In another Dutch study, de Snoo (1997) found, in a three-year trial, increased species diversity in unsprayed field edges in sugar beet, potatoes and winter wheat, primarily as a consequence of an increase in the number of dicotyledonous plants.

Effect on the flora through spray drift

There exists a set of standardised values from Germany for spray drift. The values are based on 16 field trials in the period from 1989 to 1992, where, on the basis of a 95% percentile, a so-called "realistic worst case" was established (Ganzelmeier et al. 1995). On the basis of these values and known effect thresholds (PC Plant Protection), a qualitative analysis can be carried out of the effects on plant growth. The method used by Ganzelmeier is not necessarily ecologically relevant. The deposition was measured during spraying with a single spray plume, and the spray product was collected on flat targets laid on the ground. Such data are relevant for estimating the effect on plants that have not yet germinated and for "flat" areas like ponds and lakes. However, plants that have germinated and are established "catch" more of the spray product. Both Davis et al. (1993) and Bui et al. (1998) found that different "targets" had different "catch efficiencies". "Targets" that rise above the ground and have a complex structure catch more spray product than objects lying flat on the ground. Finally, Nordby and Skuterud (1975) found that the dose of spray product needed to trigger a given effect is smaller for plants in the drift zone than for plants directly under the sprayer. An American study showed that sweet cherry is damaged by herbicide drift (chlorsulfuron) at doses down to 1/100 the normal field dose (Al-Khatib et al. 1992). At doses 1/3 to 1/10 the normal dose, several herbicides (2,4-D, glyphosate) caused significant damage. A number of studies (Marrs et al. 1989, 1993; Davis et al. 1993, 1994) of the effect of spray-product drift on plants showed that plants were affected up to 50 m from the sprayed area. However, the majority of the plants were only affected over a distance of 0 to 5 m from the field.

Effects on forest-floor flora

Actual studies of the effect of pesticides on forest-floor flora are rare, so the assessment has been based on knowledge concerning the mode of action of herbicides and knowledge concerning the ecology of forest-floor flora. It is only the effect of herbicides that has been considered because, according to Elmegaard et al. (1996), there are not stated to be any known effects from other groups of pesticides on forest-floor flora.

Østergaard et al. (1998) state that glyphosate is applied once before clear cutting of deciduous trees and conifers and once or twice in the first few years thereafter. This application practice is thought to have a radical effect on the forest-floor plants, so that all individuals of the flora associated with the type of forest in question may be eradicated (F. Rune, Danish Forest and Landscape Research Institute, personal communication). There will still be a seed pool, but it will also be seriously reduced, partly because of the repeated spraying and partly because of changes in the forest climate for a time when renewal takes place by means of clear cutting. Plants from seeds that germinate in the first period after clear cutting, possibly provoked into germinating by the increased amount of light, will often die, either as a consequence of spraying or because of drought, frost-nipping or scorching by the sun. In addition, forest-floor plants have a short-lived seed pool, so these species have no possibility of surviving an unfavourable period during the seed stage (Graae 1999). Even if the treatment is carried out over a limited number of years, it will have a serious impact on the forest-floor flora. Seen over a rotation period, the relatively small treatment frequency index thus has a big impact. In Christmas tree and ornamental greenery cultures, where herbicides are used during the entire lifetime of the culture, there is virtually no forest-floor flora. So massive are the effects that there is no flora at all – which is, of course, the whole idea of using herbicides in these cultures. When Christmas trees and ornamental greenery are produced without herbicides, a flora develops that is dependent on the way the soil is treated, and the method of renewal can be more or less authentic (M. Strandberg, DMU, personal communication).

The rate of recolonisation by forest-floor flora species is very slow (0 - 1m/year) (Brunet & von Oheimb 1998), so it is only in areas in the immediate vicinity of the forest with elements of the original flora that one can expect partial recolonisation by the species that have disappeared. Indeed, Brunet and von Oheimb (1998) also recommend that the slow recolonisation rate of forest-floor flora be taken into account in forestry planning. Inghe and Tamm (1985) have shown in Swedish forests that individuals of blue anemone are more than 40 years old, and it is not unlikely that many species of forest-floor flora can reach a higher age than trees. Danish studies have shown that forests with long continuity (>200 years) have a better developed forest-floor flora than younger forests (Graae 1999), so for Danish forests, too, it is reasonable to expect impacts on the forest-floor flora if herbicides are used in connection with clear cutting and reestablishment of cultures. According to Graae (1999), species propagated mainly by clonal growth will recolonise very slowly, while those dispersed by animals and the wind recolonise more quickly. Mechanical soil treatment instead of the use of herbicides presumably has similar effects on the forest-floor flora, but this has not yet been studied.

Impact on the flora of nature areas through atmospheric transport of pesticides

Herbicides are not normally used on nature areas, but many herbicides are transported over long distances and small amounts of them are thereby deposited on nature areas. No information has yet been found on measurements of direct impacts from pesticide drift on the flora in nature areas apart from boundary areas such as hedgerows. It is therefore necessary to use model calculations. In the Netherlands, the average combined herbicide consumption is 1.35 dose equivalents per year, 5.5% of which evaporates. On this basis and import/export considerations concerning atmospheric transport, it was calculated in a Dutch model study (Klepper et al. 1998) that the Dutch nature areas received an average of 0.02 dose equivalents per year. By means of a dose-response model for the potentially affected natural vegetation, this deposition was used to predict how large a percentage of the species were affected beyond NOEC (No Observed Effect Concentration). The result was that 2% (median value) of the species were affected beyond their NOEC. The percentage of affected species was highest in agricultural areas and in areas with fruit and berry growing. There are no similar calculations for Danish conditions, but the use of herbicides with a treatment frequency index of 1.65 in 1997 (DEPA 1998a) is comparable to the Dutch consumption, since the frequency index corresponds to the Dutch dose equivalent. It cannot be concluded directly from the Dutch calculations that around 2% of the species in Danish nature areas are unacceptably affected by herbicides. The level of impact depends, in part, on how the nature areas are situated in relation to areas in which herbicides are used and on the magnitude of the emission, the wind conditions and the sensitivity of the local plant community. In the Dutch calculations, the biggest uncertainties were reportedly due to the emission calculation and the effect models (Klepper et al. 1998). A diffuse dispersal of pesticides, e.g. via the atmosphere with precipitation, must be regarded as having less effect on the composition of the flora in nature areas than increased supply of nutrition and changed nature management.

The effect of pesticides in rainwater

The occurrence of pesticides in rainwater in Denmark is discussed in section 4.5. Herbicides have also been detected in rainwater in countries in Scandinavia and Northern Europe (Kirknel, Felding 1995ab), but no direct effects on flora as a consequence of this have yet been found (Felding 1998b). It is known from American studies that deposition of atmospheric herbicide residues (sulphonylurea) can produce symptoms of damage in some crops, such as peas and beans (Felsot et al. 1996). It has similarly been shown that even small doses of chlorsulfuron (1/100th to 1/1000th part of normal dose) greatly reduce the plant biomass and seed production in persecaria (Fletcher et al. 1996). In a Danish project on the occurrence of pesticides in precipitation and effects on plants and plant communities, the effects of mechlorprop have been investigated in concentrations corresponding to those found in rainwater. The study covers sensitive species – particularly the crucifers – but no effects have been found (Solveig Mathiassen, DIAS, personal communication). One can assess possible effects by combining data for the deposition of pesticides with effect data.

5.2.1 Conclusions

Together with crop rotation and other cultivation measures, the use of herbicides has considerably reduced the flora in farmland under cultivation. Accidental spray drift can have adverse effects on plants in hedgerows and small biotopes. In particular circumstances, herbicides in rainwater can presumably cause damage to plants outside the cultivated area.

The following specific conclusions can be drawn:

- The number and frequency of plant species in an average field have halved in the last 20-25 years. From an agricultural point of view, this has been a desirable development, but it has adverse consequences for the natural species. The main reason for the decline is the use of herbicides, but changes in cultivation practice have also had a major effect.

- Herbicide drift can affect the flora in hedgerows, small biotopes and nature areas.

- In Denmark, pesticides have been detected in rainwater, but effects in plants have not yet been detected. However, American studies have shown that even small doses of some herbicides can harm particular plant species. The studies in question are limited in numbers and cover only a few pesticides.

- There is a lack of systematic studies of how pesticides in large, connected areas affect wild plants and associated animals in hedgerows, ditches and other small biotopes, and neighbouring nature areas.
- The impact on the flora caused by long-distance transport and deposition of herbicides in Denmark is not known. We know from a Dutch study that effects are probable, but studies of both the effects and the atmospheric transport are needed in order to determine them more exactly.

- There is also a lack of specific studies of the effect of herbicide use on ground flora in forests, but there is no doubt that even the limited use of herbicides in forestry has a great and adverse effect on the original ground flora. Many woodland plant species have a very slow recolonisation rate (0-1 metre per year), which makes them very sensitive to herbicides, even if herbicides are used only in connection with clear cutting and establishment.

- There have been no systematic studies of the combined effect of fertilisers, pesticides and crop rotation on the flora in areas near fields.

- The sub-committee recommends more consistent and systematic use than hitherto of permanent unsprayed headlands and protection borders as buffer zones to protect original vegetation in small biotopes and remaining nature areas. In this connection, it must be ensured that linked dispersal corridors are established. Where the vegetation of small terrestrial biotopes has been seriously affected by the last few decades' intensive use of both herbicides and fertilisers, recolonisation will normally take a very long time. Here, it will be necessary to establish both spray-free and fertiliser-free boundary zones where restoration of the vegetation and the associated fauna is desired. Sowing of wild plants is also recommended as a way of re-establishing original vegetation.

5.3 Impacts on flora and fauna in watercourses, lakes and coastal waters

Pesticides can be transported to watercourses via the atmosphere, through wind drift from field spraying or long-distance transport, via groundwater, drain water and surface run-off, and through unlawful spraying in or near watercourses within the 2-metre buffer zones. From the watercourses, the pesticides can be led to lakes or coastal waters. These can also receive pesticides by the same transport paths as watercourses. All transport of pesticides to fresh water in Denmark is undesirable. Data are available on the occurrence of pesticides in watercourses and ponds, as described in sections 4.2 and 4.3, but there have not yet been any systematic studies of the occurrence in Danish lakes and coastal waters. Studies in lakes have been initiated in connection with Aquatic Environment Plan II.

In this section we describe the impacts of pesticides in fresh water. Since there are only a few Danish studies, the description is based primarily on foreign studies, with the main emphasis on field studies (Friberg 1998). In order to assess the effects of current practice for use of pesticides, concentration levels given in Mogensen and Spliid (1997) are combined with results from the literature. Denmark has distance requirements for many pesticides, which must not be applied closer than 10 or 20 metres to lakes and watercourses. Table 5.3 shows the active ingredients to which such distance requirements currently apply. Some of these ingredients affect organisms in the aquatic environment at lower concentrations than 1 microgramme per litre and a few at lower concentrations than 0.1 microgramme per litre.

Table 5.3
Pesticides subject to special distance requirements. The distance requirement is generally 2 m to watercourses and lakes. The table shows the pesticide, its active ingredients, the type (F = fungicide; H =herbicide; I = insecticide; P = growth regulator). Also shown is the lowest concentration for individual substances that cause 50% mortality or inhibition of activity in laboratory tests with aquatic organisms (fish, crustaceans and algae) (μg/L = microgramme per litre).

Pesticide	Active ingredients	Type	Distance requirement		Acute effect
			10 m	20 m	μg/L
Daconil 500 F	chlorothalonil	B	x		44
Corbel	fenpropimorph	B		x	290
Folicur EW 250	tebuconazole	B	x		6400
Rival	fenpropimorph and prochloraz	B		x	73
Sportak EW	prochloraz	B	x		73
Tilt 250 EC	propiconazole	B		x	680

Tilt Megaturbo	fenpropimorph and propiconazole	B		x	73
Tattoo	propamocarb and mancozeb	B	x		1500
Tilt top	fenpropimorph and propiconazole	B		x	73
Vondac DG	maneb	B	x		220
Dimethoate/Perfekthion	dimethoate	I	x		30000
Cyperb/CympaTi Ekstra	cypermethrin	I		x	0,9
Malathion/Maladan	malathion	I	x		2,2
Mavrik 2F	tau-fluvalinate	I		x	0,018
Karate	lambda-cyhalothrin	I	x		0,21
Pirimor/Pirimicarb	pirimicarb	I	x		19
Cycocel Extra	chlormequat-chloride	P	x		7400
Cycocel 750/CCC 750/	chlormequat-chloride	P	x		7400
Stabilan Extra/Tricorta 750	chlormequat-chloride	P	x		7400
Terpal	mepiquat-chloride and ethephon	P	x		68500
Agil/Propaquisafob	propaquizafob	H	x		190
Ally	metsulfuron-methyl	H		x	2900
Ariane Super	MCPA, fluroxypyr and clopyralid	H	x		10000
Oxitril	ioxynil (octane-acid ester) and bromoxynil (octane-acid ester)	H		x	60
Avenge 150	difenzoquat-methyl-sulphate	H	x		290
Briotril	bromoxynil and ioxynil (like octane-acid ester)	H		x	60
Barnon Plus	flamprop-M-isopropyl	H	x		2400
Totril	ioxynil (octane-acid ester)	H		x	3900
Basagran 480	bentazone	H	x		47000
Basagran M 75	bentazone and MCPA	H	x		10000
Betanal SC/Herbasan	phenmedipham	H	x		130
Betanal Optima/	ethofumesate, phenmedipham and desmedipham	H	x		130
Betaron/Spar 2	phenmedipham and ethofumesate	H	x		130
Boxer	prosulfocarb	H	x		90
Ethosan	ethofumesate	H	x		15000
Ethuron	ethofumesate	H	x		15000
Ethofumesat/Nortron SC	ethofumesate	H	x		15000
Gallant/Haloxyfob	haloxyfob-ethoxy-ethyl	H	x		284
Gardoprim	terbuthylazine	H	x		20
Folar	terbuthylazine and glyphosate	H	x		20
Karmex/Diuron	diuron	H	x		42
Laddok TE	bentazone and terbuthylazine	H	x		20
Logran 20 WG	triasulfuron	H	x		770
Primera	fenoxaprop-P-ethyl	H	x		460
Puma Super	fenoxaprop-P-ethyl	H	x		460
Safari	trisulfuron-methyl	H	x		500
Sencor	metribuzin	H	x		7,8
Simazine/Gesatop 500 FW	simazine	H	x		290
Stomp SC	pendimethalin	H	x		33
Toloran	terbuthylazine and isoxaben	H	x		20
Treflan/Trifluralin	trifluralin	H	x		>12

The effect of pesticides depends on whether the recipient is a watercourse or stagnant water. The effect of pesticides on aquatic organisms generally depends on the retention time and thus on the exposure time. In watercourses, the retention time depends on the average rate of flow and the presence of areas with a low rate of flow. In a watercourse to which a herbicide was added, a stretch with a high rate of flow directly downstream from the treated area was analysed and compared with a more slow-flowing stretch 225 m downstream (Thomson et al. 1995). Although the concentration was briefly higher in the upstream stretch in connection with the spraying, the retention time of the substance in a concentration of more than 1 microgramme per litre was twice as long in the stretch of water 225 m downstream. In watercourses, the concentration of pesticides also decreases at a given distance downstream of the source, depending on dilution and deposition/metabolism. In stagnant water, the effect of the pesticides depends particularly on the volume of water and the rate of water replacement.

Small and slow-flowing watercourses and small ponds are therefore most exposed to any pesticides. Moreover, these systems are closely linked to the surroundings and are therefore more likely to be affected by any use of pesticides in the surrounding areas.

Biologically, watercourses differ from stagnant waters by being open systems. There is permanent drift of organisms with the current, which means that stretches of watercourses are generally recolonised quickly. That means that watercourses are generally very resilient and therefore quickly return to normal once a chemical impact has ended.

Effects on primary producers

There are many documented instances of effects of herbicides on primary producers in freshwater ecosystems, whereas insecticides seldom seem to have any direct effect on plants. The effect of herbicides is usually that they reduce productivity, whereas, in the short term, the biomass is not affected. There is a clear tendency for the adverse effects to end very quickly when the exposure is over. Besides the direct effects of herbicides on primary producers in watercourses, indirect effects have been found in a number of studies. For instance, photosynthesis in an algae community increased at a concentration of more than 4 microgrammes per litre of the insecticide lindane owing to a reduction in the number of grazing invertebrates (Pearson, Crossland 1996).

With the concentrations found for the herbicide atrazine, it is unlikely that algae and macrophytes will be affected. Generally speaking, the concentration has to be much higher than 50 microgrammes per litre before the ecosystems are affected (Solomon et al. 1996). In the case of the herbicide hexazinone, the measured concentrations are also so low that no serious effect on the primary producers is expected. However, up to 43 microgrammes per litre have been found in a drain water sample, which could affect aquatic plants locally if there were little dilution in the recipient watercourse. EC_{50} (4 hours) for hexazinone has been found to be 3.6 microgrammes per litre for aquatic plants in watercourses, and a concentration of 145-432 microgrammes per litre reduced the productivity of aquatic plants by 80% (Schneider et al. 1995).

Effects of insecticides on fauna

A large number of studies show that pesticides can affect the fauna in freshwater ecosystems, both directly and indirectly. Generally speaking, insecticides, in particular, have an adverse effect on the fauna, whereas direct effects from herbicides are often seen only at relatively high concentrations. Indirect effects are seen particularly in the highest trophic levels (fish, amphibians and birds) owing to reduced quantities of prey or in the form of changes in the function of the entire ecosystem. For example, Wallace et al. (1991) found that the decomposition of leaves into fine organic matter fell considerably in a forest watercourse after treatment with the insecticide methoxychlor owing to elimination of the insects that comminute the leaves. Methoxychlor may no longer be used in Denmark. If the possibility of recolonisation of a watercourse is poor, e.g. owing to barriers or the geographical location, it can take a long time (years) for the watercourse's biological conditions to be reestablished, even if the supply of pesticide ceases. In the case of stagnant freshwater systems, the effects of pesticides seem to disappear within a similar period of time. These ecosystems are generally affected by both fertilisers and pesticides.

Effects of herbicides on fauna

In the case of the herbicide atrazine, the concentrations found in watercourses are generally so low that no effect on the fauna is likely. For example, in a study by Grande et al. (1994), the mortality among trout fry, which are more sensitive than adult fish, only increased at atrazine concentrations of more than 50 microgrammes per litre. However, Lampert et al. (1989) showed that concentrations right down to 0.1 microgramme per litre could affect daphnia in stagnant water, even though, in a single-species test, EC_{50} was 2 microgrammes per litre. The study shows that the sensitivity at community level is far greater because both direct and indirect effects play a part. Atrazine concentrations of more than 0.1 microgramme per litre have been found in a pond near Køge, but there are very few other measurements. As in the case of atrazine, the concentrations of hexazine that have been found are so small that no serious effect on the fauna is likely.

The fungicide propiconazole has been found in concentrations up to 0.8 microgramme per litre in a watercourse and 0.1 microgramme per litre in a pond. These concentrations are below the concentration found to have an effect on zooplankton, invertebrates and fish.

The insecticide dimethoate has been found to affect (increase) activity in watercourse invertebrates at concentrations of more than 1 microgramme per litre and to reduce the density of some species (Bækken, Aanes 1994). In the case of zooplankton, an LC_{50}-value of around 20 microgramme per litre has been found in mesocosm experiments (Hessen et al. 1994). The concentrations in Danish watercourses and lakes lie below these values but not significantly below the concentrations that produce effects.

The pyrethroid insecticides are generally very toxic to largely all freshwater fauna, i.e. to zooplankton, invertebrates, crustaceans, fish and amphibians, in very small concentrations – normally less than 1 microgramme per litre. Besides that, the substances accumulate in the organisms (e.g. Andersen 1982), but are eliminated when the exposure ends. The pyrethroid fenvalerate has been found in ponds in a concentration of 0.12 microgramme per litre. Anderson (1982) observed behavioural changes and mortality in invertebrates – particularly amphipods – at fenvalerate concentrations from 0.022 microgramme per litre.

Effects on amphibians

There are only a few studies of the effect of pesticides on amphibians. In a Danish study, the insecticide esfenvalerate caused paralysis in embryos of the fire-bellied toad and the xenopus at a concentration of 1 microgramme per litre. At 5 microgrammes per litre, 80% of the embryos of the xenopus had deformed bodies, oedema and deformities of the spine, brain and intestine (Larsen, Sørensen in prep). Esfenvalerate was detected in a stream, Lillebæk, on Funen in the period 1994-1996 in a concentration of 0.2 microgramme per litre. (Funen County 1997). In that period, the recommended field dosage of esfenvalerate was 25 grammes per hectare. In a pond test in northern USA, esfenvalerate was found to have an adverse effect on daphnia and copepods at a concentration of 0.01 microgramme per litre (Lozano et al. 1992).

Unlawful use of pesticides

With our present level of knowledge, it is not possible to determine how large a part of the measured concentrations of pesticides in fresh water are due to unlawful use.

Watercourses must generally be deemed to be very sensitive to accidents with pesticides at washing sites and similar because, in many cases, the water is led directly to the nearest watercourse. Danish watercourses are also generally small, i.e. more than 80% of them are less than 2 metres wide, and they have low rates of flow. Therefore, even a short spillage of pesticides could have a major, acute effect on the ecological conditions in them.

Effects of pesticides in rainwater

On the basis of rainwater data given in Mogensen and Spliid (1997), the pesticide content must be assumed to be generally so low that it will have no effect on the biological conditions after further dilution in the fresh water system (irrespective of size). However, that does not exclude the possibility of drift from neighbouring fields resulting in local increases in the concentration of pesticides to a level that can be harmful to the freshwater environment. All the same, this problem is probably limited provided the distance requirements for spraying are observed.

Other environmental factors and pesticides

The effects of a given pesticide depend on the other ecological factors in the freshwater environment. For example, Caux and Kent (1995) found that a green alga *Selenastrum capricornutum* was affected differently by atrazine, depending on the chemical composition of the water. The role played by this has not been taken into account in this report. Furthermore, pesticides in watercourses often occur in pulses, especially with unlawful use. It is during such an episode that the concentration of pesticides must be measured for the effects to be assessed. This is seldom possible because the water containing the pesticide passes the sampling site within a very short space of time, so the chance of extracting a sample of the polluted water is extremely small. The measured concentrations are therefore probably often lower than the maximum that has occurred in the system. Another factor that probably has a significant influence on the effect of pesticides in watercourses is the physical conditions. Most Danish watercourses have been physically altered to ensure drainage of surrounding fields, whereby they have been made unnaturally wide and physically uniform. Both the degradation time and the effect on the ecological conditions presumably depend on the physical heterogeneity, so – all else being equal – physically uniform watercourses will be affected most by any supply of pesticides.

5.3.1 Conclusions

There are very few Danish studies of the occurrence and effects of pesticides in Danish watercourses and ponds and, as yet, no systematic studies in lakes and coastal waters. The assessment of the effects of pesticides has therefore been based primarily on foreign studies, and importance has been attached to field studies. It has not been possible, either, to find any studies of the effects of all the pesticides detected in Danish freshwater ecosystems. Since there are often differences in the species composition and the structure and function of the ecosystems in Denmark, compared with the foreign studies, the sensitivity to a given pesticide should be treated with caution. Owing to the relatively low water temperatures in Denmark, compared with more southerly countries, the degradation time for pesticides is shorter in Denmark, so the exposure time and thus the risk of effects are greater. With our present level of knowledge it is therefore difficult to judge how the present use of pesticides affects Denmark's freshwater systems. However, several measurements indicate that pyrethroids and thiophosphate insecticides have been detected in concentrations at the level that has effects according to the existing literature. In particular, the available concentration levels indicate that it is insecticides – and especially the pyrethroids – that can have an adverse effect. In addition, by reason of their persistence, the pyrethroids can occur in freshwater ecosystems for a long period, during which they can be absorbed by, for example, invertebrates that live from dead organic material.

In connection with authorisation of pesticides, tests are carried out to determine their toxic effect on individual species of algae, daphnia, fish and other organisms. Mesocosm analyses that simulate entire ecosystems are also performed. However, these analyses do not provide insight into the many natural factors that interact in nature and they do not cover the combination of the many different pesticides detected in the aquatic environment.

It is therefore likely that the freshwater environment is affected by the present use of pesticides, but it is not yet possible to determine the magnitude of the impact owing to lack of data and knowledge. The county authorities, in their regulatory capacity, have provisionally estimated that around 2% of the unfulfilled targets in approx. 11,000 km of watercourses are due to toxic substances, including pesticides (Windolf 1997). However, this figure is based on a subjective evaluation and will also vary with the region, the sampling method and the frequency.

The following specific conclusions can be drawn:

- Some pesticides – particularly pyrethroid insecticides and thiophosphates – are toxic to aquatic organisms in lower concentrations than the limit value of 0.1 microgramme per litre for drinking water.

- Pesticide concentrations in watercourses are transported with the current. The highest concentrations are probably rarely detected because the water containing the pesticides passes the sampling site within such a short space of time that there is very little chance of extracting a sample of the polluted water.
- Small, slow-flowing watercourses and small ponds are most exposed to any pesticide load.

- The impact on the flora and fauna in watercourses is brief, but even a short pulse of pesticides can have a major, acute effect on the watercourses' ecological conditions. If the possibilities of recolonisation are poor, e.g. due to barriers or geographical location, the effects can in some cases be observed for more than one year.

- The pesticide concentration in ponds and lakes will be longer-lasting than the concentration in watercourses. It will not be possible to evaluate the occurrence and effect of pesticide concentrations in lakes until data are available from the monitoring programme in connection with Aquatic Environment Plan II.

- In watercourses, insecticides have been detected in concentrations that very probably affect the fauna, and there are documented cases of effects of herbicides on algae and other primary producers.

- There is no national registration of the effects on the aquatic flora and fauna.

- The sub-committee recommends that more consistent and systematic use than hitherto be made of permanent spray-free zones and protection borders, which, as buffer zones, would help to protect watercourses, lakes and ponds.

5.4 The sub-committee's conclusions and recommendations concerning environmental impacts

The main impacts occur in connection with the application of pesticides, with organisms being hit directly, and with indirect effects occurring as a consequence of the effect on food chains. Here, plants play a key role as the first link in the food chains. A Danish study has shown that the number and frequency of plant species in field studies have halved in the last 20-25 years. From an agricultural point of view, this has been a desirable development, but it has adverse consequences for the natural species. The main reason for the decline is the use of herbicides, but changes in cultivation practice, including the use of fertilisers, have also had a major effect.

During spraying, there is spray drift to the surrounding areas. However, hedgerows, dikes, dry stone walls and other small biotopes are of such small width that they should in practice be included in the area that is affected by spray products. Spray drift can affect both terrestrial and aquatic ecosystems. In the case of the aquatic environment, any effect from pesticides is undesirable, including changes of flora and fauna in coastal waters, lakes, ponds and watercourses. Among the aquatic ecosystems, it is particularly ponds, watercourses and lakes near fields that could potentially be affected.

The freshwater environment is in all probability affected by the present use of pesticides, but it is not possible on the basis of the existing data to quantify the magnitude of the impact nationally. On the basis of information from the county authorities, it is provisionally estimated that around 2% of the unfulfilled targets of about 11,000 km watercourses can be due to toxic substances, including pesticides. In particular, the concentration levels measured indicate that it is insecticides – and especially pyrethroids – that can have an adverse effect. Owing to their persistence, pyrethroids can also occur in the freshwater ecosystems for a long period of time. There are also documented cases of effects of herbicides on algae and other primary producers. Several measurements indicate concentrations of pyrethroids and certain thiophosphate insecticides that are close to the level that has effects according to the existing literature. For some pesticides, this level is lower than the limit value of 0.1 microgramme per litre for drinking water.

In both cultivated areas and the adjacent biotopes, the use of pesticides involves a risk of reduced populations of flora and fauna, changed biodiversity, changes in the cultivation medium and natural pest regulation, and of food-chain effects and other indirect effects. Seen overall, it is not the individual field and its possible loss of wild flora that are the problem, but rather the total, countrywide effects on characteristic farmland flora and the associated fauna.

In forestry, very little use is made of pesticides, whereas, in Christmas tree and ornamental greenery cultures, the same quantities are used as in farming. The treatment frequency index in nurseries and market gardens is high. There is a lack of specific studies of the effect of herbicides on forest-floor plant species, but there is no doubt that even the limited use made of pesticides in forestry has adverse effects. Many woodland plant species have a very slow recolonisation rate of less than 1 metre per year, which makes them particularly sensitive to herbicides, even though these are only applied in connection with clear cutting and afforestation.

The sub-committee's recommendations concerning the impacts of pesticides in the environment

For the scenarios in which pesticides are used, there are no systematic studies of how pesticides in large, connected areas affect wild flora and the associated fauna in hedgerows, waysides and other small biotopes and in neighbouring nature areas. The effects on the flora caused by precipitation of long-distance transported herbicides in Denmark is not known. Foreign studies show that effects probably exist, but further investigations of both the atmospheric transport and the effects are needed for any closer determination. There is also a need to assess the effect of pesticides on aquatic organisms in relation to the actual finds in watercourses and surface water. The sub-committee recommends that the necessary knowledge be built up and that time series be established to document any effects on the terrestrial and aquatic ecosystems seen in relation to the proven occurrence of pesticides in the environment.

The sub-committee recommends more consistent and systematic use than hitherto of permanent unsprayed headlands and protection borders as buffer zones to help protect watercourses, lakes and ponds, together with well-preserved vegetation in small biotopes and nature areas, where such still exist. In this connection, it must be ensured that linked dispersal corridors are established. Where the vegetation of small terrestrial biotopes has been seriously affected by the last few decades' intensive use of both herbicides and fertilisers, recolonisation will normally take a very long time. Here, it will be necessary to establish both spray-free and fertiliser-free boundary zones where restoration of the vegetation and the associated fauna is desired. The sub-committee also recommends nature restoration by sowing of wild plants and the introduction of species of fauna with a low dispersal potential.

6 Exposure of humans and health effects

6.1 Exposure of, and effects on, agricultural workers

6.1.1 Introduction

Agriculture and health and safety

Primary agriculture comprises farms, market gardens, poultry farms, fur farms and nurseries. The total number of persons employed is approx. 96,000, corresponding to just under 4% of total employment. Of that figure, about 12,000 are employed within market gardening. In 1997 there were 60,900 farms with an average size of 44 ha. Of these, about 400 farms have five or more employees (Danmarks Statistik 1998). As at 1 January 1999, these farms are required to have a safety representative. The average age of farmers is 52 years.

There is relatively little data on health and safety conditions in market gardening, but more data on farming. Besides occupational injuries, in farming there are many of the classic health and safety problems known from other industries – for example:

- work in dusty surroundings (stables) containing allergenic materials from animals and plants
- very hard physical labour (milking, heavy lifting, tractor operation, work with animals)
- noise (pig sheds, tractor operation)
- handling and working with chemical substances (spray products, mixing, placement)
- contact with other chemical products in connection with repair and maintenance of machines/buildings (paint, organic solvents, welding fumes)
- various tools (motor-saws and similar)
- working on one's own.

As background for section 6.1, interviews were held in October-November 1998 with key people within the area (Bjørn, Rothmann 1998) and various players within agriculture were contacted by phone. The section is otherwise based on publicly accessible information.

The treatment frequency index for pesticides in market gardening and fruit growing is considerably higher than in farming. The index is thus typically 20-25 in the production of apples, 11 in strawberries and 4-12 in vegetables. In nurseries, the index is 4-14. There are no figures for the treatment frequency index in greenhouses, but it is presumably higher than the outdoor index. An exception is greenhouse production of cucumbers and tomatoes, where biological control is used.

Health and safety factors in weed control

Table 6.1 shows factors that are of importance to health and safety with and without pesticides. It is mentioned in the table that vegetables need manual weeding as well as mechanical weed control. For example, carrots have to be weeded manually once per season and onions twice per season. In large production units, a trolley is used. On this, 10-15 people lie on their stomachs with their heads supported. The trolley is pulled along at a speed of about 600 metres per hour over the rows, which are weeded by hand.

Table 6.1
Factors of importance to health and safety with and without pesticides (Based on Bjørn, Rothmann 1998).

Without pesticides	With pesticides
Mechanical and manual weed control.	Chemical control and (mechanical) weed control.
Cereals, rape, seed, maize and vegetables: treatment 2-3 times with interrow cultivation and harrowing. Vegetables also require manual weeding.	Spraying 3-20 times, depending on the crop, weather conditions, insect and fungal attack. Often includes one application of herbicides.
Time on tractor/machine.	Time on tractor.
The operator can be exposed to dust if the tractor cab is not closed.	The operator can be exposed to dust and pesticides if the tractor cab is not closed.
The operator has to work sitting down on the tractor and often has to turn/twist his body and neck to look behind him. It is difficult to use mirrors.	The operator has to work sitting down on the tractor and often has to turn/twist his body and neck to look behind him. It is difficult to use mirrors.
Noise from the tractor and machines, depending on the sound insulation of the cab.	Noise from the tractor and machines, depending on the sound insulation of the cab.
Accidents in connection with tractor operation, repair and maintenance of machines.	Accidents in connection with tractor operation, repair and maintenance of machines.
Happier when one does not have to spray.	Anxiety and unease about working with spray products: aquatic environment, long-term effects on health and the environment, public opinion.
No exposure to pesticides.	Exposure to pesticides during filling, emptying, cleaning and repair of spraying equipment.
Asthma and bronchitis caused by dust from plants and animals.	Asthma and bronchitis caused by dust from plants and animals.

General ergonomic problems

Driving a tractor can seriously load the driver’s back because he often has to sit with his back turned in order to keep an eye on the work. This applies not only during ploughing, harrowing and other forms of weed control, but also during sowing and spraying. In connection with sowing there is a risk of back injury because sacks of seed weigh 50 kg. In addition manual collection of fieldstones involves a risk of physical injury, both from handling heavy stones and from use of a stone fork for smaller stones. Stable work, including handling of farm animals, is often hard, physical work. It seems to be generally accepted by farm workers that their work involves a serious risk of physical wear and of injury. The most common health complaints are “back problems”, “bad foot” and “squeezed fingers”. On the other hand, it seems that young farm workers are no longer willing to expose themselves to heavy loads or to use methods that are regarded as physically wearing.

Particular problems with pesticides

The risk in connection with the use of pesticides can be considerably reduced by using suitable safety equipment and by following the prescribed safety rules. Even so, some users are not happy about using pesticides because of doubts concerning the efficacy of gloves, breathing equipment and other safety equipment (Bjørn, Rothmann 1998). Since it is not possible in practice completely to avoid contact with the products, some users are worried about possible chronic effects. Others put ensuring the harvest ahead of any long-term effects, so the working environment does not have the highest priority.

6.1.2 Accidents and injuries

Reported occupational injuries

The Danish Working Environment Authority (WEA) has analysed the statistical data for the period 1993-1997 concerning reported occupational injuries in farming (Bjørn, Rothmann 1998), using employment figures from farming as at 1 January 1994. In the three largest sectors, the employment figures were as follows:

1. Dairy farming	29,564 persons
2. Arable farming	25,498 persons
3. Mixed farming	21,284 persons

About 75% of the people working in agriculture were employed in these three sectors, and it is also these three that have the biggest number of reported industrial accidents.

In the period 1993-1995 26 fatal accidents were reported, 20 of which occurred in the said three sectors. Most of the serious accidents reported – resulting, for example, in amputation, broken bones or injury to extensive parts of the body, also occurred in these three sectors, namely, 256 reports out of 395. For the whole of agriculture, occupational injuries were reported for 1,318 persons.

The largest number of “very serious accidents” (331 out of 395) was reported for persons of 45 or under. The largest number of fatalities (21 out of 26) was reported for persons over 45. It should be noted that even though about 50% of the employees were over 50, it is the younger age groups that had the highest report incidence (8-12 reports per 1000 employees). The average incidence for reported industrial accidents in the whole of agriculture was 4 reports per 1000 employees. The age groups 18-24 years, 25-29 years and 30-34 years accounted for 54% of all reported industrial accidents. The 18-24 year age group accounted for 27% of reported, very serious industrial accidents. Most of the industrial accidents occurred in August-September.

In the case of children and young people under the age of 18, most reports related to the 16-17 year age group. 84% of children and young people employed in agriculture were less than 18 years of age. For this group, most of the industrial accidents were reported within the first six months of employment. Most of the reports concerning children and young people were received in June-July. Farming has more fatalities than any other sector of industry.

Type of accident event

About one third of the types of accident events are classified as “lost control of machines, aids and systems”, but accidents in connection with work with animals (aggressive animal/animal out of control) and accidents involving falls also together account for one third. In the period

1993-1997 a total of 2,429 industrial accidents and 979 cases of work-related diseases were reported. Only the material for the period 1993-1995 has been thoroughly analysed.

Tractor accidents

In the period 1993-1995 there were 26 fatal accidents. In 12 of them the cause was “lost control of machines, aids and systems”, and in six, a tractor was involved. Of four fatalities due to falls, two were falls from a tractor. One of two fatal traffic accidents was caused by a reversing tractor. In the period in question, 72 industrial accidents with tractors were reported. These accidents are often very serious. There are relatively many fatal accidents, namely 9 out of 72 in which tractors are involved.

Accidents resulting in musculoskeletal injury

Under the classification “lost control of own movement” (musculoskeletal injury), 79 industrial accidents were reported in the period 1993-95, six of which were serious (primarily broken bones). These accidents frequently occur during lifting, pushing and/or pulling of objects and animals.

Occupational diseases

Most of the occupational diseases reported in the period 1993-1995 were within the diagnostic category “musculoskeletal diseases”. They were followed by hearing damage and skin diseases and then by pulmonary diseases, both allergic and non-allergic. One case of cancer was reported in the period. It has not been possible to find more than one named pesticide exposure, namely methylparathion, listed under “other diseases”. There is no mention of the specific diseases that resulted from this exposure. A few other pesticide exposures may be listed in the category “chemical effect without specification”.

The “Ringkøbing study”

In view of the large number of accidents that occur in farming, Ringkøbing County’s Occupational Medicine Clinic and Herning Central Hospital, in cooperation with the Agricultural Advisory Service, have analysed possible causes of accidents in farming. The project was divided into three phases (quoted by Bjørn, Rothmann 1998).

First phase

The first phase consisted in recording all serious farming accidents in Ringkøbing County. This was done in 1992. 257 serious occupational accidents were found, four of which were fatal. There are around 8,000 farms in the county.

Second phase

In the second phase, about 400 farms with about 1,600 farmers, farm workers, spouses and children were chosen at random from three Danish Agricultural Advisory Centres in Herning and Holstebro. For one year (1993-1994), the farmers were asked to record once a week both small and large accident events occurring in connection with farm work. At the same time, the hours spent on the different types of work, such as field work, stable work, repair work, etc., were recorded. During the year, 389 accidents resulting in injury were recorded. Of these, 28% required medical treatment. After adjustment for work time used, the work-related accidents hit all age groups equally. 62% of all independent farmers had one accident resulting in injury per year. The corresponding figure for farm workers was 22%. 45% of the accidents occurred in connection with direct contact with animals. When fall accidents in stables and work-related accidents during use of stable machines are included, accidents in stables accounted for 51% of all accidents.

Animals require many hours of work. Taking this into account, the frequency of accidents with animals and machines is almost the same. With this time weighting, repair and maintenance involve an almost seven times higher risk of a work-related accident than ordinary farm work.

Most work-related accidents occur in the autumn, when most hours are also spent on work on the farm. With more working hours, the number of work-related accidents increases, but adjusting for the increased risk time, one finds no increase in frequency due to long working hours.

Third phase

In the third phase, a safety inspection of the farms was carried out. At the same time, a team of 10-15 instructors held a safety course at which work habits and methods of work were discussed. Before this preventive intervention, the farms in the test group had 29.2 accidents per 100,000 working hours. After the intervention, this figure fell by just under 40% to 17.5 accidents per 100,000 working hours. In the control group, 21.3 accidents per 100,000 working hours were recorded at the start of the same period, and 20.0 accidents per 100,000 working hour at the end of it. More serious work-related accidents were also reduced by about 40% in the test group. In the analysis, a relationship was found between stress and work-related accidents, with the persons indicating the most stress symptoms also being those with the most accidents. Those participating in the project were asked about the time they spent on field spraying. The average was 39.5 hours per farm per year. For the individual farm, the time spent on spraying per year varied from 0 to 1,133 hours (Bjørn, Rotmann 1998).

The organic sector's status in South Jutland

The working environment at organic farms was included in a special questionnaire-based survey in South Jutland County among farmers from both organic and conventional farms and among agricultural advisers. The survey, which covered 90 persons, is reported in Bjørn and Rothmann (1998). In all, 48 responses were received.

36 responses came in on health and safety. Of these, 24 farmers stated that the organic form of production had not involved more manual work. 12 farmers thought it had given rise to more manual work in the form of feeding, lifting beets, moving cows and spreading straw. One farmer mentioned osteoarthritis, which figures as the only stated work-related injury.

In reply to the question of whether the restructuring had caused problems with dust, 41 persons replied “no”, while two farmers said “yes” and mentioned spreading of straw and hoeing of potatoes. In reply to the question of whether they had experienced a beneficial effect from no longer using spray products, 26 farmers replied that they had, while 8 farmers replied that they had not experienced any beneficial effect. The main reasons given for switching to organic farming were a desire for new challenges and suspicions about pesticides.

6.1.3 Work-related factors with pesticides and mechanical methods

The sprayer operator's exposure to pesticides

There is extensive knowledge concerning the exposure of sprayer operators in different spraying scenarios (EUROPOEM 1997). This knowledge has been put on the Internet (DIAS 1998). Figures 6.1 and 6.2 show scenarios for an average Danish farming scenario with use of a tractor-drawn boom sprayer, where the sprayer operator fills the tank and sprays, using either a spray fluid (figure 6.1) or a powder pesticide product (WP, wettable powder) (DIAS 1998). It is assumed in the scenarios that the sprayer operator wears protective clothing and that the gloves and the clothing retain 50%. A daily work time of 6 hours is assumed, during which 20 ha are sprayed. There is potential exposure of the skin, i.e. the amount of pesticide lying on the skin, since the amount absorbed by the organism depends on the ability of the individual pesticide to penetrate the skin. It will be seen from the figures that 85-99% of the exposure occurs during filling of the tank, even though this work only accounts for a small part of the total working time spent on spraying.

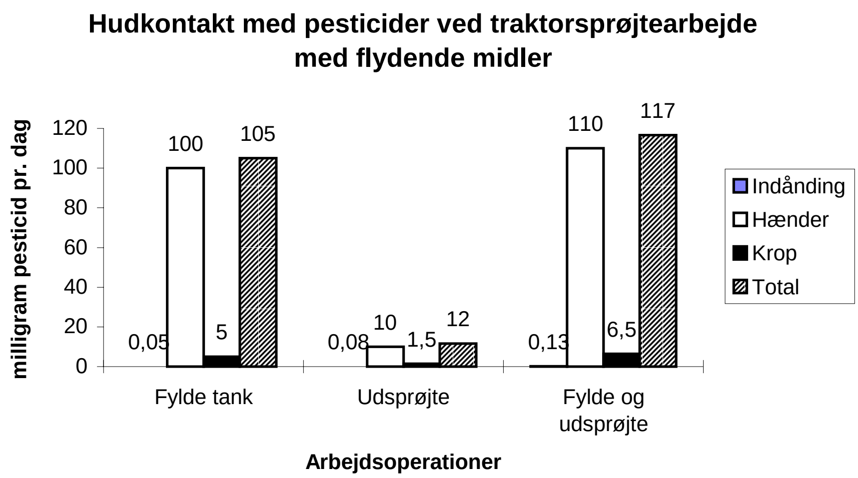


Figure 6.1
The tractor operator's exposure to ***liquid products*** *via inhalation, hands and body in different work operations (filling of tank and the actual spraying). The total exposure for the two operations is shown on the right (DIAS 1998; EUROPOEM 1997).*

(Figure text:
Skin contact with pesticides during spraying with liquid products
milligram pesticide pr dag = milligrammes of pesticide per day
Fylde tank = Filling tank
Udsprøjte = Spraying
Fylde og udsprøjte = Filling and spraying
Indånding = Inhalation
Hænder = Hands
Krop = Body
Total = Total
Arbejdsoperationer = Work operations

The hands' share of the total load is 62-94%. With powder products there is also relatively big exposure of the rest of the body. The exposure via the lungs is minimal compared with the total load. However, it should be noted that exposure via the lungs is normally more dangerous than exposure through the skin. The load averages 117 mg per day with liquid products, while the average exposure with powder products is 822 mg per day. Protection aids and clothing provide a low level of protection (50%), but if they are not used or are not functioning as they should, the exposure can be twice as big.

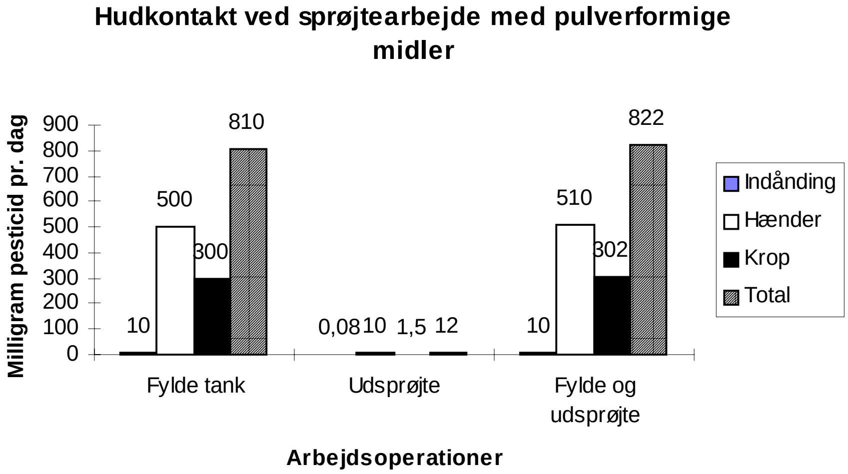


Figure 6.2
The sprayer operator's exposure to ***powder products*** *via inhalation, hands and body during different work operations (filling of tank and the actual spraying). The total exposure for the two operations is shown on the right (DIAS 1998; EUROPOEM 1997).*

(Figure text:
Skin contact with pesticides during spraying with powder products
milligram pesticid pr dag = milligrammes of pesticide per day
Fylde tank = Filling tank
Udsprøjte = Spraying
Fylde og udsprøjte = Filling and spraying
Indånding = Inhalation
Hænder = Hands
Krop = Body
Total = Total
Arbejdsoperationer = Work operations

It is known that the potential exposure can be reduced by about 75% by using extra equipment in the form of, for example, preparation-filling equipment, hydraulic boom lift, hydraulic folding-in and out of the boom, non-drip valves, self-cleaning filter and tank-washing nozzle (Lund, Kirknel 1995). The yearly exposure of sprayer operators to pesticides depends on how many days per year they carry out spraying. Since the exposure per spraying day can be 500-4000 times greater than the average daily intake of pesticides via food (see section 6.2), the annual exposure of sprayer operators with many working days is considerably higher than the annual exposure via food products.

Exposure of greenhouse gardeners

For nurserymen working in greenhouses, exposure can occur during the spraying itself and in connection with work processes in the greenhouse after spraying. After spraying, the exposure depends on the time that elapses after spraying until the work in the greenhouse is carried out –

the so-called re-entry time. During the work, the amount of pesticides and the area of leaves touched by the nurseryman during a working day are of critical importance. Important factors include the length of the working day and the substance's degradation, evaporation and transferability from the treated plant surfaces to the nurseryman.

There are very few studies of greenhouse workers' exposure to pesticides that can be used as models for exposure. Kirknel et al. (1997) mention a few German and some Dutch studies in this area. The result of the Danish studies accords with those of the German and Dutch studies. The Danish studies must be regarded as representative of a broad section of work functions in pot-plant nurseries in that they include not only work directly with plants but also moving of work-benches and packing of plants. Dutch studies in tall crops in greenhouses, such as tomatoes and cucumbers, fall within the result of the Danish model. The result of the Danish model is expressed as the 90-percentile, i.e. the highest exposure that 90% of a group of nurserymen can be exposed to. This cut-off point is generally regarded as high, with good safety. The Danish studies do not include the spraying of pesticides. Most spraying of pesticides in greenhouses is done automatically, with little risk of exposure. However, there is some limited spraying in Danish greenhouses with a hand-held spray gun, where the exposure is considered to be relatively high. Measurements of this work function are being studied in the UK (personal information, Erik Kirknel).

Kirknel et al. (1997) have developed a model for the exposure to and absorption of pesticides on re-entry into greenhouses. The daily potential exposure can here reach approx. 100 milligrammes of pesticide per working day, but typically lies in the interval 1-60 milligrammes in a working day of 6 hours with contact with the treated plants one day after the pesticide treatment. The most critical variable is the rate at which the pesticide disappears from the plant's surface. In the exposure model, account is also taken of the amount of pesticide that can penetrate the skin. It is only the amount that penetrates the skin that causes possible health effects. The amount is normally less than the amount that lands on the skin.

6.1.4 Risk of cancer

Pesticides and cancer

Human data on exposure to pesticides and cancer are mainly based on occupational exposure in farming, forestry and horticulture and among workers employed in the production of pesticides. Reviews of these studies have not revealed a significant rise in the total mortality from cancer among persons occupationally exposed to pesticides (Dich et al. 1997; Maroni, Fait 1993; Blair, Zahm 1991). Furthermore, the total mortality was found to be lower among these groups of persons exposed to pesticides than among the general population. This has usually been ascribed to a "healthy worker effect" and, in the case of people employed in farming, to a healthier lifestyle among farming families. However, farmers, in particular, seem to have a higher occurrence of some types of cancer, including non-Hodgkin's lymphoma, Hodgkin's disease, multiple myeloma, leukaemia, soft-tissue sarcoma and cerebral cancer, skin cancer, lip cancer, stomach cancer and prostate cancer (Dich et al. 1997; Blair, Zahm 1995: Blair et al. 1992). Most epidemiological studies of cancer and pesticides have dealt with pesticides as a whole and are short on detailed information about the exposure. There are very few studies that have evaluated individual substances or classes of pesticides. Such studies are both difficult to design and difficult to interpret because people are seldom exposed to only one pesticide. Organochlorine compounds (to which the banned substance DDT belongs) have been associated with chronic lymphatic leukaemia, malignant lymphoma, multiple myeloma and soft-tissue sarcomas, and organophosphates and phenoxy acids have been associated with non-Hodgkin's lymphoma. In cohort studies, insecticides as a group have been associated with increased risk of lung cancer, cerebral cancer and pancreatic cancer. A review of epidemiological studies of herbicides and cancer revealed reasonable evidence for assuming an association between non-Hodgkin's lymphoma and phenoxy acid herbicides (Morrison et al. 1992). Furthermore, several studies found big increases in the risk of soft-tissue sarcomas from exposure to phenoxy acids but lacked proof of a dose-response relationship. Triazine herbicides have also been associated with non-Hodgkin's lymphoma and soft-tissue sarcomas and with leukaemia, multiple myeloma, bowel cancer and ovarian cancer. However, in a review it has been found that the epidemiological data are insufficient to determine whether a relationship exists between exposure to triazines and cancer in humans (Sathiakumar, Delzell 1997).

Cancer in children of users of pesticides

There are only a few studies on the relationship between low-dose exposure to pesticides and cancer in children. The studies are based on different exposure scenarios – prenatal, postnatal, exposure in the home and parents' potential exposure to pesticides in their occupation. Most of the data are from case control studies, and most of the research has been concentrated on leukaemia and brain tumours , presumably as an expression of the low occurrence of other types of cancer in children. The studies are limited by unspecific information on the pesticide exposure, potential recall bias, few cases, and most comparisons usually based on less than 10 exposed persons. However, many of the types of cancer that, in children, are associated with pesticides are the same types as are repeatedly associated with pesticide exposure among adults (Zahm et al. 1997), which could indicate a probable relationship. In addition, the observed risks are often greater among children than adults, which could indicate that children are more vulnerable to the carcinogenic effect of pesticides. Cerebral cancer is an example of a type of cancer in children that is frequently related to exposure to pesticides.

Other types of cancer that have been associated with exposure to pesticides include osteosarcoma, soft-tissue sarcoma, colorectal cancer, testicular cancer and other malignity in gametes, Hodgkin's disease and retinoblastoma. With very few studies for each type, conclusions cannot be drawn about the possible significance of pesticides to the etiology of these types of cancer.

Limitations in the study of cancer in children

The studies generally suffer from methodological limitations. Incorrect classification of exposure, insufficient group sizes, bias in the choice of control persons and unchecked confusion are some of the main limitations in the case control studies of pesticides and cancer in children. Only a few studies have differentiated between the different groups of pesticides, and the exposure is usually dichotomised into having used pesticides at some time or another and never having used them, with regard for the frequency or duration of the exposure. The exposure data in all the studies are indirect and based on the parents' job titles, occupation and use of pesticides in the home. In addition, it must be presumed that there is some degree of recall bias concerning details about the frequency and time of the use of pesticides in relation to conception, pregnancy and the child's diagnosis – all things that can go back many years. The studies in which an association was found between pesticides and cancer seem to be those in which more detailed information had been received about the exposure with respect to timing, intensity or type of pesticide. Although several studies hint at an association between pesticide exposure and certain types of cancer, there does not seem to be sufficient epidemiological evidence of an etiological relationship between exposure to pesticides and cancer in children (Daniels et al. 1997; Zahm, Ward 1998).

Studies of the risk of cancer in connection with the use of pesticides are often complicated by the fact that the individual farmer uses many different kinds of spray products and that the individual pesticides have different toxicological profiles. Many studies have raised a suspicion of pesticide exposure as the possible cause of increased frequency of certain form of cancer in the blood and lymphatic tissue (Zahm et al.1997). Genotoxic damage, as seen in non-Hodgkin's lymphoma patients, has also been found in lymphocytes from peripheral blood in persons exposed to pesticides (Garry et al. 1996). In this connection, it must be mentioned that farm workers have been exposed many times. Such repeated exposure may also affect the individual farmer's immune system (Blair, Zahm 1995).

In Denmark there have not been any real epidemiological studies concerning pesticide exposure of farm workers, but several researchers have studied pesticide exposure in horticultural workers. There have been a few studies of "mortality and occupation".

Studies of frequency of cancer

An analysis of cancer cases related to occupation in the years 1970-79 showed an over-frequency in agriculture of some forms of cancer in the blood and lymphatic tissue. In the case of men employed in agriculture, 22 cases of acute leukaemia were found, against an expected 12 cases. In addition, a significantly increased risk of chronic leukaemia was found among men in agriculture, with 32 cases of non-acute leukaemia against an expected 19.2 cases. In this study, there were considerably fewer cases of lung cancer among agricultural workers than expected (Olsen, Jensen 1987). There is no follow-up on this study from the period after 1979.

6.1.5 Other effects

Studies in this section have been discussed by Skadhauge (1998). However, the best-documented studies of pesticides were carried out with substances that are no longer used or that have never been used in Denmark.

Reproductive toxicity

It has been documented that occupational exposure to pesticides can have a negative effect on fertility (Smith et al. 1997; Strohmer et al. 1993; de Cock et al. 1994). A known example is the substance dibromide-chloropropane (DBCP), which caused azoospermia and oligospermia among Californian workers working with the substance (Whorton, Foliart

1983). Other pesticides, such as ethylene dibromide, kepon and carbaryl have been associated with reproductive effects in males (Baker, Wilkinson 1990). In some studies an association has been found between miscarriage and foetal death and occupational exposure to pesticides (Pastore et al. 1997; Goulet, Thériault 1991), whereas other studies have been unable to demonstrate such a relationship (Restrepo et al. 1990; Willis et al. 1993; Kristensen et al. 1997a).

In a review article from 1995 it is concluded that there is no clear epidemiological evidence of a relationship between exposure to pesticides and increased reproductive risk (Nurminen 1995). A large Norwegian study of congenital deformities in children born of parents that were registered as farmers found an association between pesticides and deformed sex organs (Kristensen et al. 1997b). A large review article was published recently on studies concerning potential associations between foetal deaths, miscarriages and stillbirths and specific pesticides, together with parents' employment in occupations with potential exposure (Arbuckle, Sever 1998). Data indicated an increased risk of foetal death associated with pesticides in general and the mother's employment in agriculture. However, it was concluded in the review that the studies carried out to date do not answer the question concerning the toxic effect of individual pesticides on human reproduction.

Effects on reproduction

A study of greenhouse workers showed significantly reduced plasma-cholinesterase activity compared with an unexposed control group (Lander et al. 1995). In a study of semen quality and chromosomal damage in greenhouse workers exposed to pesticides, no link was found between individual factors, including exposure to pesticides. That applied both to specific linkage with measured exposures to pesticides and broad linkage with the market garden's use of pesticides (Abell et al. 1997). The most important observation was that both chromosomal damage and sperm quality were related to the current pesticide exposure and that spraying was less important than exposure on re-entry. The study revealed no differences between the greenhouse workers' sperm quality and the sperm quality of organic cultivators. In addition, the greenhouse workers had a generally higher sperm quality than the general population. On the other hand, it was observed that the longer the persons studied had worked in horticulture, the poorer the sperm quality. However, this was not unambiguously correlated with pesticide exposure, nor was a correlation found between the pesticide consumption of the market garden in question and sperm quality, although the workers with a low exposure had a better sperm quality than those with a high exposure. The results of the study indicate a need for increased action to reduce exposure of greenhouse workers when handling sprayed plants.

Developmental toxicity

Several studies have shown developmental effects as a consequence of parents' occupational exposure to pesticides. In the above-mentioned Norwegian study of congenital deformities among newborn children of parents registered as farmers, a moderately increased risk of spina bifida and hydrocephalus was found, compared with children born of parents in other occupations in rural communities. The risk was greatest in the case of exposure to pesticides in orchards and greenhouses (Kristensen et al. 1997b). Exposure to pesticides, particularly in the case of arable farmers, was also associated with limb defects. A Dutch study from 1996 showed an increased risk of spina bifida in children born of mothers employed in farming, compared with a control group, but the association could not be explained by use of pesticides (Blatter et al. 1996). However, in a Finnish study of congenital deformities and mothers working in farming, the risk to workers exposed to pesticides was found to be no greater than the risk to unexposed farm workers (Nurminen et al. 1995). A recent review article describes methods and results of studies of occupational exposure to pesticides, mainly among farm workers, and the risk of congenital deformities. However, on the basis of the available information, there seems to be insufficient evidence to date to either confirm or disprove a relationship between exposure to pesticides and deformities (García 1998).

Neurotoxicity

With respect to neurotoxic effects of pesticides in adult populations, it has been found in several studies of workers exposed to pesticides that effects can occur in the peripheral nervous system in workers with either acute poisoning or with chronic occupational exposure without obvious neuropathic syndromes (Keifer, Mahurin 1997; Ecobichon 1996). Most of the studies of the cognitive effects of exposure to pesticides have concerned organophosphates because of their widespread use.

Following acute exposure to high doses of organophosphates, with repeated, acute, clinically significant intoxication, toxic effects have occasionally been observed with long-term effects on behaviour and on mental and visual function (Rosenstock et al. 1991; Ames et al. 1995¸Steenland et al. 1994). However, the available data do not indicate that asymptotic exposure to organophosphates is associated with an increased risk of delayed or permanent neuropsychopathological effects (Daniell et al. 1992; Eyer 1995).

Among fungicides, the dithiocarbamats have been associated with neurotoxicity in a few cases. In a study from the Netherlands, both autonomous and peripheral neurotoxic effects were found among workers chronically exposed to zineb and maneb in flower production (Ruijten et al. 1994). These pesticides are not themselves suspected of being peripheral neurotoxins, but carbon-disulphide, which is one of the metabolic products, is a known neurotoxin. Furthermore, occupational exposure to pesticides containing manganese has been mentioned as a possible cause of manganese poisoning of the central nervous system (Ferraz et al. 1988).

In an epidemiological study from Calgary, Canada, persons with earlier occupation exposure to herbicides were found to have a three time greater risk of Parkinson’s disease (Semchuk et al. 1992).

Immunotoxicity and sensitivity

In an American study of 280 cases of aplastic anaemia, an association was found with occupational exposure to organochlorine compounds and organophosphates (Fleming, Timmeny 1993). It can be concluded that there is evidence of contact hypersensitivity as a consequence of occupational exposure to pesticides.

Experimental and clinical data have shown that some pesticides (chlornitrobenzene, carbamats, captan and organophosphates) can induce contact hypersensitivity (type IV reaction) in test animals and humans (Baker, Wilkinson 1990).

Mortality among farmers

In the third report from the Ministry of Health's Life-expectancy Committee, standardised mortality ratios (SMR) were given for different occupations. For each occupation, the causes of death were also examined. The period covered was 1986-90. Compared with largely all other occupations, "independent in farming" had the lowest SMR (Ingerslev et al. 1994).

6.1.6 Conclusions

The risk of acute effects from pesticides is deemed to be considerably lower today than it was just 10 years ago. With use of the protection aids that are recommended for the individual pesticide according to its classification and labelling, there is a minimal risk of incurring chronic health problems. The possibility cannot be excluded of some risk to persons who do not observe the given rules for personal protection and correct use of the pesticides, inappropriate work routines and poor work hygiene. However, the sub-committee notes that there can be considerable exposure of the sprayer operator and of workers in greenhouses and in the production of fruit and vegetables, where frequent use is made of pesticides.

In tractor work in the field, whole-body vibrations occur. The tractor driver also has to twist his back many times. He often needs to look behind, whereby his spinal column, neck and shoulders are loaded. Farmers have a generally increased risk of osteoarthritis, which is associated with milking, tractor work and heavy physical work, which are often started before the age of 16 years. Persons working in dusty conditions have an increased risk of asthma and chronic bronchitis.

Farm workers are exposed to noise, partly through work in stables and partly from tractors and other agricultural machines.

The following specific conclusions can be drawn:

- Traditionally, neither conventional nor organic farmers think very much about the working environment, and not all injures are reported. However, the general mortality is low compared with other occupations.

- There are many serious accidents in farming and more fatal accidents than in all other occupations.

- EGA (monotonous, repetitive work) can occur during manual weed control in special crops, with a risk of lower back and back problems.

- The risk of accidents in connection with mechanical weed control may increase with the introduction of more machines requiring repair and maintenance.

- Massive under-reporting of both occupational accidents and work-related diseases has been documented in many studies.

- Long-term effects in people in connection with occupational exposure corresponding to Danish conditions have not been proven in epidemiological studies.

- The sub-committee finds that too little is known about the ability of pesticides and their coformulants to produce allergies and about their effect on the immune system.

- The long-term effect of exposure to pesticides, resulting in a higher risk of damage, cannot be reliably established corresponding to Danish conditions. In view of the intensive use of pesticides in nurseries and in the production of fruit, vegetables and berries, the sub-committee recommends increased action to reduce exposure to pesticides, particularly in these types of production.

6.2 Exposure and effects on the population

6.2.1 Use and risk groups

Pesticides are used in farming and horticulture to control weeds, fungi, insects and other pests and to influence the growth of crops such as fruit, vegetables and cereals. In Denmark, there are at present about 90 authorised active ingredients, which are used in approx. 550 products.

Over the years, the requirements for authorisation of the individual pesticides have been considerably tightened. As a result, some pesticides have been banned on account of their undesirable environmental and/or health properties. This applies, for example, to a number of pesticides containing chlorine, such as DDT, dieldrin, etc. However, owing to their lack of degradability, they are still found in the environment, from which they find their way into food products.

Pesticides are widely used. Within the food sector, it is particularly in connection with the production of fruit and vegetables that the risk of a residual content is greatest.

Extensive use is also made of pesticides, in the form of herbicides and fungicides, in the cultivation of cereals and to regulate growth. The crop is often sprayed long before it is harvested, so the degradation of the pesticide can be advanced. When a crop is sprayed a shorter time before harvest, it must normally be expected to have a residual content of the pesticide.

Acute and chronic effects of pesticides have been investigated in numerous experimental studies and in studies of persons with occupational exposure, both in Denmark and in other countries. Apart from high-dose exposure in connection with accidents or suicide, the general public in Denmark is subject mainly to low-dose exposure, primarily as a consequence of pesticide residues in food and drinking water or from private use of pesticides in or around the home.

Population studies

There are only extremely sparse epidemiological data concerning health effects among the general population as a consequence of low-dose exposure to pesticides. There are differences in both exposure and sensitivity to pesticides in the population, depending on age, sex, eating habits, environmental factors and/or lifestyle. Some sections of the population must thus be expected to show health effects from exposure to significantly lower doses of pesticides than those causing effects in the rest of the population. Children are a special risk group, particularly due to qualitative and quantitative differences between children and adults in their intake of different types of food. Other risk groups may be persons with a poor immune system or persons with certain chronic diseases. For further amplification of the effect of pesticides on public health, readers are referred to Skadhauge (1998).

Metabolites

In living organisms, pesticides are transformed into metabolites. The documentation on which the authorisation of pesticides is based normally includes information on most of the metabolites from the substance in question, but separate toxicological investigations of the individual metabolites are not normally performed. The toxic effect of metabolites is generally thought to be lower than that of the original substance because the metabolites are often more water-soluble and are thus eliminated faster from the organism (Hayes, Laws 1991). However, there are some important exceptions, where biotransformation results in a more toxic product (e.g. the formation of oxon derivatives of organothiophosphorous pesticides or the formation of epoxy compounds from certain insecticides, such as dieldrin and heptachlor). Atrazine's metabolites, deethylatrazine and desisopropylatrazine, are more acutely toxic than atrazine; they leach more easily than the original pesticide and may thus be a bigger problem. Where there is knowledge about such metabolites, it is taken into account in the authorisation procedure and in connection with the setting of limit values in food.

6.2.2 Risk population and individual vulnerability

In the case of exposure to a potential toxic factor, the risk population is traditionally taken to be the part of the population that is subject to 1) increased exposure, 2) increased dose with the same exposure, 3) increased effect with the same exposure in relation to the rest of the population.

Increased exposure can occur in the case of accidents or occupational exposure, but it can, for example, also occur to some extent in population groups with special eating habits (e.g. vegetarians or persons with another food base) or neighbouring on sprayed land.

Children as a risk group

Children are a risk group because they are often exposed to a larger dose of pesticides than adults with the same type of exposure. Owing to more rapid breathing in relation to their body weight than adults, children inhale relatively more air. Children's special diet patterns and intake of pesticide residues are the subject of a report from the American National Research Council (NRC). Here, both qualitative and quantitative differences were found between children and adults with respect to exposure (National Research Council 1993). Firstly, children take in more energy per kg body weight than adults and, secondly, children eat far fewer types of food than adults. In addition, the intake of water, both in the form of drinking water and as a food component, differs greatly between children and adults. The council concluded that differences in diet and thus in dietary exposure to pesticide residues could explain most of the differences in pesticide-related health risks between children and adults. Differences in exposure were generally a more important cause of differences in risk than age-related differences in the way the substances act in the organism. However, the council found that, among other things, effects on neurological and immunological development processes were insufficiently clarified.

With respect to an increased effect with the same exposure to pesticides, there is agreement that foetuses and children are a special risk group (Goldman 1995; Reigart 1995). As stated in the above-mentioned report from NRC, there are both qualitative and quantitative differences between children and adults with respect to the toxicity of chemical substances, including pesticides (National Research Council 1993). The report gives examples, mostly concerning medical drugs, where children are more or less sensitive to the individual substances. These differences result from the fact that the substances are degraded at a different rate in the body in children than in adults and from the greater or lesser toxicity of the degradation products compared with the parent substance. The qualitative differences in toxicity are due to exposure in particularly sensitive periods in early development, when exposure to a toxic substance can permanently change the structure or function of an organ system. The quantitative differences in toxicity between children and adults are due partly to age-related differences in absorption, metabolism, detoxification and excretion of the environmentally foreign substances and partly to differences in size, not fully developed biochemical and physiological functions and variations in the composition of the body (water, fat, protein and mineral content), all of which can affect the degree of toxicity. Since new-born infants are the group that differ most from adults, anatomically and physiologically, they must be regarded as having the most pronounced quantitative differences in sensitivity to pesticides. The report found that quantitative differences in toxicity between children and adults were normally lower than a factor of 10.

With reference to the foregoing, the US Environmental Protection Agency (US-EPA) estimates that children constitute a special risk group. Accordingly, in individual cases in the USA, an extra uncertainty factor of 100 is used when setting maximum limit values in connection with risk analyses that are based on animal tests and that are not deemed to throw sufficient light on the special situation of children. Examples of such substances and the related uncertainty factors (in brackets with the year) are: heptachlor (200 in 1990), triazophos (500 in 1990), fentin (200 in 1970; 500 in 1991), abamectin (500 in 1992), amitrol (provisional uncertainty factor of 1000 in 1993), phosalon (200 in 1993) and propylene thiourea (metabolite of probineb, 1000 in 1993).

Other risk groups

Pregnant women, the elderly and persons with a poorly functioning immune system are other groups that must be presumed to be particularly at risk with respect to health effects from exposure to pesticides.

6.2.3 Exposure of the population

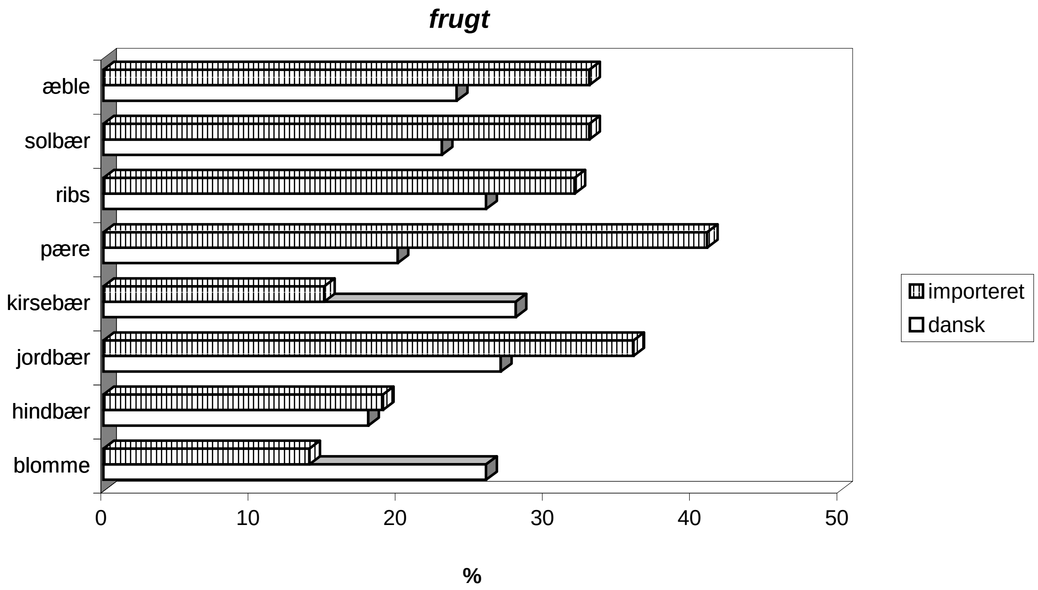
The general population can be exposed to pesticides through their intake of pesticide residues in food and via drinking water or through use of pesticides in and around the home, schools, offices, public parks and farms (drift and evaporation). Exposure can also occur through accidents, leakages due to incorrect storage, spills and pollution from production plants or landfill sites. Children, in particular, can be exposed to pesticides from eating contaminated soil, from contact with pets treated with pesticides or from parents exposed to pesticides in their work.

Exposure in the home

Exposure to pesticides can occur in connection with their use in and around the home, e.g. in combating insects and treating pets. Besides direct indoor treatment with pesticides, pesticides can be given off by pot plants treated with pesticides at the nursery. There have been no studies of this exposure in Denmark (Skadhauge 1998).

Exposure via food

The main exposure of the population to pesticides must be assumed to occur via food. Around 60% of this intake occurs via imported food products. Exposure via vegetables and, particularly, via berries and fruit predominates. The sources of the information on this are the Veterinary and Food Administrations' annual reports on the nationwide control and monitoring of the residual content of pesticides in vegetable and animal food products on the Danish market. The samples are extracted at the wholesale level. The studies cover both Danish and imported food products and are carried out as a random sample control, supplemented by targeted control.



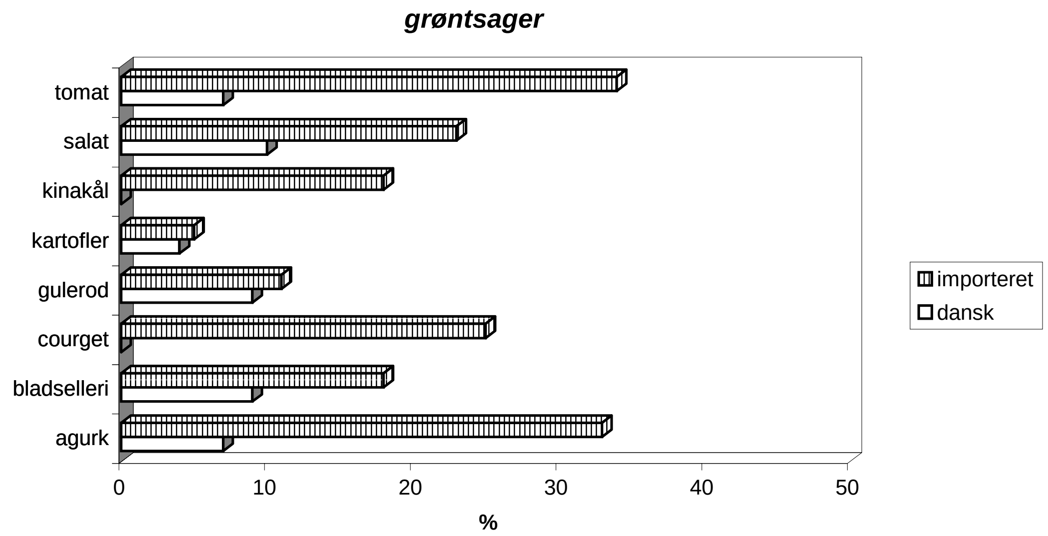


Figure 6.3
Frequency of fruit and vegetables with pesticide residues for Danish and imported crops, 1993-1997 (fruit and vegetables with the highest number of samples are presented). On average, pesticide residues have been detected in about one quarter of the Danish and imported fruit shown in the figure. For the vegetables, pesticide residues have been detected in an average of 20% of the imported vegetables in the figure, compared with 6% of the Danish vegetables.

Figure text:
frugt = fruit
æbler = apples
solbær = blackcurrants
ribs = redcurrants
pære = pears
kirsebær = cherries
jordbær = strawberries
hindbær = raspberries
blomme = plums

grøntsager = vegetables
tomat = tomatoes
salat = lettuce
kinakål = Chinese cabbage
kartofler = potatoes
gulerod = carrots
courget = courgette
bladselleri = celery
agurk = cucumber
importeret = imported
dansk = Danish

Food products

In the national monitoring programme, the samples are extracted at random (randomised) from the crops that it has been decided to check in the year in question. The programme is designed to determine the level of residues in the crops checked. The samples are taken at wholesalers, producers and importers. The sampling is carried out by the food inspection units, together with the Plant Directorate and the Danish Veterinary and Food Administration. The samples are generally extracted with a geographical distribution and distributed over the whole of the year In the case of fruit and vegetables, samples are taken weekly. In 1997 1,947 samples were extracted – 83% fruit and vegetables (1,613 samples), 3% honey (Danish and imported), 8% meat, 6% cereal (including 1/3 imported cereal). The 1,613 samples of fruit and vegetables comprised 919 samples of imported products and 694 Danish products. In both 1996 and 1997, the monitoring programme constituted about 0.0002% of the Danish production of vegetables, fruit and berries.

The national monitoring programme

In the last couple of years, studies of fruit and vegetables have covered about 150 different pesticides, comprising commonly used insecticides and fungicides and some herbicides. When the substance profile for the programme is set, the substances that have Danish MRL-values (MRL = Maximum Residue Limit; often corresponding to EU MRL-values) and/or are used here in Denmark are prioritised. Otherwise, the pesticides with low MRL-values or that are widely used are prioritised. Animal products and fish are checked for organochlorine pesticides, which used to be authorised for use and now occur as widespread environmental pollution. At the same time, the samples are tested for the industrial chemical PCB. In addition, a number of pesticides containing chlorine occur in fish – particularly oily fish. Since these substances have long since been banned, they are regulated and treated as environmental pollution. The occurrence of these substances in fish would not be affected by a reduction or possible phasing out of pesticides in Denmark.

Special investigations (targeted control)

In addition, special investigations are carried out, including so-called targeted control, that is used where and when it is suspected that current MRL-values are being exceeded. The suspicion can, for example, arise in connection with the current monitoring programme. The nature and scope of the targeted control vary from case to case and comprise two or more samples extracted at the retail and/or wholesale level.

Exceedances of limit values

For many years, the analyses carried out have shown that pesticide residues in food products on the Danish market generally meet the current regulations. The content has been found to exceed the MRL-values in 1-2% of the samples, but rarely by more than 50-100%. It is characteristic of the analyses that, with the reporting limits used, no residues were found in most of the samples. Normally, residues are detected in one third or less of the samples tested. As shown in figure 6.3, the detection frequency is higher in samples of imported food products than in Danish food products, but within the individual crops, the detections vary, both qualitatively and quantitatively from year to year, depending on economic and climatic conditions and on differences in the need for treatment (Büchert 1998). In 1996, the most frequently detected pesticides were (in alphabetical order): captan, carbendazim, chlorothalonil, dithiocarbamates, endosulfan (sum), iprodione, quintozene, tolylfluanide and vinclozolin. None of the finds gave the Veterinary & Food Administration cause for concern with respect to public health (Büchert, Engell 1998).

Finds and exceedances in relation to crops

The monitoring programme indicates a tendency towards relatively more detections of residues in fruit, including citrus fruit and grapes, than in vegetables such as cabbage and potatoes. The total human average intake of pesticides is dominated by citrus fruit in particular (oranges and mandarins), potatoes and apples and, to a slightly lesser extent, tomatoes, pears, grapes and strawberries, which account for most of the load. However, the sum of these substances covers pesticide residues with very different toxicological properties, so the substances are not directly comparable and their combined action is not known. The Ministry of Food, Agriculture and Fisheries has initiated a study that will throw light on these questions within some years. Another important factor in connection with the summation of the pesticide residues in food products is that it does not include reduction factors. Some of the pesticide residues are removed during preparation - for example, peeling of oranges, mandarins, etc., the peel of which is seldom used. However, there are as yet insufficient data to clarify the size of the reduction factors in Danish diet. This aspect will also be looked at in a new study initiated by the Ministry of Food, Agriculture and Fisheries. A closer comparison of the individual food products and their significance for the intake of pesticides, and thus their possible toxic effects, is difficult for several reasons, including the fact that the data are often too limited, but also because the individual pesticides have different toxicological properties. It must be mentioned, however, that the higher detection rate in imported crops reflects the fact that, for comparable crops, there tend to be fewer positive results in Danish products than in imported ones. This tendency is most pronounced for crops like tomatoes, cucumber and peppers, which are greenhouse crops in Denmark but outdoor crops in other countries. However, the tendency does not apply to all crops. There are also examples, e.g. blackcurrants, where pesticide residues are more frequent in Danish crops than in imported ones.

Calculation of pesticide intake from food products and drinking water on the Danish market

The following calculation of the Danes' intake of pesticides through their diet is based on monitoring data from the Danish Veterinary & Food Administration's national monitoring programme in 1996 and 1997 (Büchert 1998). These data are not only the latest data but were also obtained with comparable methods and reporting limits. It is characteristic that no content was detected in most of the samples tested. Regardless of this, it must be assumed that treated crops always have a certain residual content, so that lack of detection can only be taken to mean that the content, if any, is below the analytical detection limit.

Methods of calculation

Different models can be used to calculate the pesticide intake from crops in which no residual content has been detected. In situations in which there are sufficient data above the detection limit, the distribution under the detection limit can be determined with reasonable statistical certainty. Unfortunately, that is not the case with the available monitoring data. The residual content in samples without a detected content must therefore be expressed in a different way – for example, by putting the pesticide content at 0 (zero) or, conversely, by assuming that it corresponds to the detection limit. However, both are rather rough approximations.

In this connection it must be stressed that the analytical detection limit is not a fixed quantity. It varies from one pesticide to another and from crop to crop, just as there is a variation from one analysis to another of the same substance in the same crop. However, since the exact data are not directly accessible, the calculations are based on the more general detection limits, which are determined for the individual substances during the validation of the methods. The residual concentration in samples with concentrations above the detection limit are estimated as the mean value between the highest and lowest detected content.

The scope of the calculations

The calculations of the content in the crops analysed have been carried out for all the pesticides detected in the analyses in 1996 and 1997. It was anticipated that there was a content in both Danish and foreign crops of the same type, also when the substance was only detected in crops of one or the other origin. There is also an overestimation, in that the calculations are based on an assumption that detection of a pesticide in a single type of crop means that the entire production of the crop in question has been treated with the pesticide in question and therefore has a residual content of the pesticide that differs from 0.

The calculations do not take into account intake of pesticides that have not been detected in the national monitoring programme in either Danish or imported crops, nor do they include any intake of such substances as might occur in contents below the analytical detection limits or that are not covered by the analytical methods used.

In the calculation of Danish consumers' exposure to pesticide residues through food, the crops' estimated content is multiplied by the average daily dietary consumption of the crop in question. The dietary data used are based on diet studies from 1985 and 1995 and on trade statistics.

Variations in the population

In practice, of course, there are many deviations in the population from the average diet model with respect to sex, age, ethnic background and social conditions. For a more detailed risk analysis for such groups there is thus a need for more precise dietary data. However, it must be stressed that the model set up provides a reasonable possibility of a more general evaluation of the pesticide intake on a national level, including the broader significance of keeping Danish crops free of pesticide treatment.

The distribution between Danish and imported food products

Good data on the distribution of Danish consumption between Danish and imported crops are not available. The main reason for that is, that with the "internal market", official statistics are no longer kept of imports and exports between the Member States. In the calculations carried out, the distribution has been estimated on the basis of earlier trade figures and agricultural statistics. These indicate that the distribution between imports and domestic production is 1:1 for such fruit as apples, pears, plums, berries, etc., while exotic fruit, such as citrus fruit and kiwi are exclusively imported crops. For vegetables, the distribution is about 1:4, although not for cucumber, tomatoes and similar, where imports, distributed over the whole year, account for about 70% of the total consumption. In the case of cereals, maize and rice are exclusively imported crops, while the consumption of barley is based entirely on Danish products. In the case of rye, wheat and oats, 5%, 20% and 65%, respectively, of consumption is covered by imports.

Table 6.2 shows the average daily consumption of Danish and imported cereal and cereal products in Denmark.

Table 6.2
Average consumption of Danish and imported cereal and cereal products, given in grammes per day.

Cereal	Total	Danish	Import
Barley	0.40	0.40	
Oats	7.70	2.70	5.01
Wheat, incl. bran	100.00	80.00	20.00
Maize	7.10		7.10
Rice	7.20		7.20
Rye	59.00	56.05	2.95
Total cons.	181.40	139.15	42.26

The Danes' dietary pattern

The variation in the Danish consumers' dietary pattern can be judged on the basis of the National Food Agency's dietary study in 1995. The results of that study, which covered more than 1,800 persons, are summarised in table 6.3 below, which gives the average intake and selected fractiles for the adult part of the population.

Table 6.3
Variation in Danish diet, given in g/day for adults m/f (Büchert 1998).

DIET	VEGETABLES g/day	FRUIT g/day	CEREAL PRODUCTS g/day
Mean intake	241	162	217
Standard deviation	265	318	215
Median	163	36	162
Minimum	0.00	0.00	0.00
Maximum	2743	3640	2219
95% fractile	726	737	599
90% fractile	533	468	444
75% fractile	309	174	273
25% fractile	83	3,00	89
10% fractile	36	0,00	48
5% fractile	18	0,00	28

On the basis of the values in table 6.3 it can be calculated that the 90% fractile for dietary consumption of vegetables is about 225% of the mean intake, while, for fruit, it is about 300% and for cereal products, about 200%. The uncertainty on the figures is reflected by the fact that the values for the 90% fractiles are of the same order of magnitude as the sum of the mean content and the standard deviation. It must be added that the probabilities have not been calculated for how population groups and individuals compose their dietary consumption.

6.2.4 Calculations of the population's intake of pesticides

Reduction factors and adjustments

The intake calculations for fruit and vegetables, which, as described, are based on monitoring data, reflect the occurrence of pesticides in the raw produce, so account is not taken of the reduction of the content during preparation of the raw produce (peeling, boiling, etc.). This is because the literature contains only limited information about such reduction factors and the data are usually of such a nature that they cannot be applied to Danish conditions. Therefore, reduction factors have not been included in the current calculations of the intake of fruit and vegetables, which leads to overestimation of the intakes in relation to the real values. A lack of data on the proportion of a given crop that has been treated with a specific pesticide has also made it impossible to adjust for actual use. This applies particularly to imported products and means that, for example, the intake from citrus fruit – and thus from imported crops – has been overestimated.

Estimated intake from fruit and vegetables

The intake of pesticide residues through diet has been calculated for all the pesticides detected in the analyses of fruit and vegetables in 1996 and 1997. The intake from Danish crops and from imported crops has been calculated separately, without detailed specification of the origin of the crops (for details, see Büchert 1998). The results show a total average intake of pesticides from fruit and vegetables of about 165 microgrammes per day. The intake of six pesticides/pesticide groups – carbendazim, dithiocarbamats, iprodione, o-phenyl-phenol, procymidone and thiabendazole – corresponds to half the total intake, while the other half is distributed over about 60 individual compounds.

The calculated total intake of pesticides from fruit and vegetables is made up of around 165 microgrammes per day is approx. 60 microgrammes per day, corresponding to 36%, from Danish crops and approx. 105 microgrammes/day, corresponding to 64%, from imported crops.

It must be stressed that any size comparison of the calculated intakes should be seen in the light of the fact that the pesticides have different toxic properties and potency. A small intake of a potent substance may thus very well be more dangerous from a health point of view than a large intake of a less potent substance.

Comparison with ADI

For the pesticides that are authorised for use on edible crops, an acceptable daily intake (ADI) is fixed on the basis of the same principles as for additives, and with a requirement concerning similarly comprehensive data. ADI for pesticides is set to protect against possible long-term effects. ADI is fixed on the basis of animal tests. In each test, NOAEL (No Observed Adverse Effect Level) is fixed as the dosage that does not have any harmful effect. ADI is fixed by taking the NOAEL from the most sensitive test on animals and reducing this by an uncertainty factor that must take account of the uncertainty that lies in extrapolating from animals to humans and the variations in people’s sensitivity and lifestyle. By international agreement, an uncertainty factor of 100 is used as the basis.

A comparison has been carried out between the calculated intakes and the upper limits recommended by the experts for acceptable intakes for a person weighing 70 kg, calculated as the ADI values multiplied by the weight (ADI mg/kg bw/day times 70 kg). All the calculated intakes constitute only a small part of the intake that could be accepted without giving rise to health concerns. The mean value of the calculated intakes of the individual pesticides is 0.31% of the upper limit for their acceptable daily intakes, with a standard variation of 0.46% and with the highest individual value (for methidathion) of about 2.2%. Even with big variations in the dietary consumption of the individual crops, the consumers would remain below the ADI values.

The variations in the exposure to pesticides via fruit and vegetables have been clarified by calculating the intake at the 90% fractile. The 90% fractile for vegetables and fruit has been put at 225% and 300%, respectively, on the mean value for the group of crops in question.

An evaluation of the maximum exposures of the population can best be based on the calculated mean intakes and the values given in table 6.3 for the entire group of vegetables or fruit. An evaluation of the intake via the individual crops can also be based on the data, whereas a summation of the maximum contribution from the individual crops is not possible without calculating the probability of the same person or population group having maximum consumption of several combinations of types of crop and determining the types of crop in question. On the face of it, it is believed that a conjuncture of maximum consumption of two or more crops would be exceptional and that a major consumer of a crop would normally have a limited consumption of other types of crop. In other words, if there were a maximum exposure to pesticides via one type of crop, the exposure to the others would often be correspondingly smaller.

Estimated intake from cereals and cereal products

Since 1987, cereals and bran have been included in the regular analyses of pesticide residues in food products on the Danish market. The analyses have been carried out with a changing search profile from year to year. In the last couple of years, the samples have been analysed with a multi-method covering 24 different substances. In 1997, a special analysis was carried out of the residual content of the straw-shortening products chlormequate and mepiquate. The analyses showed that the residual content of pesticides in cereals and cereal products meets current limit values, although, generally speaking, the data are too slender for a more refined analysis of the population's exposure to pesticides from products of this type. The highest content of chlormequate – 3.8 mg per kg – was found in a sample of rolled oats from the UK. There are generally more and higher finds in Danish cereal products than in the imported products, and pesticides have been detected in almost all samples except in rice and in a sample of organic wheat. For a detailed review, readers are referred to Granby and Poulsen (1998). The calculations of the intake were based on a more conservative estimate of the residual content in the types of crop in question. The calculations were carried out in the same way as for fruit and vegetables, but covered all the pesticides detected in the entire period from 1987 to 1997.

Reduction factor

In the calculations, no direct differentiation was made between whether the residual content was detected in bran, in grain or in flour. If a substance was detected in one type of product, it was assumed that the substance was also present in others. It will normally be bran that has the largest residual content, and the residual content in flour will normally be reduced when the husks are removed and be reduced still further when the grain is milled and when the flour is baked into bread (bread was not included in the analysis). On the other hand, most of the pesticide residues will normally be in the bran product. In the case of chlormequate, it was found that milling of wheat grain into flour reduced the residues by a factor of about 4. For this reason, in the calculation of the intake from cereals and cereal products, it was assumed, as a cautious estimate, that the residual contents were reduced by a factor of 2 in relation to the measured content. In 1997, 21 bran samples were extracted (18 wheat bran and 3 oat bran), which were analysed for 26 pesticides. None of the samples exceeded the limit values, even though the residual contents were higher in bran than in whole grains and flour. However, reservation must be made for the fact that the analyses for glyphosate were of limited scope.

The results of the calculations are summarised in table 6.4, which shows the calculated pesticide intake with and without reduction through processing of the cereal. As will be seen from the table, the average intake is estimated to be about 26 microgrammes per day, with a distribution of about 2/3 from cereals produced in Denmark and 1/3 from imported cereals.

Bromide from fumigation with methyl bromide

It should be noted that the residual content of bromide is not included in the summation of the total intake. Bromide is not in itself a pesticide but is included in the analyses as an expression of any use of methyl bromide, which is used to fumigate cereals and other products. The test method for measuring methyl bromide is based on determination of bromide, but as this also exists in nature, it is a question of measuring whether the bromide content is higher than the normal content in the cereal product. In other words, the absolute content of bromide does not correspond to the residual content of methyl bromide, and it would be a gross over-estimation to include the bromide content when summing the total intake.

As in the case of fruit and vegetables, the average intake of the individual pesticide residues from cereals and cereal products is typically less than 1% of the ADI values (see Büchert 1998).

The variations in the exposure to pesticides from cereals and cereal products can be estimated from table 6.3, from which it will be seen that the 90% fractile for cereals and cereal products corresponds to approx. 200% of the mean intake.

Table 6.4
Estimated pesticide intake from imported and Danish cereals and cereal products (Büchert 1998). There are very few analyses of glyphosate in cereals and cereal products. Empty spaces indicate that residues have not been detected. The analyses included pesticides that were not detected in any of the samples.

Pesticide	Barley, µg/day		Oats, µg/day		Wheat, µg/day		Maize, µg/day	Rice, µg/day	Rye, µg/day		Total, µg/day			Total distribution	
	DK	IMP.	DK	IMP.	DK	IMP.	IMP.	IMP.	DK	IMP.	Total	DK	IMP.	DK%	IMP.%
Bromide	1.720	0.000							69.623	3.664	75.007	71.343	3.664	95.1	4.9
Carbaryl			0.051	0.094							0.145	0.051	0.094	35.0	65.0
Chlormequate			1.243	2.309	12.531	3.133			14.635	0.770	34.620	28.409	6.212	82.1	17.9
Chlorpyriphos-methyl					1.166	0.291	0.080				1.537	1.166	0.372	75.8	24.2
p,p'-DDE			0.030	0.056							0.087	0.030	0.056	35.0	65.0
Dieldrin					0.567	0.142					0.708	0.567	0.142	80.0	20.0
Dimethoate	0.006	0.000			1.102	0.276					1.384	1.109	0.276	80.1	19.9
Dithiocarbamate					4.229	1.057					5.286	4.229	1.057	80.0	20.0
Esfenvalerate					0.439	0.110					0.549	0.439	0.110	80.0	20.0
Fenitrothion							0.103	0.078			0.181	0.000	0.181	0.0	100.0
Fenvalerate			0.036	0.067	1.343	0.336			0.299	0.016	2.098	1.679	0.419	80.0	20.0
Glyphosate	0.159	0.000									0.159	0.159	0.000	100.0	0.0
Lambda-cyhalothrine					0.428	0.107					0.535	0.428	0.107	80.0	20.0
Lindane					0.408	0.102			0.299	0.016	0.825	0.707	0.118	85.7	14.3
Malathion					0.871	0.218	0.072	0.040			1.200	0.871	0.329	72.6	27.4
Mepiquate			0.023	0.042	0.066	0.017			0.743	0.039	0.929	0.832	0.098	89.5	10.5
Nitrofen									0.850	0.045	0.894	0.850	0.045	95.0	5.0
Permethrin			0.186	0.346							0.532	0.186	0.346	35.0	65.0
Pirimicarb							0.072				0.072	0.000	0.072	0.0	100.0
Pirimiphos-methyl			0.016	0.030	1.107	0.277	0.372	0.038			1.839	1.123	0.716	61.1	38.9
Pesticide intake															
Without reduction	1.886	0.000	1.585	2.944	24.257	6.064	0.699	0.155	86.448	4.550	53.581	42.833	10.747	65.6	34.4
With 50% reduction	0.943	0.000	0.793	1.472	12.129	3.032	0.350	0.078	43.224	2.275	26.791	21.417	5.374	65.6	34.4

The estimated intake from animal food products and fish

The Danish Veterinary & Food Administration has been monitoring the content of pesticide residues in animal food products for many years. The analyses have primarily been directed at the chlorinated pesticides, such as DDT, HCB and similar fat-soluble compounds, but analyses have also been carried out for residues of organophosphorous pesticides in meat.

No residual content of organophosphorous pesticides has been detected in meat, but a chronic content of chlorinated pesticide residues has been found in both animal food products and fish. However, this residual content represents substances that have been banned in pesticides for many years. Their occurrence in the food products is therefore a result of their earlier use, which has resulted in extensive and permanent environmental pollution with these persistent substances.

Since the exposure of the consumers to pesticide residues from animal food products and fish is primarily a question of “the sins of the past” and does not concern the pesticides authorised for use today, the exposure does not depend on the extent of the use of the pesticides currently used in Denmark.

The estimated intake from drinking water

In the last few years it has been recognised that there is widespread pollution of our groundwater with pesticides. There is therefore a potential risk of such contaminants in our drinking water and thus a risk of exposure of the population through the water.

Since drinking-water wells in which a residual content has been detected have hitherto been closed, the real exposure of the consumer is limited. However, this does not exclude the possibility of undiscovered pollution of local wells that can result in significant exposure of the local inhabitants.

It must therefore generally be assumed that drinking water meets current limit values, which state that the content of individual pesticide residues must not exceed 0.1 microgramme per litre, while the total content of pesticides must not exceed 0.5 microgrammes per litre.

With a normal consumption of 2 litres of water per day, a consumer thus receives less than 0.2 microgrammes of an individual pesticide, and his or her total pesticide intake from drinking water is less than 1 microgramme per day.

When the estimated maximum intake from drinking water of 1 microgramme per day is compared with the estimated intake of approx. 190 microgramme per day from fruit and vegetables, it must be concluded that the intake from drinking water is generally negligible and disappears in the uncertainty that lies in the estimation of the intake from vegetable food products.

Overall assessment of intake from food products and drinking water

As will be seen from the foregoing review of the pesticide intake from the different types of food products and drinking water, the predominant sources of the general population’s exposure to pesticides are fruit and vegetables and cereals and cereal products, while the intake from drinking water, animal food products and fish is of no significance for the total exposure.

The total average exposure from the individual types of food product and drinking water is summed in table 6.5.

Table 6.5
Estimated average pesticide intake from Danish and imported food products (Büchert 1998).

Type of food product	Total intake, µg/day			Total distribution	
	Total	DK	Import	DK %	Import %
Fruit and vegetables	162	58	104	36	64
Cereals and cereal products	27	21	5	80	20
Animal food products	<1	<1	<1	<1	<1
Fish and fish products	<1	<1	<1	<1	<1
Drinking water	<1	<1	<1	<1	<1
Total pesticide intake	190	80	110		

As will be seen from the table, the total average intake is estimated to be approx. 200 microgrammes of pesticide per day, about 60% of which comes from imported products, and the remaining 40% from Danish products, including cereals.

Variation in daily intake of pesticides

A rough calculation can be made of the variation in the intake of pesticides. These calculated extremes must be treated with caution because a closer statistical calculation is expected in the future. The lowest intake of pesticides is among people who either have a very low consumption of vegetable food products or who base their consumption solely on untreated, possibly organic, products. On the high side, the extreme must be presumed to be a so-called vegan, who bases his or her entire energy consumption on traditionally cultivated fruit and vegetables. In all probability, there are not many 100% vegans – people who live exclusively on vegetable products. A vegetarian typically covers part of his or her energy need with dairy products and eggs. For this reason, there are no detailed data on the typical composition of such vegans' diet, but a total intake of fruit and vegetables and cereals and cereal products of around 2½ kg per day must clearly be regarded as at the upper end of the real consumption. That corresponds to three times the average consumption on which the calculations of the average Dane's intake of pesticides through their diet are based. Judged in this way, the extremes for pesticide intake are estimated to lie from a very low intake to about three times the calculated average intake, corresponding to 570 microgrammes per day. Although this is an estimated calculation of the upper limit, it accords well with the calculated intake for the 90% fractile of the population.

The intake in relation to ADI

The calculations also show that the average intake at individual substance level is typically about 1% or less of the acceptable daily intake (the ADI value) for the individual compounds. Even with big variations in food consumption, the intake thus lies below the acceptable levels. As shown in figure 6.4, there are seven pesticides with a residual content of more than 1% of the ADI value for the pesticide in question, while all the other pesticides lie below 1% of ADI (Büchert 1998). This figure does not necessarily show the seven most eaten types of pesticide residues, which is illustrated by the fact that according to the diet data used, more than 90% of the two pesticides ortho-phenylphenol and methidathion are received through citrus fruit. Citrus fruits are usually peeled before being eaten, and there are today experiments that show that methidathion in citrus fruits is reduced by 95% by peeling the fruit. That means that the figures for methidathion, and presumably also for ortho-phenylphenol, can be more than 80% too high. Other pesticide residues are found mainly in crops that are not peeled or processed (e.g. cucumber, apples and pears), and the intake of these pesticides could in reality be more important than the real intake of the pesticides shown in figure 6.4. It must be stressed that it cannot be absolutely claimed that all calculations that do not include reduction factors are too high, since during preparation pesticides can be broken down into compounds that are just as harmful or more harmful than the original pesticide. However, it must generally be expected that including factors for processing/preparation of the crops in the calculations will reduce the value of the intake. In future, final and well-tested calculations that include reduction factors and that are supported by toxicological data will become available, making it possible to compare the intake of the different pesticides.

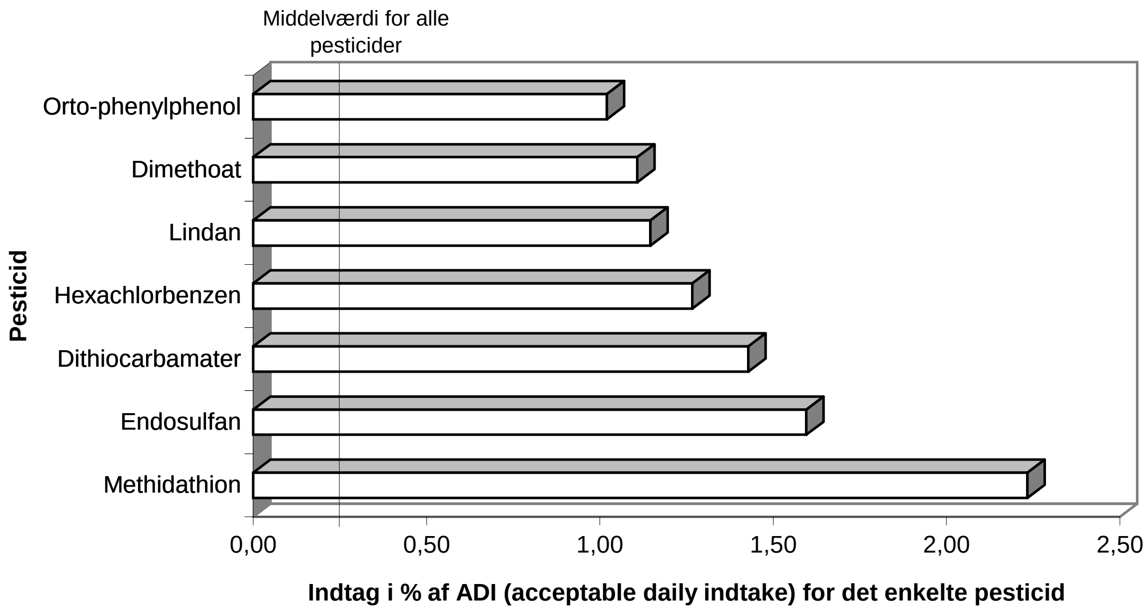


Figure 6.4
The total average intake of pesticide residues (denoted I) from different fruit and vegetables, when account is not taken of such factors as peeling and similar that reduce the residual content of pesticides. The vertical line gives the mean value for all pesticides (0.3% of ADI).

(Figure text:
Middelværdi for alle pesticider = Mean value for all pesticides
Pesticid = Pesticide
Orto-phenylphenol = Ortho-phenylphenol
Dimethoat = Dimethoate
Lindan = Lindane
Hexachlorbenzen = Hexachlorobenzene
Dithiocarbamater = Dithiocarbamates

Endosulfan = Endosulfan
Methidathion = Methidathion
Indtag i % af ADI (acceptable daily intake) for det enkelte pesticid) = Intake in % of ADI (acceptable daily intake) for the individual pesticide)

Figure 6.5 shows the main crops shown by the calculations to contribute to the daily intake of pesticides. It should be noted that account is not taken of peeling and other factors that reduce the residual content of pesticides. Since citrus fruit is eaten without the peel, and apples are eaten with the peel, the real relationship between these two intakes could be rather different from this figure. Secondly, it should be noted that the figure does not say anything about the health effects associated with the different pesticide residues in the different crops. For example, it could be misleading to report that apples, for example, contribute most to the intake of pesticides if toxicologists have shown that the pesticide residues that apples contain are less harmful than other pesticide residues.

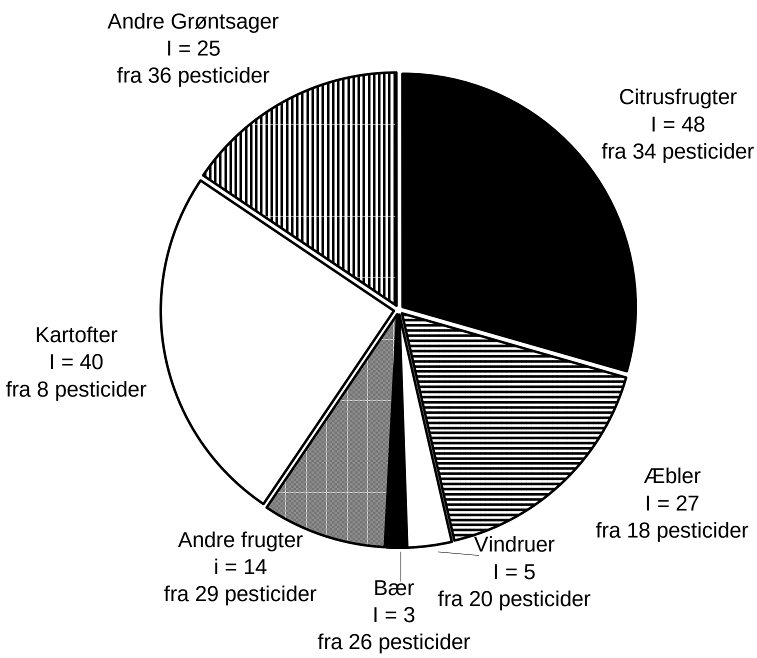


Figure 6.5
The total average intake of pesticide residues (denoted I) from different fruit and vegetables in microgramme per day. In the calculation, account has not been taken of peeling and other factors that may reduce the residual content of pesticides in the food products.

(Figure text:
Citrusfrugter = Citrus fruit
Æbler = Apples
Vindruer = Grapes
Bær = Berries
Andre frugter = Other fruit

Kartofler = Potatoes
Andre grøntsager = Other vegetables
fra xx pesticider = from xx pesticides

Uncertainties and reservations

It must be remembered that the calculations are encumbered with relatively great uncertainty. That applies to the determination of the residues of the individual pesticides and to the dietary data used. At the same time, the residues used are based on a cautious evaluation, which means that the values must be assumed to lie above the real content. The result is thus an over-estimation of the intake of both Danish and imported products. There is also a big variation in the data used for intake of diet. This variation is due partly to uncertainty in the determination of the mean intake of the individual food products and partly to a variation as a consequence of different eating habits in the population. Taken overall, the intake of the individual food products shown in table 6.5 can vary by several hundred per cent from one person to another.

However, it must be stressed that a person with a relatively large consumption of one type of food will often have a smaller consumption of other types, so variations in the total pesticide intake will not necessarily vary to the same extent as the food consumption.

6.2.5 Determination of the effects of pesticides on the population

Absorption and excretion of pesticides

Uptake of pesticides takes place after oral intake and, to a lesser extent, through inhalation or via the skin. Absorption via the lungs is normally fast compared with the other exposure routes because of the thin alveolar membrane and the ample blood flow. Absorption via the skin is often slow, but for pesticides that are metabolised quickly in the liver, skin exposure can be the main exposure pathway. With respect to exposure of the foetus, it has been found in animal studies that certain pesticides – particularly organophosphates and carbamats – can pass the placenta (Salama et al. 1993).

Metabolism

Metabolism or biotransformation of the absorbed, biologically available dose (the internal dose) determines how large a part reaches the target organ. Almost all the chemical changes that pesticides undergo in the body are due to special enzymes (Hayes, Laws 1991). The first stage in the biotransformation normally takes place via microsomal enzymes, which catalyse an oxidation or reduction reaction. These enzymes include all the cytochromal P450-enzyme systems in the liver, which is the main organ for biotransformation of chemicals. The degradation products are normally less toxic and more easily eliminated than the pesticide itself. However, for some pesticides, an activation takes place, which can lead to the formation of more toxic metabolites.

Bioaccumulation

Some pesticides that accumulate in the body's fatty tissue have very long half-lives. These so-called persistent substances are now banned. They include the chlorinated pesticides, such as DDT and dieldrin.

Authorisation and risk assessment of pesticides with a view to public health

According to an EU directive (91/414/EEC) on marketing of plant protection products, a risk assessment of health and environmental properties of the product must be carried out in connection with the authorisation procedure. The magnitude of the real and the potential exposure must be determined, both for the users and for the consumers. Users should be understood to mean spraying personnel, workers and others who are exposed to the product during and after application. The consumers are exposed to the pesticides through food and drinking water or, for example, via soil pollution.

Limit values

Allocating limit values for content in food products is part of this authorisation procedure. If a substance can be authorised for use, a maximum limit value, MRL (Maximum Residue Limit), is fixed for the maximum residual content of the pesticide or its degradation or transformation products in food products.

The limit value in food products is based partly on a toxicological assessment of the health risk in connection with intake of the pesticide in question, with an Acceptable Daily Intake (ADI) being set and partly on the residual concentrations of the pesticide found in vegetable food products after use of Good Agricultural Practice (GAP). GAP means the nationally authorised methods of use that are necessary under current conditions for effective control of pests. To arrive at the maximum limit value, the health aspect (ADI) is combined with the use of the pesticide in question (GAP). This is done by combining ADI with the Theoretical Maximum Daily Intake (TMDI), calculated by means of diet models and assuming that all crops for which the pesticide may be used contain the maximum permissible amount of the pesticide. TMDI must lie below ADI for a limit value to be set. In Denmark, it is the Danish Veterinary & Food Administration that sets the limit values for food products.

Authorisation of pesticides

In connection with the authorisation procedure, not only the pesticide's physical/chemical properties and its stability and degradation in nature must be tested, but also its toxic properties. There are internationally agreed guidelines for performance of the toxicological tests that are included in the risk assessment of pesticides. Both the active ingredient and the product must thus be tested for acute effects, and the active ingredient must be tested for chronic effects through repeated, long-term exposure (carcinogenicity, mutagenicity and effects on reproduction, including malformation of the offspring). In addition, tests are required concerning the substance's absorption, metabolism, accumulation and elimination, together with any effect on enzymes and other biochemical parameters. In the toxicological testing of chemicals, account must be taken of the substance's purity, stability in the exposure set-up and reproducibility in a possibly repeated test.

In the nature of things, most of the testing of the health effects of pesticides is done on animals (usually mice and rats) rather than people. There can be differences between test animals and humans with respect to metabolism, and far higher doses are normally used in the animal tests than the general population could be exposed to.

Acute reference dose

For certain pesticides, however, there is only a rather narrow margin between the doses that are acutely toxic and the doses that have long-term effects. For such pesticides, an acute reference dose is set in addition to the usual ADI as a protection against acute toxic effects. Readers are also referred to section 8.3 on the precautionary principle.

Measurement of the potential exposure

The potential human exposure to pesticides can be investigated by direct measurements in food products, drinking water or the environment. The most accurate data for exposure are presented in case reports, but only a group designation is usually used (e.g. insecticide, fungicide or herbicide) when describing the exposure, and the amount used is self-reported. In several studies of children and pesticides, the length of time the parents have been engaged in an occupation with potential pesticide exposure, for example, and the frequency and use of pesticides are used as indirect measures of the degree of exposure. Other studies have estimated the magnitude of the exposure by combining types of crops in an area with information about the use of pesticides that are specific to the crops in question. The rougher the measure used for classification of the type and extent of the exposure, the more likely it is that any real increased risk of health effects from specific pesticides will not be discovered.

The indicators can be too rough

In many of the studies, an assessment of effects is also often based on rough indicators. An exact description of the effects is extremely important but is often problematical – as in the case, for instance, of neurotoxic effects of pesticides, which can be very difficult to reveal and quantify. Assessments are frequently based on comparisons of mean values, whereby particularly deviant small groups can be overlooked. For cancer, tissue tests may be necessary in order to make specific cancer diagnoses. Sub-types of some diseases, e.g. leukaemia, can have different causes, and mixing these sub-types can blur a possible relationship with a given exposure. Owing to poor precision in assessment of both exposure and effect in the traditional epidemiology, incorrect classification is likely, which results in these methods having a low sensitivity, see below.

Epidemiological studies

Information on relationships between exposure to pesticides or other environmental factors and the occurrence of disease in humans is often obtained by means of epidemiological studies (also called population studies). Great caution must be exercised in interpreting the results of epidemiological studies because of a number of sources of error and inherent weaknesses in the different epidemiological models. It must be firmly stated from the start that epidemiological studies - in the classic sense – are not enough on their own to establish causal relationships.

The models comprise: 1) descriptive epidemiological studies (population-based) and 2) analytical epidemiological studies (individual-based).

Cross-sectional studies (descriptive studies)

In descriptive epidemiological studies, the lifestyle or conditions of life of groups (e.g. whole countries' populations) are typically registered as causal factors. For example, the consumption of a given pesticide in different population groups can be compared with statistical data on morbidity and mortality in these population groups, or changes in the consumption of pesticides and morbidity or mortality over time in the same population group. An obvious drawback with descriptive studies is that it is not possible to make adjustment for known risk factors at individual level (e.g. smoking, obesity or alcohol consumption). In descriptive studies one can find certain patterns between exposure and disease. For example, a high consumption of pesticides and thus probably exposure to them in large, limited population groups (e.g. farmers) can be linked to an increased occurrence of cancer. However, such a relationship says nothing at all about causal relationships, i.e. that a high exposure to a pesticide cannot, from the above data, be said to be the cause of cancer but can give rise to a suspicion concerning causal relationships, which must then be examined more closely.

Analytical studies: case control studies

Case control studies are the most common type of analytical epidemiological studies. In these, one compares causal factors, e.g. lifestyle, in individuals with a given disease or other factor that one wishes to investigate, with healthy persons. The individual in the control group should be chosen at random, and with the same inclusion and exclusion criteria, from the same population base as cases. Case control studies are retrospective. Memory therefore plays a vital role. It is also the case that precisely the memory of a sick person is often seriously affected by the disease and can give rise to systematic errors (bias). It is also often uncertain which period of the sick person's life is most relevant for the study. The longer the time elapsing between a harmful effect and the occurrence of recognised disease, the greater this problem becomes. A study that compares the pesticide intake through diet in women that have borne a child with a congenital defect with the intake in women that have born healthy children is an example of a case control study that is encumbered with these possibilities of error.

Analytical studies: cohorts

Another frequently used analytical epidemiological study – the prospective cohort study – has fewer weaknesses than case control studies. In the prospective cohort study, relevant information is gathered from healthy persons, who are then monitored for a period – often a number of years – during which the morbidity of the cohort is recorded. This means that when a disease occurs one has the possibility of going back and finding the factors that characterised persons that later became ill for comparison with persons that did not do so. In cohort studies one also has the possibility of extracting and storing biological material for later analysis. For example, analyses of blood samples, fatty tissue samples and milk from nursing mothers provide information about the exposure to pesticides.

Cohort studies have the major drawback that they require many participants because the incidence (number of new cases per year) of ordinary diseases (e.g. cancer) is relatively low. Another factor is that it can take a long time for a disease to develop. In the case of cancer, 20 years or more can elapse from the initiation phase until clinical diagnosis (see later). These factors mean that cohort studies are considerably more costly and more difficult to handle than case control studies.

However, in the case of cohort studies as well, it is not possible to determine whether there is a causal relationship. Persons with a high exposure to a pesticide probably differ in other ways from persons characterised by a low exposure. In studies, one often adjusts statistically for factors that can confound the result, e.g. socioeconomic status, smoking habits, alcohol consumption, physical activity, use of hormones, etc. These factors are called "confounders" or confounding factors. However, it is important to be aware that differences in, say, lifestyle and conditions of life cover a very large number of factors and too little is known about their effect on the development of disease.

Other sources of error

Lack of big differences in exposure in the population group studied can be a problem in studies of the effect of pesticides on public health. The sources of error mentioned above are just a few of the inherent sources of error in epidemiological studies. The uncertainty concerning, for example, intake of pesticides is a particular problem when there is only a small variation in intake in the population group studied. While the true difference in risk of, say, cancer between a lower and upper level of a narrow intake interval is probably small, the observed difference decreases with increasing uncertainty of the analytical measurements. A negative result, i.e. a lack of relationship between exposure to a pesticide and the risk of disease can therefore not be taken to mean that such a relationship does not exist.

For a more detailed discussion of confounding and other sources of error in epidemiological intake/exposure studies, see Tarasuk, Brooker 1997.

No conclusive evidence

It cannot be proven on the basis of epidemiological studies that pesticides, in the quantities to which the general population is exposed, for example, via diet, are harmful to health. Conversely, one can never completely prove scientifically that a pesticide cannot cause a health risk. One can, however, show, with greater or lesser (un)certainty, the probability or lack of probability of a health risk. This applies to all scientific work, including tests carried out on animals.

6.2.6 Long-term effects of low-dose exposure

Low-dose exposure implies lengthy, continued or occasional exposure to low levels of pesticides. With this form of exposure the body slowly accumulates a quantity of one or more pesticides that is sufficient to produce undesirable effects in the body. Unlike the health effects of occupational exposure to pesticides (see section 6.1), there are very few epidemiological studies of the relationship between exposure of the general population and the risk of developing a disease. In the following, we sum up the findings from existing studies of the effect of pesticides on reproduction, the hormonal system, cancer, the nervous system and the immune system. For further amplification of the existing knowledge, readers are referred to Skadhauge (1998).

Reproductive toxicity

Toxic effects on reproduction can take the form of difficulty in conceiving (reduced fertility or unrecognised early miscarriage), infertility, miscarriage and stillbirth (Smith et al. 1997). In women, the effects can also manifest themselves in the form of paramenia (as a consequence of changes in the neuro-endocrine function in the hypothalamus, the pituitary gland and the ovaries) and, in men, in the form of a low sperm count or changes in the mobility or appearance of the sperm.

In animal tests, several pesticides have shown toxic effects on reproduction (Traina et al. 1994). Particular attention has been paid to pesticides with hormone-like() effects, but, in animal tests, a number of other chemical substances have proved able to affect the reproductive system, resulting in, for example, reduced quality of semen and infertility without it being possible to point directly to an oestrogenous effect. As stated earlier, several studies of individuals with a high occupational exposure have shown negative effects on the reproductive system and particularly on fertility. However, in the case of the general population, the data are much less certain.

In 1995, DEPA published a report that concluded that sperm quality in otherwise healthy men had been falling since the end of the 1930s (DEPA 1995a). In the same period, a marked increase in testicular cancer was recorded, particularly in younger men. An increased frequency of certain deformities of the sexual organs of boys also seemed to have occurred. However, there was insufficient documentation to determine whether (early) exposure to pesticides could have been a cause of these effects on the reproductive system. In the case of most chemical pollutants in our environment, it is unknown 1) whether they have an oestrogenous effect or not, 2) how big their effect is, individually or combined, and 3) the actual magnitude of the exposure (Editorial 1995).

Cancer

For a number of pesticides previously in use there is evidence of carcinogenicity in animals, whereas arsenic and mixtures containing arsenic are the only pesticides classified by IARC (International Agency for Research on Cancer) for which there is sufficient evidence of carcinogenicity in humans, based on an increased risk of lung cancer and skin cancer.
There are currently some few pesticides on the market that are classified as carcinogenic in group 3 (Carc 3), see section 8.1 and Lindhart et al. (1998).

Mechanism behind the development of cancer

The carcinogenic effect can be exercised in different ways. Some pesticides affect the cells' DNA and, in the worst scenario, induce precisely the changes that enable the cells to develop malignant properties (*initiators*). Other pesticides can cause cancer to develop by stimulating initiated cells to divide further (*promotors*). In relation to pesticides, attention has been paid particularly to their hormone-like effect, since oestrogens, for example, can promote hormone-dependent initiated cells (e.g. mammary gland cells). However, pesticides may also affect the development of cancer in other and more indirect ways, for example by inhibiting specific parts of the immune system.

Cancer cannot be predicted

One big difficulty in investigating a relationship between exposure to an environmental factor and the risk of cancer is that cancer often takes a very long time to develop – up to 20 years and perhaps even longer. Despite intensive research, valid biomarkers for early stages of cancer have not been identified with certainty.

Findings in epidemiological studies

There are only a few epidemiological studies of the relationship between the risk of cancer and exposure to pesticides in the general population. Most of the studies have focused on the relationship between the level of organochlorine compounds in the blood and the risk of breast cancer. In 1993, a study from New York aroused some interest (Wolf et al. 1993). In this study, an approximately 4 times higher frequency of breast cancer was found in women with a high blood concentration of DDE and PCB. Dieldrin was not measured. In 1994, a similar study was carried out in California, and there, the relationship was not nearly as strong, even though the exposure to DDT was considerably greater (Krieger et al. 1994). A third major American study was unable to establish any relationship between the blood content of organochlorine compounds and the risk of breast cancer. However, the follow-up period was short, and problems with confounder correction resulted in statistical weakness (Hunter et al. 1997). Lastly, a recently published Danish study showed a statistically significant dose-related correlation between the blood content of dieldrin and the risk of breast cancer (Høyer et al. 1998). The other relationships between risk of cancer and blood content of beta-hexachlorocyclohexane, DDT and PCB were not statistically significant.

Relationship between pesticides and cancer not documented

As the results of the above-mentioned epidemiological studies indicate, there are data that show that exposure to organochlorine compounds can be connected with an increased risk of breast cancer, although without sufficient, clear grounds to deduce the significance for the general population. A scientific panel appointed by the National Cancer Institute of Canada came to a similar conclusion in a review of studies of mainly occupational exposure and risk of cancer (Ritter 1997). The panel concluded that there was insufficient scientific evidence that pesticides contributed significantly to total cancer mortality.

Hormonal toxicity

It is well documented that a number of persistent chemicals can affect the endocrine system by affecting the hormones in the body that are responsible for maintaining homeostasis and regulating the developmental processes (Gray, Ostby 1998; Kavlock et al. 1996; Tilson, Kavlock 1997; Porter et al. 1993). Endocrine disruptors have been broadly defined as exogenous substances that disrupt production, release, transport, metabolism, sorption, action or elimination of the body’s natural hormones (Kavlock et al. 1996; Tilson, Kavlock 1997). Some of these substances can induce the cytochromal P450 systems in the liver. This can affect the metabolism of steroid hormones (including sex hormones) and thyroid hormones, whereby secondary effects can be induced in hormone-dependent organs.

However, too little is known about endocrine disruptors, and the designation has in some cases been used where the biological relationship is far from clarified. The suspicion about the very persistent substances DDT, DDE and PCB is warranted in view of the effects these substances have on wild animals (e.g. seals, otters and alligators). For the endocrine disruptors, too, there are problems in extrapolating from studies of test animals with relatively high exposures to the relatively low exposures that occur in the environment and the very small amounts that humans are exposed to. These endocrine disruptions cannot be demonstrated in present test systems, but work is going on under OECD to improve the test programme for new chemicals, so that animal tests are better able to document such effects.

Developmental toxicity

Developmental effects are effects that occur in the individual during development as a result of exposure prior to conception, in the foetal existence or postnatally until the individual is fully developed. The result of the developmental disturbances can be death, structural abnormalities, inhibited growth or functional disturbances. However, it is often difficult to determine whether miscarriage or stillbirth is due to reproductive or developmental effects.

There are too few studies on the relationship between exposure to pesticides and developmental effects. This also applies to the potential of pesticides and fertilisers in contaminated groundwater to produce reproductive and developmental toxic effects in humans.

Neurotoxicity

The term neurotoxicity is used to describe a substance's potential to change the structure or function of the nervous system, defined by neurochemical, neuropathological organ changes, behaviour and specific psychological processes such as sense perception, learning and memory. Many of these disturbances can be directly measured with neurochemical, neurophysiological and neuropathological methods, whereas others can only be interpreted by looking at the behaviour. The action mechanism of many groups of pesticides – particularly the insecticides – the intended target of which is the peripheral nervous system, leads directly to consideration of their potential neurotoxicity, whereas the neurotoxic potential of other groups is less clear. Studies of neurotoxic effects are difficult to perform and interpret, for which reason there are very few conclusive studies.

Experimental studies have shown that the nervous system is more vulnerable to exposure to chemical substances during development than when it is fully developed. Animal tests have shown that neurotoxicity as a consequence of low-dose exposure to such pesticides as organophosphates, pyrethroids, DDT and paraquat during development of the brain can lead to irreversible changes in the adult brain and induce behavioural and cholinergic changes in the adult animal, whereas exposure of an adult to the same substance has little or no effect (Eriksson 1997; Williams et al. 1997). Exposure to chemical substances during development of the nervous system can vary, both qualitatively and quantitatively, depending on the phase of development of the nervous system (non-linear dose-response curve). It can therefore be difficult to assess the effects of long term low-dose exposure on the basis of short-term studies. In addition, the development of the nervous system depends on the endocrine systems, which are responsible for sexual development and growth and are closely associated with the presence of circulating thyroid hormones. Moderate to major changes in the concentration of thyroid hormone during development result in motoric dysfunction, cognitive defects and other neurological abnormalities (Porterfield, Hendrich 1993). As stated, it can be difficult to assess neurotoxic effects. The National Research Council (1993) found that the present strategy for testing toxicity was inadequate for assessing toxicity to several organ systems, including neurological development processes.

In several epidemiological studies, Parkinson's disease has been linked to pesticide use (including Semchuk et al. 1992). The main suspect was paraquat, the chemical structure of which is somewhat similar to a chemical (MPTP), which can induce parkinsonian symptoms in laboratory animals. There are no studies specifically elucidating the effect of paraquat.

Neurotoxicity in children

There are very few studies of children and neurotoxic effects as a consequence of exposure to pesticides, and clear conclusions cannot be drawn from them. There seems to be insufficient documentation of neurotoxic effects in the fully developed nervous system as a consequence of low-dose exposure to pesticides. However, experimental data provide a basis for assuming that the nervous system is vulnerable to pesticide exposure during development, partly due to disruption of endocrine systems, which are of importance for normal development of the nervous system.

Immunotoxicity

The toxicological tests required as a minimum before a plant protection product can be authorised can to some extent show whether a chemical substance has a potential immunotoxic effect when the organism is exposed to it. However, the test methods have some constraints, particularly with respect to sensitivity, i.e. their ability to show any weak immunotoxic effects. Generally speaking, chemical substances with a clear immunotoxic effect, including pesticides, will be identified in the required toxicological tests, whereas there can be a problem with substances with a medium to weak effect.

Immunotoxic effects of chemical substances, including pesticides, can occur as a consequence of the immune system being either weakened or strengthened, or if the immune system responds to the chemical substance as an antigen, which can lead to allergy or autoimmunity.

Several animal studies have shown immunological changes after acute or chronic exposure to pesticides (Banerjee et al. 1996; WHO 1996). In many cases, the results from these studies are difficult to interpret, and some of the studies could indicate that the immunotoxic effect can be a consequence of another, systemic, toxic effect. However, the tests show that pesticides, as well as other chemical substances, can have a potential effect on the organism's immune system (WHO 1996).

Animal tests using rodents indicate that the immune system in the developing organism is more vulnerable than the fully developed organism. Experimental and clinical data from the working environment have also shown that chemical substances, including certain pesticides (chlornitrobenzene, captan og organophosphates) can induce contact hypersensitivity (type IV reaction) in test animals and humans (Cronin 1980).

The epidemiological evidence of immunotoxic effects as a consequence of exposure to pesticides is sparse. Immediate reactions (type I reaction) are thus only described in a few case reports that have been difficult to confirm (Baker, Wilkinson 1990).

Data from studies of chemical substances, including certain pesticides, show that these can affect the immune system under special experimental conditions. The tests on which the toxicological assessment is usually based can identify the pesticides that have a potential serious effect on the immune system. With the exception of contact hypersensitivity as a consequence of occupational exposure to pesticides, there are insufficient data to conclude that exposure to pesticides in the environment in normal circumstances will cause damage to health in the general population as a consequence of an effect on the immune system (Baker, Wilkinson 1990; Banerjee et al. 1996; WHO 1996).

6.2.7 Conclusions

There is insufficient epidemiological evidence to either prove or disprove a relationship between health effects and long-term low-dose exposure to pesticides. There are several reasons why there are considerable difficulties in gaining more certain knowledge about the effect of pesticides on human health. The epidemiological studies concerning the effects on humans of exposure to pesticides are characterised by imprecise measures for both exposure and effect, a relatively short follow-up period and lack of control of confounding factors. Due to limited group sizes, data are often collected in large groups, which further reduces the sensitivity. Owing to low exposure contrast and many confounding factors, there are often problems in proving any effects.

The following specific conclusions can be drawn:

- For a relationship to be demonstrated epidemiologically, better measures are needed for both exposure and effect. The development of biomarkers may be a step in this direction.

- It is important to constantly update the test methods for animal tests based on scientific development on the basis of experience in humans.

- The review of the pesticide intake from food products and drinking water shows that the main sources of the population’s exposure is the intake from berries, fruit and vegetables and, to some extent, cereals and cereal products, while the intake from drinking water, animal food products and fish is of no significance to the total exposure.

- The total average load from food products is estimated to be approx. 200 microgrammes pesticide per day, more than half of which comes from just a few types of food products, namely citrus fruit, potatoes and apples. Around 60% come from imported products and 40% from Danish products. There are big variations in the calculated numerical values, and, in practice, the total intake is believed to range between a very low intake and about 600 microgrammes per day. Since most of the pesticide residues in citrus fruits are in the peel, which is not eaten, the actual daily intake of pesticides is less than 200 microgrammes per day. In the last-mentioned scenario, the intake via Danish products would be greater than 50% of the total intake.

- In treated crops it is assumed that there is generally some residual content of pesticides that decreases the longer the time that elapses between spraying and harvesting. This is, however, a factor that is particularly important if the pesticide is applied on crops or parts of plants that are edible at the time of harvest, i.e. after the end of flowering, seeding and similar. However, in farming practice, there are a number of other factors that influence the pesticide content of the crop. This applies not only to the plant’s development stage at the time of treatment but also to the concentration used, the method of application, etc. However, failure to detect residues does not mean that the crop is free of pesticides, but rather that the content is below the analytical detection level.

- Residual content in harvested crops usually comes from pesticides applied at times and in forms of treatment in which the spray product is applied directly on plants in their seed-bearing, berry-bearing or fruit-bearing growth stages. The residual content in vegetable food products with high residual concentration levels could therefore be reduced by use of longer intervals between spraying and harvest, including restricting spraying to before the end of flowering, earing or similar.

- The average load at single substance level is typically about 1% or less of the Acceptable Daily Intake (the ADI value) fixed on a mainly experimental, toxicological basis, where the safety margin between average human exposure and zero-effect level for the most sensitive effect in the most sensitive of the existing test systems is more than 1000.

- The safety margin in the use of pesticides is based mainly on animal tests, since the safety margin with lifetime, low-dose exposure cannot, for ethical or practical reasons, be established on the basis of human tests.

- The discovery of new effects that have not previously been studied or to which importance has not previously been attached, e.g. effects on the endocrine system and the nervous system during development, illustrates the importance of constant research. For example, the existing animals tests for authorisation of pesticides need improving with respect to detection of endocrine disruptors.

- Differences in sensitivity between animals and humans and between one human and another make it necessary to use (un)certainty factors when ADI has to be fixed on the basis of data.

- As a consequence of the aforementioned difficulties in carrying out long-term epidemiological studies of the effects of low-dose exposure, consideration could, however, be given to concentrating the research on areas in which deficient documentation should suggest caution, e.g. the possible need to introduce an extra uncertainty factor in order to protect children in cases in which there is insufficient toxicological information.

- Risk assessment of the coformulants, considerable quantities of which are often used, should receive more attention in the assessment of the individual pesticide products, and the appropriateness of using the individual substances should be regularly reviewed.

- For degradation products of pesticides in the environment, knowledge is lacking in some cases about their health effects. This applies particularly if other metabolites are formed in the environment than in test animals and humans.

- In the health assessment, particularly for the risk groups (children and pregnant women) greater attention should be paid to the fact that many different chemical substances are taken in at the same time.

- It cannot be proven on the basis of epidemiological studies that pesticides, in the quantities to which the general population is exposed, for example, via diet, are harmful to health. Conversely, one can never completely prove scientifically that a pesticide cannot cause a health risk. One can, however, show, with greater or lesser (un)certainty, the probability or lack of probability of a health risk. This applies to all scientific work, including tests carried out on animals. Furthermore, every statement about safety in connection with the use of chemical substances is based on the existing body of knowledge, so there is always the possibility of later findings with now unforeseeable effects.

- The epidemiological studies of effects on humans of exposure to pesticides are characterised by imprecise measures for both exposure and effect, short follow-up times and lack of confounder control. In addition, limited group sizes mean that data are often pooled, whereby the sensitivity is further reduced.

- There are practically no epidemiological studies of effects of metabolites that are formed in the environment.

- In epidemiological studies, insufficient attention is paid to coformulants.

6.3 Poisoning caused by pesticides

The National Board of Health has carried out a study of hospital admissions, outpatient attendance and deaths in Denmark caused by pesticides in the period 1987-1996, using data from the National Registry of Patients and the Cause of Death Registry. However, the admission figures from the period before 1994 are encumbered with incorrect diagnostic codes (Skadhauge 1998). In the period 1994-1996, there were 88 admissions in all. Of these, 48% were children under the age of 11 years and 39% were women. With respect to outpatients, the first countrywide records are from 1995. 127 cases were recorded in 1951 and 51 in 1996. However, some of the codings in 1995 could be incorrect diagnostic codes. A manual examination of death certificates revealed 48 deaths, 45 of which were suicide and three accidents in children. For the admissions and outpatient cases, it is not possible to determine whether the poisoning occurred in connection with work in farming. The three child deaths all occurred in rural communities. Two of the cases were due to unlawful storage in unmarked packaging.

The Poisons Information Office of the Occupational and Environmental Medicine Clinic at Bispebjerg Hospital received 163 calls about pesticide poisoning in 1997. 47% concerned children aged 0-14 years. The calls covered the following groups of substances:

Herbicides	40	(of which, 6 admissions)
Fungicides/algicides	6	(of which, 0 admissions)
Insecticides	84	(of which, 21 admissions)
Other	33	(of which, 4 admissions)

Some of the calls concerned parathion, which has not been used professionally for many years. In two thirds of the cases, the accident occurred in the home or garden, 12% occurred within farming and 5% in forestry undertakings or market gardens. However, it must be stressed that the figures cannot be regarded as representative, since the calls constitute only a small proportion of the events actually occurring.

6.3.1 Conclusions

- A relatively large number of cases of pesticide poisoning are recorded each year. Deaths have occurred through suicide and accidents among children. About half the recorded admissions in connection with pesticide poisoning relate to children.

- Cases of poisoning with pesticides that have been out of use for many years still occur.

6.4 The sub-committee’s conclusions and recommendations

The sub-committee deems the risk of acute effects from pesticides to be considerably lower today than it was just 10 years ago because the most harmful products are no longer permitted. The possibility cannot be excluded of some risk to persons who do not observe the given rules for personal protection and correct use of the pesticides, inappropriate work routines and poor work hygiene. However, the sub-committee notes that there can be considerable exposure of the sprayer operator and of workers in greenhouses and in the production of fruit and vegetables, where frequent use is made of pesticides.

The sub-committee concludes that the risk of occupational accidents in connection with mechanical weed control could rise with the introduction of more machines, which require repair and maintenance. Furthermore, increased manual weeding could result in more cases of injury due to repetitive, monotonous work (RMW). There is a generally increased risk of physical problems – particularly osteoarthritis – among workers in farming due to stable work, milking, tractor operation and heavy physical work, which are not related to the use of pesticides.

- The review of the pesticide intake from food products and drinking water shows that the main sources of the population’s exposure is the intake from berries, fruit and vegetables and, to some extent, cereals and cereal products, while the intake from drinking water, animal food products and fish is of no significance to the total exposure.

- Treated crops must always be assumed to have a certain residual content, so failure to detect a content can only be taken to mean that the content is in such case below the analytical detection level.

- Limiting permission to spray after flowering or seeding would reduce the residual contents.

- The total average load from food products is estimated to be approx. 200 microgrammes pesticide per day, more than half of which comes from just a few types of food products, namely citrus fruit, potatoes and apples. Around 60% come from imported products and 40% from

Danish products. There are big variations in the calculated numerical values, and, in practice, the total intake is believed to range between a very low intake and about 600 microgrammes per day. Since most of the pesticide residues in citrus fruits are in the peel, which is not eaten, the actual daily intake of pesticides is less than 200 microgrammes per day. In this estimate, the intake via Danish products would be more than 50% of the total intake.

- The average intake at single-substance level from food products is typically around 1% or less of the present Acceptable Daily Intake (the ADI value).

- It cannot be proven on the basis of epidemiological studies that pesticides, in the quantities to which the general population is exposed, for example, via diet, are harmful to health. Conversely, one can never completely prove scientifically that a pesticide cannot cause a health risk. One can, however, show, with greater or lesser (un)certainty, the probability or lack of probability of a health risk. This applies to all scientific work, including tests carried out on animals. Furthermore, every statement about safety in connection with the use of chemical substances is based on the existing body of knowledge, so there is always the possibility of later findings with now unforeseeable effects.

- Epidemiological studies of effects of metabolites and inert substances, which often make up a large part of the products, are largely non-existent.

6.4.1 The sub-committee's recommendations

- In both conventional and organic farming, farmers and workers are unaccustomed to thinking about health and safety, and not all injuries are reported despite the fact that there are many serious accidents in farming and more fatal accidents than in any other occupation. The sub-committee recommends that health and safety be given greater priority in both conventional and organic farming.

- The sub-committee finds that too little is known about the ability of pesticides and their coformulants to produce allergies and about their effect on the immune system.

- As a consequence of the intensive use of pesticides in nurseries and the production of fruit, vegetables and berries, the sub-committee recommends intensified action to reduce exposure to pesticides.

- More extensive use of biomarkers for exposure to and the effects of pesticides would make it easier to demonstrate a relationship epidemiologically.

- The discovery of new effects that have not previously been studied or paid much attention, such as effects on the endocrine system (hormones) and the nervous system during development shows the importance of constant research in these areas.

- In the health assessment of pesticides, particularly with respect to risk groups, greater account should be taken of the fact that many different chemical substances are taken in at the same time.

7 Coformulants and other chemical substances, including substances occurring naturally in agriculture

7.1 Coformulants in pesticides

A number of chemical coformulants are added to pesticide formulations. They include carriers, solvents, surfactants, dispersants, spreading products, adhesives, absorption-improving products, antioxidants, bactericides, colouring products, fillers and perfume. In 1997, around 69% of pesticides sold in Denmark consisted of coformulants, corresponding to about 10,000 tonnes. Part of the quantity of coformulants is water. Coformulants are also called inert ingredients (Danish Environmental Protection Agency 1998a). The coformulants comprise a motley collection of chemicals, some of which are more acutely toxic than the active ingredients, e.g. organic solvents (information from the Danish Working Environment Authority). Isophoron is a commonly used solvent in a number of products, and the total quantity used is large. The substance has recently been classified as Carcinogenic Cat3. Some of the substances feature in DEPA's list of undesirable compounds. The coformulants have been in focus because they include organic solvents and because it was found in 1997 that they included alkylphenols and alkylphenolethoxylates, which, in experimental studies, show hormonal effects on mammals. These coformulants are now being phased out, which means that many products are being reformulated, using substitute coformulants whose known properties are deemed to be less harmful.

Authorisation of coformulants

Coformulants (or additives) in pesticides are not in themselves subject to authorisation. The various substances are subject to the regulation as described for chemicals in the Act on Chemical Substances and Products. For pesticides there are therefore no actual requirements concerning analyses of the individual ingredients. However, the authorities must know the precise composition of the products, so that all the ingredients can be identified. DEPA can also demand so-called data sheets for the individual coformulants. These data sheets contain brief information about the substances' physical, chemical and toxicological properties, where these have been determined. When assessing coformulants, DEPA also consults the list of dangerous substances, which gives the classification of a number of chemicals (including some pesticides).

The toxicological properties of coformulants can also to some extent be seen from the tests required on the formulated product. These tests include tests for acute toxicity with oral intake, intake through the skin and inhalation, skin and eye irritation and, in some cases, ecotoxicological tests on aquatic organisms, bees, worms, microflora, etc. If a coformulant has a serious long-term effect and is included in the product in a sufficiently high concentration, the product is classified accordingly and has to undergo an exposure and risk analysis, even if the active ingredient does not have serious effects. DEPA can withdraw authorisation of a product simply on grounds of a coformulant. In addition, a coformulant must be declared on the label if it occurs in a concentration of 0.2% or more in the case of very toxic and toxic substances and 5% or more in the case of harmful or caustic substances.

7.2 Proportionality: the chemical impact in agriculture

Definition of proportionality

Here, proportionality should be understood to mean a proportional assessment of the harmful effects of pesticides on the environment and health compared with other chemicals used in agriculture or unintentionally added to the cultivated soil. It lies outside the scope of the sub-committee's mandate to examine the use of chemicals in other sectors of society and to compare these environmental impacts with the environmental impact resulting from the chemicals used in agriculture. In addition, the pesticides have been assessed against naturally occurring toxins, and the use of naturally occurring substances as pesticides has also been assessed. The assessment thus covers:

- chemical substances in agriculture
- chemical substances in food products

In the assessment, the sub-committee has assessed the current size of the environmental load and its development, together with its regulation, and – lastly – the size of the load in relation to the occurrence and effects of the pesticides.

7.2.1 Chemical substances in agriculture

Like the rest of society, conventional farmers are dependent on chemical substances. The extensive use of fertilisers leads to loss of nitrogen and phosphorus to the aquatic environment and loss of ammonia to uncultivated land and forests. The use of chemical products has become more widespread in the agricultural sectors in step with the increasing demands concerning productivity. Such aids as fertiliser, ground chalk and pesticides are used in the production of crops, wood pulp, ornamental greenery, etc. Various waste products are used as fertilisers, some of which can contain xenobiotic substances. Pharmaceuticals, growth promoters and disinfectants are used in animal husbandry. Finally, pollutants are transported in the air. They derive, e.g., from the combustion of oil, coal, straw and waste, and traffic. The herbicidal substance DNOC can be formed from air-pollution components during atmospheric, chemical reactions, see section 4.5. Ozone is formed in a complicated interaction between oxygen, combustion products and the sunlight. Ozone can cause considerable damage to crops (Fenger 1995).

Heavy metals

Cultivated land receives heavy metals from fertilisers, ground chalk, sludge and other waste products and from manure. It also receives heavy metals from the atmosphere. Both in Denmark and internationally, pollution with heavy metals – particularly cadmium, lead and mercury – has been considerably reduced. There are thus strict requirements concerning the content of heavy metals in fertilisers, chalk, sludge and other waste products. Cadmium is particularly problematical because both manmade and natural dispersal of cadmium is diffuse and because most cadmium compounds are relatively mobile in the environment. Cadmium is absorbed by plants parallel with phosphorus and thus makes cereal crops a major source of people's intake of cadmium. People's intake of lead, cadmium and mercury is generally high. Lead is not absorbed by plants but lands on their surfaces in the form of small particles from the atmosphere. However, national and long-range transboundary air pollution with heavy metals has been considerably reduced in the last 15 years. Better treatment of flue gas and a ban on lead in petrol have reduced air pollution. Since 1978, the deposition of cadmium has been reduced by 66%, and atmospheric emissions of lead have fallen by more than 75%. The use of copper and zinc as growth promoters in pig production means that the content of these metals is rising on soil regularly fertilised with pig manure from herds in which these growth promoters are used. Both metals affect the soil's microorganisms and, in high concentrations, can inhibit plant growth.

The metals are not a serious problem in cultivated land today. However, this does not apply to really contaminated land, e.g. former industrial sites. Even so, taken together, the different sources can cause an increase in the soil's content of heavy metals. The environmental authorities are therefore taking targeted action to reduce the use of heavy metals – particularly cadmium, lead and mercury – in society. Seen in proportion to the impact of pesticides, heavy metals are a bigger health problem than pesticides, but are not a big environmental problem. With the environment policy pursued, the problem is being reduced at source, both nationally and internationally. Owing to the continuing although diminishing supply, the load from heavy metals must be monitored on a long-term basis.

Xenobiotic substances

A very large number of chemical substances are used in society. Some of them end up in wastewater sludge and are thereby conveyed to land under cultivation. In 1997, the Danish Environmental Protection Agency introduced limit values for significant and representative, xenobiotic organic substances in sludge. It took this action to protect the environment and to promote the phasing-out of these substances from their cycles in society. There are now limit values for a number of tar substances (PAHs), the surfactants LAS, nonylphenols and the plasticiser DEHP. At the same time, both ecotoxicological and human toxicological soil quality criteria have been set for a wide range of substances that can occur as contaminants in soil or waste products. A number of studies are in progress to determine whether these protection levels are adequate.

Xenobiotic substances can also be present in low concentrations as contaminants in animal feed. The substances in question are banned pesticides, such as DDT and toxaphen, and industrial contaminants, such as PCB. These substances can be supplied to plants during their growth period as atmospheric deposition as a consequence of long-range transfrontier atmospheric pollution, together with combustion products, such as PAHs and dioxins. The cleaning products used by farmers for cleaning stables contain LAS and nonylphenol compounds. Small amounts of plasticisers, e.g. DEHP, are released from hoses, tanks, paint and plastic objects. The total supply means that manure also contains xenobiotic substances, which reach soil under cultivation by this pathway. Lastly, there is a direct supply of contaminants from the atmosphere to plant surfaces and the soil. The contaminants in question are PAHs, PCB, dioxins, chlorinated phenols and benzenes, together with a number of other, persistent organic contaminants. With frequent application of sludge on the same area, the total quantity of xenobiotic substances can be of the same order of magnitude as the pesticide load.

Most of the xenobiotic organic substances that are supplied to cultivated land are degradable, but as a rule over a very long period of time. The presence of xenobiotic substances is undesirable, so for precautionary reasons, consumption and dispersal are limited as much as possible or, in the case of persistent organic substances, for example, a ban is introduced. The exposure of the agricultural sector to xenobiotic substances is low compared with other sectors. Compared with the effect of pesticides, the direct effect of xenobiotic substances on cultivated soil and thus on crops is small. However, relatively little is known about potential, indirect pollution by xenobiotic substances, for example via air or through accidental loss, spillage or discharge to water. There may therefore be grounds for concern since the long-term effects of even small concentrations are not known. The aim of environment policy in this area is a reduction at source, both nationally and internationally, but in view of the continuing supply, the load from xenobiotic substances must be monitored on a long-term basis.

Tropospheric ozone

The formation of tropospheric ozone is closely linked with nitrogen oxide pollution from traffic, industry and energy production. Tropospheric ozone must not be confused with the ozone in the stratosphere, which is *beneficial* because it provides protection against UV radiation. Ozone is formed by the action of sunlight on nitrogen oxides and organic compounds – especially hydrocarbons. Ozone is a constituent of smog and affects the eyes, throat and lungs. It is particularly harmful to asthmatics. Ozone has a harmful effect on vegetation when it penetrates the plant cells. The damage occurs especially when the concentration of ozone in the air is over 40 ppb. The most serious effect of ozone, both ecologically and economically, is the effect on plant growth and seeding.

Seen in relation to pesticides, ozone is an example of a component of air pollution that is formed from emissions from traffic, energy production and industry and that causes considerable losses to the agricultural sector in the form of reduced yields. Work is going on within both the EU and UN-ECE FN-ECE to reduce the formation of ozone.

Veterinary drugs and growth promoters

In animal husbandry, regular use is made of a number of veterinary drugs. Besides drugs for treatment of diseases, large quantities of prophylactic drugs are used, including the so-called growth promoters. Growth promoters are usually antibiotics but can also be salts of copper or zinc. Owing to the suspicion that use of certain pharmaceuticals can lead to the development of resistant bacteria, attention has recently focused on farmers' use of antibiotics. The substances can also be spread in the environment with manure. Since the substances in question can be both biologically active in low concentrations, persistent and mobile in soil, the possibility cannot be excluded that some of the veterinary pharmaceuticals can constitute a risk to the environment in line with many other xenobiotic substances. Studies have been initiated under the Danish Environmental Research Programme to throw light on these questions. It will be some years before the final results can be expected, but preliminary studies indicate that particularly the broad-spectrum antibiotics have serious effects on microorganisms, whereas the effects on soil arthropods are relatively limited. Seen in relation to pesticides, veterinary pharmaceuticals and growth promoters constitute a potential risk of development of resistance in microorganisms, making treatment of infections in domestic animals and humans difficult. As far as the effects in the environment are concerned, veterinary pharmaceuticals and growth promoters probably constitute less of a risk than pesticides. However, there is a lack of studies of these matters - particularly of the risk of pollution of the groundwater.

7.2.2 Chemical substances in food products

Besides pesticide residues, food products contain a large number of contaminants and chemical substances, partly anthropogenous and partly of natural origin. In the Government's report on food safety, these food components are systematically reviewed (Danish Government 1998). There follows a comparative analysis of the health consequences of pesticide residues in food products.

Many factors affect food safety. They include:

- naturally occurring toxic substances, e.g. algal toxins in mussels
- residues from medical treatment of animals, e.g., antibiotics
- contaminants from the environment, e.g. dioxins
- pesticide residues, e.g. from weed control
- additives and aromatics added intentionally to improve, for example, colour, taste and shelf-life
- migration from packaging
- chemical compounds formed during preparation, e.g. fried food mutagens.

Table 7.1 lists the health effects of the different contaminants of food products. The cause of health effects is shown, together with an assessment of the risk to humans given as the number of deaths or cases of poisoning per year or a safety margin between the actual exposure and NOAEL. The table shows that residues of the (individual) present pesticides have a large safety margin of 1000. They are thus less dangerous than the old, persistent chlorinated pesticides, which have a safety margin of 10-500, depending on the individual substance. The heavy metals lead, cadmium and mercury are far more dangerous to humans that pesticide residues, having a safety margin of only 2-10. It is at the same time thought that toxic constituents in food plants, such as glycoalkaloids in potatoes and tomatoes, lectins in dried beans, prussic acid glycosides in apricot kernels, bamboo shoots and flax seed, together with phenylhydrazines in mushrooms, constitute a greater risk than pesticide residues. There is growing interest in these toxic substances because their content in food plants can be inadvertently increased by genetic modification. Special attention is being paid to this in the risk analysis of genetically modified plants. Lastly, there is nitrate, which is deemed to be a bigger problem in drinking water than pesticide residues in the current concentrations.

Table 7.1
Health effects from different contaminants in food products. For each type of contaminant, the figure shows the number of deaths, cases of poisoning or other

effect that can be expected per year or the safety margin between the actual level and the level at which it begins to become possible to observe the effects (Danish Government 1998). The individual pesticide, which has a margin of more than 1000, is thus less dangerous than any of the metals lead, cadmium and mercury, which have a low margin of 2-10. Question marks indicate that there is too little knowledge on which to base an assessment.

Cause of effect	Human risk or safety margin
Natural toxic substances	
Aflatoxins	<0.1 cancer deaths per million per year
Ochratoxins	Margin>500
Trichotecenes	Margin>1000
Fumonisines	Margin>1000
Algal toxins	?
Toxic constituents in food plants	Estimated > 20 cases of poisoning per million per year
Toxic constituents in edible fungi	?
Toxic constituents in health-food plants	?
Chemicals in food	
Additives	Margin>100
Aromatics	?
Pesticides	Margin>1000
Veterinary drugs	Margin>100
Lead, cadmium, mercury	Margin 2 - 10
Nickel	?
Other metals, boron, platinum, arsenic	?
Nitrate	Margin < 10 (*)
Dioxins	Margin 5 -10
PCBs	Margin 5 -10
Persistent chlorinated pesticides	Margin 10 -500
Other persistent organic environmental contaminants	?
Other organic environmental contaminants	?
Migration from packaging, phthalates and bisphenol A	?
PAH	20-60 extra deaths from cancer per million per year
Nitrosamines	0.04-0.4 extra deaths from cancer per million per year

(*): Nitrate can be converted into nitrite, which can cause acute poisoning in infants and can contribute to the formation of carcinogenic nitrosamines. It is not possible to set a margin.

7.3 Natural substances

All plants contain varying concentrations of toxic substances to protect themselves against attack by viruses, microorganisms and herbivores, particularly insects. However, through evolution, the different species of microorganisms and animals have specialised in living from plants that are otherwise poisonous to other organisms. Common examples of such poisonous plants are deadly nightshade, spring groundsel and cow parsnip. The last two of these are imported, non-indigenous species that are not regulated by natural enemies that tolerate the plants' constituents. Humans eat only a few plant species – normally less than 100. Although some crop plants contain substances that have a toxic effect on certain other groups of organisms, most of them have very little toxic effect on humans, who have deliberately selected the crops that are acceptable and edible. Humans also use poisonous plants, such as the coffee plant and the tobacco plant. The tobacco plant, in particular, and its special uses present a considerable risk of cancer in humans. In connection with the introduction of so-called "Novel Food" products, including products made from genetically modified plants, the authorities are carrying out a risk analysis in line with the analysis of pesticides with a view to protecting the consumers.

Environmental exposure to natural substances

Unlike pesticides, natural toxins are mainly inside the plant and only exhibit their toxic effect when other organisms approach the plant, touch it or eat it. Pesticides, on the other hand, are normally spread over large areas with the aim of eliminating pests with at least 90% effect on the whole area. All organisms within the area are thereby exposed to and hit by the pesticide or later eat parts of plants containing pesticide residues.

Naturally occurring active ingredients

A count of authorised plant protection products carried out in 1998 (Environmental Protection Agency1998b) shows that a total of 9 naturally occurring active ingredients have been authorised. Two others are at the application stage. As shown in table 7.2, six are extracted from plants, two from minerals and two from animals. Application has been made for use of a wide range of microbiological products as insecticides or fungicides.

Table 7.2
Naturally occurring substances authorised for use as pesticides, or at the application stage, in Denmark. See also table 9.1 concerning microbiological pesticides.

Name	Type	Extracted from
"soaps"	insecticide/herbicide	plants
Pyrethrin I & II	Insecticide	plants
Soya oil	Insecticide	plants
Rotenon	Insecticide	plants
Citronella oil	Repellant	plants
Sulphur	Fungicide	mineral
Paraffin oil	Insecticide	mineral
Gelatine	Insecticide	animals
Dried blood product	Repellant	animals
Azadirachtin*	Insecticide	plants

**at the application stage*

Apart from the mineral sulphur, these naturally occurring substances are relatively easily degradable, so their action time is short. They are currently used only on small areas of land, where, as in the case of synthetic active ingredients, the aim is to knock out more than 90% of the pests. In principle, there is thus no difference between these substances and synthetic pesticides, and the insecticides mentioned can be expected to have similar sideeffects on non-target organisms to those described in section 5.1.

Comparison between naturally occurring and synthetic active ingredients

The naturally occurring active ingredients shown in table 7.2 are much less toxic to mammals and degrade considerably faster than synthetic pesticides. An example is the insecticide pyrethrin I and II, which is extracted from the chrysanthemum flower. Pyrethrin is poisonous to insects and has a low potential for producing toxicity in humans. If injected directly into the blood, the substance has a highly toxic effect on mammals. The normally low toxicity is due to slow absorption through the skin or in the gastrointestinal tract in mammals. Pyrethrins are very unstable and break down almost instantaneously in sunlight. The effect of this mixture is increased in the spray product by adding a synergist, piperonylbutoxide. This substance is only slightly toxic in itself, but impedes the enzyme systems that break pyrethrins down, enabling them to act for a longer period of time in insects.

Synthetic pesticides have changed molecular properties

One of the main groups of modern synthetic pesticides is the so-called pyrethroids, which contain the same chemical, active group as pyrethrum, but in which the molecule has been made more stable by use of aromatic structures, halogenation or reaction with cyanide. This considerably increases the toxic effect on insects – 1000 times, for instance, for deltamethrin compared with naturally occurring pyrethrins. The increased stability of the molecules at the same time gives a risk of dispersal in the atmosphere and to surface water and ground water. The pyrethroid example illustrates the fact that synthetic pesticides usually contain chemical structures that are seldom found in nature. The physical and chemical properties of the molecule, and thus its toxicity, are thereby changed. This effect depends particularly on changes in the direction of lower degradability, greater persistence, changed solubility and increased penetration in membranes.

7.4 The sub-committee's conclusions and recommendations

Conclusion concerning coformulants

Coformulants, which are added to pesticide formulations, are not covered by an authorisation scheme of the same scope as for active pesticide chemicals. Coformulants are a very broad and extensive group of substances, the composition of which can vary within the individual product or type of product. The coformulants are normally less harmful to the environment and health than the active ingredient, but often occur in large concentrations, and substances that are harmful to the environment and/or health can be used – e.g. substances that produce acute or chronic toxicity. Some of the substances can thus be more harmful to the environment or health than the active ingredient to which they are added. A few of the substances feature in DEPA's list of undesirable substances.

Conclusion concerning natural substances compared with pesticides

All plants contain varying concentrations of toxic substances to protect themselves against attack by viruses, microorganisms and herbivores. Most herbivores eat only specific food plants. Humans thus eat only a limited number of plant species – less than 100 – that have been selected and used for many generations as components in human food. Therefore, even though crop plants contain substances that have a toxic effect on certain other groups of organisms, in most cases they produce very little toxicity in humans. Unlike pesticides, the toxic natural substances are inside the plant and only exhibit their toxic effect when other organisms approach it, touch it or eat it. Pesticides, on the other hand, are normally spread over larger areas of land, with the aim of knocking out pests – often with around 90% effect in the entire area. All organisms in the area in question are thus exposed to and hit by the pesticide or later eat plant parts containing pesticide residues. Synthetic pesticides usually contain chemical structures that are seldom found in nature. The physical and chemical properties of the molecule, and thus its toxicity, are thereby changed. This effect depends particularly on changes in the direction of lower degradability, greater persistence, changed solubility and increased penetration in membranes.

The following specific conclusions can be drawn:

- The heavy metals cadmium, lead and mercury present a greater health problem than pesticides, but are not a serious problem environmentally. However, attention must be paid to a potential accumulation in cultivated soil of, in particular, cadmium, lead and copper.

- Compared with the effect of pesticides, the direct effect of xenobiotic substances on cultivated soil and thus on crops is small. However, relatively little is known about potential, indirect pollution by xenobiotic substances, for example via air or through accidental loss, spillage or discharge to water. There may therefore be grounds for concern since the long-term effects of even small concentrations are not known. With the environment policy now pursued, efforts are being made, both nationally and internationally, to ensure a reduction at source, but owing to the continuing supply of such substances, the load must be monitored on a long-term basis.

- Organic pollutants are not generally a problem in cultivated soil. With frequent application of sludge on the same area, the total quantity of xenobiotic substances can be of the same order of magnitude as the pesticide load.

- The use of veterinary drugs and growth promoters involves a risk of the development of resistant microorganisms, and too little is as yet known about the possible effect of manure on cultivated land to assess veterinary drugs and growth promoters in relation to pesticides.

- A number of naturally occurring substances are to a limited extent used as pesticides. The substances in question are relatively easily degradable, so their action time is short, but the sub-committee finds that there is in principle no difference between these substances and synthetic pesticides. The sub-committee concludes that, compared with natural substances, pesticides have a considerably greater potential for environmentally harmful effects because of the way they are used, their relatively low degradability and their chemically determined, intensified mode of action. With respect to human health, the sub-committee finds that some naturally occurring constituents of plants can present a risk and that, for example in connection with "Novel Food" products, they should be subjected to a risk analysis in line with pesticides.

The sub-committee's recommendations concerning coformulants

- The sub-committee recommends that the authorisation scheme be expanded so that the requirements concerning coformulants approach the requirements made concerning active ingredients. In this connection, all carcinogenic substances should be banned. However, coformulants are also used for other purposes than pesticide formulations. Therefore, the regulations on the use of these substances should be generally tightened for all applications.

8 Identification of environmentally harmful and dangerous pesticides, and operationalisation of the precautionary principle

8.1 Ranking of environmentally harmful and dangerous pesticides

In this chapter we assess the possibility of identifying the most harmful pesticides by means of ranking methods. The chapter is based on an analysis by Lindhardt et al. (1998). The analysis covers the risk of groundwater pollution, the impact on terrestrial and aquatic environments and effects on human health.

It is possible to rank the toxicity of chemical substances, e.g. effect measurements or toxicity equivalents, and a number of intrinsic dangerous properties in connection with the substances' hazard *classification*. It is also possible to rank emissions, dispersal and load, e.g. emissions in quantities or concentrations, emission measurements, or exposure in quantities or concentrations, just as a number of substances are regulated by means of *limit values* or threshold values. In other areas, ranking is based on *vulnerability*, e.g. through recommendations for pregnant women or children as special risk groups in a health context. In some areas, the problem is so complex and the underlying knowledge so limited that it is not possible to carry out a classification at all – as, for example, when a normally geologically determined soil classification is to be converted for use in ranking the vulnerability of the soil to infiltration by chemicals.

It is possible on this basis to set up different index systems for the environment field:

- *Risk indices*, which combine the classification and the limit-value setting

- *Load indices*, which combine the limit-value setting and the vulnerability assessment

- *'Pollution' indices*, which combine the classification, the limit-value setting and the vulnerability assessment.

Such indices, which are used in practice, are usually linked to some few single elements that can be ranked separately, but that unavoidably become diffuse and lose their value when many variables are combined because the uncertainty grows as a consequence of the elements' interaction. Specifically in connection with such complex systems, there is a need to apply the precautionary principle in relation to the same uncertainties and a desire to be able to regulate in a simple way the individual elements included in the complex system. These matters will be illustrated in the following, using pesticide pollution of groundwater as an example.

International cooperation

In 1997, a conference was held, under the OECD, on risk indicators for pesticides with a view to measuring trends in the risks associated with the use of pesticides. Indicators have been developed for different purposes, one of which is to assess national risk reductions and identify those pesticides that contribute most to the total risk. Since the indicators used differ in their structure, pesticides can in some cases be indexed differently. It was also pointed out that a number of indicators would be preferable to a single indicator because there are no satisfactory methods for combining different types of risk for each pesticide. The OECD working group Pesticide Forum is now continuing work on the development of risk indicators for pesticides on the basis of the conference's recommendations. The results of this work were presented at a workshop in June 1999.

Under the EU, work started in 1998 on a project called Concerted Action on Pesticide Environmental Risk Indicators (CAPER). The purpose of the project is to compare eight different indicators for the environmental effects of pesticides. The eight indicators have been developed for decision-support systems, for example, and for comparison of farming systems. Most of these indicators have not yet been published. It should be noted that, in EU contexts, too, there is a need to recognise the extent to which ranking models can be used to identify the most environmentally harmful pesticides (Lindhardt et al. 1998).

8.1.1 Risk of groundwater pollution

There are several methods for calculating indices that allow ranking of pesticides with respect to the load on the groundwater. Table 8.1 shows the methods that are relevant for Danish conditions and the parameters and data used in them.

Table 8.1
Methods of ranking the potential of pesticides for leaching to groundwater. The methods are listed in order of increasing complexity and data requirements. The table also shows the types of parameters used in the methods.

Method	Dose	Degradation	Adsorption in soil	Soil parameters	Water transport	Spatial variation in the soil	Climate
GUS index		x	x				
Hasse diagram	x	(x)	x				
AF index		x	x	x	x		
Dutch point system	x	(x)	x	x	x		
Yardstick method	(x)	x	x	x	x		
Fuzzy expert model	x	x	x	(x)	(x)	(x)	(x)
Expert assessment	x	x	x	x	(x)	(x)	(x)
Deterministic models	x	x	x	x	x	x	(x)
Stochastic models	x	x	x	x	x	x	x

GUS index

The GUS index was developed by the California Department of Food and Agriculture (Gustafson 1989). It is a very simple index for the risk of leaching to the groundwater. The index is based only on the inherent properties of the active ingredient. It divides pesticides into three categories: “probably leachable”, “possibly leachable” and “probably not leachable”.

Hasse diagram

The Hasse diagram is used to compare pesticides’ potential for leaching by comparing their dosage and adsorption to soil (Sørensen et al. 1997). Degradation can easily be included in the method, but there seems to be a lack of correlation between the degradation time and the actual findings in the environment in major studies. In addition, the inclusion of degradation is problematical owing to other factors, which are described under the Dutch point system, see below. For these reasons, it is proposed in this analysis only to use dosage and adsorption to soil. The strength of the method lies in the fact that less stringent model assumptions can be used to calculate the statistical probability of a pesticide’s ranking with respect to leaching. For a pesticide to be judged “better” than another, all the parameters mentioned must exhibit a smaller potential for leaching. If that is not the case, the two pesticides cannot be compared directly, but are compared indirectly through their ranking in relation to other comparable pesticides.

AF index

The AF index was also developed in the USA (Rao et al. 1985). AF stands for Attenuation Factor. It is not only based on the pesticide’s inherent degradability and ability to adsorb to soil but also includes soil parameters that describe the adsorption and degradation, together with the percolation of net precipitation. The aim of the AF index is to express the proportion of the amount of pesticide supplied that will pass a selected depth in the soil and could thus give rise to groundwater pollution. The infiltration is described by a simple, one-dimensional transport equation, with the degradation and adsorption assumed to be constant in the soil profile. The advantage of the AF index over the GUS index is that the leaching can be related to the infiltrating water, the soil parameters and the pesticide dosage.

Dutch point system

In the Netherlands, use is made of a point system comprising four main elements: the consumption of the individual pesticide; the location of the treated area in relation to important drinking water aquifers; the solubility of the pesticide, which can be used as an indirect measure of the adsorption to soil; and the degradability in soil. However, the degradability is considered separately because of a lack of data on some substances’ degradation. In addition, data on degradation under aerobic conditions can be misleading because anaerobic conditions can occur in soil environments. Lastly, some substances are broken down into more mobile metabolites, so data showing rapid degradation of the parent substance are misleading in these cases. The individual substances are indexed in relation to each other on the basis of the sum of points. The method is based on risk thinking and therefore cannot be used directly to rank pesticides because it depends on local environmental conditions.

Yardstick method

The Dutch “Yardstick” method was developed by the “Centre for Agriculture and Environment” in the Netherlands (Boesten, Van der Linden 1991; Reus, Pak 1993). It is intended for the individual farmer, who can use it to try to reduce the environmental impact of his spraying programme. The Yardstick is a point system, in which the environmental impact is calculated in the form of “environmental impact points”. The system covers several environmental impacts. The model calculates the concentration of pesticides in the uppermost groundwater by means of the deterministic model PESTLA, using data for degradation and adsorption to soil. The Yardstick operates with sandy soil, which is typical for the Netherlands. The results are given for five classes of soil and spring and autumn spraying, where the temperature and precipitation vary. Since the method is based on the same simple indexing methods or on the deterministic model PESTLA, it does not produce results fundamentally different from these. Like the Dutch point system, the method is based on risk thinking and therefore cannot be used directly for ranking pesticides because it depends partly on local environmental conditions and partly on the actual cultivation practice.

Fuzzy Expert model

This method was developed in the Netherlands (van der Werf, Zimmer 1998). The risk of groundwater pollution is assessed partly on the basis of a GUS index and partly on the basis of a "leaching risk" parameter. This parameter requires supplementary considerations or model analyses. A high level of expert knowledge is needed to use the method, making it difficult to work with. The method can therefore not be used under Danish conditions without considerable input from a variety of experts. For this reason, the model has not been used here to assess leaching. However, the method also covers other environmental aspects than groundwater so its use could be considered in continuing work on environmental indices.

Expert assessment

In an expert assessment, one or more experienced experts designate substances on the basis of existing data and an integrated assessment. An expert assessment thus includes a systematic review of data and assessment elements that can be classified and ranked in the normal way, but must at the same time be combined with an experience-based assessment of lacking data and unclassifiable elements. A large number of factors are considered in the assessment of the risk of leaching to the groundwater within the framework of the authorisation scheme for pesticides. They include the inherent properties of the substances and their metabolites and degradation products, combined with the dosage, the time of application and any finds in groundwater. On the basis of experience, some substances are judged to lie closer to the critical limit for leaching to groundwater than others. This assessment determines whether a product can be authorised or not. Precise designation of the most problematical substances requires a thorough examination of the documentation and assessment of monitoring results, and possibly calculations with a leaching model, e.g. MACRO (see below). This form of assessment has been used in the assessment of many of the pesticides that have been placed on the blacklist.

Deterministic models: the MACRO model

A number of actual transport models that describe the transport of pesticides down through the root zone have been developed (e.g. LEACHM, PELMO, PESTLA and MACRO). These are so-called deterministic models in which it is assumed that the outcome under given assumptions will always be the same. The so-called stochastic (or probabilistic) models, on the other hand, take account of variations in the system and thus only talk about the probability of a given outcome. There are as yet no suitable stochastic models for ranking pesticides' potential leaching to the groundwater. Unlike the simple index methods, both deterministic and stochastic models give a more varied description of pesticides' movement in the soil.

The models can to a varying extent include the variations in different types of soil (root zone), special geological and geochemical conditions, transport mechanisms, climatic conditions, crops and application practice. PESTLA has been used to index the potential leaching of pesticides under Dutch conditions. The MACRO model, which can compute both the unsaturated and saturated water flow in a piece of cultivated land, is of particular interest. The model can also take account of saturated flow to drainage systems. Unlike other models, such as PESTLA and PELMO, MACRO can take account of preferential flow via macropores, and it can also handle degradation products, which PESTLA and PELMO cannot.

MACRO is gaining ground in the Danish authorisation procedure. It is used when the available documentation does not provide a clear answer to the question of whether a substance leaches to the groundwater or not. To make it easy to handle, two scenarios are described with given types of soil, precipitation events and other necessary parameters. The model calculations are one of several elements in the overall assessment. However, neither MACRO nor other leaching models have been sufficiently validated to warrant basing a registration procedure directly on the results of the model. Since the uncertainty in the model's outcome is thus not yet known, DEPA now uses so-called "realistic worst case" data in the model.

The advantage of using numerical models to describe metabolism and transport of pesticides in soil is the possibility of testing many more combinations of types of soil, climatic conditions, time of application, plant cover, etc. than is technically and financially feasible with lysimeter and field tests. The model may therefore prove suitable for ranking pesticides' potential for leaching.

Comparison of the methods

Of the methods mentioned, the GUS index, the Hasse diagram, the AF index and the expert assessment have been used to compare and rank 73 different pesticides used in agriculture (Lindhardt et al. 1998). The Fuzzy expert model, the Yardstick method and the Dutch point system have also been considered as a basis for ranking. However, as these methods would not give results fundamentally different from the above-mentioned methods, they have not been used. Ranking on the basis of calculations using a real transport model such as MACRO has also been considered, but has not been done for reasons of time (Lindhardt et al. 1998). Besides that, MACRO, too, is based on the same fundamental parameters for description of the mobility of pesticides as the simpler methods.

Lack of accordance between the methods

The study shows a lack of accordance between the different models. It is thus not possible to identify clearly those pesticides that have the greatest potential for leaching to the groundwater. One of the reasons for this is great variation in data, which means that the choice of data can determine how a pesticide is ranked. The rankings set up are primarily based on data concerning the pesticides' adsorption in soil (K_{OC}) and degradation time (DT_{50}). In the case of the Hasse diagram, data are also included on the dosage, while net infiltration and soil parameters are included in the AF index. Major international studies indicate that pesticide consumption, in particular, and to some extent also K_{OC}, are of significance for the occurrence in newly formed groundwater, whereas DT_{50} does not seem to have any significant correlation with field data. The fact that the Hasse diagram includes the dosage (consumption at field level) and adsorption to soil (measured as K_{OC}) is an attempt to base the rankings on the results of these studies.

Setting up a gross list with a view to reviewing pesticide leaching

There is thus considerable uncertainty about the rankings set up. This is due particularly to the fact that leaching of pesticides to the groundwater depends on factors that cannot be described by simple indices – for example, extreme climatic conditions and seepage through cracks in the soil (preferential flow). However, the results of the different ranking methods can be used to draw up a *gross list* of the pesticides singled out as problematical using the different methods. The gross list, which comprises 35 pesticides, is shown in table 8.2. It is important to note that the list is relative, i.e., it primarily compares substances with each other and does not directly indicate substances as problematical in relation to the groundwater.

Table 8.2

Gross list of pesticides singled out in three ranking methods as potentially leachable in classes given as high (h) or low (l). Active substances with potentially high leachability in all three methods are denoted hhh, in two methods, lhh, hlh or hhl, and in one method, llh, lhl or hll. Active ingredients with low leachability are denoted lll.

		AF index[a]	GUS index[b]	Hasse diagram[c]
	Class	log(AF) l/kg		d,Koc p factor
2,4D	hhh	-1	S	0.97
clopyralid	hhh	-2	S	1
metaldehyde	hhh	-1	S	0.99
dicamba	hhh	-3	S	1
metabenzthiazuron	hhh	-3	S	1
fluroxypyr	hhh	-3	S	1
isoproturon	hhh	-3	S	1
bentazone	hhh	-4	S	0.96
carbofuran	hhh	-5	S	1
difenzoquat	hhh	-5	S	1
mechlorprop-P	hhh	-5	S	1
MCPA	hhh	-6	S	1
metsulfuron-methyl	hhl	-1	S	0.39
flamprop-M-isopropyl	hhl	-2	S	0.87
metribuzin	hhl	-4	S	0.88
triasulfuron	hhl	-1	S	0.81
ethofumesate	hhl	-6	S	0.76
haloxyfop-ethoxyethyl	hhl	-2	S	0.79
imidacloprid	hhl	-1	S	0.58
fenitrothion	hlh	-9	M	0.99
terbuthylazine	hlh	-9	M	0.94
pirimicarb	hhl	-7	S	0.64
azoxystrobin	hll	-8	M	0.76
isoxaben	hll	-8	M	0.27
tebuconazole	hll	-3	M	0.56
dimethoate	llh	-22	I	0.97
metamitron	llh	-19	M	0.95
chlormequat-chloride (CCC)	llh	-45	I	1

triallate	llh	-55	I	0.98
prosulfocarb	llh	-81	I	1
mancozeb	llh	-162	I	1
pencycuron	llh	-84	I	1
tolclofos-methyl	llh	-96	I	1
malathion	llh	-289	I	0.94
dichlorprop-P	llh	-13	M	0.97
linuron	lll	-11	M	0.85
propiconazole	lll	-11	M	0.49
phenmedipham	lll	-18	M	0.76
propaquizafop	lll	-26	M	0.47
triflusulfuron-methyl	lll	-21	M	0.65
chlorfenvinphos	lll	-26	I	0.88
esfenvalerate	lll	-19	I	0.44
fluazinam	lll	-32	I	0.53
propyzamide	lll	-74	I	0.65
ioxynil	lll	-167	I	0.7
fuberidazole	lll	-163	I	0.11
prochloraz	lll	-44	I	0.46
fenpropidin	lll	-44	I	0.6
chlorothalonil	lll	-98	I	0.84
propamocarb	lll	-171	I	0.76
mepiquat-chloride	lll	-209	I	0.57
bromoxynil	lll	-199	I	0.64
imazalil	lll	-60	I	0.07
fenpiclonil	lll	-12	I	0.22
maneb	lll	-300	I	1
napropamide	lll	-119	I	0.46
ethephon	lll	-300	I	0.43
furathiocarb	lll	-300	I	0.33
fenpropimorph	lll	-300	I	0.57
cypermethrin	lll	-165	I	0.14
aclonifen	lll	-190	I	0.79
fluazifop-P-butyl	lll	-300	I	0.33
desmedipham	lll	-256	I	0.2
fenoxaprop-P-ethyl	lll	-300	I	0.17
pendimethalin	lll	-234	I	0.55
permethrin	lll	-300	I	0.2
trinexapac-ethyl	lll	-300	I	0.53
tefluthrin	lll	-300	I	0.18
glyphosate	lll	-300	I	0.53
alpha-cypermethrin	lll	-300	I	0.09
fludioxonil	lll	-82	I	0.09
tau-fluvalinate	lll	-300	I	0.06
lambda-cyhalothrin	lll	-300	I	0.06

[a] = AF index: log(AF): high = greater than or equal to -10; low = less than -10
[b] = GUS index: high = S; low = M or I
[c] = Hasse diagram: high = greater than or equal to 0.9; low = less than 0.9

The cut-off values in table 8.2 are critical for the analysis and are open to discussion. Since the list is regarded as a relative comparison between substances, the cut-off values have been chosen such that each index identifies 25-30% of the pesticides as more leachable than others. The analyses accord well with each other, although the GUS index is more closely related to the AF index than the Hasse diagram is to the Gus and AF indices. That is because the dosage is only included in the Hasse diagram and because the Hasse diagram does not include the degradation, which is included in the other two indices.

The substances on this gross list should be subjected to a more detailed risk assessment in line with that used in the authorisation scheme. In addition, all the substances could be run through MACRO after it has been decided what data and scenarios are relevant.

The examination of the ranking methods also showed:

- that, in the case of 9 pesticides, there was not complete laboratory data for their adsorption to soil or degradation in soil

- that leachable metabolites are not included as part of the basis for ranking in the methods studied, except for the expert assessment

- that, with a view to reviewing pesticides' leaching, the gross list can be included in recommendations on substitution with less dangerous substances in the treatment situation.

Better monitoring of the groundwater

To clarify the extent to which the use of pesticides threatens our groundwater resources, a number of activities have been initiated in the last few years, partly to determine the extent to which our groundwater is affected by the pesticides authorised for use today and partly to clarify the more fundamental problems relating to the risk assessment. In order to learn more about the leaching of pesticides to the groundwater, the countrywide monitoring programmes for groundwater (LOOP and GRUMO) have been considerably expanded. The results of this will begin to emerge in the middle of 2000.

Early warning of the risk of leaching to the groundwater

The groundwater analysed is mainly more than five years old and often more than 25 years old. Feedback cannot occur before substantial parts of the groundwater resources must be presumed to be affected if the authorised pesticides or their metabolites leach to the groundwater. GEUS, DIAS, DEPA and DMU must together plan and establish a warning system that monitors young groundwater for pesticides that are used under the current rules. The warning system must make it possible to assess quickly and possibly remove authorised pesticides if, with lawful use under Danish conditions, they prove able to leach to the groundwater in concentrations that exceed the limit value. The first results are expected to become available in the second half of 2000.

Clarification of fundamental problems

Do we understand properly the transport of pesticides from the ploughing layer down to the groundwater and on to the extraction wells? As the results from the monitoring programmes have emerged over the last 10 years, showing that the groundwater is polluted with pesticides, several different hypotheses have been advanced on the reasons for this: they include preferential flow, colloidal transport or the right description of the degradation process of the individual substances. To achieve greater understanding of these problems, a number of research activities have been initiated, including The Danish Environmental Research Programme (SMP96): "Pesticides and Groundwater", which runs from 1996 to 2000, and the Interministerial Pesticide Research Programme, 1995-1998. Activities under SMP96 will shed light on the importance of preferential flow for the transport of pesticides in structured soil from the ploughing layer down to the groundwater, the transport and metabolism of pesticides in the groundwater itself, and the possibilities of describing the transport of pesticides on a regional scale by means of mathematical models. The results of these research activities can be expected to become available in the next couple of years.

Basic need for knowledge

There are four reasons why it has not been possible to identify the pesticides authorised for use today that present the greatest threat to the groundwater:

1) It is not certain that we properly understand the main processes responsible for the transport of pesticides down to the groundwater – e.g. the importance of preferential flow.
2) We have only limited understanding of the variation in a number of the main parameters (e.g. degradation and adsorption in soil) included in the description of the leaching of pesticides to the groundwater.
3) There is a lack of recognised methods for rapidly assessing the leachability of the individual substances.
4) There is a lack of data for the different models – particularly the complicated models such as MACRO.

1) Need for more knowledge about the geological factors
In the last few years a lot of new knowledge has been gained about the main processes of pesticide leaching to the groundwater. However, the results indicate that we have insufficient understanding of the spatial variation in the hydraulic parameters that govern the transport of pesticides from the ploughing layer to the groundwater. We need to translate the knowledge gained concerning the flow in structured soils into a quantitative mapping of the geographical extent of these properties.

2) Need for more knowledge about the individual pesticides
Despite the considerable resources that have gone into research activities aimed at increasing our general understanding of the transport of pesticides down to and in the groundwater, there are a number of vital problems that remain to be answered in relation to risk assessment of the individual pesticides. One of those problems is the variation in the parameters that are important in the description of the individual pesticides.

- Variation in degradation paths and rates, and the substances' adsorption in the ploughing layer, which can vary considerably, both within the individual field and between different fields.

- Variation in these parameters down through the soil profile. Analyses carried out in soil from the ploughing layer do not necessarily describe the fate of the substances when they get down below the ploughing layer.

- The information on possible metabolites from the individual substances is insufficient. It is not enough to know the degradation paths in the ploughing layer. In the case of relatively mobile substances, it is also important to know the degradation paths in the subsoil and possibly in the groundwater.

This information can be procured in future by tightening the requirements for authorisation of pesticides, but this method will only help in the assessment of new substances or in actual reviews. It may also be necessary to obtain EU agreement to such requirements. It will at any rate take time before the desired data are available. Before the requirements can be tightened, agreement must be reached on which data are necessary and sufficient, and a procedure must be laid down for procuring them.

3) New decision-making tools based on statistical methods
Although ranking methods are based on a very simple understanding of the process and therefore cannot stand alone in an assessment, major studies indicate that there is, in spite of everything, some relationship between relatively simple parameters and the occurrence of pesticides that is observed. Much of the observed variation in occurrence can in fact be explained on the basis of relatively simple relationships (Koplin et al. 1998; Kreuger, Tornqvist 1998). As results come in from still more studies (national and international), it is recommended that decision-making tools be developed (simple ranking index) on the basis of statistically documented relationships with a view to generalising the studies to uninvestigated areas and pesticides. The possibility of developing simple, stochastic (probabilistic) models should also be looked into.

4) Better data for the deterministic models
The question has been raised of whether one could use model calculations to rank authorised pesticides on the basis of their leaching risk. The calculation of leaching by means of MACRO covers a range of factors that are not taken into account in the simple indices – the relevant dosage for a specific crop, plant cover, dosing time, Danish climatic conditions (precipitation and temperature) and preferential flow for structured soils. However, some factors have to be clarified before MACRO can be used to rank the authorised pesticides:

- Quality-assured data have to be obtained for each pesticide's degradation and adsorption in different types and strata of soil, together with the dosage.
- It must be clarified how the uncertainty on the variables describing the degradation and adsorption is to be assessed.
- Limit values must be defined.
- It must be clarified how representative the scenarios used by DEPA are.

Ranking by means of MACRO does not directly include an assessment of the extent to which metabolites are formed, which must be considered a serious constraint.

Even if satisfactory data are obtained and other factors can be satisfactorily clarified, ranking by means of MACRO cannot stand alone. An integrated expert assessment will also be needed.

8.1.2 Impacts on the environment

Pesticides can be ranked solely on the basis of their toxicity to different organisms. The toxicity can also be expressed as the tolerable limit value, which can be calculated on the basis of all species or groups of organisms or be expressed as a value for the most sensitive species. The intended effect of the pesticides in the terrestrial environment is direct and considerable in cultivated areas and their immediate surroundings. The effect of herbicides on the flora is obvious. The indirect effects on the fauna through impact on the primary links in the food chain are described in section 4.2.1.

Treatment frequency index as a measure of the load on the terrestrial environment

It is for mammals and birds that we have the most complete toxicity data for the terrestrial environment. However, the risk of direct poisoning of humans, other mammals and birds has been reduced considerably by reviewing existing substances and changing the authorisation scheme for new pesticides, so that all the substances in practice have a low level of toxicity to vertebrates. It is therefore not possible to rank modern Danish pesticides on the basis of their toxicity to these groups of fauna. That is because characteristic farmland fauna and, particularly, birds are considerably more affected by the indirect effects of pesticide use. These indirect effects are related to the effect of the product on the target organism and on other species belonging to the same group of organisms. Since the indirect effects are the most extensive, it is important to include them in the load and risk assessments. The dosage is determined by means of field trials, the aim being to achieve an effect on the target organisms that results in at least 90% reduction of the population density. The recommended field dosage is thus a realistic and accurate indicator of the effect of the product in the field, compared with the toxicity determined in laboratory tests. The treatment frequency index is based precisely on the recommended field dosage with a view to the direct effect on the target organisms. Since the target organisms' related species – fungi, plants or arthropods – are also affected by fungicides, herbicides or insecticides, respectively, the treatment frequency index is also an indicator of the indirect impact on the ecosystem as a consequence of changes in the quantity and type of food in the food chains.

Critical loads for plants and animals in terrestrial natural areas

It is possible to carry out calculations for each pesticide that show the dosage that will be harmless for most faun and flora in hedges, small biotopes and other areas bordering on cultivated areas. This value is called the critical load. It expresses the total supply of chemical substance that is considered to be harmless to the environment. The calculations do not take into account the fact that there can be increased effects from applying several substances on the same area. Calculations have only been carried out for a few, selected substances (Jensen, Løkke 1998) because considerable resources are needed to collect and assess data for all relevant pesticides. Moreover, there are insufficient data for all pesticides. Calculations for four substances show that the critical load for insecticides and herbicides lies in the interval from one thousandth part to one ten-thousandth part of the field dosage. A system could possibly be developed for ranking pesticides' load on the terrestrial environment on uncultivated land. However, the load depends primarily on how much of each pesticide is used and on spraying practice. If, however, it were found that there was no great variation in the critical load for different pesticides, the most important factors would be the consumption figure and the dispersal outside the cultivated areas. In such case, the treatment frequency index could give an indication of the load on the uncultivated areas as well.

Impact index for the aquatic environment based on acute toxicity

In the aquatic environment, the most problematical substances for fish, crustaceans and algae are assessed. Ranking solely on the basis of the substances' toxicity is not sufficient because the effects depend on the exposure of the environment. The ranking can be based on an impact index defined as the relationship between dosage as an expression of the exposure and the acute toxicity. This ranking shows that, for fish and crustaceans, it is particularly the eight authorised pyrethroids, all of which are used as insecticides, that have the highest ranking (Lindhardt et al. 1998). In the case of algae, it is the herbicides that head the list. The method is encumbered with considerable uncertainty because it does not include exposure considerations and long-term effects. The method cannot be recommended as the only basis for identifying the pesticides that are most harmful to aquatic organisms. That requires a real risk assessment, as is done in connection with the present authorisation scheme.

Ranking on the basis of an expert assessment of the safe distance to watercourses and lakes

In the authorisation of pesticides, an expert assessment is carried out. This can lead to authorisation with a condition attached to it to the effect that the substance must not be used within a given distance from watercourses and lakes. Such distance requirements indicate that the substance (the product) is problematical in relation to aquatic organisms, and they can be used directly to rank the pesticides. Prior to the change in administrative practice in 1993, any conditions concerning distance to watercourses and lakes were based on an assessment of the hazard of the substances' inherent properties. Since 1993, distance requirements have been based on a risk assessment in which the exposure is taken into account. If the distance requirements are to be used for ranking purposes, the substances (products) that were assessed before 1993 must also undergo a risk assessment. This would in any case be done in connection with the review required by law at intervals of not more than 10 years.

8.1.3 Effects inhealth

With respect to health effects, ADI/TDI values or the classification could be used for ranking pesticides. Classification means dividing pesticides into classes for level of hazard – in this connection, the hazard of the toxic effect – in accordance with Statutory Order on Pesticides. ADI represents a quantitative measure of the load to which one can be exposed from cradle to grave without any overt risk of harmful effects. This is a safety value calculated on the basis of the highest dose of the substances that does not produce the critical effect, i.e. the most sensitive effect in the most sensitive species of test animals or in humans if data are available on that.

The classification covers a number of undesirable biological effects resulting from exposure to a chemical substance (cancer, reproductive damage, etc.), for which there is a high probability that humans develop such diseases through contact with the substance. The assessment is a qualitative one or an assessment of evidence that a given pesticide with the biological action as an inherent property can have a harmful effect on humans.

Ranking on the basis of different health effects

Ranking can be based on a number of different biological effects. For example, pesticides can be classified on the basis of growing evidence of their ability to cause cancer. None of the pesticides authorised today is classified as carcinogenic in category 1 or 2. Pesticides classified as carcinogenic in category 3 can be authorised if a risk assessment shows that there is no risk of cancer developing with normal use. It is thus possible to rank between substances that are classified in category 3 and substances that are not classified as carcinogenic.

Ranking on the basis of the distance between ADI and the exposure

If one chose to use ADI as the basis for the prioritisation with respect to phasing out pesticides, the distance between ADI and the assessed or measured exposure to the substance could be used as the basis for ranking them. It would thereby be possible to identify the substances with the smallest safety margin with the current exposure of humans. ADI and the classification cannot be directly combined in a ranking system because the critical effect used in setting ADI is not necessarily the effect for which the substance is classified. For example, a substance that has produced skin irritation in several toxicological tests and epidemiological studies can in many cases have another undesirable biological effect that forms the basis for setting ADI because this effect is seen at lower dosages in the toxicological tests. However, it might be possible to combine the above two criteria by assigning the substances a prioritisation value for each of the criteria and then using the total ranking sum as the basis for the main prioritisation with a view to a phase-out.

8.1.4 The sub-committee's conclusions and recommendations

The sub-committee has considered the question of ranking in the following areas:

- groundwater pollution
- impact on the terrestrial environment
- impact on the aquatic environment
- health effects

Leaching to groundwater

- The sub-committee concludes that it is not possible with the existing, simple methods to rank pesticides clearly with respect to their ability to leach to the groundwater. However, by using four different methods, it is possible to set up a gross list comprising 35 authorised substances. The substances on this gross list should be more closely assessed, using mathematical models, the latest knowledge and the results of measurements.

- The sub-committee recommends that, with a view to reassessing the leaching of pesticides, the gross list be included in recommendations concerning substitution with less dangerous substances in the treatment situation.

International cooperation

International fora are also working on ranking models with a view to identifying the most environmentally harmful pesticides. Both within the OECD and the EU, indicators are being developed or tested for assessing the environmentally harmful effects of pesticides. The OECD's preliminary work was presented in 1997. It showed that many of the existing indices differed in their structure, leading to different indexing of pesticides. Within the EU, a Concerted Action (CAPER) has commenced. The object is to compare the usefulness of eight different indicators.

Knowledge-building in the groundwater field

- In the years ahead, research programmes now in progress will add to our knowledge concerning the fundamental problems, and improvements that are being made in the monitoring of groundwater and early warning of the risk of leaching of pesticides to the groundwater will increase the safety level.

Need for knowledge in the groundwater field

- The sub-committee wishes to point out that improved risk assessment depends on continued clarification of the processes governing the transport of pesticides to the groundwater and in the groundwater aquifers and on greater understanding of the spatial variation in the parameters governing the transport of pesticides. As results come in from an ever-growing number of both national and international studies, decision-making tools should be developed on the basis of statistically documented relationships for pesticides' potential leaching with a view to generalising the studies to uninvestigated areas and pesticides. In connection with increased use of mathematical models (e.g. MACRO) in the assessment of the risk of pesticide leaching, the sub-committee recommends that work continue on assessing their validity. In this connection, there is a particular need for geological and substance-specific data. The possibility of developing simple stochastic (probabilistic) models should be investigated.

Terrestrial ecosystems

- With respect to the terrestrial environment, it is not possible to indicate a method for ranking the direct effects, because the indirect effects and the combination of many pesticides play the biggest role. However, the treatment frequency index can be used as a measure of the impact because it is based on the biologically active field dosage and can thus be used as a simple indicator of both the direct effect on the target organisms and related species and for the indirect impact on the ecosystem as a consequence of changes in quantity and type of food in the food chains. It would also be possible to calculate an index for the dosage believed, with our present level of knowledge, to be harmless to most animals and plants in uncultivated areas that receive pesticides via spray drift or atmospheric transport (tolerable limits).

Aquatic ecosystems

- For the aquatic environment, the present authorisation scheme includes an expert assessment that can result in new pesticides or products being authorised on condition that a given distance is maintained to watercourses and lakes. Such distance requirements indicate that the substance (the product) is problematical in relation to aquatic organisms and could be directly used for ranking or classifying the pesticides.

Human health

- For the human-toxicological area one could use the relationship between the Acceptable Daily Intake, ADI, and the estimated exposure to the substance as a basis for ranking pesticides. In Denmark, with the present use of pesticides, the exposure at single substance level through food products is around 1% or less. Ranking would enable identification of those substances that, with the current use, have the lowest safety margin for humans. However, since the effects of the individual substances are not comparable, ranking alone would not be enough but would have to be supplemented by an expert assessment.

8.2 Precautionary principle and risk

The reasons for using a precautionary principle are as follows:

- The uncertainty and variation that are always associated with the data on which decisions are based – with respect to both the individual measurement and the generalisation from limited studies to the entire environment or ecosystem and all the species and populations that are to be protected.

- Some systems (e.g. meteorological and ecological systems) can in some circumstances exhibit indeterminable, e.g. chaotic, behaviour. In such cases it is in principle impossible to predict the consequences of an exposure.

- Incomplete knowledge about how ecosystems are affected by and react to pesticides and about the extent to which the systems can regenerate or be re-established after a harmful exposure.

- The risk associated with making a mistake – i.e. underestimating a risk with lasting consequences for humans and the environment.

- The desire to protect specially exposed groups, e.g. children, even better.

- The fact that mistakes could have a serious future effect, e.g. through accumulation of pesticides in groundwater or the atmosphere.

The "precautionary principle" has gained a considerable following in the environmental field (Danish Environmental Protection Agency 1998c) but has not been precisely defined. The following framing of the concept can be used:

- The purpose of the precautionary principle is to provide greater certainty that damage will not occur.

- The desire for more extensive use of the precautionary principle is based on the view that neither the environment nor human health should suffer as a consequence of behaviour about which there is scientific doubt or uncertainty.

- The precautionary principle allows the authorities to require less evidence of a polluting effect from a given form of behaviour and to take action to regulate the behaviour if there is just some possibility of pollution.

In relation to the weighing up of risks, the main content of the precautionary principle can be construed in the form of a question: *"Who is to suffer the consequences of the uncertainty that must exist scientifically concerning the polluting effect of a specific type of behaviour?"* This is illustrated by the following three concrete examples of application of the precautionary principle:

1) Carcinogens (The Delaney Clause)
The best known and most frequently mentioned example is undoubtedly the American health and food legislation's so-called *Delaney-Clause*, which states that colour additives, other additives or pesticide residues must not be authorised in the USA if, at any level, they have been found to induce cancer in experimental animals or man. This rule was already controversial at the time of its introduction in 1958, in part because it was expressed as a requirement of "no risk", which, scientifically, is regarded as unachievable unless the requirement is linked to a direct ban on use in the individual cases or every assessment of additives/pollution is interpreted as a requirement of negligible or *"de minimis"* risk. The discussion of this interpretation of the precautionary principle is still going on. In the USA, the situation is that the requirement concerning actual banning of carcinogens is enforced in the case of real additives, including food additives, whereas pesticide residues (cf. Amendment PL104-170 of 3 August 1996) are, rather, assessed on the basis of the *"de minimis"* rule, interpreted as a lifetime cancer risk for one individual out of 1 million (1×10^{-6}). Viewed as the risk rate, i.e. numerically, most experts, including FDA officials, describe this – largely unchallenged – as "negligible, trivial, insignificant or even non-existent".

2) Spraying of seed-bearing and fruit-bearing crops
Right back in the first decades with growing use of spraying, i.e. from around 1955 to the mid-1970s, it was established in most countries, including Denmark, that rules for pesticides and instructions for their use should be provided in accordance with the individual countries' agricultural needs. This was normally verified by means of controlled spraying tests carried out under the special 'climatic and cultivation conditions' of the country in question.

Tests of this nature were carried out in Denmark in the period 1963-1975 by the National Plant Pathology Research Institute in cooperation with the National Food Institute (now the National Food Agency) with a view to authorisation of the products by the Ministry of Agriculture's Poisons Board. The results of the tests often showed that substantial parts of the Danish fruit, vegetable and berry production at that time could be kept free of detectable pesticide residues provided the spraying times, waiting times before harvest and similar were fixed at 'before flowering ends' and 'before seed-setting' etc. This was largely accepted as a well-defined basis for 'Good Agricultural Practice' and thus met the requirements and wishes already formulated at that time concerning no (or only negligible or "immeasurable") residues in crops ready for eating.

Many of the regulations and recommendations given by the Poisons Board and, later, in DEPA's authorisation schemes, thus contained significant elements of a restriction on use that went beyond the risk assessment requirements formulated for purely health and environment reasons. A similar situation arose in the summer of 1998 in connection with the discussion on the use of the herbicide glyphosate to combat couch grass in cereal crops shortly before harvest.

3) Drinking water from water supply systems
Owing to human error, a serious pollution situation occurred in a provincial town (Fåborg) in Denmark in the middle of the 1970s. The error resulted in the insecticide Parathion (Bladan) being sucked into the pipe network, contaminating large parts of the town's public water supply system. The unavoidable decision taken was naturally that the system was to be closed down and to remain closed 'until the plant and pipe network were free of *any measurable* residue of Bladan'. In other words, the precautionary principle was applied even though, in the case in question, a higher residual content than the limit applying at that time (given as 0.1 microgramme per litre) could have been accepted on the basis of a toxicological, health assessment. As a pollution situation that attracted great public attention, this case (together with similar cases in other countries in Europe), had both direct and long-lasting consequences for many subsequent cases, leading to today's requirement of no (i.e. 'immeasurable' or only negligible) pesticide residues in drinking water/groundwater.

8.2.1 Approaches to the precautionary principle
The following two approaches to the precautionary principle can be described:

1) An effect assessment/risk management approach
The effect assessment/risk management approach is based on extensive knowledge of data and other technical and scientific information. Using statistically or pragmatically fixed (un)certainty factors, one assesses the hazard of individual substances and the risk associated with their use. In that connection, dose-effect curves and lowest effect values are as far as possible established. Tools in this connection include setting of limit values, threshold values, pollution standards, etc., often supplemented by emission requirements based on health and environment considerations and, possibly, regulation of use. This approach is illustrated in figure 8.1 below.

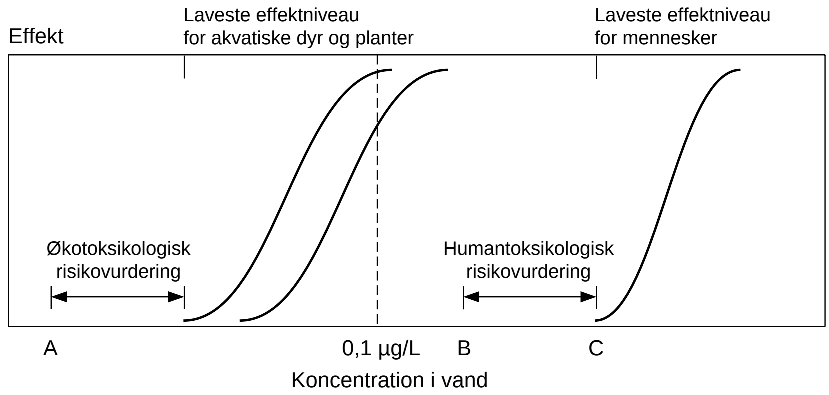


Figure 8.1
The risk assessment approach with relationship between dose and effect for humans and for aquatic organisms and plants. C = lowest effect level for humans, B = toxicologically set zero effect level using a safety factor,

A = ecotoxicologically set zero effect level for aquatic organisms using a safety factor. 0.1µg/L = the limit value for pesticides given in the Drinking Water Directive (µg/L = microgramme per litre).

(Figure text:
Effekt = Effect
Laveste effektniveau for akvatiske dyr og planter = Lowest effect level for aquatic organisms and plants
Lavest effektniveau for mennesker = Lowest effect level for humans
Økotoksikologisk risikovurdering = Ecotoxicological risk assessment
Humantoksikologisk risikovurdering = Human-toxicological risk assessment
Koncentration i vand = Concentration in water)

2) A zero value approach
In the zero value approach, basis is set by uncertainties, random variations and possible erroneous assessments, including insufficient data or a direct lack of knowledge, and greater importance is attached to a general recognition of the fact that data, documentation and/or concrete knowledge must always, scientifically, be regarded as deficient. From a desire for a "zero concentration or dose", requirements can be made concerning insignificant, possibly 'immeasurable' content/doses/loads etc. for exposed individuals, populations and/or environments. This is illustrated in figure 8.2.

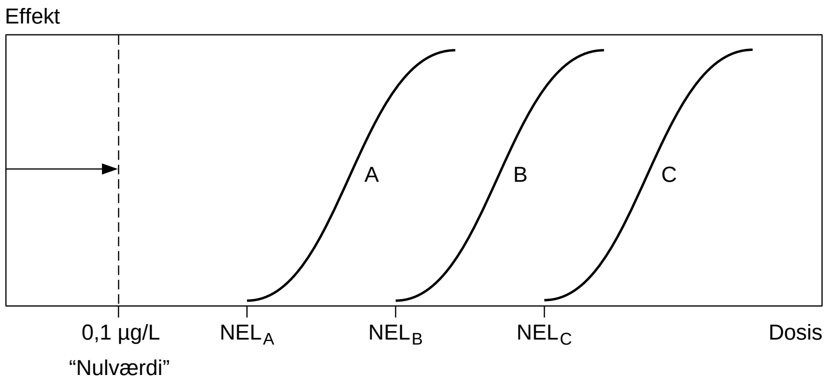


Figure 8.2
The zero value approach with a fixed, low limit. A, B and C refer to individual pesticides with different toxicity. The curves can be the lowest toxic dose/effect curves for humans: NEL_A, NEL_B and NEL_C = lowest effect level for A, B and C, respectively. 0,1µg/L = the limit value for pesticides given in the Drinking Water Directive (µg/L = microgramme per litre).

(Figure text:
Effekt = Effect
Nulværdi = Zero value
Dosis = Dose)

Uncertainties and variations

Operationalisation of the approaches must accordingly be linked to the assessment of documentation and data, including – particularly, the lack of material and data, which can be concretised to a number of variations and uncertainties comprising:

- *Measuring uncertainty* in the experimental procurement of biological, chemical and physical-chemical data. This is *characterised* by the fact that we can calculate both probability for effects and uncertainty for concrete biological or physical systems.

- *The uncertainty in the assessment* in the further interpretation of performed tests, often by transformation on extrapolation of laboratory (and epidemiological) observations and measurements for use with other organisms (e.g. animals to humans) or pollution situations (e.g. aquatic environment to soil or air). This is *characterised* by the fact that we have some knowledge about the systems we describe, but variation and probability of risk depend on estimation via interpretation of knowledge from one system or one situation to another.

- *Uncertainty of knowledge or direct ignorance* with insufficient or no understanding or knowledge of effects or mechanisms behind effects, including naturally also a lack of possibility of predicting effects that are insufficiently described or that have not previously been observed. This is *characterised* by the fact that we do not know the system and/or the effects we have to describe and that we have no basis for predicting risk, let alone calculate the probability of effect.

- *Uncertainty concerning use or other uncertainty* is linked to *indeterminacy* in commercial and societal development, marketing and use of pesticides. This is *characterised* by the fact that we normally do not fully know the systems in which pesticide use and dissipation is taking place - and we know that we do not know them.

These four areas of uncertainty are characterised by an increasing lack of knowledge, which thus reduces the scientific basis for decisions and correspondingly increases the need for administrative or politically based decisions.

The memorandum "Discussion of caution and risk" (Sub-committee for Environment and Health 1998) gives a detailed description of different areas of uncertainty and variation.

8.2.2 Groundwater and drinking water as a case

In Ministry of Environment and Energy Order on Water Quality and Supervision of Water Supply systems, No. 515 of 29 August 1998, the following is stated in chapter 2, section 4, concerning the quality of water from water supply systems:

The water from water supply systems that supply people with water for household use must meet the limit values for content of substances in the water given as the highest permissible values in Annex 1 to this Order. However, efforts must be made to ensure that the values are lower than or within the values given as guideline values in Annex 1.

In Annex 1 to the Order, the guideline limit value for pesticides and related products is put at "u.d.", i.e. under the detection limit for a method that can measure one tenth of the highest permissible value, which is fixed at 0.1 microgramme per litre in the Drinking Water Directive. A guideline limit value for pesticides is thus 0.01 microgramme per litre for each substance.

The Drinking Water Directive's limit value of 0.1 microgramme per litre for pesticides has been fixed on the basis of a *zero value approach,* which is expressed by a *negligible ('immeasurable')* limit value *covering all pesticides*, instead of a *risk principle*, which would mean setting concrete, individual pollution levels judged on a *toxicological/health basis* to be acceptable or permissible from the point of view of health.

Areas of variation and uncertainty in risk assessment and risk management, on the one hand, and implementation of the zero value approach, on the other, are based on concrete studies and knowledge, but oblige us also to pinpoint/define our lack of knowledge or uncertain knowledge.

Toxicological and ecotoxicological testing of a chemical substance and assessment of the possibility of this substance affecting health and the environment are illustrated in figure 8.2. A single chemical substance is tested for a number of effects in experiments on mammals (e.g. mortality, acute, sub-acute and chronic effects, and, if possible, cancer and reproductive disorders) or on other live organisms (e.g. fish, daphnia, algae). For each of these an attempt is made to establish a dose/effect curve, as illustrated in figure 8.2, although it is recognised that in some cases these effects do not necessarily have any well-defined relationship between dose and effect.

For each of the measured effects, an attempt is made to establish a so-called zero effect dose for use in setting limit values or threshold values. This serves as a basis for risk assessments, i.e. the possibility/probability of (harmful) effects occurring through exposure even though the dose is smaller than the estimated zero effect dose.

The area of 'uncertainty' close to the zero effect value must be regarded as a grey zone within which a *residual effect*, an *unmeasured* effect or an *unknown* effect could occur. Such situations can be counteracted:

- either by including one or more pragmatically fixed 'uncertainty factors' (UF) in relation to the zero effect or threshold level and as the basis for an accepted/tolerated concentration or dose (the risk acceptance model)

- or by fixing a so-called negligible content/dose that is based on a zero concentration or dose and that gives greater certainty that a "grey zone" will not be entered (the zero value /precautionary model).

Of the two forms of assessment, it is the first, i.e. *the risk acceptance approach* that is normally practised, possibly modified by including a supplementary principle concerning 'good treatment practice' (see below), while the *zero value approach* is used for pesticide residues in drinking water. However, as mentioned above, the zero value approach is also known in other connections – for example in assessment and regulation of carcinogenic, chemical substances (cf. the *Delaney Clause*, see above) or as an element of a restrictive treatment practice with specific requirements concerning time limits for spraying seed-bearing, berry-bearing and fruit-bearing crops etc.

With respect to the rules on pesticide residues in groundwater and drinking water, there is a distinct difference between the health assessment of the limit value and the environmental importance of the limit value, as also illustrated in figure 8.1 above. Whereas, with respect to human toxicology, all known pesticides have up to the present time been found acceptable/tolerable with respect to the groundwater criterion of 0.1 microgramme per litre, the figure with two concentration effect curves exemplifies how the lethal effect level for aquatic organisms (measured as EC_{50} or LV_{50}) can be exceeded at values below 0.1 microgramme per litre. There are several such examples, particularly among insecticides, and for an environmental point of view, the value 0.1 microgramme per litre is in this case *not* an expression of the precautionary principle of the zero value approach. A risk assessment of these individual substances on the basis of existing laboratory data would lead to a lower limit value than 0.1 microgramme per litre for aquatic organisms.

It should also be noted that limit values set on the basis of detection limits are not static quantities. For example, technological development, with growing use of detection by means of mass spectrometry, means that it is now possible to determine the occurrence of a number of substances down to detection levels of 0.005 microgramme (µg) per litre, i.e. concentrations up to 20 times lower than was technically possible in 1980, when the limit value of 0.1 microgramme per litre was set.

There are thus no technical obstacles to reducing the guideline limit value of pesticide residues in drinking water, and one could, in principle, continue reducing it in step with the development of analytical methods. This would mean that, as a consequence of the zero value approach's precautionary principle, one would not only move away from the precautionary principles of the effect assessment/risk management approach, but would also, in some years' time, approach a limit value that very few pesticides could meet.

Continued reduction of the limit values in step with the development of methods of analysis would thus ultimately mean banning all use of pesticides if one maintained that one would not accept measurable quantities.

8.2.3 The sub-committee's conclusions and recommendations

Two different approaches to the precautionary principle can be used – here called the risk assessment approach and the zero value approach.

Use of the risk assessment approach can imply a "conservative" (= "cautious") assessment based on concrete, empirical evidence, whereas use of the zero value approach can be based on an initially value-determined quality requirement that is only deviated from after assessment based on definable protection requirements.

If the risk assessment approach could be based on a sufficient quantity of scientific data to ensure complete protection of health and the environment, then, for example, the use of uncertainty factors (UH) could be held to be a satisfactory implementation of the precautionary principle. Such an approach would thus mean that the precautionary principle did not add anything to the traditional risk assessment. The authorisation scheme thus seeks to implement the precautionary principle, using all data and taking account of negative consequences of uncertain or unforeseen exposure, incorrect use, etc. With this approach, there should be no need for greater use of the precautionary principle, although this neither solves the problem of the possible inadequacy of the uncertainty factors nor answers questions about uncertainties as a consequence of lack of knowledge or indeterminacy related to the role of pesticides in society.

Conversely, the zero value approach would not answer directly the question of the actual size of uncertainty factors, but would be based on a value-determined requirement concerning a zero risk society.

The zero value approach could tentatively be used within an authorisation scheme for pesticides in the following areas:

1. reduction of the limit value for pesticide residues in food products to the lowest detection level at any time
2. reduction of the limit value for pesticides in groundwater to the lowest possible detection limit at any time or authorisation only of pesticides meeting a requirement of no or negligible mobility in soil
3. no authorisation of substances classified as Carc3, Mut3 and Rep3
4. no authorisation of substances subject to greater distance requirements than 6 m to watercourses and lakes
5. greater possibility of restricting use with a view to avoiding the use of pesticides directly on crops, trees and bushes in their seed-bearing, fruit-bearing and berry-bearing periods.

It must be stressed that it has not been assessed whether the zero value approach should be used for the above-mentioned examples, since that would require a dialogue between the following players:

1. scientific experts to define the limit for what can be predicted and isolate what cannot be elucidated
2. an administrative instance to decide what can be operationalised
3. political decision-makers, i.e. non-experts, to make the final decision on behalf of the public, partly on the basis of trust in the scientific knowledge and partly on the basis of ethical and political considerations.

It should also be noted that in the foregoing examples use is made of limit values fixed on the basis of the currently achievable analytical detection limit. Therefore, as a consequence of continuing technological development, the limit values will regularly be reduced, ending near zero. This could ultimately lead to a total ban on the use of pesticides.

9 Environmental and health assessment of alternative or new methods of weed control and control of pests

9.1 Introduction

In the following, an assessment is made of the environmental and health consequences of non-chemical methods of preventing and controlling pests in agriculture. The assessment is based on the work of the Sub-committee on Agriculture. It is followed by a discussion of:

- possible improvements at sites for washing and filling sprayers
- the interaction between pesticides and the production of toxins
- mineralisation in the soil with increased soil treatment in connection with no use of pesticides
- changes in energy consumption and emission of greenhouse gases in connection with no use of pesticides
- new pesticides.

9.2 Weed control

Prevention of weed problems and use of mechanical control methods

To achieve adequate control of weeds in the event of a total or partial phase-out of pesticides, it would be necessary to combine prevention and control through cultural practices and non-chemical, alternative methods. That means that the crop rotation would have to be adjusted towards less winter cereal, leading to a more diversified crop rotation and greater biodiversity than in a crop rotation including monoculture of cereals. In addition, the autumn sowing would have to be done later and it might be necessary to sow some crops with a wider row spacing to enable mechanical weeding. If the mechanical weeding were very effective, the amount of weeds would not differ much from the amount in fields treated with pesticides, so there would be no environmental benefit for the wild flora. In crops such as rape, mechanical methods are already competitive, compared with chemical methods. Mechanical weed control has a considerable negative impact on the soil’s mesofauna and macrofauna, particularly springtails and earthworms, and harrowing can damage the crop. On the other hand, increased mechanical control of weeds in farming would be generally environmentally beneficial because it does not involve any risk of pollution of groundwater or of spreading of pesticides to adjacent areas. Placing fertiliser at the individual plant is deemed to be another good way of improving the crop’s ability to compete with weeds. All else being equal, this could reduce fertiliser consumption and thus reduce the loss to the surroundings.

Cover of vegetation all year round

According to Action Plan II, “Organic Farming in Development”, it is possible to keep the soil covered with vegetation all year round (Danish Directorate for Development 1999). In organic farming, extensive use is already made of undersown and second crops. Consideration could also be given to the use of “undersown crops” in the form of low-growing herbaceous plants, such as white clover, but other plant species could also be grown. Leguminous plants are an obvious choice with respect to nitrogen fixation, but species that are good “catch crops” could also be used and would be advantageous with respect to holding on to the nitrogen until the crop can absorb most of the amount available. In addition, undersown crops would give more varied cover, thereby promoting part of the fauna – particularly earthworms and surface predators. Lastly, a cover of undersown crop would reduce the weed’s possibility of germinating both in the crop and after harvesting.

On the health side, the main change in connection with the prevention of weed problems and the use of mechanical control methods instead of pesticides would be reduced exposure of agricultural workers and less pesticide residue in the crops. Potential problems with physical loading in connection with increased mechanical or manual weed control are discussed in section 6.1.

9.3 Prevention and control of diseases

Prevention of disease in cereal crops through the use of resistant plants

In a scenario without pesticides it would be important to use crop species with good resistance to diseases in order to reduce the loss from infection by leaf diseases. The biggest losses from diseases occur in potatoes, wheat and winter barley. There are at present no varieties with sufficient resistance to all leaf diseases in these crops.

There is a big potential for improving the resistance of the varieties both by traditional breeding and by genetic modification, but it is difficult to breed, at one and the same time, resistance to leaf diseases and seed-borne diseases, better weed competition, stem strength, winter resistance, a high yield and high quality.

The environmental benefit of developing and using resistant varieties is the obviously reduced consumption of pesticides, with consequently reduced risk of pollution of the groundwater and the surroundings. The health benefit would be less exposure of farm workers and less pesticide residue in crops.

Prevention and regulation of problems with seed-borne diseases in cereals

In Denmark today, 85-90 % of all cereal seed is dressed today, as is a large proportion of other crops in Denmark. It is believed that generally omitting such treatment would lead to a rapid spread of many of the seed-borne diseases that cause heavy losses.

It would be possible to reduce the consumption of pesticides by continuing to dress the first generations of cereal and then assessing the need to dress the subsequent seed batches. However, this practice would first have to be more thoroughly analysed and tested. An assessment of the need for dressing would require fast and reliable methods of analysis, separation of seed batches and presumably rejection of substantial quantities of grain for multiplication. In beets, too, there could be considerably losses owing to uncertain establishment if dressing products were prohibited. In this case, however, the losses would be due to a combination of both diseases and pests. Today, research is in progress on several alternative methods of combating seed-borne diseases, including use of resistant varieties, use of biological products and technical methods involving the use of hot water/air or brushes. None of these methods is yet ready for use and a great deal of research and development remains to be done.

The environmental benefit from developing alternative methods, including the use of resistant varieties, increased assessment of the need and biological protection products, is reduced use of pesticides, although the pesticide consumption is very small. With seed dressing, between 10 and 50 g pesticide per hectare are often used, which is of the same order of magnitude as when spraying with mini-products and pyrethroids. Since the seed is covered with soil, very little pesticide is spread to the air and surface water. However, pesticides in seed-dressing products can leach in the soil in the same way as spray products. Seed dressing also involves a risk to birds and small mammals, which eat the seed. The plants and thus food products made from them can also contain residues of systemic seed-dressing products.

The health benefit of omitting treatment with seed-dressing products would be no exposure during production, although this is usually in the form of wet-dressing in large, closed dressing plants. Exposure also occurs during handling of the seed in connection with sowing. Lastly, some residues of the systemic pesticides (i.e. the pesticides absorbed by the plants) could be present in the crops and thus in food products.

9.4 Prevention and control of pests

Prevention of pest attack in crops through the use of insect-resistant plants

Very little is known about the insect resistance of Danish varieties. Simple screening for receptivity to pests may reveal an unexploited potential. Only limited use is at present made of biological control of pests in fields, so such methods are not yet a realistic alternative to chemical control. It is a well-known fact that the field's natural fauna affect the pest population, but little is known about how much these beneficial organisms affect the development of, for example, aphids.

The environmental and health benefit from developing and using insect-resistant varieties is obviously less use of insecticides with a consequent reduction in the risk of pollution of surface water, groundwater and the surroundings in general.

The health benefit would be less exposure of farm workers and less pesticide residue in crops.

Biological prevention and control of diseases and pests in farm and market garden crops

Biological methods, which include both beneficial organisms and microbiological products, have a big potential against pests in greenhouse production. They are already used extensively in greenhouse vegetable production but not within greenhouse production of ornamental plants. Effective biological methods of combating diseases in greenhouses are still limited. In fields, biological methods of controlling pests are believed to have some potential within special crops, whereas, in the short term, biological methods of combating diseases are only thought to have a potential in the case of seed-borne diseases and fungi that affect germination.

Table 9.1
A number of microbiological insecticides and fungicides are at the application stage.

Name	Type	Extracted from
Phlebiopsis giganta	Fungicide	microorganism
Streptomyces griseovirides	Fungicide	microorganism
Bacillus thuringiensis ssp. israelensis	Insecticide	microorganism
Bacillus thuringiensis ssp. kurstaki	Insecticide	microorganism
Bacillus thuringiensis ssp. tenebrionis	Insecticide	microorganism
Trichoderma harzianum	Fungicide	microorganism
Trichoderma harzianum og *Trichoderma polysporum*	Fungicide	microorganisms
Verticillum lecanii	Insecticide	microorganism
Agrotis segetum granulosis virus	Insecticide	microorganism
Paecilomyces fumosoroseus	Insecticide	microorganism
Pseudomonas chloroaphis	Fungicide	microorganism
Ampelomyces quisqualis	Fungicide	microorganism

As in the case of disease-resistant or insect-resistant varieties, biological control would result in an obviously reduced consumption of pesticides and a consequently reduced risk of pollution of groundwater, food products and the surroundings. There would be a corresponding health benefit of less exposure of agricultural workers and less pesticide residue in crops.

However, the use of beneficial organisms and microbiological products would involve a serious risk of proliferation of foreign organisms, which could have a detrimental effect on the environment. It should be noted that the beneficial organisms currently used in greenhouses cannot survive out of doors in Denmark. Theoretically, the proliferation of indigenous species could also upset natural ecological balances. The use of microbiological products could involve a risk of harmful effects in the form of allergies and bronchial diseases. An authorisation scheme for these products is under construction and will include an assessment of possible health effects.

Prevention of pest attack in agricultural crops through the use of alternative methods and crops

The crop rotation used and the crops grown are of great importance for the level of diseases, weeds and pests. Generally speaking, the level of pests can be reduced by means of a varied and diversified crop rotation, alternating between spring and winter crops, monocotyledonous and dicotyledonous crops, and annual and perennial crops. As a rule, there are fewest problems with pests in dairy farm crop rotations with a large proportion of grass compared with large areas with specialised plant production. When planning the crop rotation it is important to take account of crop-rotation diseases and ensure a sufficient number of years between such crops as potatoes, rape, sugar beets, etc. There does not seem to be any direct possibility of cultivating new, alternative crops or intercropping.

Mulching

According to Action Plan II, “Organic Farming in Development”, mulching could reduce evaporation from the surface of the soil, which would promote both plant growth and the soil fauna, particularly in dry summers (Directorate for Development 1999). Mulching would also promote surface predators (spiders and ground beetles), which play a role in combating pests, and would reduce the weed's possibility of germinating. It would be possible to mulch after the cereal harvest by cutting the straw and leaving it on the field. One of the problems of mulching is whether it is possible to sow the crop directly in the mulch in such a way that it can germinate unhindered. The effects of such a procedure on diseases and pests and on crop growth should also be investigated.

Use of warning and damage threshold models in agriculture

In recent years, damage thresholds and decision-support systems have been developed for many of the main agricultural crops as support for the farmer in judging the need for prevention and control and the choice of pesticides. Although the systems are now relatively widely used, not all farmers have been reached. Damage threshold systems still have to be developed for a large number of crops and several of the existing systems need improving. It is considered possible to achieve a 20-50% reduction in the use of pesticides in a number of crops by combining decision-support systems with chemical and non-chemical methods. Research has shown that targeted use of fertiliser, pesticides and other factors related to the phase-out can contribute to satisfying environmental requirements and simultaneously optimise production economically. The use of decision-support systems offers an obvious possibility of reducing the exposure of both the environment and people.

Conclusion

The environmental and health benefit from the use of preventive cultivation methods would be an obviously reduced consumption of pesticides and a consequently reduced risk of pollution of groundwater and the surroundings. An added health benefit would be less exposure of agricultural workers and less pesticide residue in crops.

9.5 Use of genetically modified crops in agriculture

In Denmark, researchers are working on the development of genetically modified plants. Most progress has been made on herbicide-tolerant plants, which should be ready for marketing in a few years' time. The introduction of genetically modified, herbicide-tolerant varieties of beet is expected to result in a significant reduction in herbicide usage - about 1 kg active ingredient per ha. In the case of herbicide-tolerant rape and maize, there does not seem to be any significant reduction in herbicide consumption. Intensive research is going on all over the world in the field of molecular biology. In time, that will undoubtedly lead to significant changes in our cultivated plants. Of particular interest is the development of genetically modified disease-resistant plants, which must be presumed to create a means of reducing losses from diseases without the use of pesticides. The use of genetically modified plants with resistance to pests in maize and other crops is spreading globally. However, crops with resistance to pests are unlikely to gain a footing in Denmark for some years (around 10).

Genetically modified plants provide the possibility of reducing the use of pesticides and thus exposure of both the environment and people. However, there could be a risk of some of these crops proliferating and subsequently harming the environment. That applies particularly to plants whose ability to establish in competition with the natural flora is improved. In addition, plants that are resistant to insects could affect other species than the pest itself. This applies particularly to predatory insects and birds that eat herbivores living in the genetically modified crop. Such insects and birds could either be affected directly because the prey eaten is poisonous to them or indirectly through changed food resources. Such effects also occur with the use of spray products. However, possible effects of insect-resistant plants differ from those of spray products by being able to occur throughout the growth season. However, it is likely that some non-target organisms would be less affected by genetically modified plants than they are by conventional use of spray products. The authorisation process for genetically modified plants will include a risk assessment of both the environmental impacts and the effects on health, cf. section 7.3.

9.6 Use of spraying techniques to reduce spray drift

Efforts have been made to improve the biological effect of pesticides by using different types of nozzles, quantities of water and pressure. The aim has been to be able to use lower dosages. Compared with current spraying techniques, the use of new types of spraying equipment offers only a limited possibility of reducing the amounts of pesticide used. However, in the last few years, research has been going on within site-specific application of pesticides, which means limiting the treatment to those areas of the field where there is a need to control or regulate pests. With the present spraying practice, more than 95% of the spray product may hit the soil surface in the early growth stages of the plants.

It is believed that the development of methods that can handle such a system would help to reduce pesticide consumption considerably. There are also good possibilities of reducing the risk of spray drift by lowering the boom height and by using new nozzles that minimise the proportion of droplets with a potential for drift. Some of the new types of spraying equipment have a bigger spraying capacity than earlier sprayers, which improves the possibility of spraying quickly, while the weather is calm, e.g. in the morning hours. In fruit crops, new, shielded sprayers that collect spray residues are believed to offer a good possibility of reducing the impacts on the surrounding environment.

On the health side, a reduced need to spray would directly reduce the exposure of the sprayer operator.

9.7 Reduced pollution during cleaning and filling of spray equipment

Even small spills of concentrated spray product can greatly increase the risk of leaching, as described in section 4.6.5, on pollution from sites for filling and washing of sprayers. The risk of leaching is even greater if the spill occurs at traditional sites for filling and washing, where the surface is often covered with gravel or fine shingle, and with very thin or no topsoil or vegetation. There is also a particular risk of pollution of local water supplies or ground water when pesticides are used and tractors and spraying equipment are cleaned near wells or borings.

There are a number of simple rules and recommendations for reducing or completely avoiding pollution with pesticides during cleaning and filling of spraying equipment (Jensen et al. 1998). Filling of tanks with concentrated pesticide and washing of spraying equipment should thus be done on an area of topsoil with vegetation, which should be moved at regular intervals, or on a biobed. Filling and washing can also be done on a concrete yard with a drain to a separate tank. A grass-covered area is also suitable. Grass prevents run-off and the formation of channels in the soil. Remaining spray product should never be emptied out onto topsoil or a paved area. Remains of spray product should never be put into a liquid manure tank unless it can be done without risk in relation to later use of the liquid manure on crops.

Remaining spray product (5 - 50 l) should be diluted and sprayed onto the crop. The strongly diluted washing liquid can be emptied out on a field, over as large an area as possible. One way of doing this is to remove the bottom bung and empty the tank while driving in the field. The diluted washing liquid can also be emptied into the liquid manure tank. Washing and filling of sprayers should never be done on gravel or concreted areas from which the washing water and spills are led to seepage or to a sewer, drain or watercourse. Besides that, it must never be done near a well. The packaging and any unused pesticide residues must be disposed of through the municipal waste scheme.

International standards

As an element of the work of preventing pollution of the environment, a European standard is being prepared for field sprayers and vapour sprayers. Consideration for the environment and health and safety are key points in the standard. The work, which began six years ago, is being carried out under CEN (Comité Europien de Normalisation), in which Denmark is represented through the Danish Standardisation Council. In the introduction to the coming standard, the following main points are mentioned:

- A uniform distribution and good placing of the spray product
- Prevention of unintended spreading of pesticides to the surroundings
- Improved operation of the equipment.

To achieve these objectives, the sprayer must be equipped with a clean water tank of a specific size in relation to the size of the sprayer. The sprayer must be washed out with the water before it leaves the field. If possible, the first cleaning of the outside of the sprayer must be done with clean water in the field. In addition to the clean water tank there must be a tank with clean water for washing of hands etc. Standards will also be prepared for filling equipment and equipment for cleaning chemical packaging.

Compliance with a standard is normally voluntary, but in some countries, the standard will form the basis for authorisation of spraying equipment. In Denmark, there is already a trend towards mounting clean water tanks on sprayers on a voluntary basis. From a technical point of view, clean water tanks can be post-mounted on most sprayers without major problems.

Biobeds

An alternative to filling and cleaning the sprayer in the field is the establishment of a biobed (Helweg, Hansen 1997). A biobed is a biological filter or mini treatment plant for any pesticide that is spilled during filling or washed off during washing of the spraying equipment. The biobed material is characterised by high microbiological activity and a good sorption for the pesticides. Tests going on at the Danish Institute of Agricultural Sciences and the National Department of Plant Production have shown that biobeds have a good ability to bind and break down pesticides. The tests also show, however, that the biobed should be closed at the bottom in order to ensure against leaching through the bed. It must also be ensured that percolating water can be collected at the bottom of the bed. There are at present no real guidelines or recommendations on biobeds because they cannot be given before official authorisation of a prototype. Also lacking is official acceptance of disposal of biobed material by spreading in the field. That is not expected to be a problem. If more complicated methods of disposal were required, farmers would probably lose interest in biobeds.

Municipal environmental supervision

In 1998, DEPA directed Denmark’s local authorities to give higher priority to checking the handling of pesticides when carrying out environmental inspections at the individual farms. The main things to be checked are whether the sprayer operator holds a spraying certificate, whether washing and filling sites are properly arranged from an environmental point of view and whether the products used are properly and safely stored and disposed of.

9.8 Interaction between pesticides, including growth regulators, and production of toxins

Some of the fungi that occur in plant production can produce so-called mycotoxins, many of which are extremely toxic to humans and animals. The following survey of this area is based on a report by Elmholt (1998). Mycotoxins can be absorbed through the gastrointestinal tract, the mouth, the lungs or the skin. At least 300 different mycotoxins have been identified, but only about 20 of them are today thought to be of importance with respect to animal feed and human nutrition. Some mycotoxins, e.g. trichothecenes and ochratoxin A, are found in crops produced in the EU, while others, e.g. aflatoxin, occurs particularly in crops imported from the tropics. The occurrence of these mycotoxins is thus unrelated to changes in the use of pesticides in Denmark. It is estimated that 20% of the cereal crops used for fodder contain measurable quantities of mycotoxins (Smith et al. 1994).

Fungi that form mycotoxins

Different families of fungi can form toxins under Danish conditions. The main ones are *Penicillium* and *Fusarium* (Elmholt 1998). Only a few species within the families present a real risk. The Nordic Council of Ministers (1998) carried out an analysis of the intake of mycotoxins in the Nordic countries and a risk assessment of selected *fusarium* toxins. There is also often some variation in the capacity to produce toxins between strains within the same species. In the case of many of the fungi that produce mycotoxins, little is known about why they produce the toxins and what triggers their formation. The main members of genera on Danish produced cereals are *Pencillium verrucosum*, which forms ochratoxin A and citrinin, and members of the *Fusarium* genera, which form zearalenon and trichothecenes.

The main mycotoxins

The effects of the toxins on animals and humans are described in Smith et al. (1994). Ochratoxin A is one of the most poisonous mycotoxins in Danish produced cereals and is also found in processed products. Ochratoxin A has a toxic effect on the kidneys and is on the list of carcinogens. The Danish Veterinary and Food Administration has shown that, particularly in years with wet harvests, there is a real risk of ingesting so much ochratoxin A via cereal products that the Nordic limit value for daily intake of 5 microgrammes per kg body weight is exceeded. Citrinin and some glucopepsides also have a harmful effect on the kidneys. Trichothecenes are another of the main mycotoxins in cereals and food products containing cereals. Some trichothecenes already form while the cereal is standing in the field (Pettersson 1996). That applies, for example, to T-2 toxin and to deoxynivalenol (DON), which is found in agricultural crops all over the world, even after processing. DON (= vomitoxin) has toxic effects on the digestive system and is known to cause vomiting and reduced appetite in pigs. There are as yet no Danish rules, but, in most cases, the amount of DON normally contained in cereals lies far below the limit values used in the USA. The far more toxic, but also rarer, trichothecenes, T-2 toxin and DAS, affect the immune system and, in the worst event, can cause serious illness (ATA syndrome) in humans and animals. Trichothecenes also play a role in fungal attacks on plants. Zearalenon is also an important mycotoxin. It is formed by several different genera and is known for its oestrogenous effect, i.e. it is one of the naturally occurring hormone-like substances. Fusarin C, which can be formed by several different members of the *Fusarium* genera, is mutagenic and possibly carcinogenic.

Importance of climatic conditions, harvest conditions and drying

The occurrence and growth of fungi increase in moist growth conditions. This is reflected by the fact that large consignments of grain are infected with, for example, *Fusarium* fungi after moist growth seasons. Grain harvests with a water content of more than 14-15% can cause problems with subsequent development of different types of fungi during storage of the grain. This means that unless the grain is dried immediately after harvest, a lot of toxin-producing fungi can develop. Particularly in years with long periods of unsettled weather and a lot of precipitation, it can be difficult to get the harvested grain dried. A good example of this is known from the screening for “mouldy kidneys” carried out by abattoirs. All kidneys exhibiting macroscopic lesions, which indicate that the animal suffered from “porcine nephropathy”, are tested for residues of ochratoxin A. The entire carcass is rejected if a concentration of more than 25 microgrammes per kg is found in the kidneys. This threshold has been applied since 1979. The results show that “mouldy kidneys” do not occur with the same frequency every year. In many cases, they were found after pigs had been fed with grain harvested in 1978, 1983 and 1987. Closer studies of the cases in 1978 and 1983 show that they were not uniformly distributed in regions, and the occurrences could in many cases be related with the harvest conditions in the various regions of the country (Frisvad, Viuf 1986; Büchmann, Hald 1985). The Ministry of

Food has shown that there is a real risk in connection with wet harvest years of so much ochratoxin A being ingested via cereal products that the Nordic limit values for daily intake are exceeded (Jørgensen et al. 1996; Danish Food Agency 1997). However, fast and effective drying of grain would in most seasons reduce the risk of toxin production during storage.

Malt barley and gushing

A number of members of *Fusarium* genera are found on malt barley (Thrane et al. 1992). It is assumed that the occurrence of *Fusarium* on malt barley can cause what is called gushing in the brewing industry, and a German study showed a significant relationship between the concentration of DON and gushing in beer brewed both on wheat and on barley (Niessen et al. 1993).

Direct effects of fungicides on fungi and the formation of toxins

Today, extensive use is made of broad-spectrum fungicides in cereal crops. A number of studies indicate that different members of the *Penicillium* genera are not sensitive to propiconazole and other ergosterol-inhibiting fungicides, which are the predominant fungicides used today (Elmholt 1998). It should be mentioned, however, that these findings were based on fungi growing on soil. Most fungicides have only a limited effect on *Fusarium*, which mainly attacks grains in connection with flowering. Tebuconazole is active against several members of the *Fusarium* genera, and azoxystrobin is also known to affect a few of them. Generally, however, chemical control of *Fusarium* fungi is not recommended in Denmark because it is extremely difficult to hit the right spraying time for some effect to be achieved.

Although a fungicide like tebuconazole reduces the occurrence of *Fusarium culmorum*, it does not necessarily reduce the risk of toxins forming in the grain. A German study indicates that the opposite is the case: it showed that treatment of *Fusarium culmorum* with Matador (tebuconazole+triadimenol) greatly increased the content of the trichothecene NIV in relation to untreated control plots (Gareis, Ceynowa 1994). Similarly, Moss and Frank (1985) found that tridemorph stimulated production of T-2 toxin in *Fusarium sporotrichoides* at concentrations that inhibited the fungus's growth. However, Swedish studies have not confirmed these trends (Pettersson 1996).

Indirect effects of fungicides

Although the fungicides used today are broad-spectrum, there are usually some fungi on which they have little or no effect (Elmholt 1998). When combating fungi in cereals, the composition of the fungal flora on the plants can change. In some cases, this means an increased proportion of the fungi that are most difficult to combat. This is particularly unfortunate if the species in question are pathogenic and/or able to form mycotoxins. Foreign studies have shown that some members of the *Fusarium* genera increase after fungicides are used on other fungi in cereals. Norwegian studies showed that some fungicides (including Tilt top, which contains the fungicides fenpropimorph and propiconazole) resulted in stronger attacks of *Fusarium* than in untreated crops. The author argues that propiconazole, in particular, perhaps makes the plants more receptive to *Fusarium* attack or makes them more accessible by knocking their competitors out (Elen 1997). A German study (Liggitt et al. 1997) showed, for example, that three common types of fungi on wheat inhibited the development of *Fusarium culmorums*. Laboratory tests showed that the fungi's growth was affected very differently by different fungicides. In some cases (including tebucanazole), pathogenic types of *Fusarium* fungi were more inhibited than saprophytic types, i.e. the types that break down dead organic material, because the fungicide intensified the competitive effect. In other cases, the opposite happened, so the competition weakened. However, it should be noted that reduced growth of toxin-producing fungi can in some cases result in increased toxin production.

Ochratoxin-forming fungi in Denmark

The Ministry of Food's monitoring programme shows that there is a tendency towards higher occurrences of ochratoxin A in organically cultivated cereal, i.e. in cereal from areas where pesticides are not used, than in conventionally grown cereal. In a Danish study carried out by the Danish Institute of Agricultural Sciences, the fungus *Penicillium verrucosum,* which forms ochratoxin A, was detected in 11 of 64 localities in Denmark (Elmholt 1998). The preliminary results thus show for the first time that *Penicillium verrucosum* is to be found in Danish agricultural soil. They also show that the fungus seems to prefer clayey soil to sandy soil and that it apparently occurs more regularly in organically cultivated soil than in conventionally cultivated soil. One reason for that is a larger quantity of weeds in organic farming, which increases the moisture in the crop compared with conventional farming. This may have something to do with the fact that the seed used in organic farming is not dressed with fungicides. The seed lies in store for at least one year, and that may in some cases lead to an increasing population of *Penicillium verrucosum* and other fungi. After sowing, the population of these fungi could increase rapidly in the soil. When seed dressing is omitted, it is necessary to pay more attention to the problems of seed-borne fungi in cereals.

Effects of lodging

Lodging in cereals occurs for a number of reasons - cultivation of weak-stemmed varieties, over-fertilisation, too many plants, attack by straw-based diseases and heavy precipitation and wind. Today, farmers avoid the problem by growing mainly strong-stemmed varieties and by adjusting the plant density and the level of fertilisation. The risk of lodging is also reduced by some use of growth regulators. Greater use is made of growth regulators in rye than in wheat because the stems of rye varieties are weaker than wheat. If the use of growth regulators were to cease, an increased risk of lodged corn would be expected in certain soils and on certain farms. This would cause major problems when drying the crop for harvesting. It would also result in increased attack by soil-borne fungi, including members of the *Penicillium* (Hill, Lacey 1984) and *Fusarium* genera. The biggest problem in this connection would probably be *Fusarium culmorum,* which is very common in soil, and which can form a number of mycotoxins.

9.8.1 Conclusions

Mycotoxins are a general problem in both conventional and organic farming because they can develop in moist conditions. They can also proliferate if grain is dried too slowly. The sub-committee finds that mycotoxins from fungi in cereals can constitute a risk to public health and recommends strengthening of the control of the content of mycotoxins in food products.

9.9 Mineralisation in the soil and other environmental impacts from increased soil treatment in the event of a phase-out of pesticides

Soil treatment affects the chemical, physical and biological conditions in the soil and is therefore of great indirect significance for mineralisation, for release and leaching of nutrient salts and for persistence and leaching of pesticides. If soil treatment is increased, some of the macropores would be destroyed. As a result, pesticides may stay longer in the surface soil, where the potential for degradation is greatest, and leaching may be reduced. On the other hand, surface run-off would increase. If soil treatment were reduced or omitted, increased transport in macropores might result in increased leaching of pesticides (Fomsgaard 1998).

Mechanical control of couch grass in the autumn is believed to have an adverse side effect in the form of increased nitrogen leaching in the winter months because of increased nitrogen mineralisation, while mechanical weed control in the spring is also known to increase nitrogen metabolism, which is often seen as having a positive effect on the crops because, in the growth season, they have a good possibility of utilising the nitrogen released (Sub-committee on Agriculture 1998).

Compared with normal soil treatment, reduced treatment may cause increased evaporation of pesticides. If soil preparation were to be reduced, the content of organic material would increase in the long term. As a result, the soil has greater porosity and thus an increased potential for degradation and changed degradation kinetics for the pesticides. The effect of soil treatment on pesticide metabolism, including evaporation, is therefore important (Fomsgaard 1998).

Effect of soil treatment on wild plants in the field

Ploughing has a particularly large effect on root weeds but also affects annual seed weeds. In cultivation without ploughing, there is a risk of proliferation of root weeds because one loses the weakening of the vegetative propagation organs achieved by ploughing. For annual species, ordinary winter ploughing normally buries about 95% of the seed from the surface of the soil to a depth of more than 5 cm. That is deeper than most plant species are able to germinate from. In the next ploughing, many of the seeds emerge again. The plant numbers can be kept at a low level by varying the ploughing depth, ploughing very deep in years with high seed rain and then more shallowly in the following year. With this practice, most of the wild plants that germinate during ploughing come from seeds that are more than one year old, whereas, without ploughing, they come from seeds that are less than one year old. Species with low seed durability can therefore proliferate if ploughing is omitted but are less able to proliferate with ploughing. To keep the number of wild plants down, farmers grow the same type of crop for two successive years and follow that up with another type of crop. The weed seed dropped in the first crop is ploughed down before the next. Then, when the soil is ploughed again, a different type of crop is sown, in which the species in question do not have such good conditions for establishment and development (Tersbøl et al. 1998).

Soil treatment also affects the fauna. More frequent soil treatment has a harmful effect on the soil's organisms, e.g. earthworms and springtails, and can present a risk to farmland birds nesting in the field.

9.10 Changes in energy consumption and emissions of greenhouse gases

The changes in the consumption of fossil fuel from restructuring for pesticide-free farming have been studied by Dalgaard (1998), who concludes that if livestock production is to be maintained in Denmark, then – taken overall - restructuring for pesticide-free farming would result in increased energy consumption. The increase would mainly be due to increased energy consumption for importation of feed because of the fall in yield in the 0-scenario. On the other hand, energy consumption for crop production would fall, due primarily to saved energy for production of pesticides and a falling consumption of fertiliser-nitrogen.

Example: Energy consumption with present production and with pesticide-free cultivation of winter wheat

Table 9.2
Example of calculation of fossil fuel consumption for cultivation of winter wheat with present production (1996) and with pesticide-free production (from Dalgaard 1998).

	Present production GJ/ha	Pesticide-free production, GJ/ha
Oil, lubricants, etc.		
Soil treatment & sowing	1.7	1.7
Fertilisation	0.8	0.8
Plant protection*	0.7	0.9
Harvesting	1.0	0.8
Transport, handling, etc.	0.5	0.4
Electricity	0.7	0.5
Nitrogenous commercial fertilisers**	9.7	8.6
Other fertilisers and chalk	0.8	0.8
Pesticides	0.2	0.0
Machinery	1.4	1.4
Total (GJ/ha)	17.4	15.9
Yield (hkg/ha)	72	53
Energy (MJ/hkg)	240	300

*) incl. pre-emergence harrowing, extra ploughing of stubble etc.
**) 100% commercial fertiliser

Special factors and uncertainties

There can be a number of factors concerning production changes that are not included in the calculations, which might increase energy consumption in pesticide-free farming. For example, reduced soil treatment would not be possible in the 0-scenario, which would result in extra energy consumption for increased soil treatment. However, experience indicates that competitive second crops reduce the need for mechanical weed control in the autumn, which is relatively energy-intensive. In addition, the energy consumption for drying of crops and changes in the use of straw for energy purposes would have to be included in the energy scenarios (Nielsen 1999). Correspondingly, some items that have not been included in the analyses of the consequences of pesticide-free farming could reduce energy consumption. For example, new wells might have to be established because of pollution of the groundwater and measures might have to be taken to protect the surrounding environment.

9.10.1 Conclusion

In the event of restructuring for pesticide-free farming, direct energy consumption for mechanical weed control would rise, but this would be partially balanced by saved indirect energy consumption for production of pesticides (table 9.2). The conclusion must be that total energy consumption in arable farming in Denmark would not change very much with restructuring for pesticide-free production, but that this must be seen in relation to the considerable fall in yield – about 25%. However, a real estimate of the various forms of energy consumption would require a more comprehensive analysis in line with the analyses in Dalgaard et al. (1998).

Emissions of greenhouse gases

According to Dalgaard et al. (1998), the agricultural sector's contribution to the greenhouse effect is approx. 13 Tg CO_2-equivalents. CO_2 from fossil fuel consumption accounts for around one quarter of this, and methane and nitrous oxide for the remainder. The need to import feed to compensate for the reduced yield means that energy consumption would be higher than if pesticides were used. Changes in emissions of methane and nitrous oxide have not been taken into account in the assessment of the change in the agricultural sector's contribution to the greenhouse effect (Dalgaard 1998), nor has the extent to which a different production pattern, e.g. reduced livestock production or organic farming, would reduce energy consumption.

9.11 New pesticides

The agrochemical industry is continuously developing new pesticides. However, it is not clear how much the new pesticides will change the pattern of use, apart from the fact that there has been a trend towards substances that require smaller quantities of pesticide per hectare. For example, in the case of the products developed in the 1940s, the usage was about 1.5 kg a.i. per ha, whereas for recent products, the average is 100 grammes a.i. per ha. In addition, the cost of environmental studies accounts for a growing proportion of the total cost of developing pesticides.

Within herbicides, low-dose products, e.g. sulfunylurea products, of which only a few grammes are used per hectare, have been developed. In Denmark, efforts to synthesise herbicides from natural substances have so far produced the substance glufosinate (Basta). Attention has also focused on substances whose effect is closely linked to processes in plants in order to reduce their toxic effects on humans and animals.

Within fungicides, efforts have been made to use substances that occur naturally in bacteria and fungi. For example, the new storibilurin fungicides are based on a substance that is produced by fungi that degrade wood. Fungicides have also been developed that activate the plant's own immune defence without having any toxic effect on the fungi. Work has also been done on a substance that is extracted from a brown alga species.

Within insecticides, products have been developed that have different action mechanisms from earlier insecticides and that can overcome resistance to previously used insecticides. The substances are effective in doses from 5 to 20 grammes per hectare. Substances that are used as pheromones for specific pests are also being developed. The pests are caught in traps treated with the pheromone and are then killed with insecticides.

There has been a move towards substances that are more specific, that originate from existing biologically active substances in the environment, and that can be used in far smaller quantities per hectare. As far as the environmental impacts of combating weeds, diseases and pests are concerned, the new pesticides are unlikely to make much difference. On the other hand, the general environmental risk will probably be reduced because of the stricter environmental requirements for the authorisation of pesticides, the smaller quantities that need to be used and the lower toxicity to non-target organisms.

9.12 Conclusions

There are a number of non-chemical and alternative methods of preventing and controlling pests in agriculture that could reduce the pesticide load on the environment and improve health and safety through omission of spraying. The methods include consistent and systematic use of damage thresholds and decision-support systems. The environmental and health advantage of non-chemical methods is the absence of pollution of surface water, groundwater and the surroundings in general. Ending the use of pesticides by using mechanical weed control, preventive production methods, development of resistant varieties, biological control of pests and the use of genetically modified plants with resistance to pests would remove the exposure of workers in farming, forestry and market gardening and would remove pesticide residues from food products produced in Denmark, although not from imported products, see section 10.4.2. The Sub-committee on Agriculture believes that it is possible to achieve a 20-50% reduction in some crops by combining decision-support systems and chemical and non-chemical methods. However, some of these methods also have various impacts on the environment and health that do not directly imply significantly improved conditions for environment and health.

It can also be concluded that there are good possibilities of reducing the load on the environment through improved spraying methods and a proper procedure for washing and filling of spraying equipment, including the arrangement of sites for filling and washing. Lastly, the sub-committee concludes that increased soil treatment in connection with a phase-out of pesticides would not result in any significant difference in the formation of fungal toxins and release of nutrients provided these factors were taken into account in cultivation practice. On the other hand, if pesticides were no longer used, energy consumption would in all probability increase.

The following specific conclusions can be drawn:

Conclusions concerning environmental impacts

- With a total phase-out of pesticides, direct exposure of flora and fauna in terrestrial and aquatic ecosystems due to spraying and spray drift would end immediately, and exposure via run-off would be greatly reduced within about one year. However, it would take considerably longer for the flora outside the cultivated areas to re-establish.

- Stopping seed-dressing would remove a risk to birds and small mammals, which eat the seed.

- If the mechanical weeding were very effective, the amount of weed would not differ significantly from the amount in fields treated with pesticides, so there would be no environmental benefit for the flora in the field itself. On the other hand, mechanical weeding would be of great importance to adjacent areas and small biotopes, since these would no longer be affected by spray drift.

- It is considered that mechanical control of couch grass in the autumn would have a negative side effect in the form of increased nitrogen leaching during the winter months because of increased nitrogen mineralisation, while mechanical control in the spring is also known to increase nitrogen metabolism, which is often seen as having a positive effect on crops, which have a good possibility of utilising the released nitrogen in the growth season.

- Mechanical weed control can have a considerable negative impact on the soil’s mesofauna and macrofauna – particularly springtails and earthworms. However, a clearly beneficial effect is achieved with a diversified crop rotation with 2-year clover.

- Increased soil treatment could increase the risk to farmland birds, which nest in the midfield.

- The use of beneficial organisms and microbiological products for biological control of pests in the field would involve a serious risk of proliferation of foreign organisms, which could have an adverse effect on the environment. Theoretically, the proliferation of indigenous species could also upset natural ecological balances. In Denmark, beneficial organisms have been used for a long time to combat pests in greenhouses. The species used cannot survive outdoors and can therefore not spread.

- Genetically modified plants that are resistant to insects could affect other species than the pest – for example, predatory insects and birds that eat herbivores living in the genetically modified crop. Furthermore, possible effects of insect-resistant plants differ from those of spray products in that they last for the whole of the growth season. However, it is likely that some non-target organisms would be less affected by genetically modified plants than by conventional spray products. Genetically modified plants that have instead been made resistant to fungi and viruses would be gentle with the insect populations.

Conclusions concerning improvement in spraying methods

- There is a good possibility of reducing spray drift of pesticides by using new nozzles that minimise the proportion of droplets with a potential for drift. Some of the new types increase the spraying capacity in relation to earlier sprayers, which at the same time increases the possibility of getting a crop sprayed quickly in calm weather. However, the new types of nozzles do not result in any significant reduction of the amount of pesticide used.

- New spraying methods are being developed that enable positional dosing of pesticides – with the treatment limited to those areas of the field that need spraying. With the present spraying practice, more than 95% of the spray product may hit the soil surface in the early growth stages of the plants.

Conclusions concerning health and safety

- Within fruit growing, a new, screened technique that collects spray residues offers good possibilities of reducing the impacts on the surrounding environment.

- The use of microbiological products involves a risk of health problems in the form of allergies and bronchial diseases.

Other conclusions

- Improvement of the physical design of sites for filling and washing of sprayers and the use of biobeds and clean water tanks would reduce point source pollution.

- Reducing or eliminating soil treatment could result in increased transport of pesticides in macropores and thus increased leaching of pesticides. An improvement with respect to leaching could thus be achieved by not reducing soil treatment, although this would result in increased energy consumption. Compared with normal soil treatment, reduced treatment may cause increased evaporation of pesticides.

Conclusion concerning mycotoxins

Mycotoxins are a general problem in both conventional and organic farming because they can develop in moist conditions. They can also develop if grain dries too slowly. The sub-committee finds that mycotoxins from fungi in cereals present a greater risk to public health than pesticide residues in cereals and therefore recommends closer control of the content of mycotoxins in food products.

Conclusion concerning changes in energy consumption

In the event of restructuring for pesticide-free agriculture, the direct energy cost for mechanical weed control would rise, but would be offset to some extent by a saved, indirect energy cost for production of pesticides. The sub-committee concludes that the total energy consumption for agricultural purposes in Denmark would not change much in the event of restructuring for pesticide-free production, but that this must be seen in relation to the considerable fall in yield of around 25%. The sub-committee has not considered the extent to which a changed production pattern, e.g. reduced livestock production, would reduce energy consumption.

Conclusion concerning emissions of greenhouse gases

The agricultural sector's domestic contribution to the greenhouse effect is approx. 13 Tg CO_2-equivalents. CO_2 from fossil fuel consumption accounts for around one quarter of this, and methane and nitrous oxide for the remainder. If the yield were reduced with pesticide-free production, import of feed would mean an overall rise in energy consumption. It has not been possible, on the existing basis, to assess changes in emissions of methane gas and nitrous oxide in the different scenarios.

Conclusions concerning leaching of nutrients

The sub-committee concludes that changes in mechanical soil treatment and in crop rotations would affect the leaching of nutrients. The changes could be both adverse and beneficial. An extensive analysis would be needed to assess the net change, but would be encumbered with great uncertainty. In the 0-scenario, the reduction in yield would, all else being equal, imply a smaller consumption of fertiliser and consequently reduced leaching. On the other hand, in the event of crop failure – for example, as a result of fungal diseases – increased leaching could be expected. Leaching would thus depend, from year to year, on an interaction between the choice of crop, the level of fertilisation, the intensity and timing of soil treatment, and plant health. The implementation of Aquatic Environment Plan II would be accelerated in step with the reduction of fertiliser consumption in the different scenarios.

10 Model calculations of the consequences of the environment and health scenarios for phasing out pesticides

10.1 Description of the scenarios

This chapter describes the consequences for the environment and health of some of the scenarios that have been coordinated with the technical sub-committees on "agriculture", "production, economy and employment" and "legislation" (Main Committee Report 1999). The scenarios are compared with present production in the agricultural sector. The scenarios are as follows:

- **Present** production (1994)
- **0**-scenario: total phase-out of pesticides
- **0+**scenario: almost total phase-out of pesticides
- +scenario: limited use of pesticides
- ++scenario: reduced use of pesticides

It should be noted that there are only sufficient data for real calculations of the consequences of a total or partial phase-out of pesticides compared with present production for the following impacts:

- Impacts on the population density of selected soil organisms (springtails and earthworms in farmland)
- Impacts on the populations of 9 farmland bird species
- Impacts on the size of the seed pool in farmland
- Probability of impacts on algae and crustaceans in ponds
- The population’s intake of pesticides

In connection with the calculations, a number of qualitative assessments have been carried out of the consequences of the various scenarios for important environmental and health aspects in connection with a total or partial phase-out of pesticides.

0-scenario: total phase-out of pesticides

The analysis is based on the 12 types of farm set up in chapter 4 of the Main Committee's report. For each of these types of farm, proposals have been made for adjustment of the crop rotations to accommodate a phase-out of pesticides.

The basis for the proposed crop rotations in this scenario is as follows: The farms' present production and structure are kept largely unchanged with respect to livestock units and types of crop. The total livestock production is maintained. In order to compensate for a reduction in greenfeed production, the acreage used for this purpose is increased slightly at the expense of the acreage used for cereals. The crop rotations with potatoes, sugar beet and seed grass are maintained without clarification of whether that is realistic in a scenario with a total phase-out of pesticides.

0+-scenario: almost total phase-out of pesticides

In the scenario with an almost total phase-out of pesticides it is assumed that pesticides are only used where the crop would not otherwise be able to meet specific, statutory requirements concerning purity or that are subject to requirements concerning prevention and control of pests covered by the quarantine rules as defined in notices from the Danish Plant Directorate or where dressing of seed to the 1st generation is required. It would thus still be permissible to use pesticides for:

- treatment of all seed to and including the 1st generation
- control of problematical species of weed in seed grass
- Seed potatoes. Use of desiccation agents and agents against potato blight.
- control of wild oat in stands in which hoeing is not possible
- prevention and control of the Colorado beetle in seed potatoes
- prevention and control of specific pests in pot plants and nursery cultures.

+-scenario: limited use of pesticides

In the scenario with limited use of pesticides, slightly more use of pesticides is permitted than in the 0-scenario. It is assessed here which crop/pest combinations it would be most difficult to cope with without pesticides. This decision depends on the yield loss as a consequence of pest attack.

Basically, the areas included are those that would produce the biggest yield loss or those where it is estimated that a profitable production of specific crops could not be maintained without pesticides. There must be a) considerable average losses (>15-20%) as a consequence of pests or b) the production would be encumbered with so much uncertainty that it might be discontinued or not fitted into the crop rotation. The fact that losses of more than 15-20% can occur in individual localities and in individual years is not taken into account in the scenario because, for most crops, it is not possible to predict how often such a situation would occur.

Use of pesticides would be permitted for the following purposes:

- minimal use to combat potato blight in ware and starch potatoes
- seed treatment and band spraying of fodder beets and sugar beet
- controlling specific species of weed in cereals (e.g. camomile and charlock)
- controlling weeds in peas
- controlling patches of perennial weeds such as thistles
- controlling grass weed in particularly infested areas
- combating serious attacks of leaf diseases in wheat and winter barley on the basis of warnings
- combating pollen beetles in spring rape in conditions in which the crop cannot compensate for attacks
- band spraying with herbicides in maize

- chemical control of couch grass in 1 out of 10 years, combined with mechanical control
- controlling poisonous weed species such as spring groundsel in greenfeed
- combating aphids when the damage threshold has been exceeded in cereals and peas
- combating snails and flea beetles in rape when the damage threshold has been exceeded
- combating clover weevil in clover seed production
- combating diseases and pests in fruit production, assessed on the basis of the level of attack
- combating diseases and pests in vegetables, assessed on the basis of the level of attack
- for desiccation and prevention and control of fungi in garden seed crops.

++scenario: reduced use of pesticides

In the third scenario with reduced use of pesticides, serious economic losses from pests are not envisaged. Production is similar to present production. The scenario is based on a proposal from the Danish Institute of Agricultural Sciences, which considered in 1996 that there was a realistic possibility of reducing the treatment frequency index without that affecting present farm-level economy.

In this scenario it is assumed that all available damage thresholds are used, together with mechanical weed control, where these methods can compete with chemical methods. A crop rotation very similar to that practised today can be expected, with economic optimisation but also optimisation with respect to minimising use of pesticides.

Treatment frequency index in the five scenarios

The 1994 treatment frequency index (Environmental Protection Agency 1995b) has been chosen as the index in present production. Figure 10.1 shows the expected treatment frequency index in the different scenarios as a national average for agricultural land.

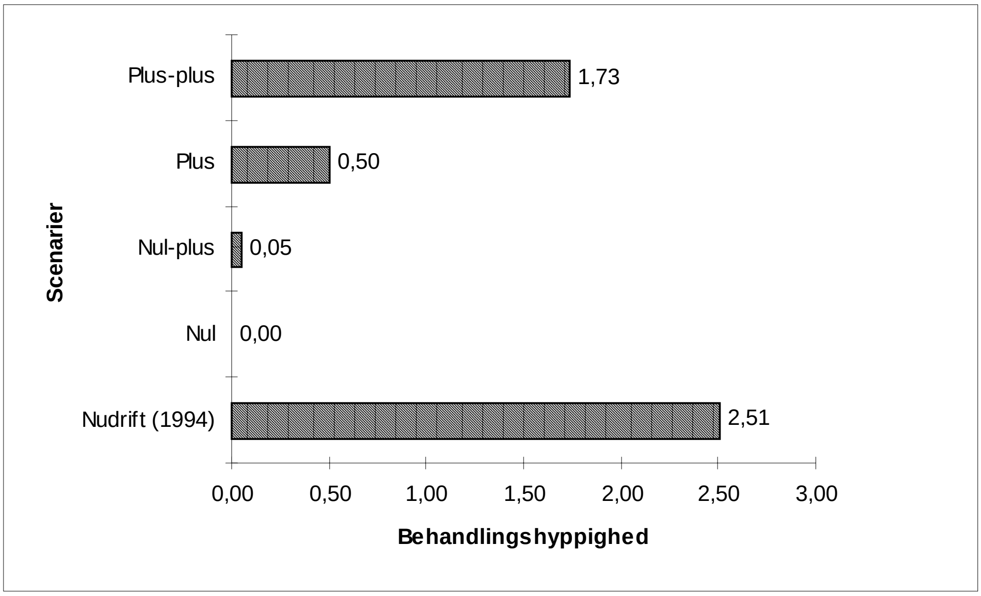


Figure 10.1
The treatment frequency index in present production and the four scenarios. The 1994 treatment frequency index is used as the index in present production.

(Figure texts:
Scenarier = scenarios
Plus-plus = ++scenario
Plus = +scenario
Nul-plus = 0+scenario
Nul = 0-scenario
Nudrift = present production
Behandlingshyppighed = Treatment frequency index)

Scenarios for forests

The following definitions are used in the assessment of the effects in forests in 10.3.1 and 10.3.2:

- **0**-scenario: No use of pesticides in forestry

- **0+**scenario: No use of pesticides in forestry, but pest control in nurseries is exempted in the case of production for export, where the product cannot be supplied without risk of pests or diseases.

- **+** and **++**scenarios: Use of pesticides in forestry permitted if not using them would mean that production could not be maintained, and greatest possible consideration for the environment. In reality that means that all groups of pesticides may be used in nurseries where they cannot reasonably be replaced by mechanical or biological control and that insecticides may be used when necessary in Christmas tree and ornamental greenery production.

10.2 Pollution and exposure of different compartments

10.2.1 Pesticides in groundwater

Weather and climate play an important role in groundwater pollution

All else being equal, reduced use of pesticides would reduce the source of groundwater pollution. Groundwater pollution depends on a complicated interaction between a number of factors that are essentially stochastic (random), since weather and climate play a decisive role. These factors and the interaction between them include, particularly:

- the spraying time in relation to the plant cover and precipitation events
- the degradation conditions in the soil, which are in turn governed by the temperature and moisture
- the physical properties of the geological formations, including water penetrability and any fissures or macropores
- water transport in the groundwater zone.

0-scenario

In the longer term, the 0-scenario means that pesticides will no longer be detected in the groundwater. The time that takes will depend on the local geological conditions, the degradation of pesticides already in the soil strata and, lastly, the movements of the groundwater. The available geological data describing the spatial extent of the soil strata and the movements of the groundwater are insufficiently detailed. Furthermore, there is a lack of knowledge about the sorption and degradation of pesticides in the very long term in the concentrations occurring in groundwater. It is therefore not possible, either nationally or locally, to calculate when the present and future pollution of the groundwater will end. However, it will obviously take some considerable time (more than 30 years). We need to know more about the quantitative "hydrogeological parameters", i.e. focus on parameter estimation and the scaling problem on a regional scale (including hydraulic conductivity, effective porosity, sorption and degradation). It is important to improve and refine existing deterministic models and possibly link them with stochastic calculation principles in order to be able to calculate the probability of detecting pesticides in a given concentration in the groundwater at a given time and in a given locality. Knowledge is lacking about the duration of pollution from total weed control, including BAM pollution and about the importance and duration of leaching from disposal of pesticides at waste disposal sites.

The other scenarios

Figure 10.2 shows the expected pesticide consumption in the various scenarios. It is assumed that, all else being equal, the load on the groundwater will diminish in proportion to the consumption. However, a number of measures already introduced will help to reduce the probability of finds in groundwater. That applies particularly to the tightening of DEPA's authorisation scheme introduced with the Prohibition Act and growing use of substances that, with the present pattern of use, have a low groundwater pollution potential. The ban on the use of pesticides in areas designated as particularly sensitive is also playing an important role in reducing the risk of future pollution of the groundwater. As shown in figure 10.2, both the +scenario and the ++scenario involve a consumption of pesticides that could, depending on the type of substance, imply a risk of groundwater pollution, although with a much lower detection frequency in time than at present. As mentioned, it is only possible to give a broad time frame for the advent of that situation.

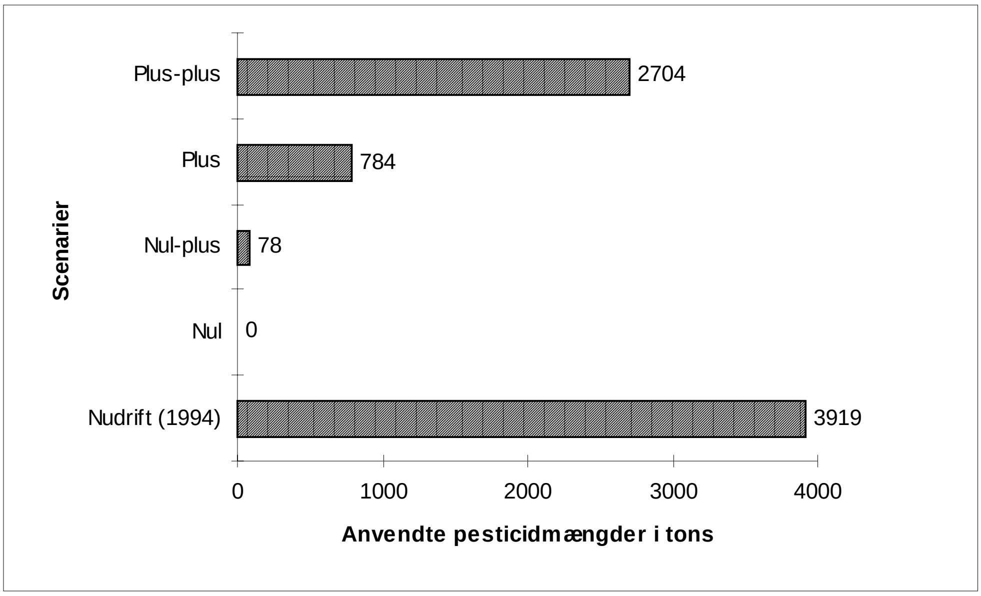


Figure 10.2
Total consumption of pesticides in present production and the various scenarios. Groundwater pollution depends on a number of climatic, biological and geological factors and on the quantity of pesticides used and the properties of the authorised substances.

(Figure texts:

Scenarier = Scenarios
Plus-plus = ++scenario
Plus = +scenario
Nul-plus = 0+scenario
Nul = 0-scenario
Nudrift = present production
Anvendt pesticidmængde i tons = Quantity of pesticide used, in tonnes)

10.2.2 Pesticides in soil, surface water and the atmosphere

Soil

After spraying, pesticides are broken down and absorbed by the soil and plants. Normally, only substances with a half-life of max. 3 months in soil at 10°C and at 20°C are authorised. In the case of substances with shorter half-lives, the residual quantity is much smaller. However, in field conditions, where the conditions for degradation are not optimal, degradation can take longer. The temperature and humidity are important factors in this connection, as described in section 4.6.4. In the winter months, the degradation process in the topsoil thus comes to a standstill at low temperatures, and in the summer months, drying out of the soil halts the degradation process. If use of the currently authorised pesticides ends in a given area, the residues in the soil will normally be degraded and thus not accessible to plants or animals, or leach to the groundwater, after a cultivation season.

Residues in the soil

Degradation of the residues of all pesticides is prevented by the fact that the molecules diffuse into microscopic pores in the soil particles, where they can no longer be reached by microorganisms. These residues can be detected with special analytical methods with effective extraction and sensitive apparatus and are of the same order of magnitude as the concentrations supplied to the cultivation systems through atmospheric deposition of pesticides transported over long distances. Lastly, it should be mentioned that it is possible to detect formerly authorised persistent pesticides, such as DDT and lindane, in relatively high concentrations in the soil in areas in which they were used more than 15 years ago. That applies particularly to orchards. It can thus be concluded that old, persistent pesticides that are no longer authorised are still being detected in soil, whereas most of the authorised pesticides will be degraded one to two years after use of them ceases.

Drain water

The supply of pesticides to drain water depends on the dosage, the degradation and adsorption in the topsoil and evaporation. If pesticides were totally phased out, the amount that could be transported down in the soil would disappear. However, leaching of the residues in the soil could continue for some years, depending on precipitation events and the soil conditions, which determine the adsorption and degradation of the substances.

The atmosphere

If pesticides were no longer used the problem of evaporation and spray drift from the areas in question would disappear. However, there would still be a supply of pesticides through long-range transboundary atmospheric transport. Pesticides would thus continue to be supplied with precipitation, although less frequently and in considerably smaller concentrations than described in section 4.5. It should be noted here that the finds described cover only some of the pesticides that could be transported to the atmosphere through spray drift and evaporation here in

Denmark and elsewhere. It is therefore not possible to calculate scenarios for the consequences of reduced use of pesticides. Lastly, the herbicide DNOC would occur in relatively high concentrations even if pesticides were phased out, partly because the substance is synthesised through atmospheric, chemical reactions with components in car exhaust fumes etc. and partly because of long-range transboundary transport (see section 4.5).

Watercourses, ponds and lakes

With a total phase-out of pesticides, spray drift to watercourses, lakes and ponds would immediately cease, whereas it would take one to several years before the residues of pesticides supplied with run-off were completely degraded. The supply to drain water would thus also continue until the last residues of pesticides disappeared from the uppermost soil strata. Watercourses and lakes are usually in hydrological connection with the groundwater. Therefore, if the groundwater was polluted with pesticides, there would be a supply with the inflowing groundwater. This supply of pesticide residues would continue for considerably longer than the supply from drain water in the uppermost soil strata. These factors are described in section 10.2.1 concerning groundwater. However, even if pesticides were totally phased out in Denmark, the surface water would still receive small quantities of pesticides via precipitation as a consequence of long-range transboundary atmospheric pollution. It is not possible to determine the importance of leaching of pesticides from buried pesticide waste and of leaching from washing and filling s and other point sources of pollution of surface water. It is therefore also difficult to determine when such pollution would cease.

Summary

With a total or partial end to the use of pesticides in soil or to the risk of pesticides hitting the soil, residues of the currently authorised pesticides would largely disappear from the uppermost soil strata within 1 to 5 years. Direct spray drift to watercourses, lakes and ponds would cease immediately, whereas the supply via surface run-off and drain water would continue for some years. The supply via groundwater that is polluted with pesticides depends on a number of factors and could in most localities continue for a long period of time. The Danish contribution from the atmosphere to soil and surface would be reduced immediately, but there would still be a small contribution via long-range transboundary atmospheric pollution.

10.3 Environmental impacts

The impacts of pesticides on flora and fauna in the terrestrial and aquatic environment are closely related to the toxic properties of the pesticide in question and to how the pesticide is spread and degraded in the environment. The impact on the individual plant or animal species depends on the exposure and sensitivity of the species to a given pesticide and on how the species is affected by changes in the populations of other species. Many of these relationships are not quantified and it is therefore not possible, with our present level of knowledge, to give a precise description of the overall effects of the current use of pesticides on terrestrial and aquatic environments. It is thus not possible, either, to give a precise description of the effect that a total or partial phase-out of pesticides would have on these environments.

On the basis of studies of the effect of pesticides on springtails, earthworms, five species of weed and nine species of bird and on algae and daphnia in the aquatic environment, models have been constructed for calculating the consequences of a total or partial phase-out of pesticides for the respective organisms. The results of the model calculations must be regarded as a best idea of the consequences on the basis of the underlying studies and assumptions, but not as an exact expression of the consequences for the organisms in question. In this connection, it must be stressed that the model calculations must not be taken, either, as an expression of the consequences for all other organisms in the terrestrial and aquatic environments.

10.3.1 The fauna in cultivated and uncultivated terrestrial ecosystems

Up through the last century, farming in Denmark has become increasingly intensive. Farm units have become larger and drainage more intensive, and there has been a high degree of specialisation. The higher degree of specialisation has resulted in monoculture of cereals and increased use of fertiliser and pesticides. In step with the intensification of farming, the cultivated land's flora and fauna have also changed. Many plants and animals that used to be common in the midfield or in hedges and small biotopes have decreased in number or disappeared altogether. In this connection, the increased use of pesticides is presumed to play a critical role with respect both to the reduced biological diversity in arable land and to the decrease observed in the populations of some animals and plants living in the agro-ecosystem.

The crop rotation is an important factor for the conditions of life in the field, since the choice of crop also partially determines the use of pesticides, soil treatment and fertilisation, and the timing of the various operations. It is estimated that the restrictions on the use of pesticides in the 0-scenario would mean a changed crop rotation. Changes in the crop rotation would affect some of those fauna that are not affected by the use of pesticides. Pesticides have a considerable impact on arthropods. They have less effect on springtails and earthworms, but changes in the crop rotation could have a big impact on their populations. For farmland birds, analyses have been carried out of the consequences of both changes in pesticide use and crop rotation.

Impact on the field's arthropods

The lower fauna are affected both directly by treatment with insecticides and indirectly through the removal of plants and microorganisms as food resources through the use of herbicides and fungicides. The effect of the different types of pesticide is partially specific and proportional to the frequency of treatment with fungicides, herbicides and insecticides (see figure 10.3). In comparisons of the scenarios, the treatment frequency index is therefore an indicator of the undesirable side-effects of pesticide use on individuals, species and communities of flora and fauna, assuming that the treatment frequency index is an expression of the size of the treated area. If treatment with herbicides were omitted, the insect fauna above the ground could be expected to increase by a factor of 2-7, measured as individuals, and by a factor of 1.5, measured as number of species per sample. If treatment with fungicides were omitted, the fungivorous insect fauna would increase for a time by a factor of 1-2.5. If insecticides were not used, the insect fauna would increase by a factor of 2-4 (Elmegaard and Axelsen 1999, from various sources). The effect of fungicides and insecticides is often shorter than the effect of herbicides because the elimination of weed affects the fauna all through the season.

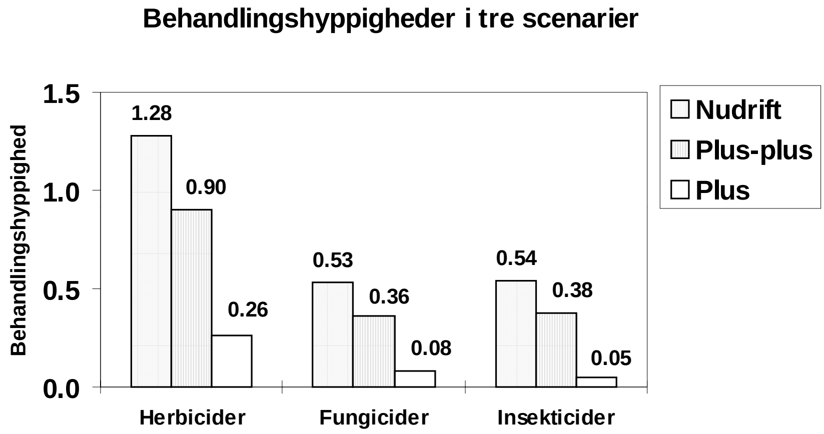


Figure 10.3
The treatment frequency indices for herbicides, fungicides and insecticides in present production (1994), the +scenario and the ++scenario. The figure does not cover growth regulators, molluscicides, etc.

(Figure texts
Behandlingshyppighed i tre scenarier = Treatment frequency indices in three scenarios
Behandlingshyppighed = Treatment frequency index
Nudrift = Present production
Plus-plus = ++scenario
Plus = +scenario
Herbicider = Herbicides
Fungicider = Fungicides
Insekticider = Insecticides)

Analyses of crop diversity at a general level do not reveal any changes in the national level between present production and the 0-scenario because differences between the crop rotations in the different types of farm counterbalance each other (Elmegaard, Axelsen 1999).

Springtails

The springtails or collembola are a group of soil organisms that is rich in species. They participate in the decomposition of dead organic matter and the release of nutrients in the soil. From springtail counts in different crop rotations in Denmark, Elmegaard and Axelsen (1999) have estimated that the average density is 21,000 springtails per square metre in arable land. Particularly in clover grass and fields fertilised with manure, the density is high – approaching 100,000 individuals per square metre. On the basis of the crop distribution, the density has been calculated for the crop rotation in present production and the 0-scenario. On the basis of existing studies it is estimated that the pesticides used in the scenario for present production have no effect on the density of springtails. The analyses show that the 0-scenario would increase the average individual density by only 2.4% compared with present production, see figure 10.4. Since the density of springtails is far more dependent on the crop rotation and other production factors, an analysis has been carried out for consistent use of second crops in spring crops. Here, it is cautiously assumed that the density of springtails would double in spring crops if second crops were used to keep the soil covered with plants almost all year round (Elmegaard, Axelsen 1999). The analyses show that, with this, the average density would increase 14%. It can thus be concluded that the density of springtails is not affected by pesticides used in the scenario for present production, but that the crop rotation, including soil treatment, fertilisation and possible second crops, plays an important role in the population density.

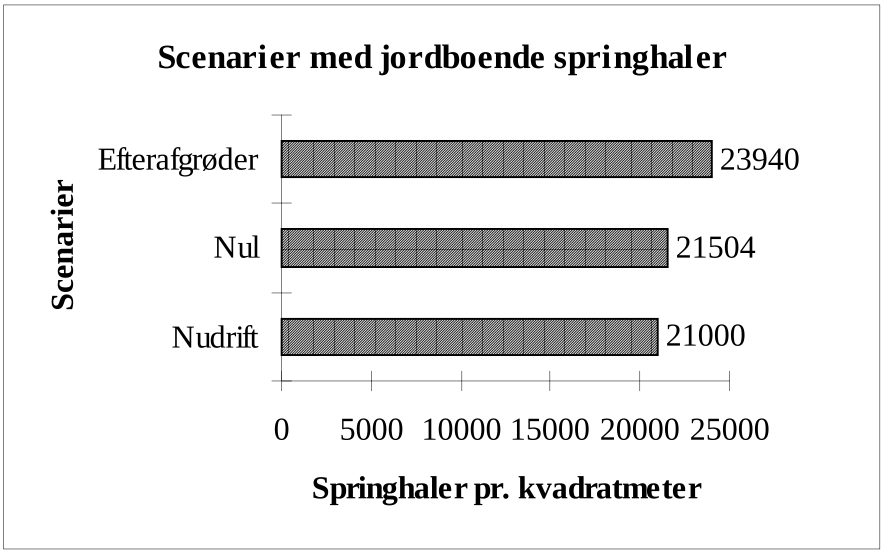


Figure 10.4
Calculations of the average density of springtails in the soil in present production and the 0-scenario. The indices were calculated by Petersen and Jensen (1998) on the basis of data from Petersen (1996), using the crop rotations proposed by the Sub-committee on Agriculture. A comparison has also been carried out with the organic scenario.

(Figure texts:
Scenarier med jordboende springhaler = Scenarios with springtails in the soil
Scenarier = Scenarios
Efterafgrøder = Second crops
Nul = Zero
Nudrift = Present production
Springhaler pr. kvadratmeter = Springtails per square metre)

Earthworms

Earthworms are most numerous in meadows. A Danish study has shown that the biggest average density of 400 individuals per square metre is found in reploughed clover-grass fields (Christensen, Mather 1997). As in the case of springtails, it is believed from the existing studies that the well-being of the various species of earthworms is not affected by the pesticides used in the scenario for present production but is affected by soil treatment, the use of manure and the crop rotation. The same method of analysis has been used as for springtails (Elmegaard, Axelsen 1999). The results of the analyses show that the crop rotation elements used in the 0-scenario would increase the average density of earthworms in farmland by 12.4%, as shown in figure 10.5. If, instead of commercial fertiliser, 25 tonnes of pig manure per hectare were used, the density of earthworms would increase by about 25%. For comparison, the density in a clover-grass field is shown. There, the highest value is reached one year after reploughing. It can thus be concluded that the density of earthworms is not affected by the pesticides used in the scenario for present production but is greatly affected by soil treatment, the use of animal manure and, particularly, the crop rotation.

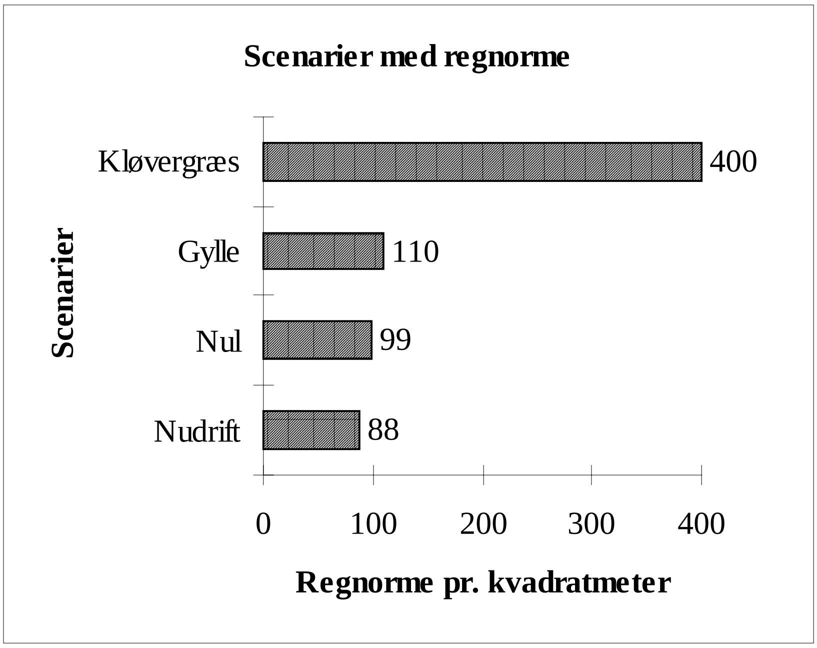


Figure 10.5
Calculations of the average density of earthworms in present production and the 0-scenario. For comparison, calculations are shown for the average density with use of pig manure and the density in clover grass one year after reploughing.

(Figure texts:
Scenarier = Scenarios
Scenarios with regnorme = Scenarios with earthworms
Kløvergræs = Clover grass
Gylle = Pig manure
Nul = 0-scenario
Nudrift = Present production
Regnorme pr. kvadratmeter = Earthworms per square metre)

Scenarios with birds

There are a number of characteristic bird species in Danish farmland. Their population development and distribution in the landscape have been studied as an element of research on the impact of pesticides on nature and the environment (Petersen, Jacobsen 1997). With this knowledge it is possible to carry out simple calculations of how the bird populations would develop in the different scenarios for land use and pesticide use (Petersen, Jensen, 1998).

Methods and calculations

There have been some studies that do not directly contain data that can be used for scenario analyses because they cannot be generalised or have been collected in conditions that do not reflect present-day Danish agricultural conditions (Petersen, Jensen, 1998). The calculation used is based on data from three years' counts of birds in the breeding season at

54 large Danish farms, where information was available on crop and biotope conditions, together with data on all pesticide treatment. The distribution of the different species in relation to biotope conditions, crops and treatment frequency indices could then be calculated and tested by means of covariance analyses. These data have been reanalysed, so the logarithm for a given species' population density in each crop is expressed as a linear function of the treatment frequency index, while the effects of the other biotope conditions are kept constant. The treatment frequency indices for the pesticides that have shown statistically significant effects and the areas used for the crops have been varied in the analyses.

Assumptions and uncertainties

It is assumed that the average field size remains unchanged, that there are no general changes in the amount of hedgerow and other hedge vegetation, that the number of small biotopes does not change and that the natural content of the farmland generally remains unchanged. It is also assumed that the population density of each species can be calculated independently of other species. Lastly, it is assumed that if herbicides and insecticides act simultaneously, then the total effect will be the product of their effects, i.e. a mutually intensifying effect. Lastly, it is assumed that the calculated population densities can be extrapolated to national level without taking account of the localities' bearing capacity. The calculated population increases can therefore be interpreted as an upper limit for the changes that could be expected.

Results of the calculations of bird populations

The results of the calculations are shown in figure 10.6. It will be seen that the populations of partridge, whitethroat and yellowhammer increase in all scenarios compared with present production and that all the scenarios show significantly increased population density for these species. This applies to the 0-scenario, the +scenario and the ++scenario. For the other species, the index would be unaffected by the use of pesticides, compared with present production. It is noteworthy that the countrywide population density of the skylark is not affected by the use of pesticides. In studies described in section 5.1, it has been found that the use of pesticides reduces the production of young as a consequence of effects on food resources. However, the relationship between the annual production of young and the population trend is not known (Elmegaard, Axelsen 1999; Petersen, Jensen 1998). Similarly, we do not know precisely how increased reproduction at field level is reflected at farm level because the redistribution of young birds in the following season depends on the density of older birds, the crop rotation, etc., and only to a minor extent on the fields' ownership conditions (farm characteristics). The partridge is adversely affected by herbicides, while the population density of whitethroat and yellow bunting is affected by both herbicides and insecticides.

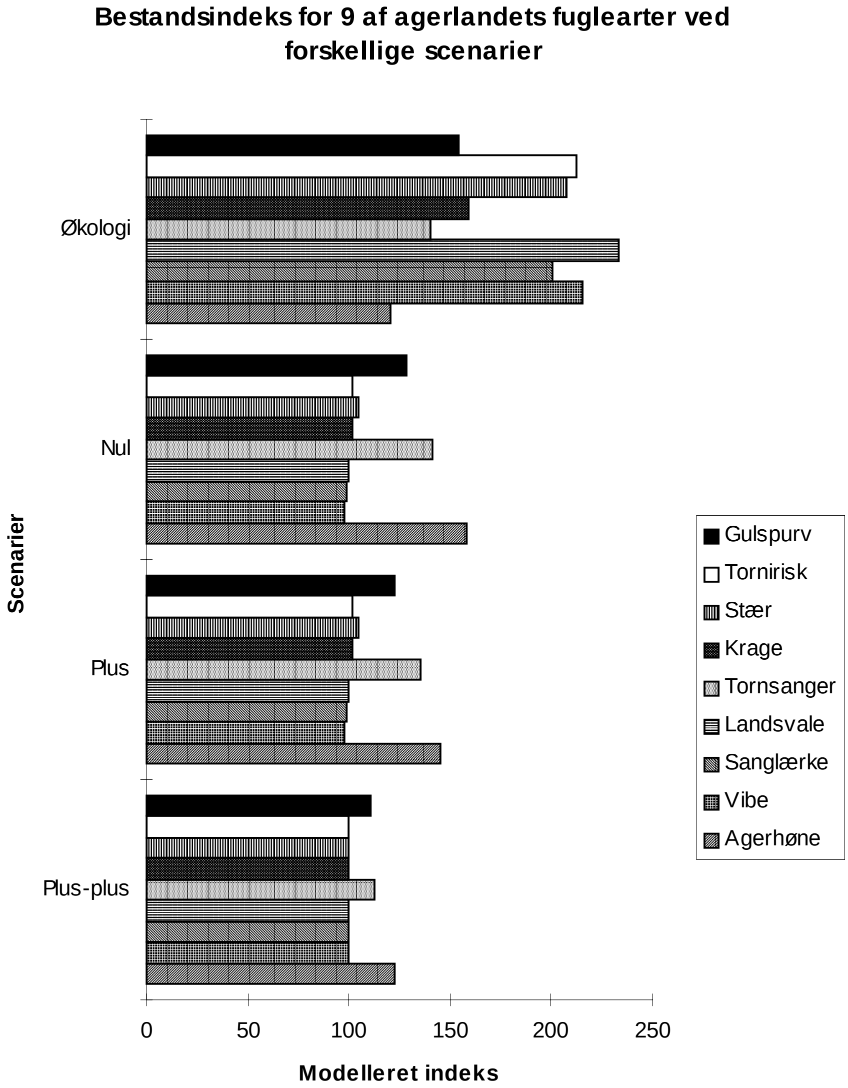


Figure 10.6
Calculated population indices for nine species of farmland birds in different scenarios, with present production put at index 100. The indices were calculated by Petersen and Jensen (1998) on the basis of data from Petersen (1996), using the agronomically and economically optimised crop rotations proposed by the Sub-committee on Agriculture. A comparison has also been carried out with the organic scenario.

(Figure texts:
Bestandsindeks for 9 af agerlandets fuglearter ved forskellige secenarier = Population index for nine farmland bird species in different scenarios
Scenarier = Scenarios
Økologi = Organic scenario
Nul = 0-scenario
Plus = +scenario
Plus-plus = ++scenario
Modelleret indeks = Modelled index
Gulspurv = Yellowhammer
Tornirisk = Linnet
Stær = Starling
Krage = Crow
Tornsanger = Whitethroat
Landsvale = Swallow

Sanglærke = Skylark
Vibe = Lapwing
Agerhøne = Partridge)

Comparison of weed control with and without pesticides

The model does not include non-chemical weed control. Since the direct toxic effects on birds today are insignificant (see section 5.1), it is the indirect impacts that would be important, e.g. changes in the birds' food resources. In this connection, it makes no difference to the birds whether their food resources are removed by means of pesticides or by mechanical or other methods. Inter-row cultivation and harrowing could constitute a risk to ground-nesting species. Similarly, early and/or more extensive soil preparation in the autumn would very probably have considerable, adverse effects on the birds because stubble fields are a very important foraging area for many species in the autumn months. Furthermore, in the wintertime, the birds get more from a stubble field than from a field with winter crops (Petersen, Jensen 1998).

Comparison with the organic scenario

For all the species with the exception of the partridge and, to some extent, the whitethroat, the calculations show a significantly larger number in the organic scenario than in the 0-scenario. This indicates the importance of the crop rotation to birds since pesticides are not used in these two scenarios. The organic scenario is based on observations at organic farms in 1980s, when the forms of production and land use differed from present-day organic farming. This applies particularly to the size of dairy herds (Petersen, Jensen 1998). Only relationships that have a significant effect on the occurrence of the species are included in the model analyses. This does not mean that the effects that produce insignificant outcomes in the underlying study are of no importance. They are simply not included in the model.

In the scenarios used, it is assumed that the number of dairy farms and grass pasture acreage are unchanged. If this were not the case, the populations of a number of species would presumably be considerably more affected than by other changes in land use. The lapwing, the swallow and the starling are thus favoured by organic production because they are linked to dairy farming and grass pasture land.

Impacts on the fauna in forests

In all the scenarios described, phasing out pesticides in forests would increase the value of the biotope of the stands in which pesticides are used today. Christmas tree and ornamental greenery stands would become a more attractive habitat for many birds because of a richer fauna. The same applies to herbivorous mammals because there would be more food. Depending on whether mechanical control of grasses, herbaceous plants and "scrub" was practised, the 0-scenario would have beneficial effect on the fauna living in forest-floor vegetation, whether as a habitat or as a food resource for herbivores. Effective mechanical weed control and, especially, deep ploughing are more harmful than pesticides. The use of pesticides in nurseries would not affect the forest fauna in all the scenarios described. It is thought that there would be some replacement of pesticides with mechanical or biological control. In the +scenario and the ++scenario, the use of insecticides would be allowed in ornamental greenery and Christmas tree cultures to combat insects that threatened the production if there were no alternative methods. This means that the value of these biotopes would remain poor for insectivores such as insects and vertebrates.

10.3.2 The flora in cultivated and uncultivated terrestrial ecosystems

Models for calculation of the seed pool and wild plants in the field

The development of plants over 25 years has been calculated using two different types of mathematical models, a "seed pool" model and a "crop rotation" model (Kjellsson, Madsen 1998b). The models have a number of constraints and have not been fully validated, but they provide a preliminary estimate of the development trends. The seed pool model was developed for continuous spring barley on sandy soil and does not contain a crop rotation (Kjellsson, Rasmussen 1995). It uses five plant species that frequently occur as weeds. The model was validated over three years. The crop rotation model was developed to simulate crop rotations with genetically modified sugar beet and with rape (Madsen et al. 1996; 1999). A crop rotation with sugar beet – barley – winter wheat – winter wheat is used in the sugar beet model, and a crop rotation with winter rape – winter wheat – winter wheat – winter barley is used in the rape model. The model tests 4-6 wild plants, together with volunteers that occur as weed. A rough estimate has also been made of the development of the weed biomass over time. In all three models, two levels of the seed pool are tested. The first level is an average seed content of 6,900 seeds per square metre, which corresponds to the median value for Danish fields in the last study (Kjellsson, Rasmussen, 1995). The other level is 22,000 seeds per square metre, corresponding to the upper limit for 80 per cent of the fields.

Scenarios for analysis of the flora in the field

The models have been used to simulate a scenario for how the seed pool and weed biomass develop over time without any form of weed control. It must be emphasised that the omission of spraying with herbicides is not replaced by suitable crop rotation measures or mechanical/biological weed control. The wild plants thus have the opportunity to increase without hindrance. The scenario has been compared with present production. An intermediate scenario has also been analysed, corresponding approximately to the +scenario since it includes band-spraying of beet crops, control of couch grass every tenth year, use of mechanical weed control and cultivation of resistant varieties.

Results of calculations with the seed pool model

In the spring barley rotation, the calculations show that the seed pool in the soil would steadily increase without weed control (see figure 10.7). In the + scenario, the number of seeds of wild plants in the soil would increase to approx. 18,000 per square metre, taking as the starting point the Danish average (median) of 6,900 seeds per square metre. With 22,000 seeds per square metre, the +scenario would result in an unchanged seed pool. The seed pool model shows that, in all the scenarios, there could be an improvement of the conditions for wild flora and for the species of fauna associated with it without the wild flora proliferating out of control provided mechanical control and limited chemical control were practised.

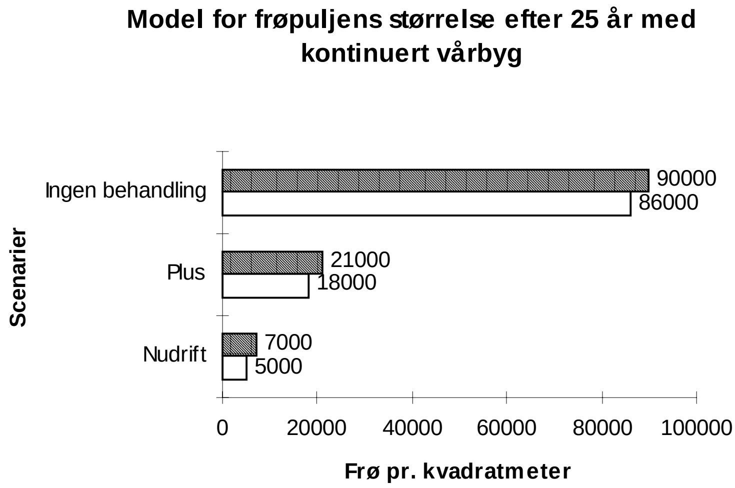


Figure 10.7
Calculations with the seed pool model in continuous spring barley. The bars show the seed pool after 25 years with an initial seed pool of 6,900 (white bars) and 22,000 (hatched bars) per square metre for present production and the +scenario, respectively. In the third scenario, no form of weed control is practised.

(Figure texts:
Model for frøpuljens størrelse efter 25 år i sædskifter med vårbyg = Model for the size of the seed pool after 25 years in crop rotations with spring barley
Scenarier = Scenarios
Ingen behandling = No treatment
Plus = +-scenario
Nudrift = Present production
Frø pr. kvadratmeter = Seeds per square metres)

Results of calculations with the crop rotation model for crop rotations with beets

In the beet crop rotation, as shown in figure 10.8, the calculations show that, with a starting point of 6,900 seeds per square metre, the seed pool would remain largely unchanged for 25 years in the +scenario, in which mechanical weed control is combined with limited use of herbicides. For the larger seed pool of 22,000 seeds per square metre, there would be a fall in the seed pool after 25 years. After only one year in the scenario without treatment, the seed pool would reach its maximum of 60,000 and 95,000 seeds, respectively, per square metre with a starting seed pool of 6,900 and 22,000 seeds. That is because beets in the model have very poor competitiveness, enabling wild plants to proliferate. The average seed pool of approx. 40,000 and approx. 44,000, respectively, would adjust itself after a couple of years and then fluctuate in step with the change in the crop rotation. In the +scenario, in which chemical control of couch grass is only carried out every ten years, there would be problems with couch grass. With both starting points for the seed pool, couch grass would reach its biggest biomass of each individual year on 1 June in the +scenario, since it would largely avoid competition from other seed weed in this scenario. The scenario without any weed control would not be feasible in practice.

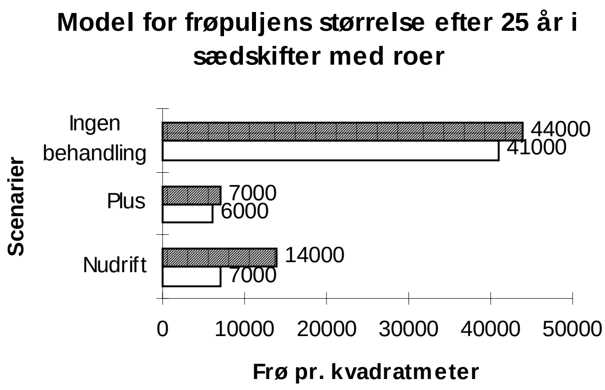


Figure 10.8
The development of the seed pool after 25 years in a crop rotation with beets. The bars show the size of the seed pool after 25 years. In the +scenario, in which mechanical weed control is combined with limited use of herbicides, the seed pool remains unchanged when the starting point is 6,900 seeds per square metre (white bars). For the larger seed pool of 22,000 seeds per square metre (hatched bars), it will be seen that there is a fall in the seed pool. In the third scenario, no form of weed control is practised.

(Figure texts:
Model for frøpuljens størrelse efter 25 år i sædskifter med roer = Model for the size of the seed pool after 25 years in crop rotations with beets
Scenarier = Scenarios
Ingen behandling = No treatment
Plus = +scenario
Nufrift = Present production
Frø pr. kvadratmeter = Seeds per square metre)

In the +scenario, a number of species of wild flora could occur more frequently. A more varied plant community could therefore be expected, providing food resources for a more varied animal community (invertebrates and their predators). However, in view of the poor competitiveness of beets, this crop rotation would hardly be profitable unless new, alternative methods were found for controlling weed in beet crops.

Results of calculations with the crop rotation model for crop rotations with rape

In the rape crop rotation, the results of the calculations of the seed pool are shown in figure 10.9. It will be seen that the seed pool would increase over 25 years if no form of weed control were practised. On the other hand, the +scenario shows a distinct fall in the number of seeds in the seed pool after 25 years compared with present production after 25 years, whether the starting point is 6,900 or 22,000 seeds. One reason for this is that chemical agents have little effect on shepherd's purse, which occurs in this crop rotation, whereas mechanical control is more effective (Kjellsson, Madsen 1998b).

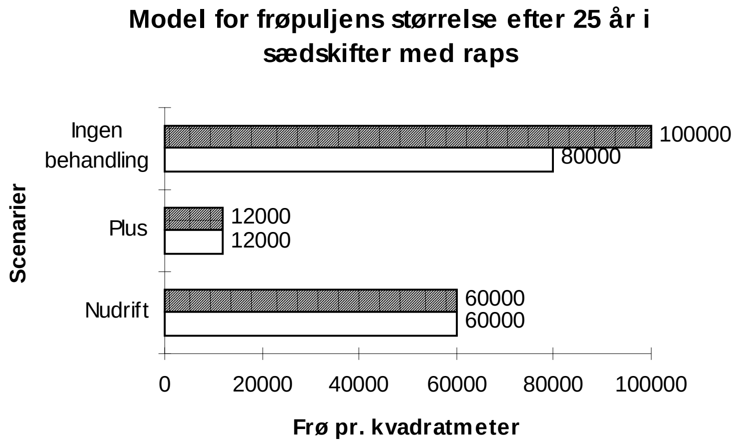


Figure 10.9
Size of the seed pool after 25 years in a crop rotation with rape. It will be seen that the seed pool would be reduced 4-5 times in the +scenario, in which mechanical weed control is combined with limited use of herbicides. The bars show the development of the seed pool from a starting point of 6,900 seeds (white bars) and 22,000 seeds (hatched bars), respectively, per square metre for present production and the +scenario. In the third scenario, no form of weed control is practised.

(Figure texts:
Model for frøpuljens størrelse efter 25 år i sædskifter med raps = Model for size of the seed pool after 25 years in crop rotations with rape
Scenarier = Scenarios
Ingen behandling = No treatment
Plus = +scenario
Nudrift = Present production
Frø pr. kvadratmeter = Seeds per square metre)

According to this model, the seed pool would reach its maximum after 10 years. However, the model probably overestimates the soil's seed pool in both the scenario without treatment and present production (Kjellsson, Madsen 1998b), since the loss of seeds eaten by animals can be put too low. Experimental studies of the seed predation in the field are needed for a better estimate. However, there would be continuous growth of the biomass of couch grass, which does not have a seed pool. The model's assumptions include effective control of couch grass with herbicides approx. every ten years. In addition, the problem of volunteers would be slightly greater in the +scenario than in present production because mechanical control methods are not fully effective against these species.

In the rape crop rotation, the biomass of the flora without control or with reduced control as in the +scenario would probably not differ significantly from the situation in present production because of the biomass of couch grass. Despite the smaller plant biomass in the +scenario compared with present production, a number of plant species would probably occur more frequently in this scenario because the present one-sided proliferation of pesticide-tolerant species would be reduced. A more varied plant community could therefore be expected, providing food resources for a more diversified animal community (invertebrates and their predators).

The importance of the +scenario for the seed pool and plant density

In the +scenario, both the herbicide dosage and the treatment frequency index would probably be somewhat reduced compared with present good farming practice. At the same time, increased use of mechanical weed control would partially compensate for the reduced effectiveness of the chemical control. On average, the consequence would probably be, at most, a 10-20% larger total seed pool than in present production.

Impacts on the wild flora in hedgerows and small biotopes

Spray drift of herbicides affects the flora in biotopes close to the field, such as hedges, field borders and ditches, and along watercourses and ponds. Within a few metres of the edges of the field, lethal effects can be observed in a number of plant species. The dose and thus the effect normally decrease rapidly with distance from the field, which means that only sub-lethal effects on plant growth and seed production are normally seen outside the local zone around the field. The magnitude of the effect depends on the sensitivity of the plant species, the composition of the plant community and the condition of the vegetation. Several studies have shown effects of spray drift over a distance of up to 50 metres from the sprayed area (Marrs et al., 1989, 1993; Davis et al., 1993, 1994). However, most of the flora were only affected in an area between 0 and 5 m from the field. However, there is a lack of experimental data on effects of herbicides in low doses on wild plant species, and the extent of spray drift and its effect on wild flora have not been systematically studied in Denmark. Both the 0-scenario and the +scenario would reduce the consumption of herbicides and thus the risk of spray drift to land close to the field. This would considerably reduce the load, whether spraying was discontinued altogether or was only carried out occasionally. However, owing to the lack of data, it is not possible to quantify the beneficial effect on the vegetation. The areas affected would be reduced in step with the herbicide consumption. In the 0+scenario, the impact would be reduced to the few localities in which pesticides were still used. In the 0-scenario, there would no longer be any impact on the neighbouring areas.

Besides being affected by herbicides, areas close to the field are normally seriously affected by nutrients supplied from the field, which contribute to a change in the composition of the flora towards a greater content of grasses and the loss of annual and sensitive perennial herbaceous plants. The established, nutrient-demanding vegetation of species of grass and tall perennials, such as creeping thistle, common nettle and cow-parsley, counteracts immigration of other species. Species with short-lived seeds, such as cornflower, anemone and scabious, often die out, making reestablishment from the seed pool impossible. All in all, this means that, in many places, a reduced herbicide load on the neighbouring areas would not result directly in changes in the plant communities in the direction of greater diversity unless there were a significantly reduced supply of nutrients and, at the same time, physical measures, such as mowing and thinning, which open the vegetation to invasion from outside or to germination of seeds in the seed pool.

The wild flora in natural areas

The diffuse dispersal of herbicides from cultivated land must generally be regarded as having little effect on the flora in natural areas except where these are directly adjacent to cultivated land. Reduced use of herbicides on cultivated land would therefore have little effect on the composition of the flora, which depends to a far greater extent on the management of the area and the supply of nutrients. There are a few research results that indicate a probability of sublethal effects from the deposition of herbicides from the atmosphere. One can thus not exclude the possibility of damage to sensitive species of flora outside cultivated land as a consequence of herbicides in rainwater. There are very few measurements of the occurrence of herbicides in rainwater and in dry depositions in Denmark, and only a few substances have been included in the measurements. Furthermore, there are only a few studies of the sensitivity of wild flora and plant communities to sublethal doses of herbicides.

Impacts on the flora in forests

In the assessment of the effects in forests, special definitions have been used, as described in section 10.3.1. If herbicides were no longer used in forests it would in time be possible to recreate a forest-floor flora that was naturally adapted to the local soil and climatic conditions. However, mechanical control of undesirable vegetation in the form of deep ploughing over large areas could have the same direct effects on the flora as herbicides and thus also the same indirect effects on the associated fauna. Besides these, there would be adverse effects on soil fauna, fungal flora, the soil profile and historical monuments. Where natural rejuvenation is not used, it is important for the forest-floor flora that areas are left untreated and that rejuvenation is in the form of shelterwood regeneration with preservation of the choice of tree species. The use of herbicides in Christmas tree and ornamental greenery cultures in the +scenario and the ++scenario would result in continued low biodiversity of the flora in the areas in question unless alternative, environment-friendly methods were found.

10.3.3 The aquatic environment

On the basis of data for the intrinsic properties with respect to degradability and toxicity, and values from the literature for run-off and spray drift of pesticides from fields to aquatic environments, a dynamic model has been set up for estimating concentrations and effects of pesticides in a model pond that is typical for Denmark. The degree of effect has been estimated with the present treatment frequency index and in scenarios with reduced treatment frequency indices and a changed crop distribution. The effects of the use of pesticides on flora and fauna in freshwater have been calculated by means of dynamic model built up with the simulation tool Stella® (Møhlenberg, Gustavson 1999). No Danish or relevant international data are available for a similar estimation applied to streams and lakes. On the basis of existing measurements, Møhlenberg and Gustavson (1999) assume that surface run-off only occurs in events with precipitation of more than 10 mm per day. The variations in the precipitation are simulated in the model so that the events occur at random and, on average, 2-3 times a year.

The pond model

In the model, the size of the pond varies with the season, the maximum size being reached in March-April (450 m^3, depth 1.5 m) and the minimum size in September (30 m^3, depth 0.5 m). This variation is typical for Danish ponds and corresponds to the surface run-off from an area of approx. 2-3 ha. The size determines the proportion of a pesticide that is deposited by spray drift and the concentration of the pesticide in the water. The Danish rules on distance to an aquatic environment when spraying with the individual pesticides (i.e. 2, 10 and 20 m) are incorporated in the model and it is assumed that spraying is not done closer to the aquatic environment than 2 metres. When pesticides are sprayed in mixtures, the biggest distance requirements for the individual pesticides in the mixture are used for the entire mixture. The model does not include transport of pesticides via rainwater or long-distance atmospheric transport. It is also assumed that the wind comes from only one direction. Lastly, it is assumed that the pond does not receive water from drains or from groundwater. If the treatment frequency index is 0.1, that corresponds to the pond being exposed once every 10 years. The data used for the simulation are data from toxicity tests in the laboratory.

Spraying scenarios

Unlike the other scenarios, the scenarios for the aquatic environment are based on the plant protection product statistics for 1997. Models have been constructed for the main crops – cereals (winter and spring cereals), rape (winter and spring), potatoes, beets, peas and maize. In the model, the consumption of pesticides (primarily glyphosate) on "areas treated post-harvest" is linked to the cultivation of cereals (winter cereals). The dosage and time of application of the various pesticides have been taken from "Guide to Plant Protection" (Danish Institute of Agricultural Sciences 1998). The effect on the aquatic environment from grass-seed and vegetable production, market gardens and forestry, has not been included in the study. Growth regulators are not included because the treatment frequency index in 1997 was only 0.05.

The following special scenarios for treatment frequency index and crop distribution have been analysed (Møhlenberg, Gustavson 1999):

- **2.34-scenario**. Corresponding to present production but with a treatment frequency index of 2.34 and a crop composition based on 1997 data.

- **1.17-scenario**. A 50% reduction in the treatment frequency index for all crops compared with the 2.34 scenario, with unchanged crop composition.

- **0.59-scenario**. Compared with the 2.34 scenario, this scenario is characterised by a radical restructuring of cultivated areas to comprise only cereal fields and set-aside, relatively more spring cereal than winter cereal, a 50% reduction of the treatment frequency index in winter cereal and only one tenth the treatment frequency index in spring cereal, making the average treatment frequency index 0.59.

- **0.26-scenario**. Compared with the 2.34 scenario, this scenario is characterised by a switch from winter cereal to spring cereal, increased set-aside and preservation of acreages used for potatoes, rape, beets, peas and maize. The average treatment frequency index is 0.26.

As a general rule, the spraying scenarios are built up with the most widely used pesticides. Pesticides with a low treatment frequency index (< 5%) are generally not included in the model if homologously acting pesticides are used on a large area. Specifically acting pesticides against, for example, wild oat-grass, are included, however, even though the treatment frequency index is low. For dressing agents and herbicides that are incorporated after application, the risk of transport to the aquatic environment is assumed to be low. They are therefore not included in the model. The model takes into account the temperature-dependent degradation of the pesticides. Spray drift constitutes not more than 1% of the area dose at a distance of 2 metres in March-April, when the pond reaches its maximum size. In practice, the transport via spray drift is lower in the model owing to adjustment for the area and cross section of the pond, and the wind is assumed to blow in one direction. The model does not include transport of pesticides via rainwater or long-distance atmospheric transport. It can be assumed that the surface run-off of pesticides constitutes 0.2% of the pesticide pool from the nearest 2 hectares in the field during precipitation events of more than 10 mm per day, as described in section 4.6.1.

Results of the model calculation, impacts on algae and crustaceans

The simulations show that, all else being equal, the use of pesticides in winter cereals, potatoes, root crops and peas constitutes a major risk to the flora and fauna in ponds. Less burdensome crops are spring cereal, spring rape, maize and, to some extent, winter rape. The model predicts that the critical pesticides for algae and aquatic plants (macrophytes) in ponds are isoproturon, glyphosate, fenpropimorph, ethofumesate, metamitron, pendimethalin, metribuzin, prosulfocarb, mancozeb, maneb and clopyralid. Crustaceans and insects are largely equally sensitive, and the simulated effects on crustaceans can in principle be considered to apply to insects as well. The critical pesticides with respect to effects on crustaceans and insects are esfenvalerate, propiconazol, pendimethalin, metribuzin, prosulfocarb, mancozeb and maneb. If there are no run-off events within a growth season, the only source of load on the pond is spray drift. The analyses show that this supply is only of importance in the case of esfenvalerate, with a 6-9% reduction in daphnia biomass.

Probability of effects

Assuming that the ponds in Denmark are distributed at random in the land under cultivation, the average pesticide load on ponds is calculated on the basis of the model's predictions concerning effects on individual crops and the area covered by individual crops. The 0-scenario is not included in the calculations because the probability of effects would be close to 0% assuming that the precipitation's content of long-distance-transported pesticides would not have any effect in ponds. The calculation shows quite a considerable probability of effects in both the 2.34 and the 1.17 scenarios, see figure 10.10. The probability of more than 10% inhibition of algae is about 85% in the 2.34 scenario and about 45% in the 1.17 scenario, about 20% in the 0.59 scenario and about 10% in the 0.26 scenario.

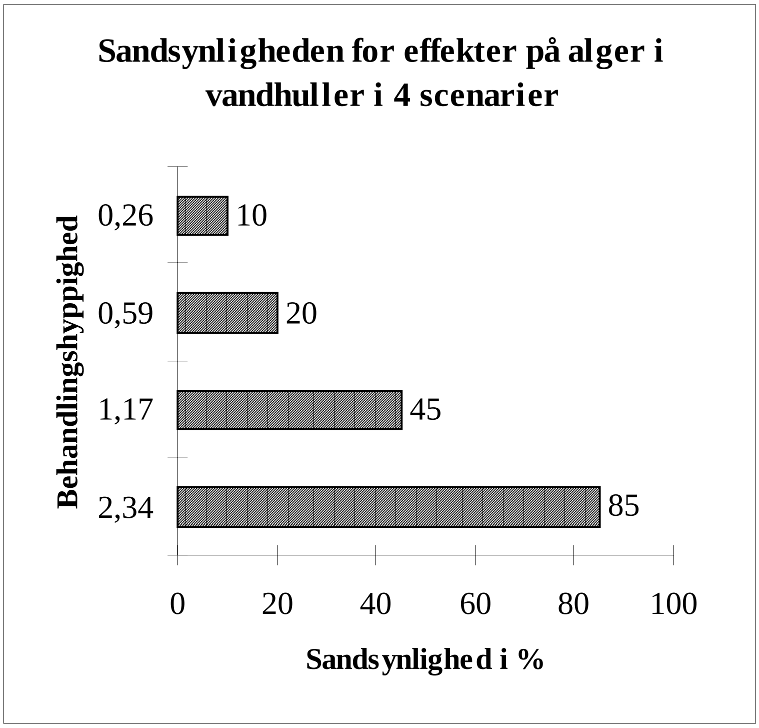


Figure 10.10
The model-based probability of effects on algae in typical Danish ponds in four scenarios with different crop distribution and treatment frequency index (from Møhlenberg, Gustavson 1999).

(Figure texts:
Sandsynligheden for effekter på alger i vandhuller i 4 scenarier = Probability of effects on algae in ponds in 4 scenarios
Behandlingshyppighed = Treatment frequency index
Sandsynlighed i % = Probability in %)

Correspondingly for crustaceans, the probability of effects with more than 10% inhibition is about 55% in the 2.34 scenario, about 25% in the 1.17 scenario, about 15% in the 0.59 scenario and about 10% in the 0.26 scenario, as shown in figure 10.11.

Halving the treatment frequency index greatly reduces the probability of effects, since several years pass between events where considerable effects can be expected. As an example, in potatoes, the frequency of 100% inhibition of crustaceans decreases from 70% in the 2.34 scenario to about 35% in the 1.17 scenario. Correspondingly, the frequency of events with sublethal inhibition (up to 10% effect) is halved from 100% in the 2.34 scenario to 50% in the 1.17 scenario (Møhlenberg, Gustavson 1999).

It can thus be concluded that the model calculations for ponds show a probability of effects on both flora and fauna as a consequence of run-off in all four scenarios. The probability of effect falls with the quantity of pesticides used in the scenarios.

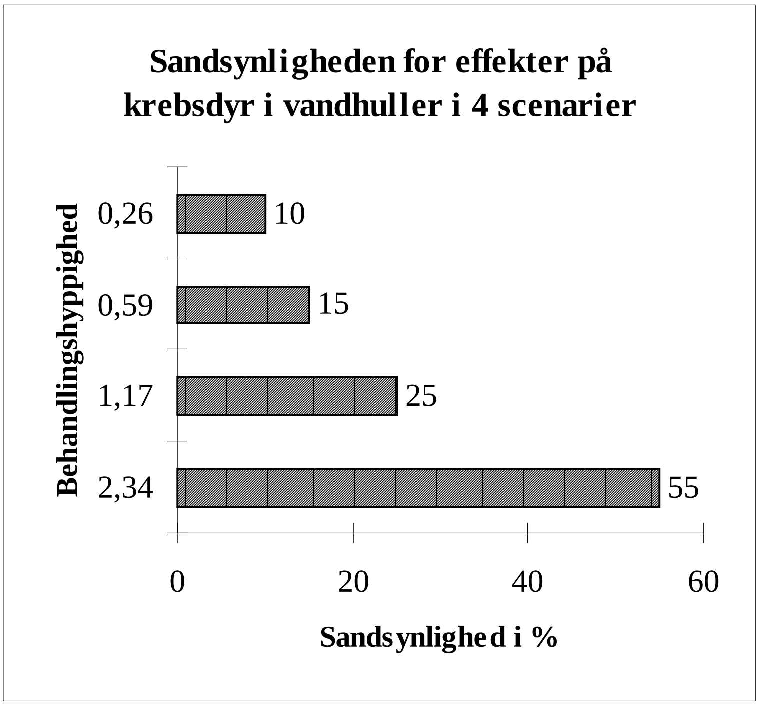


Figure 10.11
The model-based probability of effects on crustaceans in typical Danish ponds in 4 scenarios with different crop distribution and treatment frequency index (Møhlenberg, Gustavson 1999).

(Figure texts:
Sandsynligheden for effekter på krebsdyr i vandhuller i 4 scenarier = Probability of effects on crustaceans in ponds in 4 scenarios
Behandlingshyppighed = Treatment frequency index
Sandsynlighed i % = Probability in %)

10.4 Exposure of humans

10.4.1 Exposure of, and effects on, the sprayer operator

Many of the existing loads and effects from the working environment in agriculture would be the same, whether pesticides were used or not. On the other hand, the exposure to pesticides would decrease with decreasing use of the substances. In field spraying, the risk of exposure in one working day can be 1000 times greater than the daily intake via food products. If protection aids are not used, this risk can be considerably greater.

Mechanical weed control

With the present equipment for mechanical weed control, the time spent driving a tractor would presumably increase. Compared with spray booms, which have a width of 12-36 metres (most of them are 12-24 metres), such tools as weed harrowers with a width of 12 metres and brush weeders, which only handle a few metres at a time, would mean more time spent driving a tractor. However, for the biggest crop, cereals, harrowing 2-3 times would often be sufficient. That corresponds to a number of field runs close to the treatment frequency index for cereals in conventional farming, particularly when spraying against insects and fungi is included.

When combating weeds in special crops, such as onions, carrots and leeks, mechanical inter-row cultivation can be used. As things are today, this has to be followed by manual weeding in the rows. This means workers down on their knees removing weeds. In some places an attempt has been made to solve this problem by using instead a slanting trolley drawn by a tractor. Up to 10-15 people lie side by side on the trolley, removing weeds as the tractor moves along at 500-600 metres per hour. At small production units, weeds could be removed in the "old" way, using hoe and hands. This form of weed control requires a lot of people. It has been calculated that 75,000 persons are needed in a 4-week period for weeding in beets with the present beet acreage. An organic farmer who has tried both manual weeding, using workers lying on a special trolley, and "old-style" weeding estimates that use of the trolley saves a lot of manpower in the 3-5 week period in which weed has to be removed in special crops. The arrangement of the workplace in connection with weed control in special crops has not otherwise been assessed in practice.

Manual weeding with a hoe can be done standing or kneeling or lying on a trolley. All these work postures strain the body, even when the work takes place over a relatively short period. The work can be regarded as MRW (monotonous, repetitive work). Persons working on their knees or squatting are at risk of increased damage to their knees, back and neck/shoulders. The longer the time spent on the work, the greater the risk. However, there are technical and other ways of establishing satisfactory working conditions by changing the planning of the work and its performance.

Other factors

The risk of accidents is deemed to be the same in the different scenarios. There would perhaps be an increased risk associated with more repair and maintenance work because more tools are used in mechanical weed control in the scenarios with reduced use of pesticides.

The 0-scenario and the intermediate scenarios are not in themselves deemed to cause more cases of hearing damage. Since there is an unknown number of old tractors still in use in agriculture, there will continue to be situations in which noise and vibrations can have injurious effects. For farmers who do not feel safe using pesticides, the scenarios with significantly reduced use of pesticides could provide a better mental working environment.

10.4.2 Scenarios for the population's intake of pesticides

The occurrence and intake of pesticide residues in food products are described in section 6.2. Roughly 60% of this intake occurs through imported food products. The predominant sources of exposure are vegetables and, particularly, berries and fruits. The sources of information on this are the annual reports from the Veterinary & Food Administration, which has carried out countrywide random sampling and monitoring of pesticide residues in both vegetable and animal food products on the Danish market for many years. In 1996, the most frequently detected pesticides were (in alphabetical order): captan, carbendazim, chlorothalonil, dithiocarbamates, endosulfan (sum), iprodione, quintozene, tolylfluanide and vinclozolin. None of the finds gave the Veterinary & Food Administration cause for concern with respect to public health (Büchert, Engell 1998).

There is a lack of data on the distribution of Danish consumption between Danish and imported food products. The main reason for that is, that with the "internal market", official statistics are no longer kept of imports and exports between the Member States. On the basis of earlier trade figures and agricultural statistics, it has been estimated that the distribution between imports and domestic production is 1:1 for such fruit as apples, pears, plums, berries, etc., while exotic fruit, such as citrus fruit and kiwi, are all imported food products. For vegetables, the distribution is about 1:4, although not for cucumber, tomatoes and similar, where imports, distributed over the whole year, account for about 70% of the total consumption. In the case of cereals, maize and rice are exclusively imported food products, while the consumption of barley is based entirely on Danish products. In the case of rye, wheat and oats, 5%, 20% and 65%, respectively, of consumption is covered by imports.

The Dane's dietary pattern and daily intake of pesticides

The variation in the Danish consumers' dietary pattern can be judged on the basis of the National Food Agency's dietary study in 1995. The results of this study, which covered more than 1,800 persons, are summarised in table 6.2 in section 6.2. This table gives the average intake and selected fractiles for the adult population. The intake of pesticide residues was calculated as described in section 6.2 for all the pesticides detected in the studies of fruit and vegetables in 1996 and 1997. The intakes from Danish and imported food products were calculated separately, without detailed specification of the origin of the products (for details, see Büchert 1998). The results show a total average intake of pesticides of 190 microgrammes per day. The intake of 6 pesticides/groups of pesticides, carbendazim, dithiocarbamates, iprodione, o-phenyl-phenol, procymidon and thiabendazol, corresponds to half the total intake, while the other half is distributed over about 60 individual compounds.

The total average load from food products is estimated to be approx. 200 microgrammes of pesticide per day, more than half of which comes from some few types of food products – namely, citrus fruit, potatoes and apples. Around 60% comes from imported products and 40% from Danish products. There are big variations in the calculated numerical values, and, in practice, the total intake is estimated to lie between very low and about 600 microgrammes per day. However, since most of the residual content in citrus fruit is in the peel, which is not eaten, the actual daily intake of pesticides is less than 200 microgrammes per day. In this estimate, the intake via Danish products accounts for more than 50% of the total intake.

Calculation of the daily intake in different scenarios for reduced use of pesticides

The calculations of the daily intake cover both Danish and imported food products. Assuming that the diet's relative composition of Danish and imported food products does not change, the daily intake can be estimated for the scenarios set up. These involve a reduction of the use of pesticides in Denmark of 31% in the ++scenario, 80% in the +scenario, 95% in the 0+scenario and 100% in the 0-scenario. The results are shown in figure 10.12.

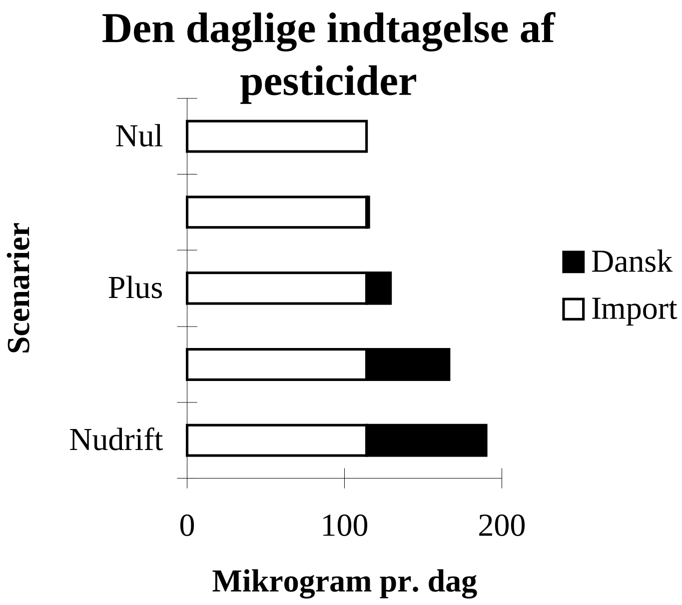


Figure 10.12
Simple calculation of Danes' intake of pesticides assuming unchanged size of import and pesticide residues. In present production, approx. 60% of the intake of pesticide residues comes from imports, which dominate the intake in all scenarios, including a total phase-out of pesticide use in Denmark.

(Figure texts:

Den daglige indtagelse af pesticider = Daily intake of pesticides
Scenarier = Scenarios
Nul = 0-scenario
Plus = +scenario
Nudrift = Present production
Dansk = Danish
Import = Import
Mikrogram pr. day = Microgrammes per day)

It will be seen from figure 10.12 that the pesticide residues from imported food products, which dominate the intake in all scenarios, would still be there with a total phase-out of pesticide use in Denmark. One can conjecture about changes in the Danish population's dietary pattern in the event of a partial or total phase-out of pesticides, but such predictions are very uncertain. They would depend, for example, on the development of society both in Denmark and elsewhere and on the derivative market mechanisms, which are discussed in the report from the Sub-committee on Production, Economy and Employment. It is basically assumed that the intake via imported food products would remain unchanged despite movements between the individual products. As described in section 6.2.4, peeling of citrus fruit means less than 200 microgrammes per day, but at the same time, crops produced in Denmark would contribute more than 50% of the daily intake.

11 The sub-committee’s summary with conclusions and recommendations

11.1 Introduction and mandate

On 15 May 1997 the Folketing (the Danish Parliament) unanimously passed a parliamentary resolution urging the government to appoint a committee with independent expertise to analyse all the consequences of totally or partially phasing out the use of pesticides in agriculture and to examine alternative methods of preventing and controlling plant diseases, pests and weeds.

The mandate for the **Sub-committee for Environment and Health** stated that the sub-committee was to assess the environmental consequences of a total or partial phase-out of pesticides, including the effects on groundwater as a resource for the population and the natural environment, surface water as a resource for flora and fauna, and the terrestrial ecosystems in agriculture and forestry as a resource for flora and fauna.

In its assessment of the health consequences, the sub-committee was to include the effects of pesticides on the people using them and the effects of using the proposed cultivation systems. On the other hand, the sub-committee was not required to consider the health and environmental aspects of the industrial production of pesticides.

In its work, the sub-committee has analysed the following scenarios in relation to present production practice, which is characterised by a treatment frequency index of 2.51:

- A total phase-out of pesticides (the 0-scenario). This scenario is described as a reference situation, and the environmental and health consequences of a total phase-out are compared with the present situation. Here, the treatment frequency index is 0.

- Use of pesticides only for pests covered by the quarantine laws (the 0+scenario). In this scenario, pesticides would be used to comply with specific requirements concerning purity or for controlling pests defined in orders from the Plant Department. Here, the treatment frequency index is 0,05.

- Use of pesticides in crops with serious losses (the +scenario). In this scenario, pesticides would only be used for limited areas in which large yield losses could be expected or where production of specific crops could not be maintained. The scenario also covers the 0+scenario’s areas. Here, the treatment frequency index is 0,50.

- Reduction of pesticide consumption to a level without yield losses (the ++scenario). In this scenario, use would be made of all available technical and cultivation methods that reduce the use of pesticides without significant economic losses. The scenario covers the areas of the 0+scenario and the +scenario and is based in part on the principle of integrated prevention and control. Here, the treatment frequency index is 1.73.

The sub-committee has included a number of consequential analyses covering soil fauna, wild flora, ponds and the daily intake of pesticide residues in food products. The sub-committee has reviewed the latest knowledge on the occurrence of pesticides in groundwater, watercourses, lakes, ponds, soil water, drain water and rainwater and has assessed the dispersal and fate of the pesticides through surface run-off, spray drift and evaporation, degradation and leaching. The pollution from filling and washing sites for spraying equipment has also been assessed. The sub-committee has assessed the effects of pesticides on flora and fauna in cultivated and uncultivated terrestrial ecosystems – watercourses, lakes and coastal waters – and the exposure of and effects on humans – both agricultural workers and the population as a whole.

The sub-committee has looked in particular at the coformulants used in connection with the pesticides and has also assessed the pesticides in relation to other chemical substances used in agriculture, including natural substances and pesticides of natural origin. In addition, the sub-committee has examined various methods for ranking pesticides and investigated the possibility of operationalising the precautionary principle in connection with pesticides.

Lastly, the sub-committee has assessed the environmental and health aspects of a number of alternative and new methods in relation to the scenarios set up for total or partial phasing-out of pesticides.

The general conclusion of the sub-committee concerning the scenarios is that only the 0-scenario and the 0+scenario are based on consistent use of the precautionary principle. The +scenario, in which the use of pesticides is reduced by 80% compared with present production would result in a marked reduction of the dispersal of pesticides and the exposure to them but would still imply a potential risk of effects where pesticides are used. In the ++scenario with a treatment frequency index of 1.73, the reduction in the use of pesticides would be smaller than the treatment frequency targets in the Pesticide Action Plan from 1986. This plan did not take account of the special problems with groundwater and surface water.

11.2 Occurrence of pesticides in the environment

The sub-committee has reviewed the latest knowledge concerning the occurrence of pesticides in groundwater, watercourses, surface water, drain water, soil water and rainwater, and has assessed the dispersal of pesticides through surface run-off, spray drift and evaporation. It has also assessed the degradation and leaching of pesticides and the pollution from filling and washing sites. The sub-committee has drawn specific conclusions in the individual areas and has arrived at the following general conclusions and recommendations:

Conclusion concerning lack of time series

1. There are studies of pesticides in the different compartments: groundwater, watercourses, drain water, soil water and rainwater. There are only a few measurements of pesticides in ponds and lakes. Only for the groundwater are there time series, but the measuring programmes have not been going on long enough to allow the trends to be discerned. The monitoring programme in connection with Aquatic Environment Plan II will in future supply data for such time series.

Conclusion concerning pesticides in groundwater

2. In the expanded analytical programmes in the national groundwater monitoring programme, pesticides or degradation products have been detected in 34% of the analysed screens in the interval 0-10 metres below ground level. The limit value was exceeded in 23% of these screens. The detection frequency decreases with the depth, which may indicate that pesticide residues from the last 50 years' consumption, which has been rising throughout that period, are moving towards the deeper aquifers, with increasing future groundwater pollution as a consequence. Another explanation might be that degradation occurs during the downward movement because the concentrations in the deeper soil strata have been exposed to biological and chemical degradation for a longer period than the concentrations found in the uppermost soil strata. Only when sufficiently long time series from the monitoring programmes become available – in 5 to 10 years time – will it be possible to assess these hypotheses. The latest research indicates that some pesticides in aquifers degrade very slowly, while others show degradation.

Conclusion concerning size of the finds

3. In the expanded analyses in the groundwater monitoring programme, pesticides or degradation products were found in 21% of the screens examined. The limit value was exceeded in 13% of these screens. The degradation product BAM from the now banned herbicide dichlobenil has been detected in about 30% of the wells covered by the water companies' raw-water monitoring system. However, many other substances used to treat crops have also been detected in relatively many of the wells included in the monitoring system. The finds of pesticides in drain water and soil water are higher than the finds in groundwater and reflect the concentrations that can later move towards the groundwater, during which they can undergo degradation and possible formation of metabolites. In both watercourses and ponds, a number of pesticides have been detected in higher concentrations than the effect levels measured in laboratory tests with aquatic organisms.

Conclusion concerning market gardens and berry and fruit production units as point sources

4. With the high treatment frequency index used in nurseries, market gardens and berry and fruit production units, there is a potential risk of pollution of the surroundings, including the groundwater.

Conclusion concerning lack of data for describing the dispersal and transformation of pesticides in the environment

5. The sub-committee has noted that, in connection with the pesticides detected in the different compartments, only a fraction of the quantities of pesticide used can be accounted for, neglecting degradation. There is thus a lack of data on the total mass flows and the largest flows, including evaporation and spray drift, and a lack of concrete, systematic measurements of the degradation and metabolism as elements of the main mass flow analysis. It is thus not possible to arrive at a real and complete description of the fate of the pesticides in relation to the environmental and health loads.

Conclusion concerning future pollution of groundwater

6. The finds of authorised pesticides above the limit value in both groundwater near the surface and deeper aquifers indicate that the present authorisation scheme does not ensure completely against future pollution of the groundwater. A warning system for pesticides has therefore been established to enable rapid assessment and possible removal of authorised pesticides.

Conclusion concerning spray drift and evaporation

7. Two reasons why pesticides are found in precipitation, surface water and unsprayed areas are spray drift and evaporation. Calculations indicate that there can be considerable evaporation of the substances fenpropimorph, pendimethalin, prosulfocarb and trifluralin. There is thus a risk of these substances being dispersed in the atmosphere and detected in rainwater and surface water. The fate and occurrence of these substances in the atmosphere over Denmark have not been investigated.

The sub-committee's recommendations

In Denmark and the EU, authorisation of pesticides is at present based on analyses of research results and assessment of the consequences for health and the environment. Particularly the fate of the pesticides is thus not subjected to an analysis of the uncertainties and actual variations used in an integrated mass flow analysis because, for such an analysis, data are needed on the actual use, dispersal and degradation under Danish conditions. The sub-committee recommends that an actual mass flow analysis be carried out in connection with the review of pesticides with a view to renewal of their authorisation in pursuance of section 33(4) of the Act on Chemical Substances and Products. The analysis must include both average and "worst-case" situations based on measurements and experience gained in the period the substance in question has been in use. If data are lacking on the individual flows in this mass flow analysis, the sub-committee recommends that the precautionary principle be applied in the assessment of the substances in order to counteract or prevent any consequences of the dispersal of the pesticides for human health and the environment.

The sub-committee recommends that the gross list set up with a view to reassessment of pesticide leaching be included in recommendations on substitution with less dangerous substances in the use situation. The sub-committee also recommends that new products be assessed in relation to the gross list and in relation to alternative, non-chemical methods. Substances that are thereby placed at the critical end of the gross list or that can be replaced by suitable alternative, non-chemical methods should not be authorised. The sub-committee recommends use of the following alternative methods:

- mechanical weed control
- biological control of pests
- use of resistant varieties, including genetically modified crops
- preventive operating methods.

Since the alternative methods can also be harmful to the environment and health, their suitability should be assessed in the same way as chemical methods.

The sub-committee recommends that pesticides no longer be used in areas where groundwater is extracted for drinking purposes. In these areas, consideration can be given to nature rehabilitation with respect to flora and fauna, as proposed in the recommendations in section 11.3.

The sub-committee also recommends that evaporation and atmospheric, chemical conversion of pesticides be taken into account in the authorisation of pesticides.

The sub-committee recommends that further clarification be sought of the effect of the dispersal of pesticides from disused and existing nurseries, market gardens and berry and fruit plantations and buried waste on the present groundwater pollution and the surroundings in general. Lastly, the sub-committee recommends that improved rules be drawn up for when washing and filling of spraying equipment may take place.

11.3 Impacts of pesticides in the environment

Conclusion concerning impacts on flora and fauna

The main impacts occur in connection with the application of the pesticides, when organisms are directly hit, and where indirect effects occur as a consequence of the effect on food chains. Here, plants play a key role as the first link in the food chain. A Danish study has shown that the number of plant species and their frequency in the fields studied have halved in the last 20-25 years. From a farming point of view, this has been a desirable development, but it has had adverse consequences for the nature content. The main reason for the decline is the use of herbicides and changed cultivation practice. In both cultivated areas and the adjacent biotopes, the use of pesticides involves a risk of reductions in populations of plants and animals, changed biodiversity, changes in the cultivation medium and natural pest regulation, together with food-chain and indirect impacts. Generally speaking, it is not the individual field and its possible loss of wild flora that are the problem but, rather, the combined, countrywide impact on the characteristic farmland flora.

In a dialogue with the Sub-committee on Production, Economics and Employment, the Sub-committee on Environment and Health has estimated that a general reduction of the use of pesticides on an unchanged acreage would have a less beneficial effect on flora and fauna than if the same reduction were achieved by establishing permanent spray-free edge zones and banning spraying in environmentally sensitive areas.

Conclusions concerning impacts on arthropods in the field in the various scenarios

The lower fauna are affected both directly by treatment with insecticides and indirectly through the removal of plants and microorganisms as food resources through the use of herbicides and fungicides. The effect of the different types of pesticide is partially specific and proportional to the treatment frequency index for fungicides, herbicides and insecticides. Therefore, in comparisons of the scenarios, the treatment frequency index is an indicator of the undesirable side effects of the use of pesticides on individuals, species and communities of plants and animals (see section 5.1 and chapter 10). If treatment with herbicides were omitted, the insect fauna could be expected to increase by a factor of 2-7, measured as individuals, and by a factor of 1.5, measured as the number of species per sample. If treatment with fungicides were omitted, the fungivorous insect fauna would increase for a time by a factor of 1-2.5. If treatment with insecticides were omitted, the insect fauna would increase by a factor of 2-4. The effect of fungicides and insecticides is often shorter than the effect of herbicides because the elimination of weed affects the fauna all through the season.

Conclusion concerning impacts on soil organisms in the various scenarios

The sub-committee has assessed the scenario analyses for springtails and earthworms, since these are the only groups of soil organisms for which sufficient data are available (see chapter 10). It can be concluded that the population density of neither springtails nor earthworms is affected by the pesticides authorised in Denmark, and used in the scenario for present production, but that it is affected by crop rotation, soil treatment, fertilisation and any second crops. Scenarios that include increased use of manure and clover grass would benefit these groups of organisms.

Conclusions concerning impacts on farmland birds in the various scenarios

The sub-committee concludes from the scenario analyses carried out (see chapter 10) that the populations of partridge, whitethroat and yellowhammer would increase in all scenarios in relation to present production and that all the scenarios show a significantly increased population density for these species. This applies to the 0-scenario, the +scenario and the ++scenario. For the other species, the index would be unaffected by the use of pesticides, compared with present production. Since the direct toxic effects on birds today are insignificant (see section 5.1), it is the indirect impacts that would be important, e.g. changes in the birds' food resources. In this connection, it makes no difference to the birds whether their food resources are removed by means of pesticides or by mechanical or other methods. Inter-row cultivation and harrowing could constitute a risk to ground-nesting species. Similarly, early and/or more extensive soil preparation in the autumn would very probably have considerable, adverse effects on the birds because stubble fields are a very important foraging area for many species in the autumn months.

For all the species except partridge and, to some extent, whitethroat, the analyses show a significantly larger number in the organic scenario than in the 0-scenario because of the difference in crop rotation. However, the crop rotations used are based on organic farms as they were in the 1980s, when the forms of operation and land use differed from present-day organic farming.

Conclusion concerning analyses of changes in the quantity of seed from plants in the field in different scenarios

From the results of analyses with two different models, the sub-committee concludes that there could be an improvement in the conditions for wild plants and those animal species that depend on them as a food resource in all the scenarios without the number of wild plants growing out of control provided mechanical weed control and limited chemical control were used. In the +scenario, a number of wild plant species could occur with greater frequency in crop rotations with either beets or rape. A more varied plant community could therefore be expected, providing food resources for a more diversified animal community (invertebrates and their predators). However, in view of the poor competitiveness of beets, this crop rotation would hardly be profitable unless new, alternative methods were found for controlling weed in beet crops. For the crop rotation with rape, the analyses show that there would be a marked fall in the number of seeds in the seed pool after 25 years, compared with the situation in present production after 25 years because mechanical weed control with spraying against couch grass every ten years is more effective than conventional spraying. However, these analyses must be treated with caution because the model has not been verified in practice.

Conclusions concerning model analyses of the impacts on ponds

From the model analyses carried out, the sub-committee concludes that there would probably be effects on both flora and fauna as a consequence of run-off in scenarios corresponding to present production, the ++scenario and the +scenario. The probability of effect falls with the quantity of pesticides used in the scenarios. The models show that, all else being equal, the use of pesticides in the crops winter cereal, potatoes, beets and peas constitutes a serious risk to the flora and fauna in ponds. Less burdensome crops are spring cereal, spring rape, maize and, to some extent, winter rape. The model predicts that the critical pesticides for algae and aquatic plants (macrophytes) in ponds are isoproturon, glyphosate, fenpropimorph, ethofumesate, metamitron, pendimethalin, metribuzin, prosulfocarb, mancozeb, maneb and clopyralid. Crustaceans and insects are largely equally sensitive, and the simulated effects on crustaceans can in principle be considered to apply to insects as well. The critical pesticides with respect to effects on crustaceans and insects are esfenvalerate, propiconazol, pendimethalin, metribuzin, prosulfocarb, mancozeb and maneb. If there are no run-off events within a growth season, the only source of load on the pond is spray drift. The analyses show that this supply is only of importance in the case of esfenvalerate, with a 6-9% reduction in daphnia biomass.

Conclusions concerning spray drift and impacts on the terrestrial environment

During spraying, spray drift carries pesticides to the surrounding areas. However, hedgerows, dikes, dry stone walls and other small biotopes are so narrow that they should in practice be included in the area that is affected by spray agents. Spray drift can affect both terrestrial and aquatic ecosystems. Several studies have demonstrated effects from spray-agent drift up to 50 metres from the sprayed area. However, most of the flora were only affected in an area between 0 and 5 m from the field. However, there is a lack of experimental data on effects of herbicides in low doses on wild plant species, and the extent of spray drift and its effect on wild flora have not been systematically studied in Denmark. In both the 0-scenario and the 0+ and +scenarios, the consumption of herbicides would be reduced and thus the risk of spray drift to areas near the sprayed field. This would considerably reduce the load, whether spraying was discontinued altogether or was only carried out occasionally. However, owing to the lack of data, it is not possible to quantify the beneficial effect on the vegetation. The areas affected would be reduced in step with the herbicide consumption. In the 0+scenario, the load would be reduced to the few localities in which pesticides were used. In the 0-scenario, there would no longer be any impact on the neighbouring areas.

Conclusions concerning spray drift and impacts on the aquatic environment

For the aquatic environment, any form of impact from pesticides, including changes in the flora and fauna in coastal waters, lakes, ponds and watercourses, is undesirable. Of the aquatic ecosystems it is particularly ponds, watercourses and lakes near fields that could potentially be affected. It is likely that the freshwater environment is already affected by the present use of pesticides, but it is not possible on the basis of the existing data to quantify the impact at national level. On the basis of information from county authorities it is provisionally estimated that around 2% of the unfulfilled targets on approx. 11,000 km of watercourses are due to toxic substances, including pesticides. The available concentration levels indicate, in particular, that it is insecticides and, among these, particularly the pyrethroids, that have an adverse impact. Because of their persistence, the pyrethroids could occur in the freshwater ecosystems for a long period of time. Cases of effects of herbicides on algae and other primary producers have also been documented. However, several measurements indicate that pyrethroids and some thiophosphate insecticides are found in concentrations close to the level that causes effects according to the literature. For some pesticides this level is lower than the limit value for drinking water of 0.1 microgramme per litre.

Conclusions concerning impacts in forests

Quantitatively, little use is made of pesticides in forestry, but in Christmas tree and ornamental greenery cultures, consumption is the same as in farming. The treatment frequency index in nurseries and market gardens is also high. There is a lack of specific studies of the effect of herbicides on forest-floor flora, but there is no doubt that even the present limited use of pesticides in forestry has a serious, adverse effect on the real forest-floor flora. Many species of such flora have a very slow rate of remigration – less than 1 metre per year –, which makes them very sensitive to herbicides, even when these are only used in connection with felling and afforestation. If herbicides were no longer used in forests it would in time be possible to recreate a forest-floor flora that was naturally adapted to the local soil and climatic conditions. However, mechanical control of undesirable vegetation in the form of deep ploughing over large areas could have the same direct effects on the flora as herbicides and thus also the same indirect effects on the associated fauna. Besides these, there would be adverse effects on soil fauna, fungal flora, the soil profile and historical monuments. Where natural rejuvenation is not used, it is important for the forest-floor flora that areas are left untreated and that rejuvenation is in the form of shelterwood regeneration with preservation of the choice of tree species. The use of herbicides in Christmas tree and ornamental greenery cultures in the +scenario and the ++scenario would result in continued low biodiversity of the flora in the areas in question unless alternative, environment-friendly methods were found.

The sub-committee’s recommendations concerning the impacts of pesticides in the environment

For the scenarios in which pesticides are used there is a lack of systematic studies of how pesticides in large, continuous areas affect wild flora and the associated fauna in hedgerows, ditches and other small biotopes and in neighbouring nature areas. The effect on the flora in Denmark as a consequence of the precipitation’s content of herbicides transported over long distances is not known. Foreign studies show that effects are likely, but studies of both the effects and the atmospheric transport are needed to determine them. There is also a need to assess the effect of pesticides on aquatic organisms in relation to the actual finds in watercourses and surface water. The data and time series needed could be procured by means of a targeted monitoring programme for the affected biotopes, combined with experimental studies of the relationship between concentrations of pesticides and the level at which effects can be detected.

In the case of the use of pesticides in forestry, for the fauna it is the indirect effects that are most damaging. The long-term effects on both flora and fauna cannot be assessed owing to a lack of tools and knowledge.

For the intermediate scenarios in which pesticides are used, the sub-committee recommends more consistent and systematic use of permanent spray-free zones and protection borders to help protect watercourses, lakes and ponds and preserve the vegetation in small biotopes and nature areas, where these still exist. In this connection it must be ensured that continuous dispersal corridors are established. Where the vegetation of small terrestrial biotopes has been seriously affected by both herbicides and fertilisers in the last few decades, recolonisation will normally be very slow. Here, it will be necessary to establish permanent spray-free and fertiliser-free edge zones where it is found desirable to get the vegetation and associated fauna re-established. In addition, the sub-committee recommends actual nature rehabilitation, including recreation of a more diverse flora and fauna (e.g. introduction of amphibians and invertebrates with a low capacity for recolonisation).

The sub-committee also thinks that consideration should be given to increasing the distance requirements to watercourses and lakes.

11.4 The sub-committee's conclusions and recommendations concerning health and safety

Conclusions concerning exposure to pesticides in the working environment

The risk of acute effects from pesticides is deemed to be considerably lower today than it was just 10 years ago because the most harmful products may no longer be used. Some risk cannot be excluded for persons who do not observe the rules on personal protection and correct use of pesticides and persons who use inappropriate work routines and do not practise good work hygiene. The sub-committee notes, however, that there can be considerable exposure of sprayer operators and workers in greenhouses and in the production of fruit and vegetables, where frequent use is made of pesticides.

Conclusions concerning accidents in connection with alternative methods

The sub-committee concludes that the risk of occupational injuries may rise in connection with mechanical weed control through the introduction of more machines and thus more repair work and maintenance. In addition, increased manual weeding could result in a higher frequency of injuries in connection with monotonous, repetitive work (MRW). There is a generally higher risk of physical damage, particularly in the form of rheumatism, in agricultural workers. This risk is associated with stable work, milking, tractor operation and heavy physical work and is thus not related to the use of pesticides.

The sub-committee's recommendations concerning health and safety

Neither conventional nor organic farmers are accustomed to thinking very much about health and safety, and injuries are not always reported despite the fact that the agricultural sector has many serious accidents and more fatal accidents than all other sectors of industry. The sub-committee recommends that higher priority be given to health and safety in the agricultural sector, in connection with both conventional and pesticide-free operation.

The sub-committee wishes to draw attention to the fact that knowledge is lacking concerning the ability of pesticides and their coformulants to produce allergies and their effect on the immune system. The sub-committee therefore recommends that more knowledge be built up in this area.

In view of the intensive use of pesticides in nurseries and in the production of fruit, vegetables and berries, the sub-committee recommends intensified action to reduce the exposure to pesticides in these areas.

11.5 The sub-committee's conclusions and recommendations concerning public health

Conclusions concerning the population's intake of pesticides

The sub-committee's examination of the pesticide intake from food products and drinking water shows that the main source of the load on the population is the intake from berries, fruit and vegetables and, to some extent, cereals and cereal products, whereas the intake from drinking water, animal food products and fish is negligible.

In treated crops it is generally assumed that there is some residual content, so that lack of detection is usually taken to mean that the content, if any, is below the analytical detection limit.

The total average load from food products is estimated to be approx. 200 microgrammes of pesticide per day, more than half of which comes from some few types of food products – namely, citrus fruit, potatoes and apples. Around 60% comes from imported products and 40% from Danish products. There are big variations in the calculated numerical values, and, in practice, the total intake is estimated to lie between very low and about 600 microgrammes per day. However, since most of the residual content in citrus fruit is in the peel, which is not eaten, the actual daily intake of pesticides is less than 200 microgrammes per day. In this estimate, the intake via Danish products accounts for more than 50% of the total intake.

The average load at single-substance level from food products is typically around 1% or less of the current Acceptable Daily Intake (the ADI value).

Conclusions concerning epidemiological studies

The sub-committee concludes that epidemiological studies do not provide evidence that pesticides are harmful in the quantities to which the general public is exposed through, for example, diet. Similarly, one can never completely prove scientifically that a pesticide cannot result in a risk to health, but one can show, with greater or lesser certainty, the probability of a risk to health or of no risk to health. This applies to all scientific work, including tests on animals. In addition, every statement about safety in connection with the use of chemical substances is based on present knowledge, so there will always be a possibility of unforeseeable effects being found at a later date.

Epidemiological studies on effects of metabolites and non-active ingredients, which often constitute a substantial part of the products, are largely non-existent.

In the case of degradation products of pesticides in the environment, little is known in some cases about their effects on health. This applies particularly where different metabolites are formed in the environment than in test animals and humans.

More extensive use of biomarkers for exposure to and effect of pesticides would make it easier to demonstrate epidemiologically a correlation between exposure and any effects.

Conclusion concerning mycotoxins

Mycotoxins are a general problem in both conventional and organic farming because they can develop in moist conditions. They can also develop if grain dries too slowly. The sub-committee finds that mycotoxins in grain attacked by fungi are a greater risk to public health than pesticide residues in cereals and therefore recommends better control of the water content of grain, improved drying procedures and similar control measures at source. The sub-committee also recommends tightening control of the content of mycotoxins in food products.

The sub-committee's recommendations in the health area

- The residual content of pesticides in crops usually comes from treatment carried out at times when plants are exposed in their seeding or berry- or fruit-bearing stages. The sub-committee recommends that spraying be limited to before the end of flowering, earing or similar. To support the assessment of the residual concentrations, the sub-committee recommends that residual concentration analyses be carried out under Danish climatic and cultivation conditions in connection with the assessment of pesticides.

- There is a need to include new effects that have not previously been studied or considered important – for example, effects on the endocrinal system (hormones) and on developing nervous systems. The sub-committee recommends continued research in this area because the problems must at the same time be accepted as a matter that calls for use of the precautionary principle in future assessments and authorisation schemes for both new and existing pesticides.

- The sub-committee recommends that greater weight be attached in the overall assessment of the individual pesticide products to the coformulants, which are often used in considerable quantities, and that the appropriateness of using the individual substances be regularly assessed.

- The sub-committee recommends that greater attention be paid in the health assessment of pesticides, particularly for risk groups, to the fact that many different chemical substances are taken in at the same time.

11.6 The sub-committee’s conclusions and recommendations concerning the precautionary principle

The sub-committee has operated with two different approaches to the precautionary principle – a risk assessment approach and a zero value approach.

Use of the risk assessment approach can imply a "conservative" (= "cautious") assessment based on concrete empirical evidence, whereas the zero value approach can be based on initially value-determined quality requirements that may only be deviated from after an assessment based on definable protection requirements.

If the risk assessment approach can be based on sufficient scientific data to ensure complete protection of health and the environment, the use of uncertainty factors can be said to be a satisfactory implementation of the precautionary principle. Such an approach would thus mean that the precautionary principle did not add anything to the traditional risk assessment based on existing knowledge. However, there are still unsolved questions about the possible inadequacy of uncertainty factors and the general questions concerning uncertainties due to lack of knowledge or indeterminacy related to the role of pesticides in society.

The sub-committee has specifically examined possible applications of the precautionary principle beyond the existing authorisation scheme, which can be described as a scientifically based risk assessment.

The sub-committee’s considerations concerning use of the precautionary principle in the health area

The sub-committee has discussed whether the zero value approach could be used within an authorisation scheme for pesticides – in the following areas, for example – if it were found desirable to use this approach in the health area.

1. Reduction of the limit value for pesticide residues in food products to the lowest detection limit applying at any time.
2. Reduction of the limit value for pesticides in groundwater to the lowest possible detection limit at any time or authorisation only of pesticides that meet requirements concerning zero mobility or only negligible mobility in soil.
3. No authorisation of substances classified as carcinogenic in cat3, mutagenic in cat3 or reproductive effect in cat3.
4. Wider powers to impose restrictions on use with a view to avoiding direct application on crops, trees and bushes in their seed- and fruit- and berry-bearing periods. Treatment after these periods implies direct application of chemicals to what will be the edible crop. Spraying practice should thus be changed with a view to reducing the residual contents found today to below the detection limit. In other words, the precautionary principle should be applied as it is in the case of the limit for drinking water.

It must be stressed that the sub-committee has not carried out an assessment of whether the zero value approach should be used for the above-mentioned examples, since that would require a dialogue between the following players:

1. scientific experts to set the limit for what can be predicated and pinpoint what cannot be elucidated
2. an administrative instance to decide what can be operationalised
3. political decision-makers, i.e. non-experts, to make the final decision on behalf of the public on the basis of trust in the scientific knowledge and ethical and political considerations.

The sub-committee also wishes to draw attention to the fact that the limit values used in the above-mentioned examples are based on the currently achievable analytical detection limits. This means that the limit values will be continuously adjusted downwards towards zero in step with the technological development. The sub-committee wishes to point out that this could ultimately lead to a total ban on the use of pesticides in Denmark.

11.7 The sub-committee's conclusions and recommendations concerning ranking

Ranking with respect to groundwater pollution

The sub-committee concludes that it is not possible, with the existing simple methods, to rank pesticides clearly with respect to their ability to leach to the groundwater. However, it is possible, using four different methods, to set up a gross list covering 35 of the authorised substances. The substances on this gross list should be assessed more closely, using mathematical models, the latest knowledge and the results of measurements.

In the years ahead, current research programmes will provide more knowledge about the basic problems, and steps already in progress to improve groundwater monitoring and early warning of the risk of leaching pesticides to the groundwater will increase safety.

The sub-committee's recommendations concerning ranking with respect to groundwater pollution

The sub-committee wishes to point out that, for improved risk assessment, more work is needed to clarify the processes governing the transport of pesticides to the groundwater and in aquifers, and greater understanding must be developed of the spatial variation in the parameters governing this transport. As results come in from the constantly growing number of both national and international studies, decision-making tools should be developed on the basis of statistically documented relations for potential leaching of pesticides with a view to generalising the studies to uninvestigated areas and pesticides. In this connection, the sub-committee recommends greater use of mathematical models (e.g. MACRO) in the assessment of the risk of leaching of pesticides and further work on evaluating their validity. In this connection, there is a particular need to procure the necessary geological and substance-specific data. The possibility of developing simple stochastic (probabilistic) models should be looked into.

The sub-committee recommends that the gross list set up with a view to reassessment of pesticide leaching be included in recommendations on substitution with less dangerous substances in the use situation. It also recommends that new products be assessed in relation to the gross list and in relation to any non-chemical, alternative methods.

Ranking with respect to impacts on the terrestrial environment

In the case of the terrestrial environment it is not possible to indicate a method for ranking the direct effects because it is the indirect effects and the combination of many pesticides that play the biggest role. However, the treatment frequency index can be used as a measure of the load because it is based on the biologically active field dosage and is thus a simple indicator of both the direct effect on the target organisms and their related species and the indirect load on the ecosystem as a consequence of changes in the quantity and type of food resources in the food chains. It would also be possible to calculate an index for the dose that, as far as is known at present, would be harmless to the vast majority of the flora and fauna in uncultivated areas that receive pesticides via spray drift or atmospheric transport (critical loads).

The sub-committee's recommendations concerning impacts on the terrestrial environment

As a starting point, the sub-committee recommends that the treatment frequency index be used as index for the entire load on flora and fauna in the field and its immediate surroundings.

Ranking with respect to the aquatic environment

In the case of the aquatic environment, in the present authorisation scheme an expert assessment is carried out that can lead to authorisation of new pesticides or products on certain conditions concerning distance to watercourses and lakes. Such distance requirements indicate that the substance (the product) is problematical with respect to aquatic organisms and could be used directly for ranking or classifying pesticides.

The sub-committee's recommendation with respect to the aquatic environment

The sub-committee recommends that the administratively set distance requirements be used for ranking or classifying pesticides.

Ranking with respect to public health

For the human-toxicological area one could use the relationship between the Acceptable Daily Intake, ADI, and the estimated exposure to the substance as the basis for ranking pesticides. Generally speaking, with the current use of pesticides, the exposure at single substance level through food products is around 1% or less of ADI. A ranking scheme would enable identification of substances that, with their present use, have the lowest safety margin for humans. However, since the effects of the individual substances are not comparable, a ranking scheme would not suffice alone but would have to be supplemented by an expert assessment.

The sub-committee's recommendations with respect to public health

The sub-committee recommends that a ranking scheme be based on the relationship between the Acceptable Daily Intake of the individual active ingredient and the actual intake.

11.8 The sub-committee's conclusions concerning energy consumption, emissions of greenhouse gases and nutrient leaching

Conclusion concerning changes in energy consumption

In the event of restructuring for pesticide-free agriculture, the direct energy cost for mechanical weed control would rise, but would be offset to some extent by a saved, indirect energy cost for production of pesticides. The sub-committee concludes that the total energy cost for arable farming in Denmark would not change significantly in the event of restructuring for pesticide-free operation, but that this must be seen in relation to a considerable fall in yield – about 25%. The sub-committee has not considered the extent to which a changed production pattern, e.g. reduced livestock production, would reduce energy consumption.

Conclusion concerning emissions of greenhouse gases

The agricultural sector's domestic contribution to the greenhouse effect is approx. 13 Tg CO_2-equivalents. CO_2 from fossil fuel consumption accounts for around one quarter of this, and methane and nitrous oxide for the remainder. If the yield was reduced by pesticide-free operation, import of feedstuff would mean a higher overall energy consumption. It has not been possible, on the existing basis, to assess changes in emissions of methane gas and nitrous oxide in the different scenarios.

Conclusions concerning leaching of nutrients

The sub-committee believes that changes in mechanical soil treatment and changed crop rotations would affect the leaching of nutrients. The changes could be both adverse and beneficial. An extensive analysis would be needed to assess the net change, but would be encumbered with great uncertainty. All else being equal, in the 0-pesticide scenario, the reduction in yield would result in a smaller consumption of fertiliser and thus reduced leaching. On the other hand, in the event of crop failure – for example, as a result of fungal diseases – increased leaching could be expected. Leaching would thus depend, from year to year, on an interaction between the choice of crop, the level of fertilisation, the intensity and timing of soil treatment, and plant health. The implementation of Aquatic Environment Plan II would be accelerated in step with the reduction of fertiliser consumption in the different scenarios.

11.9 The sub-committee's conclusions and recommendations concerning proportionality

The sub-committee's conclusions concerning proportionality

- The heavy metals cadmium, lead and mercury present a bigger health problem than pesticides but are not a serious problem environmentally. However, attention must be paid to a potential accumulation in cultivated soil of, in particular, cadmium, lead and copper.

- Compared with the effects of pesticides, the direct effect of xenobiotic substances on cultivated soil and thus on crops is small. However, little is known about potential, indirect pollution by xenobiotic substances, for example via air or through accidental loss, spillage or discharge to water. There may therefore be grounds for concern since the long-term effects of even small concentrations are not known. With the environment policy now pursued, efforts are being made, both nationally and internationally, to ensure a reduction at source, but owing to the continuing supply of such substances, the load must be monitored on a long-term basis.

- Organic pollutants are not generally a problem in cultivated soil. With frequent application of sludge on the same area, the total quantity of xenobiotic substances can be of the same order of magnitude as the pesticide load.

- The content of nitrate in drinking water in Denmark is a bigger health problem today than the pesticide residues in drinking water owing to a low safety margin in connection with the formation of nitrite in water used for newborn infant formulae.

- The use of veterinary drugs and growth promoters involves a risk of the development of resistant microorganisms, and too little is as yet known about the possible effect of manure on cultivated land to assess veterinary drugs and growth promoters in relation to pesticides. Some of the leachable growth promoters that are used have properties that are reminiscent of pesticides, but their behaviour in the soil has not yet been sufficiently clarified to assess a possible risk of leaching to the groundwater.

- A number of naturally occurring substances are to a limited extent used as pesticides. The substances in question are relatively easily degradable, so their action time is short, but the sub-committee finds that there is in principle no difference between these substances and synthetic pesticides. The sub-committee concludes that, compared with natural substances, pesticides have a considerably greater potential for environmentally harmful effects because of the way they are used, relatively low degradability and their chemically determined, intensified mode of action. With respect to human health, the sub-committee finds that some naturally occurring constituents of plants can present a risk and that, for example, in connection with “Novel Food” products or GMO products, they should be subjected to a risk analysis in line with pesticides.

The sub-committee’s recommendations concerning proportionality

In view of the widespread occurrence of small quantities of many chemicals in all compartments, the effects of which should perhaps be added together to give a realistic picture, the sub-committee recommends, in accordance with the precautionary principle, that the total chemical load on the environment be reduced as much as possible in order to reduce the exposure of both humans and the environment.

Conclusions concerning coformulants

The sub-committee has, in particular, assessed the coformulants that are added to pesticide formulations. These coformulants are not covered by an authorisation scheme of the same scope as in the case of active pesticide ingredients. Coformulants are a very large group of substances, which may vary between different batches of a product or between different types of the same product. The coformulants are normally less harmful to the environment and health than the active ingredients. However, they often occur in large concentrations and some of them are harmful to the environment and/or health, e.g. acutely or chronically toxic substances. Some of the substances can thus be more harmful to the environment or health than the active ingredient to which they are added. A few of them are included in the Danish Environmental Protection Agency’s Blacklist.

The sub-committee’s recommendations concerning coformulants

The sub-committee recommends that the authorisation scheme be expanded so that the requirements concerning coformulants approach the requirements made concerning active ingredients. This includes banning all carcinogenic substances. However, the coformulants are also used for other purposes than pesticide formulations. The regulations governing the use of these substances should therefore be generally tightened for all applications.

Conclusions concerning natural substances compared with pesticides

All plants contain varying concentrations of toxic substances to protect themselves against attack by viruses, microorganisms and herbivores. Most herbivores eat only specific food plants. Humans thus eat only a limited number of plant species – less than 100 – that have been selected and used for many generations as components in human food. Therefore, even though crop plants contain substances that have a toxic effect on certain other groups of organisms, in most cases they produce very little toxicity in humans. Unlike pesticides, the toxic natural substances are inside the plant and only exhibit their toxic effect when other organisms approach the plant, touch it or eat it. Pesticides, on the other hand, are normally dispersed over large areas of land, with the aim of knocking out pests – often with around 90% effect in the entire area. All organisms in the area in question are thus exposed to and hit by the pesticide or later eat plant parts containing pesticide residues. Synthetic pesticides usually contain chemical structures that are seldom found in nature. The physical and chemical properties of the molecule, and thus its toxicity, are thereby changed. This effect depends particularly on changes in the direction of lower degradability, greater persistence, changed solubility and increased penetration in membranes.

Recommendations concerning pesticides compared with natural substances

The sub-committee recommends that pesticides continue to be treated as a separate group of chemical substances – firstly because they have an inherent, characteristic and often powerful biological effect; secondly because they are spread over a large or small continuous area in effective doses; and thirdly because they often contain xenobiotic chemical structures. The way pesticides are used and their inherent properties together mean that they differ, environmentally, from “natural substances”.

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Annex 1

Data required for authorisation of pesticides

When application is made for authorisation of pesticides, the applicant must supply the data, with appurtenant analyses, specified in Annexes 5.1 and 5.3 to Ministry of Environment and Energy Order No. 241 of 27 April 1998 on Pesticides. For substances that are new in the EU (i.e. for which application is made after 15 June 1993), the data requirements for the active ingredient have been slightly expanded, and for these pesticides, too, more information is required concerning the formulated products. That is, however, of no relevance in this context because it concerns only a very limited number of substances.

In the environmental area, data are required concerning some of the active ingredient's physical and chemical properties, its "fate" in soil and water and its toxicity to a number of aquatic and terrestrial organisms.

The minimum information required concerning the active ingredient is listed below.

- Physical and chemical data (that are of relevance to the environmental risk assessment): solubility in water and organic solvents, vapour pressure, hydrolytic stability and distribution coefficient n-octanol/water.

- Metabolism and degradation in soil: photolysis on ground surface, rate of degradation in three types of soil under aerobic conditions, metabolism, rate of degradation at two temperatures and at two dosages, dependence of rate of degradation on water content, rate of degradation in sterile soil and under anaerobic conditions, evaporation from soil (calculated on the basis of the physical and chemical properties).

- Mobility in soil: leaching tests in soil columns with the active ingredient, performed with three different types of soil, leaching tests in soil columns with aged active ingredient, performed in one type of soil, adsorption and desorption tests.

- Metabolism and degradation in water: BOD value and BOD/COD ratio, adsorption to organic material (plankton and sediment), accumulation in sediment (BOD = Biological Oxygen Demand; COD = Chemical Oxygen Demand).

- Test for bioaccumulation in aquatic ecosystems if the distribution coefficient n-octanol/water is greater than 1000.

- Toxic effect on aquatic organisms: acute toxicity in fish (2 species), acute toxicity in daphnia (1 species), reproduction test on daphnia (1 species), acute toxicity in algae.

- Toxic effect on terrestrial organisms: acute toxicity in worms, effect on soil respiration, effect on ammonification, effect on nitrification, effect on asymbiotic N-fixation and, in some cases, effect on symbiotic N-fixation.

- Toxic effect on birds: toxicity caused by food intake in species with different food resources (2 species), reproduction test (1 species).

The following toxicological data for assessment of effects on humans must be provided for the active ingredient:

1) Acute toxicity
Toxicity with a single dose of the substance. Measured as LD_{50} (the dose needed for half the animals to die). Must be tested in separate tests with swallowing, skin contact and inhalation.

2) Local irritation
Skin irritation, eye irritation and allergenic properties in connection with skin contact must also be investigated.

3) Sub-chronic toxicity
Toxicity with daily dosing for 3-6 months. Two tests are required: one on rats (of 3 months duration) and one on non-rodents (e.g. dogs) of 3-6 months duration.

4) Chronic toxicity
Toxicity with long-term dosing. Chronic toxicity and carcinogenicity are often combined in the same 2-year test. Two tests are required on different species of mammal. If dogs are more sensitive than rats, a separate 1-year toxicity test on dogs is required.

5) Carcinogenic effect

6) Mutagenicity
The ability of the substance to cause damage to the genetic material. Must be tested in test-tube tests (in vitro) and in animal tests (in vivo). If the substance is found to be positive in the above tests, it must be tested in gametes.

7) Tests on impairment of fertility
Multi-generational tests; the possible ability of the substance to reduce fertility must be tested by feeding with the substance through several generations.

8) Teratogenicity tests
The ability of the substance to damage the foetus during pregnancy must be tested in two species of mammal. The pregnant dam must receive the substance by tube in the most sensitive period of the pregnancy.

9) Neurotoxicity
Particularly for the so-called cholinesterase inhibitors.

10) Toxicity of any metabolites, degradation products and impurities.

11) Metabolism in animals
The substance’s absorption, distribution, degradation and elimination.
12) Toxicity to humans
Experience gained during, for example, production.

The following toxicological data are required for the product:

1. Acute oral toxicity
2. Acute toxicity through the skin
3. Acute toxicity when inhaled
4. Skin irritation
5. Eye irritation
6. Other toxicological data for the product
7. Toxicological data for non-active ingredients.

The above data have normally been obtained by means of laboratory tests. In cases in which the laboratory tests indicate that the substance is problematical, supplementary laboratory tests or tests under semi-field or field conditions have in some cases been carried out. Typically, field tests have been carried out concerning degradation of the active ingredient, semi-field tests concerning mobility (lysimeter tests) or mesocosm tests concerning toxicity in aquatic organisms.

The quality of the tests and the relevance of the data to Danish conditions are evaluated before the data are used in the risk assessment.

Annex 2

The general rules for risk assessment of environmental impacts and classification of health impacts

1 Environmental impacts

1.1 Risk of persistence, mobility and bioaccumulation
With respect to properties relating to persistence, mobility and bioaccumulation, it is judged whether there is a risk of the prescribed values for whether an product can be directly accepted being exceeded in the given conditions of use. Initially, the available laboratory tests are assessed. If, on this basis, it is judged that there is no risk of use of the product resulting in the acceptance values being exceeded, the product is regarded as acceptable without further tests. If, on the other hand, the acceptance values are exceeded, the product cannot be authorised without lysimeter tests or field tests that – assessed on the basis of a "realistic worst case" situation with respect to used dosages, conditions of use, climate, etc. – prove that use of the product does not imply an unacceptable risk of persistence, leaching to the groundwater and bioaccumulation.

1.2 Risk of effects on aquatic and terrestrial organisms
For the impact area, the risk assessment is based on the so-called quotient method, in which the relationship between toxicity and exposure is calculated, cf. The Uniform Principles, EU's Council Directive 97/57/EEC.

1.3 Toxicity
It is judged whether the exposure exceeds the toxic level with a ≥1 x (un)certainty factor of between 5 and 1,000, depending on the organism and on whether the toxicity is acute or chronic.

The higher the quotient, i.e. the lower the exposure and/or toxicity, the lower the risk from use of the substance.

The exposure (PEC = Predicted Environmental Concentration) is estimated on the basis of the intended use with respect to dosage, method of application, time of use, plant cover, etc.

The (un)certainty factor is intended to cover the variation in sensitivity between species, extrapolation from acute to chronic effects and from laboratory to field, etc.

The risk assessment is performed in stages. The first stage is a rough estimate of PEC. If this concentration lies much (corresponding to at least the (un)certainty factor) below the effect concentrations achieved in the laboratory, the pesticide is regarded as acceptable with respect to the area investigated without further analyses. If, on the other hand, the effect concentration is close to PEC, one moves to the next step, in which the PEC calculation is refined so that PEC again approaches a "realistic worst case". In cases in which a "realistic worst case" PEC and the concentration that produces toxic effects are close to each other (are less than the (un)certainty factor), the product cannot be authorised without relevant semi-field and field tests of effects on aquatic and terrestrial organisms that prove that use does not imply unacceptable effects on aquatic or terrestrial organisms.

As an example, in the analysis of the risk to aquatic organisms, it is initially assumed that watercourses are directly sprayed. If the acceptable limit values are exceeded, PEC is modified on the basis of an assumption that a certain distance to watercourses is maintained. In addition, the degradation of the substance is included in the case of chronic effects and several successive applications. If the acceptable limit values are still exceeded, different forms of field studies, typically mesocosm tests are included in the analysis. In such cases, the safety factor may have to be reduced because far more species will usually be represented in field studies and because field studies mean more realistic exposure conditions than laboratory tests. The field studies may mean that substances judged on the basis of laboratory tests to be unacceptable in relation to the prescribed acceptance level are deemed acceptable on the basis of field studies.

The conclusion of the Danish review in 1997 is that all pesticides authorised since June 1993 fulfil the minimum requirements set out in “Framework for Assessment of Plant Protection Products”. Products reviewed before June 1993 are assessed in relation to the “criteria” applying at that time, which are largely based on the substances’ inherent properties.

2 Classification of health impacts

2.1 Classification of carcinogenicity, mutagenicity and reproduction toxicity

Classification of substances for the above-mentioned effects are generally based on the following considerations:

- What properties does the substance have (qualitative)?
- How well documented are these properties?
- Are the properties of relevance to humans?

There are three categories for carcinogenicity, impairment of fertility and mutagenicity. The categories differentiate between the reliability of the *evidence*. The classification is therefore based mainly on qualitative assessments and evidence. For these three effect groups, the potency of the substance is *not* specifically included in the assessment to decide the category in which it is to be classified. In other words, the highest dose that does not cause adverse effect levels (NOAEL) is not included in the assessment. However, in the case of substances that are toxic for reproduction , if the effects are only seen in very high dosages, this must be taken into consideration when assessing whether the substance should be classified at all for the effects. Reproduction toxicity covers both damage to the foetus and impairment of fertility.

Category 1	*Carcinogenic (Carc, Cat1), mutagenic (Muta, Cat 1) or reproduction toxicity (Rep, Cat1).* • For all three, there must be epidemiological studies showing the effect of the substances. That is very rare in practice, particularly for mutagenicity, because it is often very difficult to draw any clear conclusions from the results of such studies.
Category 2	*Carc, Cat2.* • Substances that are clearly carcinogenic in two animal species or substances that are clearly carcinogenic in one animal species, supported by mutagenicity or structural similarities to other substances that are classified as carcinogenic in category 1 or 2. *Muta, Cat2.* • Substances that are clearly mutagenic in gametes *in vivo*. *Rep, Cat2.* • <u>Damage to progeny</u>: Substances clearly shown to damage the progeny in one or more animal species and where the effect is not secondary to the effect on the dam. • <u>Impairment of fertility</u>: Substances shown to reduce fertility in animal tests, supported by documentation for the mechanism of action or structural similarity to other substances that are classified as being toxic for reproduction in category 1 or 2.
Category 3	*Carc, Cat3.* • Substances suspected of being carcinogenic, but where the evidence is not sufficient to classify the substance in either category 1 or category 2. This may be because the substance has not been sufficiently investigated, but the data that are available indicate that the substance is carcinogenic. A substance may also be classified in category 3 when it has been sufficiently investigated, but where the data are ambiguous. In these cases there will normally be no sign of mutagenicity. Substances that are carcinogenic through a hormonal mechanism will not normally be classified higher than category 3. This is because hormonal effects are generally assumed to be dose-related. In other words, there exists a threshold dose, which means that if one is exposed to less than this dose, there is no risk of developing cancer. *Muta, Cat3.* • Substances that are mutagenic in *in vivo* systems on somatic cells (i.e. all cells that are not gametes), but where there is no evidence of effects in gametes. If the substance is only positive in *in vitro* tests, it will normally not be classified unless no *in vivo* tests at all have been performed and the *in vitro* results are very convincing and the substance also has points of similarity with other substances with known damaging effect on the genetic material. *Rep, Cat3* • Damage to progeny: Substances that are teratogenic but where the effect is not clear or where the damage is doubtful. There can be

problems in judging whether the damage is a secondary effect of toxicity to the dams.

- Impairment of fertility: Substances that reduce fertility without this being a secondary effect of general toxicity, but where the results are unclear. For example, the Danish Environmental Protection Agency has classified substances in this group if there have been tests that show that the substance inhibits testosterone synthesis or destroys the sperm-producing tissue, even though no direct effect has been seen on fertility in a multi-generational test (which is the test in which one normally sees effects on fertility).

2.2 Other long-term damage (chronic toxicity)

For chronic toxicity, a substance can be classified with the phrase R48 (Danger of serious damage to health by prolonged exposure) if **serious** long-term effects have been seen. To this, another phrase is added, describing partly the administration path (swallowing, skin contact or inhalation) where the substance caused the observed effects and partly the dose level. In other words, there is primarily a *qualitative* assessment, which leads to a conclusion about whether the long-term effects observed are serious enough for classification. The lowest effective dose (LOAEL = Lowest Observed Adverse Effect Level) is then taken into account in the final assessment of whether the substance must be classified, since it is a requirement for classification that the effects occur at a dose below a specific level. LOAEL is also included in the assessment of the phrase to be affixed to R48. For example, one can have a classification that is called R48/22: “Harmful: danger of serious damage to health by prolonged exposure if swallowed” or R48/25: “Toxic: danger of serious damage to health by prolonged exposure if swallowed”, with the latter indicating a more potent substance than the former, both classifications being based on tests in which the substance is administered by mouth.

When classifying for chronic toxicity, the authorities naturally also assess the evidence, but there are not differentiated groups for more or less well-documented effects.

R48 is a classification that is used in connection with a wide range of long-term effects – for example, anaemia, cataract, reduced immune defence and damage to the central nervous system (CNS). In the case of CNS, specific studies are not required today because there are no established guidelines in this area. One may see certain signs of CNS damage from long-term studies, but cannot determine a specific effect with any certainty. Effects that are not regarded as “serious” and that are therefore not classified with R48 include changes in organ weights without signs of functional disturbances, species-specific effects and small changes in biochemical parameters that are of doubtful toxicological significance.

A substance can also be classified with R39 (Danger of very serious irreversible effects) if *irreversible damage* has been observed from *a single* exposure.

The classification rules used in Denmark are used throughout the EU. The rules are regularly revised and expanded and are regarded as a reasonable and usable system for describing the inherent toxicological properties of chemical substances.

3 Short-term risk to health

Products with moderate and high acute toxicity are classified as Toxic or Very toxic. These classifications include toxicity if swallowed, if in contact with skin or if inhaled. The effects are measured by means of the LD_{50} method (the dose that kills 50% of the animals when administered by the path in question). The Executive Order on Pesticides includes minimum limits for LD_{50} for classification as Harmful, Toxic or Very Toxic for both solids and liquids. Caustic products are classified with R34 (Causes burns). If the substance is not caustic but still causes serious eye damage, it is classified with R41 (Risk of serious damage to eyes).