The Bichel Committee 1999

Report from the Sub-comittee on Agriculture

Miljøstyrelsen
Miljø- og Energiministeriet

Preface

The Sub-committee on Agriculture, which is part of the Bichel Committee, was appointed in autumn 1997 to assess the agricultural consequences 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 four background reports cover: the consequences for environment and health, production and economy, the consequences for the economy and employment, the legal possibilities of phasing out the use of pesticides and, lastly, the overall consequences of a total switch to 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 the total or partial phasing-out of pesticide use and of a total restructuring for organic production.

The sub-committee has proposed cultivation systems for agriculture in connection with a total and partial phasing-out of pesticides and has found that a total phase-out or very limited use will require major changes in crop rotations. Even with an adjustment of the regimes, there will be a substantial reduction in the yield for many crops – and particularly for special crops. Within market gardening and fruit growing, the knowledge base is weaker than for farming proper, and this has made it far more difficult to carry out analyses in this sector.

The sub-committee has analysed a number of alternative, non-chemical methods for combating diseases, pests and weeds. Several of these methods already have a considerable potential for use, while others require further research and development to become real alternatives.

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

Arent B. Josefsen

5 March 1999

Summary

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.

Mandate

The mandate for **the Sub-committee on Agriculture** stipulated that the committee evaluate scenarios for total and partial phasing-out of pesticides and consider the consequences of restructuring for organic farming. In particular, the Sub-committee on Agriculture was to:

- illuminate alternative, non-chemical methods of controlling plant diseases, pests and weeds
- propose cultivation systems for agriculture under a total or partial phase-out of pesticides
- evaluate the consequences of restructuring for organic farming
- consider the possibilities of maintaining production of cattle and pigs
- make the greatest possible use of experience from existing organic production in the agricultural sector
- identify any areas in which a phase-out would give rise to particular problems
- propose solutions to those problems – e.g. through research and development.

A description of restructuring for organic farming is provided in separate reports examining cultivation-related, economic, employment-related and environmental factors and will therefore not be dealt with in this report.

Choice of scenarios

The sub-committee has specifically described agricultural production as it is today, compared with a total phase-out and 3 scenarios for partial phasing-out of pesticides. Intermediate scenarios were specified by the main committee:

- 0-scenario with no use of pesticides
- 0+scenario, in which pesticides are allowed to enable compliance with the present phytosanitary rules (almost total phase-out)
- +scenario, in which pesticides are used with a view to avoiding the biggest losses in yields (limited use)
- ++scenario, in which pesticides are used so that economic losses caused by pests are generally avoided (optimised use).

The scenarios are based on a division of Danish farms into 12 types, each of which is assessed separately. Two of these farm types cover farms with less than 20 ha and have not been analysed in detail. In the case of market gardening and forestry, the principal forms of production have been analysed. Within farming, a short description is given of each scenario separately, while total phasing-out and partial phasing-out within market gardening and forestry are dealt with together.

Agronomic and optimized crop rotation

In the different scenarios the sub-committee has worked with "agronomic crop rotations" and "optimised crop rotations". The agronomic crop rotations come only from the Sub-committee on Agriculture's work, while the optimised crop rotations have been developed and used in the Sub-committee on Production, Economics and Employment's analyses. However, both these types of crop rotation contain agronomic and economic elements. The contribution margin has not been optimised in the agronomic crop rotations, but has been in the optimised crop rotations, which, however, also contain a large number of constraints based on agronomic considerations. In the agronomic crop rotations, the production of special crops is retained, while this is not the case in the optimised crop rotations. In the optimised crop rotations it is permissible, where there is no animal husbandry, to have up to 30% set-aside, which is competitive with several other crops.

The Sub-committee on Agriculture has based its analysis of total and partial phasing-out of pesticides primarily on yields and production losses in the different crops and crop rotations. For the farm types, however, figures are presented for contribution margin II per ha as the average of 10 farm types. The economic consequences of production losses as a result of attack by pests have been analysed and calculated by the Sub-committee on Production, Economics and Employment.

The basis used for assessing the need for control, in both present-day production and the intermediate scenarios described, has been an evaluation of whether, from existing knowledge, it pays to treat the individual pests. This means that at least the cost of the treatment must be covered.

Present-day agricultural production

Crop Distribution

In Denmark, about 2.7m ha land are under cultivation. More than 50% is used for cereal production and about 35% for winter cereals. Grass and greenfeed account for about 20%, while special crops, beets, potatoes, rape and pulses together account for 13%. In the last few years, the total set-aside acreage has varied between 5% and 8%.

The crop rotations and choice of crops used at conventional farms today are largely a result of the fact that pesticides are available. Agricultural production and pesticide consumption generally depend on the relationship between treatment costs and crop prices.

Weed control

In conventional farming, dicotyledonous weeds in all crops are controlled with herbicides. In the parts of the country with the biggest production of winter cereals, both monocotyledonous and dicotyledonous weeds are controlled. Herbicides are used mainly for sugar beet and mangolds, which are sprayed 2-3 times. Couch grass is treated every 3-6 years in the crop rotation, typically every four years on the same acreage. Soil preparation (mechanical weed control) is rarely if ever used for controlling weeds in cereals. In the case of winter rape, a move has started towards sowing in widely spaced rows (5% of the acreage in 1998/99) and hoeing to remove weeds.

Disease control

At least 85% of cereal seed is treated with dressing agents to prevent seed-borne fungal diseases. Cereals are sprayed frequently to prevent leaf diseases. Wheat fields are sprayed about twice, while about half the acreage with spring barley is treated against leaf diseases, depending on the pressure of disease and the resistance of the varieties used. In peas and rape, control measures against fungal attack are only needed approximately every 10 years. In potatoes, intensive control of potato blight is practised – with approx. 5-6 applications. Potatoes are dressed against black scurf to ensure good establishment and avoid loss of yield.

Pest control

A number of crops are sprayed with pesticides. Rape is sprayed once or twice every year. On average, about one quarter to one half of the acreage with wheat and spring barley is sprayed against aphids. Peas are sprayed with pesticides approx. every 18 months, and fields with beets are sprayed twice a year against aphids and other pests or a combination of seed dressing and one spraying is used.

Growth regulation

Growth regulators are used on about 10% of winter cereal and in the production of certain varieties of grass seed. Growth regulation of winter wheat in conventional farming is believed to be on the way out because varieties with good stem strength are now being grown and less nitrogen is being used. There is still deemed to be a need for growth regulation in certain varieties of rye and grass-seed species.

In the case of both plant diseases and pests there is a very considerable variation in the need for control and in the percentage losses from year to year. For weeds there is a more uniform need for control to keep down the general pressure of weeds.

Assumptions for description of present production

The evaluation of present production is based on yields from 1993-96 and the treatment frequency index (TFI) from 1994. The farming scenarios are based on a breakdown of Danish agriculture into 12 dominant types of farm on the basis of 13,000 operating accounts from 1995-96. These 12 types of farm can be scaled up so that they are in accordance with current crop figures from Danmarks Statistik. The 12 farm types provide a generally comprehensive picture of the factors to be clarified but do not, of course, reflect all existing farm combinations.

Pattern of pesticid consumption

Herbicides account for around two thirds of all pesticide treatment, insecticides for 10-15%, fungicides for around 20%, and growth regulators for 2-5%. The proportion of sprayed land at the different types of farm varies between 60% at dairy farms and 90% at pig farms. The large proportion of unsprayed land at dairy farms is due to the large areas of grass.

Approximately 15% of all spraying is done in the autumn, while more than 65% is done in April, May and June. Owing to the large proportion of land used for cereals, around 65% of all spraying takes place in cereal crops. The intensity is generally greatest in special crops. Most spraying is done on clayey soil, where the greatest specialisation in arable farming is to be found. The sub-committee has thus found an average treatment frequency index of 3.3 in Storstrøm County, where there is a large proportion of sugar beet, compared with 1.9 in Ringkøbing County, where there is a large proportion of dairy farms. There is a bigger consumption of pesticides at the largest farms, due in part to the land use at these farms.

Denmark contra EU

Pesticide consumption is low in Denmark compared with many other EU countries. Sweden and Finland, however, use even less than Denmark. The need to use pesticides varies considerably from country to country. The variation is due to differences in the crops grown, crop rotations, climatic conditions and a considerable variation in the pressure of diseases and pests. The consumption of active ingredients in different countries varies widely, from less than one kg/ha in Finland and Sweden to more than 10 kg/ha in the Netherlands and Belgium. Only limited information is available on the precise pattern of pesticide consumption in different crops and only Denmark calculates the consumption in terms of treatment frequency indices.

0-scenario in agriculture

Farm evaluations

In the 0-scenario, crop rotations have been set up for 10 different types of farm. The direct production loss in the crop rotations compared with present production would typically be between 10 and 25%. For dairy farms on sandy soil, restructuring would cause only limited losses, while the biggest losses would be suffered by specialised arable farms, which have a substantial production of, for example, seed, potatoes and sugar beet. It would presumably be impossible to maintain these special productions in the event of a total ban on pesticides.

Restructuring of farms

A 0-pesticide scenario would require considerable restructuring of farms compared with present production. For example, it would be necessary to use crop rotations with a substantially smaller proportion of winter cereals (max. 40% of the crop rotation) to reduce grass weed problems. Clover grass and wholecrop would replace mangolds and maize. To maintain the requirements concerning 65% green crops, second crops have been inserted in the scenario in connection with the cultivation of spring-sown cereals. The scenario also includes a large number of cultural practices that would be needed to minimise pest problems.

It is estimated that there would be losses on all crops as a consequence of cultivation without pesticides. The losses have been estimated assuming the use of alternative methods to minimise losses caused by pests. The annual production losses caused by pests are expected to vary considerably, thereby reducing the existing stability of cultivation. It must be expected that some productions with big requirements concerning purity and freedom from disease would have to be abandoned.

There is generally considerable uncertainty in the estimation of percentages in a 0-pesticide scenario due to significant differences in the epidemiology and population dynamics of the pests. At the present time, there is thus only very limited research documentation on which to base an evaluation of a 0-scenario.

Yield losses due to pests in individual crops

The losses for the individual crops have been broken down between different pests. The total average production losses for different crops would vary between 3% and 50%. For potatoes, the loss as a consequence of potato blight, for example, would be around 38%, while for seed grass, it is estimated that the net yield would be halved owing to weed problems and problems with removing weed seed. For wheat, the total loss is estimated at 27-29% as a result of a loss of 7-9% from leaf diseases, 14% because of weeds and damage to the crop during harrowing, and around 3% from pests, while other factors, such as postponing the sowing time and use of resistant species, give a 7-8% loss. It is estimated that grass and winter rape, which would only be very slightly affected, would have the smallest losses. For the individual crops a maximum loss has also been calculated, based on a pest causing particularly heavy losses, which happens in some years.

If seed-dressing products for controlling seed-borne diseases were phased out, the risk could arise of an uncontrollable and unforeseeable proliferation of seed-borne diseases and great concomitant losses. In fields with severe attacks of stinking bunt, the crop would be worthless as either animal feed or human food. Owing to the uncertainty concerning these losses, the sub-committee suggests that dispensation be granted for control of seed-borne diseases in the early generations of seed. The calculated yields in the 0-scenario are based on an assumption of dispensation. If seed-dressing of the first generations were retained up to and including C1, followed by a need assessment of C2, the dressed area could presumably be reduced to less than 10% of the present consumption.

Economic consequences in agronomic crop rotations

Contribution margin II per hectare, which includes yield losses/yield gains and changed costs, has been used to assess the success of the farms. Assuming that the present proportion of special crops is maintained, contribution margin II at the farm types shows a total reduction of 4-8% for dairy farms on sandy soil, 31% and 48%, respectively, for arable farms on sandy and clayey soil, and 50% and 93%, respectively, for arable farms with seed production and sugar beet, while the reduction for arable farms with a big potato production would be 66% (table 2).

Consequences for optimised farms

Besides the crop rotations proposed with a view to reducing the level of pests and maintaining the present acreage with special crops, an economic optimisation model has been used to arrive at some agronomically and economically optimised types of farm. In a 0-scenario, these farms would almost totally phase out special crops. This accords well with the loss levels described in these crops, where one can expect high costs for weed control and losses as a consequence of, for example, mould, mildew and blight attacks. In a 0-scenario, special crops would thus naturally be out-competed by other crops. Because of the substantial losses in many crops, the economy of the farms would be so impaired that set-aside would become advantageous. The proportion of set-aside acreage has been put at a maximum of 30% at pure arable farms, which do not have to consider handling of liquid manure and harmonisation rules. In the agronomic 0-scenario, it is proposed that some rape and peas be included in many crop rotations. These crops would not be found competitive where economic optimisation was practised, but would be replaced by rotation set-aside, which is also assigned a previous-crop value. Spring-sown cereals would be favoured at the cost of winter cereals. Economic analyses of contribution margin II for these optimised farms, where there are largely no special crops, show a total reduction of 21-24% for dairy farms on sandy soil, 26 and 34%, respectively, for arable farms on sandy and clayey soil, and 35% and 39%, respectively, for arable farms with seed production and sugar beet, while the reduction for arable farms with a large production of potatoes would be 51%. In the case of potatoes, only a small production of Danish ware potatoes would be retained. It is assumed that some consumers prefer Danish potatoes and would be willing to pay a higher price for them.

Main problems in a 0-scenario

The success of a 0-pesticide scenario would depend greatly on whether the current quality requirements concerning, for example, seed, seed potatoes, starch potatoes, and similar crops, could still be met. For crops grown in rows, manual weeding would be necessary until new methods had been developed. Whether it would be possible to procure sufficient manpower for such seasonal work is another open question and one of the factors that would determine whether sugar beet production could be maintained. The lower yields and, in some cases, larger additional costs for e.g. weeding and drying, must be judged in relation to the possibility of achieving a higher price for crops that have not been treated with pesticides.

The stated percentages in the 0-scenario are deemed to be relatively optimistic for the following reasons:

- The expected losses due to weeds have been put at half those observed at organic farms today. On the other hand, a larger loss has been added as a consequence of crop damage in connection with mechanical control.
- It is not known whether disease epidemics would develop more quickly and be more widespread without control measures.
- Adjustment has not been made for those situations in which the assumptions made do not hold. This applies, for example, to certain species of weed on organic soil, which are difficult to control.
- Allowance has not been made to any great extent for the fact that production management would not be optimal in all situations.
- Mechanical weed control generally requires a big machine capacity and dry weather. Problems might therefore arise with getting fields harrowed at the times when the crop is least affected and the weeds are mostly easily controlled.
- Account has not been taken of the fact that the latest fungicides (strobilurines) make it possible to harvest a bigger yield than those traditionally used for the past 15 years.

Unused method

There are several unused alternatives to chemical control that could improve the cultivation conditions in a 0-pesticide scenario. The most obvious of them are better utilisation of disease resistance and broader distribution and further development of methods of mechanical weed control. Adjustments to crop rotations would have a powerful effect when pest prevention becomes more important than direct pest control. It could thus prove necessary to change the choice of crops considerably to cope with weed problems. The sub-committee believes that the demand for alternative methods would, in itself, promote and stimulate the development of alternative methods.

Total production figures

The total production figures in a 0-scenario have been assessed by the Sub-committee on Production, Economics and Employment on the basis of a socioeconomic model. With respect to the production of sufficient feed units to maintain Denmark's present livestock production, the 0-scenario is based on sufficient arable farming at dairy farms to maintain the necessary production of feed units. Account has not been taken of whether arable farmers could receive liquid manure from livestock producers in a 0-scenario when the proportion of set-aside acreage would rise and cereal production fall. Nor has consideration been given to the question of whether sufficient straw could be harvested to fulfil present requirements. Total cereal production would fall by about 30% in both the agronomic and the optimised 0-scenario, which would make it necessary to import cereals to maintain the present pig production (table 3). In the agronomic scenario, production of both potatoes and seeds would be approximately halved, while production of both rape and peas would rise by around 30%. This rise would reduce the need for bought-in supplementary fodder. In the economically optimised scenario, this production would be largely replaced by set-aside and both potato production and sugar beet production would be reduced by more than 90% and seed production by 60%.

Intermediate scenarios in agriculture

The Sub-committee on Agriculture has considered three specific intermediate scenarios: a 0+scenario (almost total phase-out), a +scenario (limited use) and a ++scenario (optimised use). The effects have again been evaluated for 10 different types of farm. In addition, the sub-committee has provided input for calculations of economically optimised farms carried out by the Sub-Committee on Production, Economics and Employment for the + and ++scenarios. The main figures for the 0 and intermediate scenarios are given in tables 1-3.

The 0+-scenario

The 0+scenario (almost total phase-out) is a scenario in which the only aim is to comply with current quality requirements concerning plant health (phytosanitary legislation). This means seed-dressing of cereals for all early generations (to and including C1) and where a need analysis shows that seed-dressing is necessary in the C2 generation (60,000-100,000 ha), spraying of about 70,000 ha with seed production and seed potatoes, together with areas infected with wild oat. Spraying with pesticides would also be permitted in greenhouse and nursery cultures in order to comply with rules for export and home sale. The treatment frequency index would be very low in a 0+scenario. For most farm types it would be almost 0, while at farms producing potatoes and seed it would still be less than 5% of the present level. Since the scenario lies very close to the 0-scenario, its economic consequences have not been analysed.

Table 1
Treatment frequency for pesticides in 3 scenarios, shown for 10 different farm types on sandy and clayey soil

Scenario	Present production, DIAFE*	Present production, Crop Rotation Group**	++scenario		+scenario	
			Opti-mised ***	Agro-nomic ****	Opti-mised ***	Agro-nomic ****
Clayey soil						
Arable farms	2.4	2.6	1.5	1.5	0.4	0.4
Pig farms	2.5	2.4	1.3	1.4	0.4	0.4
Beet production	2.8	3.1	1.8	1.9	0.7	0.7
Seed production	2.4	2.6	1.5	1.6	0.7	0.6
Dairy farms	1.9	1.8	0.9	1.2	0.3	0.3
Sandy soil						
Arable farms	1.8	2.3	1.0	1.2	0.3	0.3
Pig farms	1.9	2.0	1.3	1.2	0.3	0.3
Potato production	3.9	3.4	2.6	2.6	0.5	1.1
Dairy farms, ext.	1.4	1.3	0.6	0.8	0.2	0.3
Dairy farms. int.	1.0	1.2	0.3	0.7	0.2	0.2
Average *****	2.44	2.5	1.45	1.7	0.47	0.41

*DIAFE's accounting statistics 1995/96. The figures are excl. of set-aside and control of couch grass.
** Based on the Crop Rotation Group's work on average pesticide consumption from 1994. The figures are excl. of set-aside and control of couch grass.
*** Economically optimised scenarios are dynamic model scenarios. The figures include set-aside.
****Agronomically optimised scenarios are static scenarios with fixed crop rotations. The figures include set-aside.
***** Average figures for the whole of Denmark, excl. set-aside and incl. control of couch grass

The +-scenario

The +scenario (limited use) is a scenario in which continued use of pesticides is permitted for control of pests of critical economic importance. Altogether, the treatment frequency index in this scenario would be below 0.5, which is a reduction of at least 80% compared with present consumption. The treatment frequency index would vary between 0.2 for dairy farms on sandy soil to 1.1 for potato production on sandy soil (table 1).

This reduction depends on largely the same restructuring of production as described in the 0-scenario. The chosen input is deemed sufficient to maintain the present production of sugar beet, seed crops and potatoes. The scenario allows the use of pesticides where pests cause an average yield loss of more than 15%. The scenario thus does not calculate the consequences that could occur in a crop in individual localities and farms in some years because, for the vast majority of crops, it is not possible to predict how often such a situation would arise. The scenario also permits sufficient use of pesticides in outdoor vegetables, fruit and berries and ornamental greenery to maintain production (approx. 20,000 ha with horticultural crops; 35,000 ha with ornamental greenery).

Economic analyses of contribution margin II for the different types of farm in a +scenario show a total reduction of 0% for dairy farms on sandy soil, 15% and 36%, respectively, for arable farms on sandy and clayey soil, and 13% and 22%, respectively, for arable farms with seed production and sugar beet, while the reduction for potato producers would be 36% (table 2). For dairy farms, the losses in the ++scenario would be large compared with the +scenario, because mangolds and maize are retained in this scenario, but are not included in the 0 and +scenarios.

Table 2

Contribution margin II in DKK/ha for 10 different types of farm with and without economic optimisation of the 0-scenario and the intermediate scenarios + and ++. The percentage reduction in contribution margin is shown for the 6 different scenarios.

Types of farm	*CM2 CP agronomic* DKK /ha*	0-scenario agronomic	+scenario agronomic	++scenario agronomic	CM2 CP optimised DKK /ha**	0-scenario optimised	+scenario optimised	++scenario optimised
Clayey soil								
Arable farms	3231	-48	-36	-1	3420	-34	-19	+0
Pig farms	2781	-29	-24	-1	3070	-34	-18	+0
Beet production	4241	-93	-22	-1	4310	-39	-23	-1
Seed production	3903	-50	-13	0	4080	-35	-15	+1
Dairy farms	2217	-25	-4	-10	2580	-34	-26	-11
Sandy soil								
Arable farms	2254	-31	-15	0	2290	-26	-8	-1
Pig farms	2106	-22	-15	0	2320	-28	-16	+0
Potato production	3778	-66	-36	0	3860	-51	-15	+3
Dairy farms, ext.	2012	-8	+2	-11	2240	-24	-15	-8
Dairy farms, int.	1986	-4	+3	-17	2420	-21	- 14	-12

**Contribution margin II in present production is determined from the crop composition, which is based on the 13,000 operating accounts. The agronomic scenarios are assessed in relation to these contribution margins.*

*** The economically optimised contribution margins II are assessed in relation to an optimised, calibrated PC scenario determined by DIAFE.*

Table 3

Principal productions in 1000 hkg (crop units) for present production. For the scenarios, the change in production is given in %. The figures are based on figures from the economic analyses at farm level.

Crops	Present Danish statistics	0 optimised	0 agronomic	0+ agronomic	+ optimised	+ agro-nomic
Total cereal production	90584	-26	-31	-31	-16	-24
Winter crops for maturity	62522	-	-41	-41	-	-34
Spring crops for maturity	28062	-	-9	-9	-	-4
Coarse fodder prod.	39320	0	0	0	0	+2
Rape	2388	-58	+29	+29	-62	+30
Seed potatoes	1658	-100	-43	-13	-100	-13
Ware potatoes	3695	-92	-43	-43	-75	-11
Starch potatoes	9537	-100	-42	-42	-100	-13
Peas	2588	-58	+38	+38	-62	+50
Seed	557	-60	-50	-5	0	-2
Sugar beet	33592	-98	-16	-16	-22	-4

In the economically optimised +scenario, the treatment frequency indices would generally be of the same order of magnitude as in the agronomic scenarios, but the reduction in contribution margin for some of the farms would probably be smaller. The reduction would 14-15% for dairy farms on sandy soil, 8% and 19%, respectively, for arable farms on sandy and clayey soil, and 15% and 23%, respectively, for arable farms with seed production and sugar beet, while the reduction for potato producers would be 15%. Only in the case of potato producers would there be a significant difference between the treatment frequency index at farms based on agronomic considerations and economically optimised farms. This is because starch potatoes are only included in the agronomic scenario.

The ++-scenario

The ++scenario (optimised use) allows sufficient continued use of pesticides to avoid serious financial losses. The scenario assumes the use of all available damage thresholds and use of harrowing and other forms of mechanical control where these methods can compete with chemical methods. Crop rotations corresponding to present-day rotations are expected to be used. Economic optimisation would have to be practised but also optimisation with respect to minimising the use of pesticides. More hours would have to be spent than in present production on monitoring pests and using decision-support tools (about 1 hour/ha per year). If the present pattern of acreage were maintained, the total treatment frequency index in this scenario would be around 1.7, corresponding to a reduction of 31% compared with the treatment frequency index in 1997 and 36% compared with the treatment frequency index in the reference period 1981-85. In the ++scenario, which is economically optimised, the treatment frequency index would vary between 0.3 at dairy farms and 2.6 at arable farms with a substantial production of potatoes. Nationally, a treatment frequency index of 1.45 is assumed in the optimised ++scenario. It is assumed in the ++scenario that CMII remains at the present production level for all farms. The economically optimised scenarios show that there is a potential for improvement of several of the farm types' present contribution margins.

The intermediate scenarios, taken overall, would definitely help to reduce the losses in the 0-scenario. In the +scenario the yield losses would typically be reduced by 25-50%, while in the ++scenario they would be almost eliminated. To reduce the losses it would be necessary, particularly for diseases and pests, to continue using existing damage thresholds and warning systems and to develop additional damage thresholds and further develop some of the existing warning systems. Since we do not have reliable damage thresholds for all areas at present, and since many of the evaluations require long-term weather forecasts in order to provide a reliable prediction of the size of the yield loss, it is very difficult to indicate the treatments that can be relied on to reduce the losses significantly (>15%). To avoid attack by diseases, a considerable breeding effort would also be needed as "resistance" became ineffective.

Practical experience with intermediate scenarios

Experience from trials and farmers' groups (on plant protection) with intensive input from agricultural advisers shows that a treatment frequency index of about 1.3 for ordinary arable farming is realistic. There is no similar experience from research or practice with a treatment frequency index of around 0.5. This makes it difficult to judge how realistic it would be in practice to indicate precisely those treatments that avoid considerable losses - of 15-20% of the yield.

Present production and total and partial phasing out of pesticides in market gardening

Production within this segment is very varied and comprises many different cultures. The requirements concerning plant health within horticultural cultures are generally high and are governed by the EU's plant health directives, which determine which pests and levels of pests can be accepted. Today, there is a considerable degree of self-sufficiency in vegetables (60-90%), while the degree of self-sufficiency in fruit and berries varies between 25% for apples and 95% for cherries.

The supply of pesticides within the market gardening sector is already relatively limited because some pesticides are no longer marketed and/or have been removed in connection with a review. There are no reliable investigations that indicate pesticide consumption within market gardening. There is therefore considerable uncertainty concerning the exact consumption, which makes it difficult to analyse the scenarios.

Outdoor vegetables and garden seed

Present production

In 1997, 6,200 ha of land were used in Denmark for production of outdoor vegetables, plus 3,700 ha for production of green peas for freezing. Most of the Danish production of vegetables takes place at specialised farms, where vegetables account for most of the farms' turnover. Outdoor vegetables are a very intensive production, requiring a big investment. At harvest, the vegetables have a value of DKK 30-100,000/ha. According to the garden seed industry, about 3,000 ha are used for vegetable seed and about 200 ha for flower seed. The area has been increasing in the last years, particularly for spinach. Around 80% of the garden seed produced is contract production for foreign firms, which make requirements concerning both supply security and quality. The production of garden seed is a production that is part of ordinary arable farming because a large number of years have to pass between the seed-producing crops. A high contribution margin depends on a high-quality crop.

Generally speaking, more pesticides are used in the production of vegetables and garden seed than in most ordinary crops. The treatment frequency index is typically between 4 and 12, depending on the culture.

Yield losses in 0-scenario

The yield losses in a 0-scenario have been estimated on the basis of estimates from organic growers because there is no usable trial material on which to base a calculation of loss magnitudes. The reduction in yield in relation to conventional cultivation is approx. 30% for onions, 25% for cabbage, 15% for carrots and 35% for peas. Production of such vegetables as cauliflower and broccoli is expected to be very uncertain, which is reflected by the fact that there is only a very small organic production of these vegetables today. Bigger fluctuations in the production than today must be expected because of severe pest attacks in some years. The sub-committee thus judges that a 0-pesticide scenario would have very serious consequences for the production of outdoor vegetables and garden seed and that most of the production would be abandoned because the estimated yield losses and/or additional costs would so large that a very substantial premium would have to be obtained to maintain unchanged contribution margins. In organic production today, a premium of 30-100% is obtained, depending on the crop. Similar premiums are deemed necessary for products in a 0-pesticide scenario. For some crops, e.g. seed onions and carrots, weed control is of great importance to the size of the yield. Both mechanical and manual control can be used, but the costs are high and it is very uncertain whether sufficient manpower could be procured for weeding.

Partial phase-out in outdoor vegetables

In a scenario with partial phase-out, there are some areas in which there are not deemed to be alternative methods that could replace the chemical methods of controlling diseases and pests. Within weed control, there is a possibility of band spraying, which could reduce consumption by 60-70%. There would be a great need to develop rational and effective methods of controlling weeds in rows mechanically or by means of cover material.

For garden seed in particular, increased costs for weed control are expected to affect production. It is estimated that cultivation security would be considerably reduced as a consequence of a greater risk of pollution with weeds and fungal attack on the seed. Most of the production is exported and it is thought that it would be difficult to keep this market if the quality could not be maintained.

Production of fruit and berries

Present production

In 1997, 7,300 ha were used for production of fruit and berries. The area used for this production has been decreasing for a number of years. Production of pomes typically takes place at specialised farms, whereas blackcurrants, redcurrants, strawberries and sour cherries are grown to some extent by ordinary arable farmers. The total Danish production gives approximately 50% self-sufficiency. Fruit and berries are quality products and are covered by common EU quality rules. Production of fruit and berries requires substantial investments. The cost of establishment is around DKK 100,000/ha for pomes and DKK 10-15,000/ha for berries. The labour input is greatest for apples, strawberries and pears, mainly because these cultures are picked by hand. Most of the production goes to direct consumption. Sour cherries and blackcurrants are industrial products that are harvested by machine.

A considerable quantity of pesticides is used in the present production of fruit and berries. In particular, there is a large consumption of fungicides to keep fungal diseases down. Apples, for example, are sprayed with fungicides about 18 times during a growing season, mainly to keep down mildew, scab and storage diseases. These diseases affect the quality of the fruit. Danish apples are generally sprayed less than foreign fruit. They are not sprayed after harvesting and are not waxed or lacquered.

Yield losses in 0-scenario

The yield losses in a 0-scenario have mainly been estimated on the basis of estimates from organic growers because there is only a limited amount of usable trial material on which to base a calculation of the magnitude of losses. Assessed on the basis of interviews with organic growers, with the current quality requirements, the losses in apple production would be around 80% of the yield. The yield in unsprayed pears would be reduced by 40-80%, depending on the variety. For sour cherries, the losses, compared with the traditional production, are estimated to be about 30% (based on 3-year trials), for blackcurrants around 50% and for strawberries around 40%. It is thus estimated that production would fall considerably. With our present choice of varieties it would not be possible to produce apples that would keep until after Christmas. All else being equal, that would have major consequences for the quantity of fruit produced in Denmark. The consumers would increasingly have to buy foreign fruit. A big reduction would have to be expected in new plantings and in new players in the sector because cultivation security would be significantly reduced. Without substantial premiums, most of the fruit and berry production would not be profitable without the use of pesticides.

Partial phase-out

In a scenario with partial phase-out, there would be some pests for which there are not deemed to be alternative methods that could directly replace the chemical methods of controlling diseases and pests. The sub-committee believes that production could be maintained to a large extent if there were agents for controlling the pests in question. It would in particular be important to have agents for controlling scab in apples overwintering on the bough. Since the ban on agents containing copper in Denmark, organic producers have had increasing problems with this form of scab.

Weed control without herbicides is possible in fruit and berry cultures, but the solutions are considerably more costly. In some of the cultures it is possible to cultivate varieties that are resistant to diseases, but in the case of apples, for example, it often takes 10-15 years to change the assortment. There are various cultural practices that reduce attacks by diseases and pests, but many of them are rather costly (removal of old foliage, cutting off infected shoots, etc.) and would considerably increase production costs.

There would be an urgent need for rational and effective alternative methods to be developed for controlling pests and weeds if pesticides were to be phased out, and it could become necessary to change the quality rules for the goods produced.

Greenhouse production

Present production

The production of both vegetables and pot plants is very intensive and highly specialised. The production is spread over 780 production units with a total greenhouse area of about 500 ha. Production in greenhouses comprises a very large number of cultures – both edible cultures and ornamental plants. The main edible cultures are tomatoes, cucumbers and lettuce. The assortment of ornamental plants comprises more than 400 different cultures. In greenhouse vegetables there is very widespread use of biological methods of controlling pests. The chemical agents used in these cultures are mainly for controlling diseases, (grey mould, mildew, etc.). Slightly less than 20% of the producers use only biological methods of control, while about 50% use combined chemical and biological control, and the remainder only chemical control.

Biological control

In ornamental plant cultures there is some use today of biological control of pests. However, the chemical methods are still used against pests in cases in which biological methods are not available or are not deemed to be sufficiently effective or competitive. Chemical agents are also used when invasion from outside makes biological control impossible and at the pre-marketing stage in order to meet the current rules on plant health, which make requirements concerning 0-tolerance pests and pests that affect quality. Fungicides are used to control soil-borne diseases, which can be very destructive in the establishment phase of pot plants, but also to control mildew, grey mould, etc. Growth regulators are used several times during the production of most pot plants to get the desired size and flowering structure.

Greenhouse production comprises many cultures

Since production in greenhouses comprises a very large number of cultures – both edible cultures and ornamental plants – it is very difficult to generalise about the consequences of a 0-scenario. However, the sub-committee believes that a 0-pesticide scenario introduced over a short time horizon would have a serious impact on the present greenhouse production, which would, for example, be unable to meet the international requirements concerning pest control in connection with exports. The visual quality of ornamental plants is of great importance for their saleability. Compactness and uniformity are major quality requirements in the export markets and would be difficult to achieve without growth regulators. In addition, the presence of pests could mean direct rejection of plants – particularly in the case of pests covered by 0-tolerance rules.

The reduction in the production of ornamental plants would be between 0 and 100%, depending on the culture and the season. This big variation must be seen in the light of legislation that permits no more than 2% common pests. In some periods of the year that is impossible to achieve using only biological agents. For all main cultures, a ban on pesticides would have far-reaching consequences. The reason for putting the loss at between 0 and 100% is that there are very big variations from one season, culture and year to another.

Partial phase-out in greenhouses

In a scenario with a partial phase-out of pesticides, it is estimated that there would be a good possibility of continued production of vegetables because extensive use is already made of biological methods of control. Biological control can cope with pests most of the time, but a market garden is not static. Biological control regularly fails. Owing to changes in the surroundings the pest gains the upper hand,

and in such cases it is necessary to control it chemically to reestablish the balance between pest and useful animal.

With a partial phase-out there would also be a need for pesticides for combating disease. Here, it is particularly pythium in propagation plants, mildew on cucumbers and grey mould on tomatoes that cause problems. The last-mentioned can often be dealt with by swabbing sore faces and removing leaves. It is thought that problems with diseases could be reduced by better hygiene etc. However, that would imply increased use of disinfectants, which must also be regarded as a kind of control agent, even though they are not included among pesticides.

IPM-production

The current situation in Denmark is that most vegetables are produced in accordance with the IPM rules. In our opinion, this, together with the fact that few plant protection agents are available in Denmark compared with other EU countries, means that the present situation is already critical for stable production.

There is thought to be a big potential for expanding biological control of pests in ornamental plants. This means that chemical agents could in time mainly be reserved for situations in which biological control does not work and for meeting 0-tolerance and the 2% rule for pests. There would, however, probably be a need for growth regulators and fungicides for a 10-year period to ensure stable production.

Nursery cultures

Present production

Nurseries produce plants for fruit growing, hedgerows, forests, landscape care, gardens, parks and plantations. The plants are propagated from seed or cutting or by grafting and are grown to a size regarded as suitable for planting out. There is a very large number of species. About 300 species are normally cultivated and there is a very large number of varieties of each of them. Only limited information is available about the sector's production of individual cultures. There are more than 300 companies producing nursery cultures. The units are typically around 10 ha and 2,300 people are employed in the production. Turnover is in the region of DKK 480 million.

It is not possible to give precise figures for pesticide consumption in nurseries because the consumption varies greatly from culture to culture and year to year and from one company to another. However, pesticide consumption is high in all cultures. It is relatively low in avenue trees, evergreen plants for gardens and conifers for forestry (TFI = 4-7), at intermediate level in deciduous trees for forestry, and high in roses, fruit trees and fruit bushes and some ornamental plants (TFI = 10-14).

0-scenario

In a 0-scenario, the sub-committee estimates that large parts of the production would cease because the cultures would be destroyed or become so expensive that it would not be possible to compete with other countries. It is estimated that 30-50% of the production would disappear because of competition problems and problems with supplying plants without pests. Nursery-garden cultures are particularly delicate in the propagation phase. This applies to propagation from both seed and cutting. The sub-committee considers that, where insecticides and fungicides are concerned, the 0-scenario would have a devastating effect on the production of many cultures. Particular problems could be expected for fruit and ornamental trees, fruit bushes, roses and many other ornamental plants because, with our present level of knowledge, there are no alternatives to the present control agents. It would therefore be difficult to produce healthy plants from, for example, blackcurrants (blackcurrant bud gall mite) and apples (apple canker), which could mean an increased need for pesticides later in the process. In the case of herbicides, a 0-scenario would have a devastating effect on production, particularly in the propagation phase, because the additional costs for mechanical control, including hand-weeding, would be so considerable that it would be difficult to compete with other countries. Different quality rules would be required for all productions if pesticides were no longer used because the phytosanitary rules make specific requirements for 0-tolerance and 2% for different pests.

Partial phase-out

It is difficult to analyse the consequences of a partial phase-out for the cultivation of nursery cultures. The sub-committee considers that part of the nursery production could be sustained, even if pesticide consumption were to be reduced, but that this would demand the availability of products for controlling acute, severe pest attacks. For some cultures – roses, fruit trees and ornamental trees, fruit bushes and certain ornamental plants, serious problems must be expected, particularly with scab and spider mite. It is in the propagation phase, which often lasts 1-2 years, that it would be most difficult to do without control agents. The sub-committee considers that a change in cultural practices would to some extent help producers cope with weed control – for example, changing to cultural practices that facilitate mechanical weed control and using cover crops or organic materials, such as chipwood, to alleviate the weed problem. Many of these alternative methods are still at the development stage.

Present production and total and partial phase-out of pesticides in forestry

Present forestry production

In all, approx. 11% of Denmark is forested. The ratio between private and state-owned forests is about 3:1. It has been agreed that the forested area must be doubled within one tree generation, and afforestation of around 3-4,000 ha a year is therefore planned. Pesticide consumption in forestry accounts for approx. 1% of the total consumption. The pesticides are mainly used for weed control in connection with the establishment of cultures, afforestation and production of ornamental greenery.

Wood-producing forestry: A ban on the use of pesticides would mean a considerably longer culture phase, incomplete cultures and increased costs for replanting, resulting in poorer economy and a different composition of forests. The sub-committee thinks that one consequence of phasing out pesticides would be that the assemblage of tree species in forests would change towards less deciduous forest. In the case of conifers, there would be problems with weevils during reestablishment on sandy soil, and in the case of deciduous trees, there would be problems with grass, and they would lead to problems with frost and mice. This would all increase the cost of reestablishment and result in a slower growth rate in the first years of growth.

Afforestation: In contrast to reestablishment in forests, afforestation offers good prospects for mechanical weed control and prevention. Considerable development work is going on in mechanical control, and a number of practicable machines have been designed for use on easy, flat land. However, only slow progress is being made on the development of machines for use on difficult, undulating land. If herbicides were prohibited in good localities for deciduous trees, one would have to expect the already slow afforestation to be further impeded. In the case of afforestation near existing coniferous forests, problems could arise with weevils. If afforestation took place far from old forests, there would only exceptionally be damage due to pests.

Ornamental greenery: The quality requirements for production of Christmas trees are high. Even small injuries, caused by either pests or weeds, can affect the saleability of trees and greenery. A total ban on pesticides would thus have a devastating effect on the present production of ornamental greenery. Alternative weed control in the form of mowing would add to the cost of production and reduce quality.

Pest problems in forestry

Pests, particularly spruce aphid in Norman fir, are a serious problem in some parts of the country and make it uncertain whether the desired quality could be achieved. The uncertainty in connection with the production of Norman fir Christmas trees is considered to be so great that large parts of the production would end. Just a few, small insect attacks can destroy a whole culture with Christmas trees, so the financial yield would fall considerably. Production of ornamental greenery extends over a lengthy period of years, so an attack by pests in a culture that is 7-8 years old would have a far more serious effect, financially, than in the case of an annual farm crop. We would expect it to be possible to produce *abies nobilis* greenery without pesticides, although there would be a considerable reduction in the yield, mainly due to problems in controlling weeds in the establishment phase.

Partial phase-out in forestry

The possibilities of a partial phase-out have not been analysed separately by the sub-committee, but they depend on how quickly alternative methods of weed control are developed. There is a need for a major research effort covering many alternatives if a usable solution is to be arrived at. If spruce aphid is to be controlled without insecticides, alternatives, including biological methods, will have to be researched. The sub-committee does not consider that all the problems of alternative weed control can be solved within a 10-year period.

Alternative methods of controlling pests without pesticides in farming and market gardening

The sub-committee has assessed alternative, non-chemical methods of controlling pests. Our conclusions are as follows:

Adjustment of crop rotation

Possibilities of regulation through changes in crop rotations and cultivation of other crops: The crop rotation used and the crops grown are of great importance for the level of diseases, weeds and pests. Thus, the level of weeds, in particular, can generally be reduced by a varied, many-sided crop rotation that switches between spring and winter crops, monocotyledonous and dicotyledonous crops, and annual and perennial crops. The problem of pests is often smallest at dairy farms with a large proportion of grass, compared with farms that use a lot of land for specialised productions. When planning the crop rotation, it is important to take account of crop-rotation diseases and ensure a sufficient number of years between the same crop - potatoes, rape, beet, etc.

Having examined the possibilities of cultivating new crops or of cultivating multiple crops that are less affected by pests, the sub-committee has come to the conclusion that, with the present level of knowledge, there is little immediate possibility of cultivating alternative crops.

Variety resistance to diseases

Disease control: With complete and partial phasing out of pesticides, the use of varieties with good resistance to diseases will be an important means of reducing losses from attacks of leaf diseases. The biggest losses from diseases occur in potatoes, wheat and winter barley. There are not at present varieties with good resistance to all leaf diseases in these crops. The varieties of spring barley generally have good resistance to mildew, so the gain from disease prevention measures is seldom significantly certain. In rape, beets and peas, maintaining varied crop rotations generally results in fewer problems with diseases, serious losses occurring only at intervals of several years.

With the types of wheat grown at present (in the years 1995-97), a tendency has been found for varieties with the best resistance to disease to produce 4-5 hkg/ha less net yield than varieties chosen for a high yield potential, while the same is not seen in other crops. It is not clear whether this factor in wheat applies to other periods of time. There is a great need for continuous improvement of resistance since resistance becomes ineffective over the years. The sub-committee believes that there is a big potential for improving resistance properties, but it is difficult to achieve resistance to leaf diseases and seed-borne diseases at the same time as better weed competition, good stem strength, winter hardiness, a high yield and other quality characteristics. Similarly, there is a potential for further development of resistance-based control strategies. A considerable breeding, research and consultancy effort is needed for full utilisation of these properties.

Foreign plant breeding is of great general significance to the Danish range of varieties and production; there is also close collaboration between Danish and foreign breeders. The feasibility of changing Danish breeding priorities in favour of breeding for resistance would thus depend on the interests of foreign breeders.

Use of variety mixtures and cultural practices

There is a not insignificant potential for strategic use of resistance (e.g. use of variety mixtures) to reduce losses from fungal diseases. Several cultural practices could be adjusted in present cultivation systems, such as the sowing time, fertilisation and the quantities sown, which would improve the possibility of minimising the problem of pests. However, diseases can neither be prevented nor minimised solely by adjusting cultural practices. Several of these cultural practices would reduce the yield level.

Within market gardening there are also various practices that help reduce attacks by diseases - for example, good plant hygiene, which includes removal or good decomposition of old foliage, together with pruning, which results in open trees. Several of these methods require increased manpower input.

Present scope of seed-dressing

<u>Prevention of seed-borne diseases</u>: 85-90% of all cereal seed is dressed today, as is a large proportion of other crops in Denmark. Seed-dressing of infected consignments is absolutely essential. Seed-dressing of other consignments could be omitted, but with present-day technology and resources, it is only to a limited extent possible to decide which consignments need seed-dressing. If seed-dressing were generally omitted, the sub-committee believes that there would be a rapid proliferation of several of the seed-borne diseases that cause heavy losses. Continued seed-dressing of the first generations of cereals, followed by a need assessment of subsequent consignments of seed, should be examined more closely and tested. Such assessment would require fast, reliable methods of analysis, separation of seed consignments and probably rejection of substantial quantities of seed for breeding.

There could also be considerable losses in beets as a consequence of uncertain establishment if seed-dressing agents were prohibited. Here, however, the losses would be due to a combination of diseases and pests. In potatoes, there could be a problem with black scurf. The problem could be reduced by using healthy seed material and an interval of at least 4 years between potatoes in the crop rotation, but it cannot be eliminated.

Alternative control of seed borne diseases

Work is in progress on several alternative methods of controlling seed-borne diseases, including use of resistant varieties, use of biological agents, technical control methods with hot water/air or brushes. The methods in question all still need a lot of research and development work before it can be determined whether they can replace the chemical methods.

Problems in phasing out seed-dressing agents

The risk, particularly in cereals, of directly phasing out the use of seed-dressing agents is so great that the sub-committee suggests that treatment with seed-dressing agents be retained where alternatives have not been developed and more rapid methods of analysis in winter cereals have not been implemented. We know too little today to be able to say whether the alternative methods could replace treatment with chemical seed-dressings within a 10-year period.

Variety resistance to pests

Prevention and control of pests: Very little is known about the resistance of Danish varieties to insects because this has so far been a largely unexplored area. Simple screening for receptivity to pests could prove it to have unused potential.

Today, little use is made of biological control of pests in fields, so this method is not at present a realistic alternative to chemical control. It is a well-known fact that natural field fauna, e.g. ground beetles and spiders, affect the pest population. In some years they contribute significantly to keeping down the aphid population, for example, while in others, they are insufficient because of high proliferation rates. We lack specific knowledge of the effects in this area.

Big attacks at interval of years

The way pest attacks develop is greatly affected by the climate, and losses are caused at regular intervals by major attacks that cannot be prevented, typically in seasons with hot weather, when the proliferation rate is high.

Cultural practices, such as sowing time, fertilisation and soil preparation, can affect the population of certain pests, and as much use as possible should be made of such methods to reduce losses from pests.

Within market gardening there are several alternative methods of controlling some pests, including placing of crops in satisfactory crop rotations, adjustment of sowing times, use of netting and watering.

Direct and indirect weed control

Weed control: To achieve sufficient control of weeds in the case of a total or partial phase-out of pesticides, it would be necessary to use a combination of cultural practices and mechanical methods. This would mean reducing the amount of winter cereal in the crop rotation. The sowing time in the autumn would also have to be postponed, and for some crops it might be necessary to sow in more widely spaced rows (rape and cereals with serious weed problems) to facilitate mechanical weed control. Applying fertiliser could also improve the crop's ability to compete with weeds. Trial results have shown that there is a potential for mechanical control in almost all crops. However, it has not been clarified what effect mechanical weed control would have in the longer term on the weed population and, particularly, on the soil's seed pool. Under most cultivation conditions, mechanical methods can already compete with chemical methods of controlling weeds in rape and potatoes.

In some situations with special types of soil, unstable weather, poor crop establishment and dominance of certain types of weed, mechanical control could cause problems. Crop damage after harrowing and generally less control of weeds would result in increased losses, and adjusting the choice of crops and cultural practices for the sake of weed control would lead to increased costs.

Poisonous plants

With the present cultivation conditions, poisonous plants in Danish farm produce present no health problems for humans. There are occasional problems with mortalities in livestock caused by poisoning. In Denmark, spring groundsel and deadly nightshade are considered to be the two most significant poisonous species.

It cannot be precluded that restructuring for pesticide-free farming would allow these species to proliferate. It is hardly likely that there would be an increased poisoning risk for humans, but there might be more cases of poisoning among livestock, which would cause some production loss in the form of reduced milk yields, reduced growth rates and suchlike.

Wild oat

Pursuant to the Act on Wild Oat, seed-bearing wild oat must not occur during the growing season. Wild oat is spread by seed and earth drift. Seeds can survive in the soil for many years and are thus difficult to eliminate. In cereal production without herbicides it would be necessary to replace chemical control of wild oat with manual weeding. This is a realistic method of control for relatively small populations of wild oat but not for large ones. In such cases, it would be necessary to change the crop rotation in favour of coarse-feed production in order to reduce the population.

Seed production

The production of grass and clover seed, as well as vegetable and flower seed, covers a broad range of cultures. Over 90% of our production is exported. In the case of all these cultures, the crop is destined for sowing and the primary price criteria are high purity and a high germination capacity. In addition, the seed must contain very little or no seed of other cultures or weeds. These criteria mean very high requirements concerning the cleanliness of the crops – requirements that, for the greater part of the production – would be difficult to meet without the use of herbicides, given our present level of expertise.

Control of couch grass

Couch grass can be controlled without pesticides on most land. Comparisons of the necessity of controlling couch grass by mechanical harrowing after harvesting or by spraying glyphosate in arable crop rotations have been assessed in several studies. Mechanical harrowing after harvesting (as a substitute for treatment with glyphosate every four years) is necessary every year in such crop rotations. We have reasonably good experience of controlling couch grass in organic dairy farming, but the crop rotations practised at organic dairy farms are very different from those practised at the various types of arable farm. Experience from organic farming shows that thistles can be a major problem. Variations in the quantities of root weeds from field to field would become greater without access to pesticides, as it can take several years to attain effective control of large stands of such weeds. There is deemed to be a big potential for improvement of the present mechanical methods, including methods to replace manual weeding. A change to non-chemical methods would require considerable retraining and supplementary training, and investments would have to be made in new machines.

Growth regulation in wheat

Growth regulation: Chemical regulation is used in about 10% of winter cereals, especially in rye. Growth regulation is also used in seed grass and ornamental plants. There are good prospects for applying alternative methods in winter wheat, to minimise the risk of lodging. The risk is thus small when cultivating varieties with good stem strength and reduced plant counts. If less strong-stemmed varieties were grown it might be necessary to reduce the amount of nitrogen applied by 10-30 kg/ha. There is a considerable risk of lodging in rye grown in the better soils, but a lower risk in sandy soils.

Growth regulation in rye

No rye varieties are free from the risk of lodging, although the risk is lower in some varieties. The risk can also be reduced by postponing sowing until the beginning of October and by reducing the quantities of seed sown and the amount of nitrogen applied. This would, however, reduce the yield by 6-7 hkg/ha (about 12%). The use of alternative methods of growth regulation in seed grass has only been clarified to a limited extent. Until more is known about the potential of alternative methods of growth regulation, a reduction of the stability cultivation must be expected in certain soils.

Growth regulation in pot plants

In pot-plant production, growth regulators are used primarily to promote the especially richly-blossoming and compact plants that have the best sales value. In practice, a combination of "negative dif" and chemical agents is used in many cultures. No methods that could replace chemical growth regulators are immediately available for pot plants. Research is in progress on alternative methods, including drought stress and reduction of phosphorus. A considerable research effort is needed to clarify whether there are alternative methods for the many different pot-plant cultures.

Biological control is effective in greenhouses

Biological control methods: These methods, which include both useful animals and microbiological agents, have a big potential for control of pests in greenhouse production. They are already widely used in vegetable production, whereas there is still an unexploited potential for their use in greenhouse production of ornamental plants. Effective methods of controlling diseases biologically in greenhouses are still limited. In field cultures, the sub-committee considers that biological methods of controlling pests have some potential within special crops, whereas, in the short term, biological disease control only appears to have a potential against seed-borne diseases and fungi that are harmful to germination. An approval scheme for microbiological organisms (MBOs) is being built up, and it is not known at the present time how many agents can be expected on the market.

Methods of assessing the need for spraying

Use of damage thresholds to reduce the need for control: In recent years, damage thresholds and decision-support systems have been developed for several of our main crops as support for the farmer in his assessment of the need for pesticides. The decision-support systems have contributed significantly to a reduction and adjustment of dosages, not only through direct use of the programs but also through advisory services and newsletters from the Danish Agricultural Advisory Centre. Decision-support systems are deemed to be an important tool for communication of the results of research in plant protection to both agricultural advisers and farmers. Although the systems have attained some popularity, it has not been possible to reach all farmers. More needs to be known about the significance of attacks by serious pests in some crops. Damage threshold systems are still lacking for a number of crops, and there is a big potential for improvement of several of the existing systems. In some crops, the sub-committee believes that it would be possible to achieve a 20-50% reduction, compared with what is feasible today, by combining decision-support systems and chemical and non-chemical methods.

Site-specific plant protection

In the last few years, research has commenced within site-specific plant protection, in which control measures are limited to those parts of the field where there is a need for control or regulation of pests. The sub-committee believes that the development of methods that can handle such a system would help to reduce consumption considerably. Trials and research have shown that targeted use of fertiliser, pesticides and other input factors can contribute to satisfying environmental requirements and simultaneously optimise production economically.

Reduction of spray drift

Spraying techniques: Compared with current spraying techniques, the introduction of new types of spraying equipment offers only limited possibilities of reducing pesticide consumption. Exceptions to this are techniques for site-specific treatment, which could in time offer the possibility of varied treatment patterns at field level with the aid of GPS (Global Positioning System) technology. There are good prospects for reducing the risk of spray drift through the use of new types of nozzles that minimise the proportion of small spray drops, which have a considerable risk of drifting. Some of the new types of nozzles increase the capacity compared with earlier sprayers, thereby also improving the possibility of getting spraying done in acceptable weather conditions. The sub-committee also considers that, in fruit growing, new, shielded sprayers (which collect spray residues) offer good prospects for reducing the impact on the surrounding environment.

Handling of pesticides

Relatively simple methods are available to farmers for minimising the risk of point-source contamination of ground water, their own wells and artesian wells, and watercourses, in connection with filling, washing and cleaning sprayers. These methods require only a limited financial investment.

Herbicide-resistant species

Genetically modified plants: Within genetically modified plants, Denmark is furthest ahead with the development of herbicide-resistant plants, which could be ready for marketing within a short period of years. The introduction of genetically modified, herbicide-tolerant species of beet is expected to result in a considerable reduction of herbicide consumption, i.e. a reduction of about 1-2 kg active ingredient/ha. In the case of herbicide-tolerant rape and maize, no great reduction is expected in herbicide consumption compared with present practice, and if mechanical control in rape gains ground, consumption might even increase.

Intensive research in GMO

With the present level of knowledge, the sub-committee does not consider it possible to predict the extent to which genetically modified plants will affect the consumption of pesticides at Danish farms over a forthcoming 10-year period.

All over the world, intensive research is taking place within molecular biology, which in time will undoubtedly change our culture plants significantly. Particular attention is being paid to improvement of genetically modified, disease-resistant plants, which must be expected to create a basis for reducing losses from attacks by diseases without the use of pesticides. Genetically modified maize that is resistant to pests is rapidly gaining ground in America and elsewhere. A similar trend could also occur in other crops. However, the sub-committee does not think it likely that major progress will be made in pest control in Denmark within a 10-year period.

Development of new pesticides

The pesticides of the future: New pesticides are constantly being developed to replace the old products, and new products are also being developed that offer new control options, for instance, for take-all disease. These products are generally used in smaller quantities than has previously been the case, and there is a growing tendency to use certain insecticides as seed-dressing agents. The search for active ingredients from nature's own substances is intensifying, although these often need considerable modification to produce stable and suitable pesticides. It costs far more to develop new pesticides nowadays because of increasingly stringent environmental and health requirements. As resistance to many products is constantly increasing, continuous development of products that act through other mechanisms is vital if we are to continue ensuring effective pest control.

General conclusions from the Sub-committee on Agriculture

Present-day production at conventional farms is a result of having pesticides available. If production is to be made less dependent on pesticides or free of them, the present crop rotations and cultivation practice will have to be changed. It is possible to practise a form of cultivation that has a preventive and reducing effect on pests, whereby the risk of yield losses can be considerably reduced. The proposed crop rotations in a 0-scenario generally have a significantly lower yield level, with an average reduction in cereal yields, for example, of 23%.

0-scenario

The sub-committee suggests that the following measures be included in the crop rotations described in the 0-scenario:

- The crop rotations must contain fewer winter cereal fields than today in order to reduce weed problems. The sub-committee suggests a maximum of 40%.
- More rye and triticale must be grown since these crops compete well with weeds and are less attacked by diseases.
- Winter wheat and winter barley must be sown later than they are today in order to reduce the pressure of weeds, which reduces the establishment reliability.
- Second crops must be included to meet the requirement of 65% winter-green fields.
- Extensive use must be made of mechanical weed control.
- Where available, disease-resistant varieties must be chosen, and in cereal crops, use can also be made of variety mixtures.
- It is a condition that dispensation be granted for seed-dressing up to and including C1 in order to avoid uncontrolled proliferation of seed-borne diseases.

In a 0-scenario we have identified crops in which there would be a risk of considerable losses from attacks by pests (e.g. potatoes and wheat). For some crops (e.g. sugar beet and outdoor vegetables), increased manual weeding would be needed, while in others (e.g. grass seed), there would be an increased risk of contamination with weed seed, which would make it difficult to sell the product.

Intermediate scenarios

In intermediate scenarios, in which a combination of alternative and chemical pest control methods would be used, there would be considerable possibilities of targeting and reducing pesticide consumption by means of concrete guidelines based on warning systems and damage threshold models.

The +scenario is based on very limited use of pesticides – less than 20% of present consumption. At farms with a large production of coarse feed, that could be practised without any serious fall in yield and contribution margin. For other farms, major changes would have to be made in the crop rotations and there would be a considerable drop in contribution margin – 13-36%.

There are no trials showing the possibilities in a +scenario. There is thus considerable uncertainty here since it is assumed in this scenario that those activities that produce substantial losses can be identified accurately. A considerable restructuring of crop rotations is also assumed, with all the uncertainty that implies.

The ++scenario is a scenario in which pesticide consumption is optimised. Depending on whether the present crop rotations are maintained or are economically optimised, an approx. 30-50% reduction of the treatment frequency index compared with present production would be possible. The sub-committee considers that this scenario could actually be practised with a limited reduction of yield and contribution margin. The reduction in treatment frequency index would vary considerably between the different types of farm and would also depend on the set-aside acreage. Trials and practical experience show that a treatment frequency index of 1.3 can be achieved for traditional arable farming with our present body of knowledge without radically changing the present crop distribution. This corresponds directly to the ++scenario described. In this scenario, too, it is important to be able to identify profitable activities. For some pests/crops, there is insufficient basis for such identification and assessments in decision-support systems. Farmers would also have to invest in single-row hoes and row-crop sprayers in order to achieve the reduction described.

Market-garden crops

It is estimated that a 0-scenario would have very serious consequences for the market gardening sector. It would be particularly difficult to meet the current quality codes. In a 0-scenario we would thus expect most greenhouse production, fruit and berry production, field vegetable production and nursery production to cease. To maintain a profitable production, prices would have to be raised in the same way as in organic production. There are several ways of reducing the use of pesticides, which are already practised in IPM production. With more research and development work on alternative methods, the need for pesticides could be reduced still further.

Forestry

In forestry, it would be very difficult to maintain the present production of Christmas trees, and alternative methods of weed control in connection with afforestation and re-afforestation could be extremely costly.

Need for research

Research is a continuous process, in which elements are clarified over time. Research and development work on alternative control methods is in progress in many fields. Completely developed methods are not at present available in all areas, but elements are available that could be put into practice now and help reduce the present level of pesticide consumption.

The sub-committee recommends more intensive action in continuation of existing research activities in the following fields:

- development of alternative methods of controlling seed-borne diseases
- development of varieties with good disease resistance, good stem strength, competitiveness with weeds, combined with high yield and quality
- development of models for estimating the long-term development of the weed population in different crop rotations
- further development of mechanical methods so that these become more effective, including development of autonomic cultivators, weeding robots, etc.
- development and further development of damage threshold models for diseases and pests that incorporate resistance-based control strategies, all relevant components of prevention and, besides economic factors, also environmental considerations; this applies to both arable crops and market gardening
- further development of biological methods of control
- development of cultivation systems in which great importance is attached to preventive methods.

Within spraying technology and handling of pesticides it is possible to include methods for reducing drift, and there are many ways of minimising or avoiding point-source contamination during handling, filling, emptying and cleaning of sprayers.

Advice and training

When presenting research results, it is vital that a co-ordinated effort be made to ensure that all available information reaches the farmers. It is important that advisory activities include:

- advice on strategic planning, with choice of varieties and crop rotation
- presentation of warnings of diseases and pests
- demonstration farms that illustrate different levels of protection
- training in the use of decision-making tools and accessibility, e.g., over the Internet

- establishment of experience groups focused on low pesticide consumption.

For a farmer to be receptive to this advice, he must be able to transfer the results to his own farm and practice.

In line with the supplementary training required for a spraying certificate, follow-up courses focused on the possibilities of minimising pesticide consumption must be developed.

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.

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

In the mandate of 4 July 1997, the Minister of Environment and Energy stipulated that a main committee be appointed with expert members from research, the agricultural industries, the “green” organisations, consumer organisations, the food and agrochemical industries, the trade unions and relevant ministries. Its members were to cover the specialist areas of agriculture, economics, legislation, employment, health, the environment and ecology.

In addition, four sub-committees were appointed. Their task would be 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 production economy and the production achieved by the agricultural industries to date. 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.

An analysis of restructuring for organic farming is given in a separate report in which factors relating to cultivation are discussed, together with economic, employment and environmental factors.

1.1 Mandate for the Sub-committee on Agriculture

According to the mandate for the Sub-committee on Agriculture, the sub-committee was to:

- illuminate alternative, non-chemical methods of controlling plant diseases, pests and weeds
- propose cultivation systems for agriculture under a total or partial phase-out of pesticides
- evaluate the consequences of restructuring for organic farming
- consider the possibilities of maintaining production of cattle and pigs
- make the greatest possible use of experience from existing organic production in agriculture
- identify any areas in which a phase-out would give rise to particular problems
- propose solutions to those problems – e.g. through research and development.

It was also stated that the proposed cultivation systems were to form the basis for the work of both the Sub-committee on Production, Economics and Employment and the Sub-committee on Environment and Health

2 Composition of the subcommittee

Arent B. Josefsen, Director, Danish Institute of Agricultural Sciences (DIAS), **Chairman**
Lisa Munk, Reader, The Royal Veterinary and Agricultural University
Professor Peter Esbjerg, The Royal Veterinary and Agricultural University
Jesper Rasmussen, Reader, The Royal Veterinary and Agricultural University
Carl Åge Pedersen, Chief Consultant, Danish Agricultural Advisory Centre
Kaj Østergård, Head of Research, Danish Forest and Landscape Research Institute
Erik Steen Kristensen, Chief Scientist, Danish Agricultural Research Centre for Organic Farming (DARCOF)
Hanne Lindhard Pedersen, Senior Scientist, Danish Institute of Agricultural Sciences
Per Kudsk, Senior Scientist, Danish Institute of Agricultural Sciences
Per Kølster, farmer (joined the sub-committee on 14 February 1998)
Troels V. Østergård, Editor (retired from the sub-committee on 4 January 1998)
Kristian Herget, Principal, School of Organic Farming
Lisbeth Frank Hansen, Consultant, Agricultural Centre for North West Zealand
Johannes Nebel, farmer
Niels Kloppenborg Skau, farmer

The following persons acted as secretaries to the sub-committee:
Kaj Juhl Madsen, Head of Section, Danish Environmental Protection Agency
Lise Nistrup Jørgensen, Senior Scientist, Danish Institute of Agricultural Sciences
Anne Marie Linderstrøm, Head of Department, Danish Environmental Protection Agency.

3 Scenarios analysed

3.1 Total Phase-out of pesticides

The sub-committee has analysed a scenario for a total phase-out of pesticides.

In this scenario it is assumed that all pesticides, both chemical and biological, are phased out and that use is not made of microbiological control methods either. The use of macrobiological agents (useful animals) is allowed, but only in greenhouse production. However, some use of seed-dressing products is assumed to prevent seed-borne diseases from proliferating. The reason for this is that the sizes of the losses in cereal growing cannot otherwise be estimated.

It is also assumed that technological development will in the long term lead to agricultural practices for preventing and controlling pests, such as use of resistant varieties, mechanical control, cultural methods, genetically modified organisms, etc., which the sub-committees must try to predict and include in their analyses.

3.2 Partial phase-out of pesticides

In the case of partial phase-out, the mandate does not specify which scenarios are to be analysed. The scenarios considered were fixed by the main committee. The sub-committee has tried to analyse the following scenarios for farming, forestry and market gardening, although focusing mainly on the farming scenarios.

The scenarios have been chosen with a view to evaluating the consequences of gradually increasing restrictions on the use of pesticides.

For the scenarios for partial phasing out of pesticides – as for the scenario for a total phase-out, our analysis has included the long-term technological development, together with the possibilities of developing less harmful pesticides and the use of GMOs (genetically modified organisms/plants).

The following three intermediate scenarios have been analysed by the sub-committee:

1. Use of pesticides in a very limited number of crops to ensure continued compliance with the phytosanitary legislation and requirements (0+scenario; almost total phase-out).
2. Use of pesticides in limited crop/pest combinations that could otherwise be expected greatly to reduce the yield level (>15% loss in the average situation). This scenario is designated the +scenario - limited use with a consumption of around 20% of the present level.
3. Optimum use of pesticides in the present crop rotations from the point of view of production economy, designated the ++scenario. In this scenario, consumption is reduced by 30-50%, depending on the type of farm and method of calculation.

4 Definition of the work and general assumptions for the analysis

4.1 Definition of the work

The sub-committee made extensive use of external consultants to procure specialist reports and data as a basis for its work and reporting. We generally sought to compose the project groups behind the specialist reports called for so that they represented experts from the universities, the sectoral research institutions and the agricultural industries' advisory services.

When the sub-committee received the specialist reports, we appointed referees from the sub-committee, who discussed the reports with the consultants before final approval. Although the specialist reports do not necessarily reflect the views of the sub-committee, they largely formed the basis for our work. In many cases, the reports are cited, but this should not be taken to mean that they were the primary source of the information. Readers desiring amplifying information in the different areas are referred to the specialist reports.

The sub-committee also regularly considered the input sent in, particularly in connection with the Midway Conference on 21 September 1998.

The sub-committee appointed a number of project groups with external experts. The project groups prepared reports on the following topics:

Alternative methods:

- Compilation of existing knowledge concerning possibilities of preventing diseases in agricultural crops through the use of resistant plants. *Mogens S. Hovmøller (DIAS), Birger Eriksen (Sejet Plant Breeding Centre), Hanne Østergaard (Risø), Lisa Munk (The Royal Veterinary and Agricultural University), Jon Birger Pedersen (Danish Agricultural Advisory Centre)*
- Compilation of existing knowledge and possibilities of preventing and controlling problems with seed-borne diseases in agricultural crops. *Bent J. Nielsen (DIAS), Anders Borgen (The Royal Veterinary and Agricultural University), Christiane Scheel (Plant Directorate), Ghita C. Nielsen (Danish Agricultural Advisory Centre)*
- Possibility of preventing pest attacks in agricultural crops through the use of insect-resistant plants. *Lars Monrad Hansen (DIAS), Arne Kirkeby Thomsen (Danish Forest and Landscape Research Institute)*
- Possibility of using biological methods of preventing and controlling diseases in agricultural and market-garden crops. *Annie Enkegaard (DIAS), Jørgens Eilenberg and Dan Funck Jensen (both from The Royal Veterinary and Agricultural University), Pernille Folker-Hansen (Horticultural Advisory Service), Klaus Paaske (DIAS), Bent Bromand (DIAS), Susanne Elmholt (DIAS)*
- Possibility of preventing attacks by pests in agricultural crops through the use of alternative methods and crops. *Jørgen E. Olesen (DIAS), Svend Erik Simmelsgaard (DIAS), Poul Flengmark (DIAS), Uffe Jørgensen (DIAS).*

- Prevention of weed problems and mechanical control of weeds and effects on the seed pool. *Michael Tersbøl (Danish Agricultural Advisory Centre), Gunnar Mikkelsen (DIAS), Ilse Rasmussen (DIAS), Svend Christensen (DIAS)*
- Possibility of reducing drift problems in connection with spraying through spraying techniques and possibilities of improving farming practice to reduce the risk of point-source contamination during cleaning and filling of sprayers. *Peter Kryger Jensen (DIAS), Lars Stenvang-Hansen (Danish Agricultural Advisory Centre), Jens Johnsen Høy (National Department of Buildings and Machines)*
- Compilation of existing knowledge concerning the possibility of using genetically modified crops in agriculture. *Preben Bach Holm (DIAS), Katrine Hauge Madsen (The Royal Veterinary and Agricultural University), Bodil Jørgensen (DIAS), Peter Ulvskov (DIAS)*
- Compilation of existing knowledge on the possibility of using warning and damage-threshold models in agriculture. *Svend Christensen (DIAS), Karen Henriksen (DIAS), Jens Erik Jensen and Peter Esbjerg (both from The Royal Veterinary and Agricultural University)*
- Descriptions of agricultural scenarios
- Description of relevant crop rotations in a 100% (present production) scenario, an economically optimised scenario and a 0% scenario within agriculture. *Gunnar Mikkelsen, Ib Sillebak Kristensen, Søren Holm, Peter Kryger Jensen, Lise Nistrup Jørgensen (all DIAS)*
- Description of relevant factors in a 0+, + and ++scenario. *Lise Nistrup Jørgensen (DIAS), Peter Kryger Jensen (DIAS), Ib Sillebak Kristensen (DIAS)*
- Compilation of existing knowledge concerning problems in connection with potato production in the event of total or partial phasing out of pesticides. *Søren Holm (DIAS)*
- Variation in the yield of agricultural crops with conventional cultivation. *Lars Kjær (Danish Agricultural Advisory Centre)*
- Evaluation of the quality aspects of vegetable production in the event of total or partial phasing out of pesticides: Problems with the content of types of weeds in the main agricultural crops must be assessed. *Peter Kryger Jensen (DIAS), Per Kudsk (DIAS), Poul Henning Petersen (Danish Agricultural Advisory Centre), Kirsten Pilegård (Danish Veterinary and Food Administration), Ole Ladefoged (Danish Veterinary and Food Administration), Torben Borggaard (DLF-Trifolium).*

Descriptions of market gardening scenarios

- Description of relevant production factors in a 100% (present production) scenario and a 0% scenario within the market gardening sector's fruit and berry production. *Hanne Lindhard (DIAS), Hans Bach-Lauritsen (Horticultural Advisory Service), Asger Nøhr Rasmussen (DIAS), Maren Korsgard (Zealand Family Farms), Jesper Thorup (organic fruit grower)*
- Description of relevant production factors in a 100% (present production) scenario and a 0% scenario within the market gardening sector's greenhouse production. *Carl Otto Ottosen (DIAS), Asger Nøhr Rasmussen (DIAS), Torben Lippert (Horticultural Advisory Service), Lars Rosager and Kalle Kristensen (Fredericia Municipal Parks and Horticulture Department)*
- Description of relevant production factors in a 100% (present production) and a 0% scenario within the market gardening sector's production of outdoor vegetables. *Kirsten Friis (Danish Agricultural Advisory Centre), Bo Melander (DIAS), Lis Sørensen (DIAS), Maren Korsgaard (Zealand Family Farms)*
- Description of relevant production factors in a 100% (present production) scenario and a 0% scenario within the market gardening sector's nursery production. *Poul Erik Brander (DIAS), Georg Noyé (DIAS), Asger Nøhr*

Rasmussen (DIAS), Bent Leonhard (Association of Danish Nursery Owners), Henrik Sivertsen (Horticultural Advisory Service)

Descriptions of forestry scenarios

- Report on scenarios for phasing out pesticides within private forestry. *Kaj Østergård (Danish Forest and Landscape Research Institute), Hans Maltha Hedegaard (Danish Forest Association), Jens Søgaard Jacobsen (Association of Danish Christmas-tree Producers), Thomas Rubow (DIAS), Ib Henning Christensen (Danish Forestry College), Torsten Dybkjær (National Forest and Nature Agency), Flemming Nielsen (National Forest and Nature Agency)*
- Comments from the Danish Agricultural Advisory Centre to the pesticide report for private forestry. *Lars Møller Nielsen*

Comments received from persons/institutions that are not members of the sub-committees:

- Comments from the Potato Starch Industry, 4 June 1998.
- Parliamentary debate on changed rules for Roundup spraying of cereal fields (12 August 1998).
- Parliamentary debate on the use of growth regulators.
- Novartis/Ole Jensen: Comments to the Sub-committee on Agriculture following the Midway Conference (28 September 1998).
- Novartis/Mads Kristensen: Comments to the Pesticide Committee (28 September 1998).
- Potato Starch Industry: Comments following the Midway Conference (25 September 1998).
- Cillus/E. Rubæk: Comments concerning the need for seed-dressing (24 September 1998).
- Køge-Ringsted Farmers' Association/Jakob Kjærsgaard: Crop-specific treatment frequency index – a necessity (23 September 1998).
- Zeneca/Freddy K. Pedersen: Comments to the Midway Conference (23 September 1998).
- Køge-Ringsted Farmers' Association: Report on zero-pesticide cultivation (3 September 1998).

Besides these, the committees' members have presented a number of written contributions, which the sub-committee has included in its work.

4.2 Assumptions for the sub-committee's work

On the basis of the background reports and written contributions, the sub-committee has carried out a critical evaluation of the consequences for farming of a total or partial phase-out of pesticides and evaluated alternative, non-chemical methods of preventing/controlling pests. The views given in the background reports do not necessarily express the views of the sub-committees.

To carry out its task, the sub-committee had to delimit it and set up specific assumptions, including those listed below:

- An evaluation has been carried out on the basis of 12 crop rotations representing cultivation on clayey and sandy soil (see the description in chapter 5). 10 of the regimes are described in detail. The two farm types covering farms of less than 20 ha on clayey and sandy soil, respectively, have been omitted from the detailed descriptions.
- Only average yields and average farms on clayey and sandy soil have been evaluated. We have thus not included problems concerning particularly difficult types of soil, such as marshy and humus soil, and have not taken

account of the fact that some types of soil have particularly large weed populations.

- Losses from diseases and pests have been extracted from trials in which the degree of attack and the effect on yields are treated as a single parameter. There are almost no data from trials in which the losses are evaluated in different crop rotations and with different cultivation parameters.
- The percentage losses as a consequence of weeds come mainly from organic all-year farms, most of which are dairy farms. These data have been modified to compensate for the small use made of mechanical control at dairy farms today (Mikkelsen *et al.*, 1998).
- In the agronomic scenarios, we have kept the present set-aside acreage with permanent grass. In the economically optimised crop rotations, 30% set-aside acreage is allowed at the individual farms. Nationally, this means 18% set-aside acreage.
- In the calculation of contribution margins we have used prices from 1995/96 and figures from 2000 farms from Danish Institute of Agricultural and Fisheries Economics (DIAFE), which are also divided into 10 types of farm.
- We have based our evaluation of the scenarios on the present production, which is not optimal in all areas. In the scenarios it is a basic assumption that the farmers will act rationally and economically optimally on the basis of the conditions set up. This cannot be expected at all farms. Some of the scenarios – particularly the economically optimised ones – are therefore generally too optimistic. This is of greatest significance for the economic analyses at farm level.

5 Present agricultural production

5.1 Different types of farm

Description of present structure

In order to evaluate the effects of phasing out pesticides in agriculture, the sub-committee prepared a relatively detailed description of present-day arable farming so as to be able to judge the effects on the different types of farm on clayey and sandy soil (Mikkelsen *et al.*, 1998).

A quantitative combination of the different types of farm was not available at the start of the work but has been established on the basis of operating accounts data from the National Department of Farm Accounting and Management of the Danish Family Farmers' Association in 1995 and 1996, which cover 13,000 farms. 12 types of farm have been set up (table 5.1). The table gives both the total acreage at the 12 types of farm and the acreage used in crop rotation. The difference between the two figures is due to set-aside acreage, permanent grass and non-food crops. These acreages have not been evaluated because they are estimated to be constant.

Table 5.1
Treatment frequency index (TFI), acreage, livestock units (LU) and relative cereal yields from the 12 types of farm. The figures have been extracted from farm accounts from the National Department of Farm Accounting and Management of the Danish Family Farmers' Association (crop rotation = acreage used in crop rotation; total = total acreage in the crop rotation). The treatment frequency index (= TFI) has been fixed on the basis of average figures from 1994. The TFI figures are exclusive of couch-grass control, which averages 0.2.

Types of farm	TFI	Ha 1000		Livestock units 1000		Rel. cereal yield
	Total	Total	Crop rotation	Pigs	Cattle	
Clayey soil 1,100,000 ha						
1. Dairy farms (all farms with milk production)	1.8	142	118	7	196	94
2. Pig farms	2.4	220	184	239	25	101
3. Arable farms with seed production (min. 10%)	2.6	162	141	47	6	108
4. Arable farms, with sugar beet (10%, min.)	3.1	168	151	53	5	111
5. Arable farms without seed production or sugar beet	2.6	218	180	19	10	97
6. Other (under 20 ha)	2.5	156	140	38	25	93
Total		1,063	914	400	264	100
Sandy soil 1,600,000 ha						
1. Dairy farms under 1.4 LU dairy cows/ha	1.3	333	268	7	345	92
2. Dairy farms over 1.4 LU dairy cows/ha	1.2	212	174	12	378	94
3. Pig farms	2.0	450	358	418	138	104
4. Arable farms with potatoes (min. 10%)	3.4	135	116	41	11	96
5. Arable farms without potatoes	2.3	279	231	24	26	108
6. Other (under 20 ha)	1.8	148	116	41	71	87
Total		1,556	1,262	541	969	100
Total	2.3	2,619	2,176	941	1,233	

For each of these 12 types of farm a crop rotation has been set up, corresponding to existing practice in agriculture. The operating accounts contain no information on the distribution of the cereal crops at the different types of farm. This breakdown has been carried out to harmonise with the total figures from Danmarks Statistik on sandy and clayey soil. The distribution is based on the following principles: At the individual types of farm, winter wheat is grown after all break crops (rape, peas, oats, potatoes, 75% of the seed-grass acreage, 25% of the sugar-beet acreage and 50% of the rotation-grass acreage. At dairy farms on sandy soil it is assumed that only 25 % of the grass in rotation is used as the crop preceding wheat. An acreage at least corresponding to the acreage with winter rape is sown with winter barley. Beyond this, the species of cereal are distributed over an acreage corresponding to the acreage used in counties with sandy and clayey soil, evaluated on the basis of data from Danmarks Statistik. Winter barley is grown on the remaining acreage.

Table 5.2 below shows the crops included in the 12 crop rotations. For a more detailed description, readers are referred to appendices 1 and 2.

Table 5.2
Description of present crop composition in crop rotations on clayey and sandy soil. In these tables arable farms with and without pigs are combined because they include the same crops. At the top of the table crops with previous-crop value are shown, followed by other crops. Miscellaneous covers small acreages with different specialised crops. Appendix 1 contains a more detailed description of the crop rotations, yield level, share of acreage and treatment frequency index.

Crop rotations on clayey soil

Arable farms with or without pigs	Specialised arable farms with sugar beet	Specialised arable farms with seed prod.	Dairy farms	Other farms
Winter rape Spring rape Peas Winter wheat, 1st yr. Winter wheat, 2nd yr. Spring cereals Winter barley Miscellaneous	Sugar beet Winter wheat, 1st yr. Winter wheat, 2nd yr. Spring cereals Miscellaneous	Seed grass Sugar beet Winter wheat, 1st yr. Winter wheat, 2nd yr. Spring barley with undersown crop Miscellaneous	Winter wheat, 1st yr. Winter wheat, 2nd yr. Spring cereals Wholecrop Grass Mangolds Miscellaneous	Sugar beet Winter wheat, 1st yr. Winter wheat, 2nd yr. Spring cereals Winter barley Winter rye Miscellaneous

Crop rotations on sandy soil

Arable farms with and without pig	Arable farms with potato production	Dairy farms, less than 1.4 LU dairy cows/ha	Dairy farms, more than 1.4 LU dairy cows/ha	Other farms less than 20 ha
Spring rape Winter rape Peas Seed grass Winter wheat, 1st yr. Winter wheat, 2nd yr. Winter rye Spring cereals Winter barley Miscellaneous	Potatoes Peas Winter cereals Spring cereals Miscellaneous	Winter cereals Spring cereals Wholecrop/maize Grass Mangolds Miscellaneous	Winter wheat, 1st yr. Spring cereals Grass Wholecrop/maize Mangolds Miscellaneous	Rape or peas Winter wheat, 1st yr. Winter wheat, 2nd yr. Spring cereals Grass Miscellaneous

Except at the dairy farms, most of the crop rotations are greatly focused on cereal production. All the crops are sold for fodder or quality cereals are produced, such as malt barley, bread-making wheat or seed for drilling. The crop rotation is practised at both pure arable farms and pig farms. The proportion of winter crops is typically around 60% of the total acreage used in the crop rotation. Three typical previous crops for cereals are represented (rape, peas, sugar beet). Three of the types of farm are arable farms with specialised production of sugar beet, seed grass or potatoes. Normal soil preparation and sowing methods are practised in all crop rotations. It is generally assumed that a great deal is done in the way of plant protection and fertilisation to optimise the yield from the crops. As can be seen from table 5.1, the treatment frequency index differs considerably for the different types of farm.

5.2 Crop Yields in present production

Background for chosen yield levels

The yields from the cash crops have been fixed on the basis of Danish statistics for the years 1993-96. In those years there were problems with overwintering of winter rape and weed control in winter rape, and the rape yields were therefore relatively low. The rape yields have therefore been fixed on the basis of the years 1989-96. Yields in the individual counties from the Agricultural Statistics (Danmarks

Statistik) (Anon. 1993-96b and Spieger, 1998) have been used to fix the cereal yields on sandy soil (North Jutland, Ringkøbing and Ribe) and clayey soil (Storstrøm, West Zealand, Bornholm, Funen, Århus, Vejle). Viborg, North Zealand, the Metropolitan Region and South Jutland have been omitted because of varying types of soil. Table 5.3 shows yields for the different crops on sandy and clayey soils. Clayey soil comprises farms No. 5, 6 and 7. Sandy soil comprises farms No. 1, 2, 3 and 4.

For the 12 types of farm described, table 5.3 shows the cereal yields adjusted for type of farm by multiplying all cereal yields from table 5.3 by the relative cereal yields shown in table 5.1 from the operating accounts in 1995 and 96. This makes it possible to reflect the effects of a 0-scenario on different yield levels found at the different types of farm.

Table 5.3
Crop yields measured in hkg/ha on sandy and clayey soil 1993-96 (rape 1989-96, seed 1992-95). Cash crop yields based on county yield figures and coarse fodder yields calculated on the basis of the farm accounts.

Crops	Clayey soil	Sandy soil	Danmarks Statistik
	Hkg/ha	Hkg/ha	Hkg/ha
Winter wheat	75	63	70
Rye	55	50	48
Winter barley	59	53	56
Spring barley, oats, spring wheat	53	44	49
Cereals, total	65	52	59
Peas	39	37	38
Winter rape (89-96)	29	23	25
Spring rape (89-96)	20	19	18
Seed grass	9.5	8	9
Sugar beet	480	440	480
Potatoes	340	367	360
	c.u./ha	c.u./ha	c.u./ha
Grass, wholecrop, maize	66	62	65
Mangolds	120	100	108
Permanent grass	20	20	37

Spring cereal, which covers both spring barley, oats and spring wheat, is put at the same yield as winter barley, which is by far the largest crop with respect to acreage. Rye/triticale is included in the 0-pesticide scenarios with a higher percentage of the acreage than in present production. This means that rye would also be grown on "better" types of soil, for which a higher yield is assumed than in present practice, in which rye is often grown on very poor cereal soil. The chosen rye yield has therefore been put 4-5 hkg higher than in table 5.3 according to Danmarks Statistik.

Coarse fodder yield

The coarse fodder yield has been estimated on the basis of the livestock's need for feed units (FU), adjusted in relation to the number, weight and production of livestock (Kristensen, 1998). Bought-in FU has been calculated on the basis of the fodder costs (DKK) in the operating accounts and an adjusted FU price (DKK/FU) (Bisgaard, 1998). The coarse fodder yield has then been calculated as the theoretical need, minus home-grown cereal, minus bought-in fodder. The average coarse fodder yield per ha has then been calculated by dividing the figure arrived at by the total acreage with coarse fodder in the crop rotation. These indirectly calculated coarse fodder yields depend greatly on the price fixed for bought-in fodder. In the calculation of the grass and wholecrop yield, the mangold yield has been fixed at 11,000 FU/ha. On average, the calculated coarse fodder yields lie 15%-units under yields measured on conventionally operated all-year experimental farms in the years 1989-93 (Halberg & Kristensen, 1997). In the scenarios, these have been harmonised to produce the same quantities of coarse fodder per livestock unit.

5.3 Pests and pesticide consumption of the present cultivation systems

In the following a short review is given of present pesticide consumption and the pests that the pesticides are mainly used to control in agriculture.

Present pesticide consumption

The treatment frequency index in 1994 (Danish Environmental Protection Agency Report No. 8/1995) has been chosen in present production. In addition, consumption has been broken down into winter cereal crops and into sandy and clayey soil for winter barley and wheat on the basis of data from AIM-Farmstat.

Table 5.4
Treatment frequency index from 1994 according to the Pesticide Statistics, plus extra breakdown of winter cereals, spring cereals and sugar beet. The figures do not include the consumption of seed-dressing products.

	Total	Herbicides	Fungicides	Insecticides	Growth regulators
Winter wheat, clay	3.2*	1.2	0.93	0.65	0.4
Winter wheat, sand	3.6*	1.6	0.93	0.65	0.4
Spring barley, clay	2.0*	0.79	0.5	0.7	0
Spring barley, sand	1.3*	0.79	0.25	0.3	0
Rye/triticale	1.4*	1.0	0.3	0.1	0.6
Winter barley	1.9*	1.3	0.6	0	0
Winter rape	2.47	1.34	0.07	1.05	0
Spring rape	2.04	0.91	0.03	1.11	0
Peas	3.32	2.1	0.38	0.83	0
Wholecrop	1.0	0.79	0.2		0
Sugar beet	4.3	2.17	0.02	2.1	0
Mangolds	4.0	2.17	0.02	1.5	0
Potatoes	6.9	1.51	5.15	0.28	0
Seed grass	1.5	0.8	0.02	0.6	0.1*
Grass	0.08	0.03	-	0.05	0
Maize	1.3	1.0	0	0.3	0
Control of couch grass	0.2	0.2	-	-	-

*adjusted in relation to the 1994 statistics

The reason for choosing 1994 is that that year best reflects the present consumption (table 5.4). Figures from 1995 and 1996 were affected by big changes in sales due to the introduction of a special tax on pesticides and are therefore not deemed to be representative. The total treatment frequency index for Danish agriculture in 1994 was 2.35, which corresponds to the level in the latest statistics from 1997, which show a treatment frequency index of 2.45.

Pattern of consumption

Herbicides account for around 2/3 of all treatment, insecticides for 10-15%, fungicides for around 20% and growth regulators for 2-5%. The proportion of sprayed acreage at the different farms varies from about 60% at dairy farms and 90% at pig farms (Schou, 1998). The large proportion of non-sprayed acreage at dairy farms is due to a large grass acreage.

Approx. 15% of all spraying is done in the autumn, while more than 65% is done in April, May and June (Schou, 1998). Owing to the large amount of land used for cereals, approx. 65% of all spraying is done in cereal crops, while the intensity is generally greatest in specialised crops. Most spraying is done on clayey soil, where there is the greatest specialisation in arable farming. An average treatment frequency index of 3.3 has for example been found in Storstrøm County, which has a large proportion of sugar beet, compared with 1.9 in Ringkøbing County, which has a large proportion of dairy farms (Schou, 1998). There is bigger consumption of pesticides at the largest farms, due in part to their use of land (Schou, 1998).

Phytotoxicity in connection with spraying

Some pesticides can cause damage to crops and thus reduce their yields. This applies mainly to herbicides. The magnitude and importance of this damage have been investigated in trials and are evaluated in connection with the approval process. The damage is generally estimated to be limited. Whether damage occurs or not depends greatly on the time of spraying. In the large crops, the risk of herbicide damage is greatest in beet. In some small crops the risk of damage is greater because of the low selectivity of herbicides. The risk of damage is generally greatest when the spraying is done in hot weather and bright sunshine.

Weed control

In almost all crops, weeds are controlled with herbicides. In cereal production at pig farms and arable farms, where the proportion of winter cereal is high compared with spring cereal, extensive use is made of agents against monocotyledonous weeds. This applies both in winter wheat and in break crops such as rape and peas. Dicotyledonous weeds are controlled in all crops. Most is done in sugar beet and mangolds, which are sprayed with herbicides 2-3 times. 1-2 crops are treated each year for couch grass in the crop rotation, which means that couch grass is typically controlled every four years on the same acreage. In cereal production that is dominated by spring cereal, herbicides are used against dicotyledonous weeds every year and against couch grass every four years. Soil preparation (mechanical treatment) is rarely if ever used to control weeds in cereals, while, in winter rape, we are seeing the start of a trend towards sowing the crop in widely spaced rows and hoeing to remove weeds.

At dairy farms with a large production of coarse fodder, less use is generally made of herbicides. Mangolds are sprayed 2-3 times. In cereals, it is almost only dicotyledonous weeds that are treated, and couch grass is treated once in a crop rotation, which typically means every four to six years.

Prevention and control of diseases

At least 85% of the seed used for cereals is treated with a fungicide to prevent seed-borne diseases. Cereal crops are treated frequently against leaf diseases. Wheat is treated about twice and winter barley less than once, depending on the pressure of disease and the resistance of the varieties grown. In the case of fungal attack, beet, peas and rape only need treating about every 10 years. Severe attacks of eyespot can develop in some fields, resulting in losses. Generally, only about 5% of the winter cereal acreage is sprayed against eyespot.

In spring barley, treatment on sandy soil differs from that on clayey soil. Figures from AIM show that much less spraying is done on sandy soil (40% of the acreage) than on clayey soil (60% of the acreage). Particularly at farms with a big production of malt barley, where a large grain size is required (good sorting), fungicides are used against leaf diseases.

In specialised productions, such as potatoes, intensive treatment is given against potato blight, although there is some variation, depending on the variety, and a large annual variation. An early attack of blight can mean that the crop is treated 7 to 8 times in a growing season. On average, treatment is given 5-6 times. The main reason for the frequent treatment is that the agents used do not have a good long-term effect. Almost all seed potatoes are dressed to avoid attack by black scurf.

Pest control

In rape, pests are controlled by spraying once or twice each year. In wheat and spring barley, about half the acreage, on average, is sprayed against aphids. There has been a considerable reduction in consumption compared with the figures in 1994. Thus, on average, only one quarter of the acreage with cereals was treated in 1997 (Danish Environmental Protection Agency, Pesticide Statistics 1997). Insecticides are not used in winter barley. Peas are treated against pests every other year, on average. Beet is treated against aphids and other pests every year with an average of two applications or seed-dressing combined with one application. Starch potatoes are treated against bugs and cicada.

Growth regulation

Growth regulators are used on between 10 and 40% of the acreage with winter cereals. The latest figures from 1997 show a treatment frequency index of 0.1 in winter cereal, corresponding to 10% of the acreage. It is believed that growth regulation in conventional cultivation of winter wheat is on the way out because varieties with good stem strength are grown and less nitrogen is used. However, we believe that there is still a need for growth regulation in some varieties of rye, just as some use is made of growth regulators in certain species of seed grass.

5.4 Annual variations in pest attack and possibility of determing the need for control

There is a very considerable variation in the need for prevention and control of both diseases and pests and in the percentage losses from year to year. The variation in the degrees of attack has traditionally been gathered via monthly surveys from the Research Centre for Plant Pathology, which monitors the strength of pest attacks in each year (Stapel, 1983). Its records go back more than 100 years. The system used has recently been replaced by the Danish Agricultural Advisory Centre’s registration system. Figure 5.1 shows the variation in the development of disease for a single fungus in wheat in different years. With a monitoring system for diseases it is possible to follow the development from week to week, both locally and nationally.

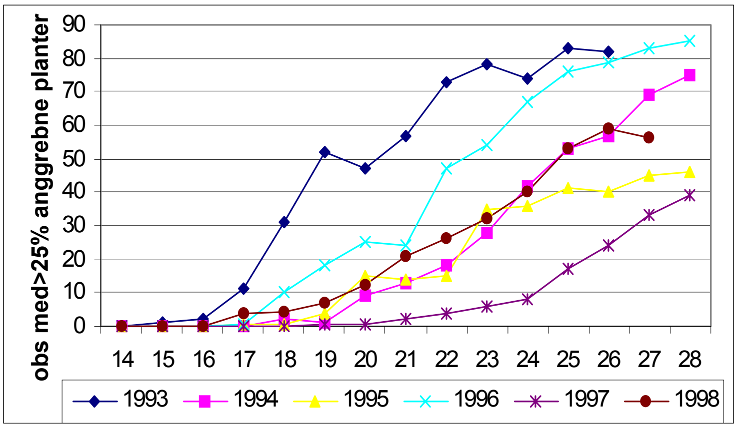
Variation in yield loss in cereals

To illustrate the big annual variation, table 5.5 shows the average annual additional yields from treatment with fungicides in a very large number of trials extracted from the Danish Agricultural Advisory Centre's field trial database (Kjær, 1998). The variation in the additional yields is due to a combination of differences in the diseases that dominate in the individual years, variations in the degree of attack and how early the attacks occur. The results can be used as an indicator of the potential additional yield/yield loss in cereals from spraying or not spraying. The latest fungicides (strobilurines), which were approved in 1998, have lifted this yield potential in wheat, for example, by 4-6 hkg/ha.

The weed population in one and same locality varies to a limited extent from year to year. It is difficult to set an actual damage threshold for control measures since a low level of dicotyledonous weed is generally desired in the crops for long-term crop rotation reasons. For monocotyledonous weeds, which have increasingly spread in recent years as a consequence of increased acreages with winter cereals, considerable average additional yields have been measured – 15-20% - with control measures against loose silky-bent and blackgrass (Annual Report of Field Trials, 1997). In some trials with very large stands of loose silky-bent, the yield can be halved. Serious proliferation of monocotyledonous weeds is thus a negative consequence of the big change from spring to winter cereals.

Table 5.5
Average additional yields in cereals (hkg/ha) after treatment with fungicides. The treatments are typical standard treatments from research programmes and can be used as indicator of the potential additional yield after spraying 2-3 times in wheat, 1-2 times in spring barley and twice in winter barley, typically with reduced dosages (source: Danish Agricultural Advisory Centre's field trial database, 92-98). The fluctuations in individual trials can be considerably larger than the annual variation.

Year	Winter cereals hkg/ha	Spring barley Hkg/ha	Winter barley hkg/ha
1990	27.1	7.3	10.8
1991	11.4	5.9	7.1
1992	3.5	0.8	2.2
1993	4.3	5.7	5.4
1994	4.0	2.3	2.3
1995	4.7	2.3	4.0
1996	5.9	1.5	3.1
1997	7.6	2.7	3.8
1998	13.4	5.9	6.2



(obs med >25% angrebne planter = observations with >25% plants attacked)

Figure 5.1
Development of mildew attack in wheat determined in the Danish Agricultural Advisory Centre's registration system. With weekly reporting, the current development of the individual diseases can be monitored nationally and regionally. The information is used in connection with advice on the need for control measures.

While dicotyledonous weeds are treated every year over almost the entire acreage, monocotyledonous weeds are generally only treated in the areas in which they occur.

Evaluation of the need for prevention and control measures

In connection with the first pesticide action plan, many activities have been initiated to get the need for prevention and control measures adjusted in relation to the degrees of attack in the individual field and the individual year with a view to avoiding unnecessary spraying. These activities have included the development of damage threshold models for diseases and pests, as for example in PC-Plant Protection. PC-Plant Protection enables farmers to carry out a real evaluation of need in respect of a number of pests. In the case of weed control, use has not generally be made of real damage thresholds. Instead, the dosage and agent have been adjusted to a given weed flora in the field.

PC-Plant Protection

The PC-based guideline programs are used by just under 2,000 subscribers. Besides this direct use of the models, the principles of damage thresholds are disseminated via newsletters from agricultural advisers, the Internet, etc. In an interview-based survey among farmers, 15% stated that they regularly used the damage thresholds from PC-Plant Protection (University of South Jutland, 1998), while another survey in 1994 showed that farmers were generally better at evaluating need today and that they were increasingly using reduced dosages of pesticides (Bager & Søgård, 1994). It has thus been found that consumption has been reduced, especially in the case of fungicides in cereals, although there has been only a limited reduction in total treatment frequency index. The latter is due partly to the fact that more winter cereals are grown now than earlier and that winter cereals generally have a greater need for control measures than spring crops. The reduction in consumption has been limited in the case of herbicides and pesticides, but considerable in the case of fungicides in all cereal crops, where the reduction target of 50% in the pesticide action plan has been achieved. Adjusted for changes in crop composition, the treatment frequency index in 1997 was down by 25% in relation to the action plan target.

5.5 Losses as a consequence of pests in the present and alternative scenarios

Farmers use pesticides to minimise or eliminate major financial losses caused by pests. In several earlier reports, an attempt was made to estimate the economic benefit of spraying in agriculture (Jørgensen *et al.,* 1997, Thonke *et al.,* 1989).

In connection with this report a new evaluation has been carried out of the total crop loss, broken down into individual crops and including alternative methods where practicable (table 5.8). The economic consequences of these losses have been calculated by the Sub-committee on Production, Economics and Employment. The losses have been calculated on the basis of the technology that is available today.

5.5.1 Method for calculating losses

Losses caused by diseases and pests

Losses from diseases and pests have been estimated mainly on the basis of data from trials carried out with pesticides by The Danish Agricultural Advisory Centre and DIAS. The size of the losses in trials cannot generally be said to be representative of the losses that can occur at different types of farm, but there are no other or better sources to use for estimating losses caused by pests. For some of the main pests, e.g. aphids in cereals, we have been able to use trial data to get a breakdown into percentage losses on sandy and clayey soil, while for others we have had to use a national average. For the individual crops we have tried to allow for what can be said to be the most realistic percentage losses on the basis of the available information. For a more detailed review of the data on which the percentage losses in the individual crops are based, see Mikkelsen *et al.*, (1998). In the following we list some factors that influence the magnitude of percentage losses from pests and the uncertainty attaching to them:

- Some types of trial result in overestimation because they are sited with the expectation of an attack. However, in some cases the attack does not materialise because the trial sites, too, are subject to local and annual variations.
- For other pests (e.g. diseases in cereals), so many trials are carried out each year that the results can be regarded as reasonably representative of the country as a whole.
- For some airborne diseases, plot trials are deemed to result in underestimation of percentage losses because the trials are often sited in fields that have been treated.
- The trials do not allow for the fact that the background infection can increase if control measures are omitted altogether.
- In the case of big attacks, the trials are often discarded because of too great a statistical uncertainty in the result, which means that the trial results will underestimate the percentage losses.

Losses as a consequence of impaired quality

Certain losses can only be calculated with difficulty, including effects on quality parameters. Especially in the case of potatoes, it is difficult to calculate losses resulting from poor storage. Consignments of potatoes with blighted tubers are particularly difficult to store in clamps and loosely layered in boxes. Infected tubers have greater respiration and give off moisture to the surroundings, thereby increasing tuber rotting. Consignments of potatoes with more than 2% infected tubers are considered high-risk consignments from a storage point of view. The calculated losses in the three types of potato production are composed as shown in table 5.6.

The losses in potatoes describe very well the differences in the level of yield between organic ware potatoes (approx. 233 hkg/ha) and conventional potatoes (approx. 400 hkg/ha) (Holm *et al*., 1998 & 1999), which give a reduction in yield of 42%. In figures for organic farms at Foulum in 1996-98, the saleable yields vary between 74 and 370 hkg/ha (Pers. com. Jens Peter Mølgaard). Supply security is therefore a very big problem for industrialised production, for example.

Table 5.6

Percentage losses in 3 different types of potato production, breakdown into damage caused by disease and damage caused by pests (Based on Holm et al., 1999).

	% loss from the following pests			
	Mould attack incl. damage to tubers	Black scurf	Bugs, cicadas	Total
Seed potatoes	37*	6	3	43
Ware potatoes	35*	7	6	43
Starch potatoes	35**	3	8	42

*Direct loss due to leaf diseases plus rejection of 20 hkg/ha with tuber mould

**Direct loss due to leaf diseases plus 5% loss in starch

The production of malting barley is another area where crop quality depends on whether or not pesticides are used. In some years, sorting (pricing is affected by the grain size) can be adversely affected by fungus or aphid attacks, which can make it impossible to sell the cereal as malting barley.

Losses as a consequence of harvesting problems and drying costs, which can occur, especially when there are large populations of weeds, are also difficult to quantify. It is similarly difficult to predict what areas of land would have to be restructured if they became overgrown with weeds.

Losses due to weeds

The size of losses that would result from a switch to mechanical weed control is encumbered with great uncertainty. Trials in which the weed effect and yield with mechanical weed control are compared with those resulting from standard herbicide treatment are few and far between, and in many cases it is not possible to distinguish between the effect of residual weeds on the yield and the effect (crop damage) of mechanical weed control. At the same time, the trials in question were carried out at conventional farms, which means that the weed population was smaller and the composition presumably different than can be expected in a herbicide-free crop rotation.

The types of weeds that are a problem in the present crop rotations are a consequence of the fact that the types are well adapted to the crops in question and to the fact that the available herbicides are not very effective against them. Examples are grass weed in crop rotations with a lot of winter cereal, shepherd's purse in rotations with winter rape and fool's parsley in rotations with a lot of beet. In the same way, a crop rotation in which weed control is based only on mechanical control measures must be expected to be dominated by weeds that are favoured in the crops in question and that would be difficult to control mechanically – e.g. camomile and charlock, both of which are very competitive types of weed.

Experience from organic farming

The sizes of the losses in cereals have been estimated on the basis of figures from organic all-year experimental farms, where weeds have been registered after mechanical weed control (Rasmussen *et al.*, 1998). On the basis of 5,173 evaluations of organic cereal fields from 1989-97 at just over 30 farms (dairy farms, egg production units and pure arable farms), an analysis has been carried out of the average incidence and composition of weeds (Kristensen, 1998). Mechanical weed control is much less intensive at the organic farms than is generally recommended for cereals (Rasmussen *et al*., 1998). It has therefore been suggested that the estimated loss in yield from the direct effect of weeds at the organic all-year farms be halved for use in calculating consequences (Mikkelsen *et al*., 1998), since it is assumed that increased mechanical weed control could reduce the losses from the present level. This reduction would, however, be cancelled out by the considerable losses resulting from the significant crop damage associated with mechanical weed control. Mechanical crop damage has thus been estimated on the basis of the comparative studies of herbicide treatment. For the other crops, which are not grown at the organic all-year farms, the losses are based on the few trials carried out and on estimates. A more detailed description of the background for the estimated losses from weeds is given in Mikkelsen *et al*., (1998). The estimated losses as a consequence of crop damage from mechanical weed control and increased residual weed are shown in table 5.7.

On land where there are serious problems with grass weed, the yield losses when wheat is grown without herbicide treatment would exceed the values given in the table in the first few years because some years would pass before the changed crop rotation reduced the weed-grass problem. On the other hand, the yield losses due to dicotylodenous weeds would be smaller than assumed in the table for a short transitional period because some years would pass before the level of weeds rose from the present level up to the level at organic farms, on which the loss calculations in the table are based.

Table 5.7
Estimated losses in per cent due to mechanical weed control measures in agricultural crops. The losses are included in the total loss function (Mikkelsen et al., 1998).

Crop	Loss due to crop damage from mechanical weed control	Loss due to residual weed	Total loss during transition to mechanical weed control
Winter cereals	5-10%	6%	11-16%
Winter barley	2-5%	3%	5-8%
Winter rye	1-3%	2%	3-5%
Spring barley	0-3%	6-12%	6-15%
Peas	3-7%	5-10%	8-17%
Winter rape	0%	0%	0%
Beet	0%	0%	0%
Seed grass	?	?	?

Losses due to adjustment of cultural practices

Chapter 8 contains a description of alternative methods of preventing and minimising pest problems. However, use of these alternative methods would have disadvantages with respect to yield, which are also listed in table 5.8. To minimise weed problems it is recommended that sowing of wheat, winter barley and rye be postponed. However, sowing in the second half of September is normally recommended to ensure a good and competitive crop. Sowing later than that would for many years reduce the chance of getting winter cereals established and is therefore not recommended. The proposed postponement could be expected to result in a small loss in yield (Kjærsgård, 1996 and Pedersen *et al*., 1997). The reduction in yield from postponing sowing from 20 September to 10 October has averaged about 7 hkg/ha. It is estimated that less than half of the fields would be sown so late that it would affect the yield. For this reason, the loss in wheat as a consequence of late sowing has been reduced to 3 hkg/ha (corresponding to 4%). In winter barley, the loss as a consequence of postponed sowing has been put at 7% (Pedersen *et al.*, Pers com.).

Another parameter that can reduce yield is use of the most resistant wheat varieties. The most resistant varieties have a lower yield potential than the highest yielding varieties, and on the basis of the trials carried out in 1995-97, it would have cost 4-5 hkg/ha to prioritise resistance over yield (Hovmøller *et al*., 1998). Since an average of all varieties in the period 1992-97 has been used in the case of losses from diseases, which means that no special allowance has been made for the losses in resistant varieties, we have chosen to halve the loss of 4-5 hkg/ha as a result of choosing resistant varieties because the additional yields in the more resistant varieties are realistically estimated to be 2 hkg/ha less than if the more sensitive varieties were used (cf. table 8.4). A loss of 3% has been added to the loss due to the use of resistant varieties of wheat, whereas there is nothing to indicate such a loss in the other varieties of cereal.

5.5.2 Method for estimating total losses

Composition of yield loss

The total loss is composed of 5 different loss sizes that are estimated to apply in the different crops (see table 5.8).

Table 5.8

Estimated percentage losses resulting from pests, etc., in different crops in the 0-scenario. Only direct yield losses are included. Losses due to the increased cost of weed control are not included in this table.

	Loss 1 average	Loss 2 average	Loss 3 Average	Loss 4 average	Loss 5 average	Total average loss	Average maximum loss
	Postponed sowing etc.	Disease attack	Pest attack	Crop damage	Weed increase	Multiplicative	1 factor gives max
Wheat, 1st yr., sandy soil	8	7	2	7	6	27	45
wheat, 1st yr., clayey soil	7	9	4	7	6	29	50
Wheat, 2nd yr., sandy soil	9	7	5	7	6	30	68
wheat, 2nd yr., clayey soil	7	7	4	7	6	27	43
Spring barley, sandy soil	-	7	3	1	7	17	33
Spring barley, clayey soil	-	6	6	1	7	19	30
Winter barley, sandy soil	7	11	0	3	3	22	32
Winter barley, clayey soil	7	10	0	3	3	21	28
Winter rye	3	4	3	1	2	12	28
Peas	-	2	9	5	7	21	26
Winter rape	-	2	5	0	0	7	26
Spring rape	-	2	17	0	5	23	48
Sugar beet	-	2	12	0	0	14	22
Mangolds	-	2	12	0	0	14	22
Clover seed	-	0	50	0	50	75	100
Seed grass	-	1	0	?	50	50	100
Potatoes	-	38	6	0	0	42	100
Wholecrop	-	3	2	1	8	13	16
Grass	-	0	0	0?	?	3	4
Oats	-	5	3	1	8	16	25
Maize	-	0	3	5	8	16	16

Here, **Loss 1** covers losses after changed cultural practices to minimise the risk of pests, including postponed sowing time and choice of resistant varieties. **Loss 2** covers losses from diseases. **Loss 3** covers losses due to pests. **Loss 4** covers losses from damage to the crop in connection with mechanical weed control. **Loss 5** covers losses due to more weed remaining after mechanical weed control than after treatment with herbicides.

The various loss sizes can be either added or multiplied. Here, the multiplication method has been chosen. The method ensures that in extreme situations one does not risk getting negative yields. The formula for calculating the total loss is as follows:

$$\text{Total loss} = \left(1 - \frac{100-\text{loss1}}{100} \times \frac{100-\text{loss2}}{100} \times \frac{100-\text{loss3}}{100} \times \frac{100-\text{loss4}}{100} \times \frac{100-\text{loss5}}{100}\right) \times 100$$

In the trials, the losses were mainly expressed in hkg/ha. They have since been converted into percentage losses. Except in the case of diseases in wheat, it has not been possible to differentiate loss sizes in relation to crop yields.

Evaluation of maximum loss in yield

Table 5.8 also shows a maximum loss. This covers the situation in which one of the five loss functions gives maximum loss and will thus establish a basis for the worst possible loss in the crop in question. As will be seen, many of the maximum losses are about twice as large as the average losses. They can occur, for example, if a potato blight attack develops very early in the growing season or if wheat suffers a severe attack of stripe rust or *Septoria*. It is difficult to estimate the frequency at which such maximum losses will occur as they usually depend very much on the weather.

5.6 Variation in yield level in present production

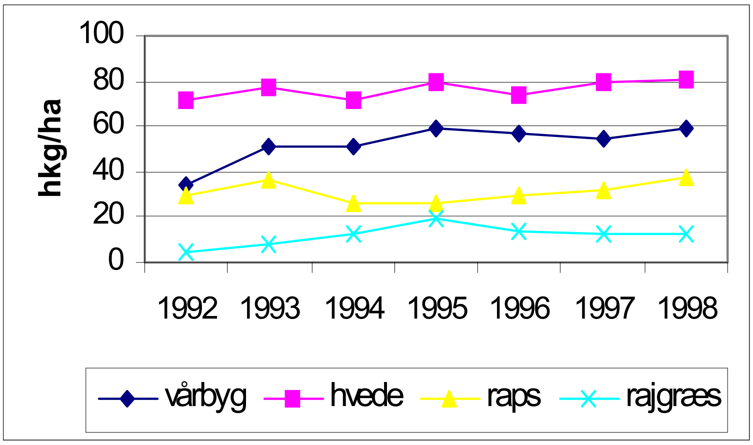
In conventional cultivation the yield level generally exhibits very high scatter because of local cultivation conditions, climatic factors in the individual years and variations in pest levels. On the face of it, greater variation must be expected if pesticides are not available because pests would have greater “freedom” to cause yield losses. This is reflected, for example, in the many trials in which increased yields were harvested after spraying.

The yield level varies from year to year

Figures from the Danish Agricultural Advisory Centre’s field trial database, which has collected data for the period 1992-1998, show very large annual yield variations for the trials in which pesticide treatment was generally carried out (see figure 5.2).

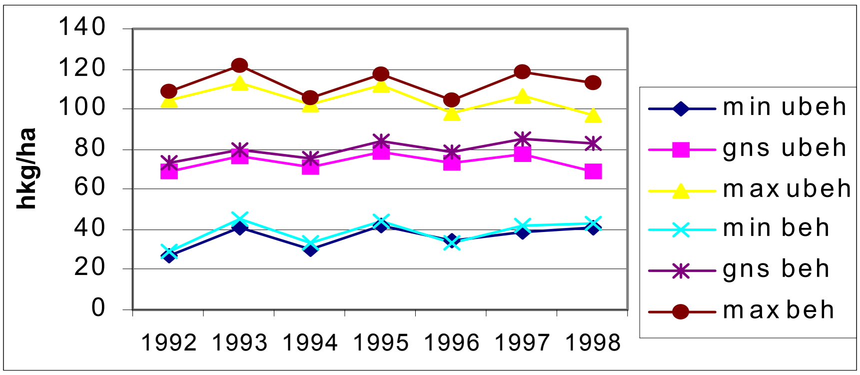
No data showing cultivation security in 0-scenario

There is no data to document the variations in yield level in areas that have not been treated with pesticides at all. Data are only available for individual factors (disease or pests or weeds). A look at the variations in the trials without fungicide treatment and how they change over the years shows that the average difference between the treated and untreated areas is in most years is simply a parallel shift in the level. In years with severe disease attack, such as 1998, there is a clear tendency for the curves to drop, which indicates reduced cultivation security (figure 5.3). Cultivation security would be impaired most in crops with the largest pesticide consumption, e.g. potatoes, vegetables and fruit and berries.



(Vårbyg = Spring barley, hvede = wheat, raps = rape, rajgræs = rye grass)

Figure 5.2
Annual variation in the average yields of four crops cultivated conventionally. In a given locality the variation can be considerably greater. Source: Danish Agricultural Advisory Centre's field trial database.



(min ubeh = min. untreated
gns ubeh = average untreated
max ubeh = max. untreated
min beh = min. treated
gns beh = average treated
max beh = max. treated)

Figure 5.3
Annual variation in the average yield level in winter wheat in untreated areas, together with indication of minimum and maximum values. Source: Danish Agricultural Advisory Centre's field trial database.

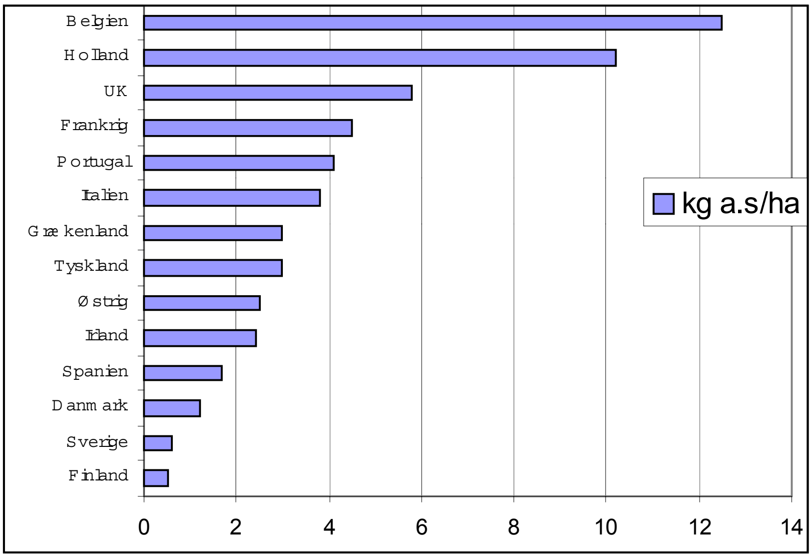
5.7 Pattern of consumption in other countries

Big differences in pesticide consumption in the EU

The need to use pesticides varies considerably from country to country, depending, for example, on the crops grown, climatic conditions and considerable differences in the pressure of disease and pests. Generally speaking, the further north one goes, the lower the pressure of damage from diseases and pests. The relatively low consumption in the other Nordic countries is due to the fact that more extensive production than in Denmark is practised in large parts of the cultivated acreage. In several of the other EU countries, including the Netherlands and Belgium, production is more intensive.

Only Denmark has figures for treatment frequency index

Figure 5.4 shows the consumption of active ingredients in different countries. As will be seen, Denmark has the third lowest level. Unfortunately, there are no figures that allow a comparison of the consumption on the basis of treatment frequency indices because Denmark is the only country that calculates consumption in this way.



(Belgien = Belgium
Holland = Netherlands
UK = UK
Frankrig = France
Portugal = Portugal
Italien = Italy
Grækenland = Greece
Tyskland = Germany
Østrig = Austria
Irland = Ireland
Spanien = Spain
Danmark = Denmark
Sverige = Sweden
Finland = Finland)

kg a.s/ha = kg active ingredient/ha

Figure 5.4
Pesticide consumption in the EU countries in 1996, calculated as kg active ingredient (a.i.) per ha agricultural land (acreage in rotation + permanent grass + perennial crops) Source: Eurostat.

Limited information on pattern of consumption in the EU

Only limited information is available on the pattern of pesticide consumption in different crops, which is needed for determining whether Danish fruit and vegetables, for example, are sprayed more than foreign products. A study from 1996 (Landell Mills) described the consumption in kg active ingredient in four countries. It has been possible to add figures for average consumption in Denmark on the basis of the Pesticides Statistics (table 5.9). In the comments from the Landell Mills study, which was carried out in 1994 at 850 farms in 13 regions in the EU, it is noteworthy that the quantities used within the individual regions vary as much as they do. This indicates that even though there are differences between regions, they are considerably smaller than between farms in the same region. The big differences are due to differences in the cultivation system, the varieties grown and the crop rotation used, variations in diseases and the pressure of pests, and the choice of agent and dosage. As will be seen, with our present body of knowledge, it is difficult to generalise about the use of pesticides in crops cultivated in different regions. Measured in kg active ingredient in the individual crops, Denmark's consumption generally lies at the lower end of the scale. An example of an area in which there is a significant difference between consumption in Denmark and consumption in neighbouring countries is the consumption of fungicides in cereals (table 5.10). The reduction that has taken place in Denmark has not happened to the same extent in the other countries (Secher & Jørgensen, 1995).

Table 5.9
Quantity of pesticide (kg active ingredient/ha) used in different crops

Crop	Region	Quantity kg a.i/ha	Variation between farms kg a.i./ha
Wheat	Germany (Hannover)	4.5	0.08-8.5
	UK (East Anglia)	4.6	0-10.1
	France (N. Central)	3.8	0.7-13.7
	Italy (Piemonte)	2.1	0.02-7.2
	Denmark	2.3	?
Potatoes	Germany (Lüneburg)	9.8	2.7-22.3
	Netherlands (Flevoland)	12.6	1.6-34.6
	UK (East Anglia)	13.1	2.0-26.7
	France (North East)	32.0	9.0-73.7
	Denmark	9.0	?
Apples	France (South East)	41.4	1.7-146.7
	Italy (Trentio)	33.7	0.6-83.4
	Spain (Lerida)	27.4	1.4-109.6
	Denmark	28.0	?

Source: Landell Mills (1996). The Danish figures have been converted on the basis of the Chemical Statistics' treatment frequency index in 1994. The figure for apples has been provided by the Association of Danish Fruit Growers.

Table 5.10
Treatment frequency index for fungicides in winter wheat in four European countries. The figures are based on consumer surveys carried out by market research companies (modified on the basis of Secher & Jørgensen 1995).

Country	1990	1992	1994	1997
UK	1.70	1.73	1.40	2.2
Germany	1.92	1.76	1.80	1.34
France	-	1.43	1.61	2.5
Denmark	1.19	0.83	0.75	0.61

5.8 Conclusion concerning present production

The production and crop rotations practised at conventional farms today are a result of the fact that pesticides are available.

As our basis for evaluating present production we have used yields from 1993-96 and treatment frequency indices from 1994. As the basis for the agricultural scenarios we have broken Danish farms down into 12 types of farm on the basis of 13,000 operating accounts from 1995-96. These 12 types of farm can be summed by scaling them so that the total figures are in accordance with figures from Danmarks Statistik. The 12 types of farm represent the main types of crop rotation on sandy and clayey soil. Unfortunately, they do not reflect all present situations, but greater differentiation was not feasible.

Scope of present prevention and control

In conventional forms of production, dicotylodenous weeds in all crops are controlled with herbicides. In some parts of the country, especially those where winter cereal is grown, both monocotyledonous and dicotyledonous weeds are controlled. The biggest use of herbicides is in sugar beet, which is sprayed 2-3 times. In 1-2 crops couch grass is controlled every year in the crop rotation, which means that it is typically controlled every four years on the same land. Soil preparation (mechanical weed control) is rarely if ever used to control weeds in cereals. In winter rape, farmers have started sowing the crop in widely spaced rows (5% of the acreage in 1998/99) and using hoeing to remove weeds.

At least 85% of seed for drilling is dressed with fungicide to prevent seed-borne diseases. Cereal crops are treated frequently against leaf diseases. Wheat fields are treated twice a year and spring barley less than once, depending on the pressure of disease across the productions. Peas and rape are treated with fungicide only about every tenth year. Potatoes are treated intensively – about 5 or 6 times - against blight. Potatoes are dressed against black scurf to ensure good establishment and avoid losses of about 3%.

Pesticides are used in a wide range of agricultural crops. Rape is sprayed once or twice each year. About one quarter to one half of the acreage with wheat and spring barley is treated against aphids. In peas, pests are controlled every other year on average, and in beet, aphids and other pests are controlled every year, either by spraying approximately twice or through a combination of seed-dressing and one spraying.

In general, only limited quantities of growth regulators are used. Growth regulation in conventional cultivation of winter wheat is thought to be on the way out because strong-stemmed varieties are now being grown and less nitrogen is being used. Growth regulation is still deemed necessary in some varieties of rye and species of grass seed.

Variation in need for prevention and control

There is a very large variation in the need for prevention and control of diseases and pests and in the percentage losses from year to year, while in the case of weeds, there is a more uniform need for control measures to keep the general pressure of weeds down.

Pesticide consumption is low in Denmark compared with many of our southern and western neighbours, while consumption in Sweden and Finland is lower than in Denmark because of a lower pressure of infection and more extensive cultivation. The need for pesticides varies considerably from country to country. The variation is due to differences in the crops grown, climatic conditions and a big variation in the pressure of disease and pests.

The consumption of active ingredients in different countries can be used as an indirect measure of the burden on the environment in the individual countries. Only limited information is available about the exact pattern of use of pesticides in different crops, which makes it difficult to compare the pattern of spraying in different countries.

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6 Present production in market gardening and fruit growing

Production within this sector is very varied and covers many cultures. It has not been possible to cover all of them. Only conditions within the main cultures are discussed here.

High requirements concerning plant health

The requirements concerning plant health for market-garden cultures are generally high and are governed by the EU's plant health directives, which indicate pests and levels of pests that cannot be accepted.

The quality standards for fruit and vegetables are given in the EU's common organisation of the market for fruit and vegetables. So far, standards have been established for 34 products. The standards contain rules for minimum requirements concerning the products, classification, possible sorting by size and labelling. The minimum requirements are generally that:

- the products shall to all intents and purposes be free of pests
- the products shall to all intents and purpose be free of damage caused by pests
- the products shall be sound; products that have been attacked by rot or impaired to such an extent that they are unsuitable for consumption are excluded.

The supply of pesticides within market gardening is already relatively limited because some are not marketed any longer and/or have been withdrawn in connection with a review. There are therefore already some combinations of crops and pests for which approved agents are no longer marketed.

No statistics for pesticide consumption

There are no reliable studies indicating the pesticide consumption within market gardening. There is therefore considerable uncertainty concerning the exact consumption.

6.1 Outdoor vegetables and garden seed

The acreage used for production of outdoor vegetables in Denmark is 6,200 ha (1997). To this must be added 3,700 ha used for peas for freezing. Most of the Danish production of vegetables takes place at specialised farms, where vegetable production accounts for most of the farms' turnover. Where production is part of ordinary arable farming, the vegetables are normally grown for sale to the industry, (Friis *et al*., 1998).

High establishment costs

Outdoor vegetables are a very intensive production that requires major investments – both general investments in irrigation systems and storage and refrigeration facilities, and special investments in machines for sowing and preparation. The establishment costs for the individual crops are much higher than those for arable crops. At harvest, the vegetables represent a value of DKK 30-100,000/ha. A considerable part of this goes to pay for labour in connection with harvesting and preparation for sale.

Production of garden seed

According to the garden seed industry, about 3,000 ha of land are used for vegetable seed and about 200 ha for flower seed. The acreage has been on the increase in recent years, particularly in the case of spinach. All garden seed is produced under contract between the farmer and one of Denmark's three garden seed firms. Approximately 80% of the garden seed is produced for foreign firms, which make requirements concerning both supply security and quality. Garden seed is a production that forms part of ordinary arable farming because many years are needed between the garden-seed crops. The average acreage per unit for vegetable seed is somewhat greater than the average acreage per unit for flower seed. The reason for the smaller acreage with flower seed is a considerably higher manpower consumption in these crops. The average contribution margin for garden seed is about DKK 14,500/ha, which has to cover investments, labour and "land rent". A high contribution margin depends on high yields of high quality (Friis *et al.*, 1998).

Generally speaking, pesticide consumption is higher in the production of outdoor vegetables and garden seed than in the production of most ordinary arable crops. The treatment frequency index is typically between 4 and 12, depending on the culture. Key figures for the production of outdoor vegetables are shown in table 6.1.

Table 6.1
Treatment frequency index (TFI), acreages, size of production (tonnes), value in mill. DKK and degree of self-sufficiency for the main outdoor vegetables in Denmark. The organic acreage is shown in brackets (Friis et al., 1998).

Crop	TFI	Acreage, ha 1997	Tonnes product	Production value in mill. DKK	Degree of self-sufficiency, %
Carrots	4-5	*1,800 (336)*	76,834	160	90
Onions	11-12	1,550 (105,)	45,625	88	75
White and red cabbage	7	564 (62)	22,478	31	85
Cauliflower and broccoli	4-5	720 (?)	6,667	51	60
Peas for freezing	5-6	4,200 (?)	23,500	41	200
Total		10,363 (728)			

6.2 Fruit and berry growing

Present production

According to Danmarks Statistik, 7,300 ha of land were used for fruit and berry production in 1997. The acreage has been decreasing for a number of years.

Pomes are generally produced at specialised farms, while some production of blackcurrants, redcurrants, strawberries and sour cherries takes place at ordinary arable farms. The total Danish production gives around 50% self-sufficiency. Fruit and berries are quality products and there are common EU quality rules for them. Only products that comply with these quality rules may be sold in the shops. Basically, the products must be whole and sound (free of diseases and pests) and meet the size requirements (Lindhard *et al.*, 1998).

Fruit and berries are a very intensive form of production. Big investments are required in machines and establishment, together with a high degree of specialisation. The establishment costs per ha are around DKK 100,000 for pomes and between DKK 10,000 and DKK 15,000 per ha for berry production.

Apples, strawberries and pears require most manpower, mainly because they are picked by hand. Almost all the production goes to direct consumption. Sour cherries and blackcurrants are industrial products and are harvested by machine.

The production of fruit and berries fluctuates greatly from year to year, depending on climatic variations, and earnings vary greatly because the prices are fixed on the basis of international supply. Table 6.2 shows key figures for the production.

Table 6.2
Treatment frequency index (TFI), acreages, size of production, value in DKK and degree of self-sufficiency for the largest fruit and berry productions in Denmark. The organic acreage is shown in brackets (Lindhard et al., 1998).

Crop	TFI	Acreage, ha 1997	Tonnes product	Produc-tion value in mill.	Degree of self-sufficiency, %
Apples	20-25	1522 (24)	18,396	77	25
Pears	16	399 (14.6)	2,626	17	16
Dessert and sour cherries	12	2703 (10)	8,656	39	95
Black currants, red currants, raspberries	15	1801 (136)	7,156	25	72
Strawberries	11	762 (25.5)	2,666	63	45
Total, 1996/1997		7291 (340)	40,500	222	50.6

High level of pesticide consumption

Considerable use is made of pesticides in the present fruit and berry production. In particular, there is a considerable consumption of fungicides to keep fungal diseases down. For example, apples are commonly sprayed with fungicides 18 times during a growing season. The main reason for spraying so much is to keep down attacks of mildew, common scab and storage diseases, which affect the quality of the fruit (Lindhard *et al.*, 1998). Unlike foreign fruit, Danish apples are not treated with pesticides after harvesting, nor are they waxed or lacquered (Anon., 1995).

Few pesticides

Six of 15 fungicides used in fruit and berry production have been banned in connection with a review. Since fungicides are by far the most commonly used agents in the fruit and berry sector, the ban on the six agents in question is having a serious effect on production. In connection with the review, the two most widely used fungicides (Captan and Fenarimol) have been banned since the 1998 season. This means that there are at present no effective agents against fruit-tree canker, grey mould in blackcurrants, redcurrants and raspberries, and mildew in strawberries.

6.3 Nurseries

Present production

Nurseries produce plants for fruit growing, hedgerows, forests, landscape care, gardens, parks and plantations. The plants are propagated from seed or cutting or by grafting and are grown to suitable size for planting out in a permanent place. There is a very large number of species, and many varieties of around 300 species are commonly cultivated (Brander *et al.*, 1998).

Nursery cultures therefore differ greatly, which makes it difficult to generalise and to give exact figures for the present pesticide consumption. A culture such as Norman fir, for example, has few pests, whereas fruit trees have many and a correspondingly big consumption of pesticides.

The production value of nursery plants is estimated to be DKK 480 mill. per year (average of the last five years), of which DKK 100-150 mill. goes to export. Only limited information is available on the sector's production of individual cultures; a cautious estimate is given in table 6.3. In all, there are 329 firms producing nursery cultures. Units are typically around 10 ha in size and 2,290 people are employed in the sector.

Pesticide consumption uncertain

It is not possible to give concrete figures for pesticide consumption within the nursery sector because consumption varies greatly from culture to culture, from year to year and from company to company. It is, however, substantial in all cultures. Consumption is small in the production of avenue trees, evergreens for gardens and conifers for forestry, medium in the production of deciduous trees for forestry and large for roses, fruit trees, fruit bushes and some ornamental plants. The treatment frequency indices given come from interviews with different producers and agricultural advisers. Most cultures are sprayed as needed when diseases and pests are beginning to develop, while some are sprayed more regularly to avoid serious diseases and pests (Brander *et al.*, 1998).

Table 6.3
Treatment frequency index (TFI), production quantity, value in DKK and degree of self-sufficiency for the principal nursery cultures in Denmark. The treatment frequency index covers a full production process and not a single growing season.

Crop	TFI	Number of units	Production value, DKK	Degree of self sufficiency
Fruit trees	11-14	0.4 mill.	30 mill.	70%
Fruit bushes	8-9	0.5 mill.	10 mill.	90%
Ornamental trees and bushes	6-10	23.7 mill.	180 mill.	95% *
Roses	12-13	3.0 mill.	30 mill.	70-90% *
Perennials	7-10	8.0 mill.	40 mill.	90% *
Hedging and shelter plants	4-12	25.0 mill.	80 mill.	90-95% *
Forest plants	5-14	40 mill.	70 mill.	90% *
Avenue trees	6-7	0.2 mill.	35 mill.	70% *
Total			480 mill.	

*There is also a substantial export of these cultures.

6.4 Greenhouse production

Present production

Both vegetables and pot plants are very intensive productions with a high degree of specialisation. Production is spread over 780 units and a total greenhouse area of 512 ha. Arable farming in greenhouses comprises a very large number of cultures – both edible cultures and ornamental plants. The main edible cultures are tomatoes, cucumber and lettuce. Tomatoes constitute more than half of the total production (Danmarks Statistik, 1998). Within ornamental plants, more than 400 different cultures are grown.

Table 6.4
Acreages, size of production and value in DKK for the main greenhouse cultures in Denmark 1997.

Crop TFI	Acreage, 1997 Ha	Tonnes	Production value mill. DKK	Export value mill. DKK
Greenhouse vegetables	116.6	34,472	317	126.5*
Cut flowers and foliage	25.0		179	19.5
Pot plants	308.3		2,504	2,340
Total	512.8		3,000	

*export, incl. field production

Use of biological control methods

Biological methods are very widely used for controlling pests in greenhouse vegetables. In these cultures, chemical agents are used mainly for prevention and control of diseases (grey mould, mildew, etc.). Slightly less than 20% of the farms use only biological methods, while around 50% use a combination of chemical and biological control (Anon., 1998).

0-tolerance pests

In ornamental plant cultures, some use is made at present of biological control of pests. However, chemical methods are still used against pests where biological methods are not available or are not deemed to be sufficiently effective or competitive. Chemical agents are also used where invasion from outside makes biological control impossible and for harvesting a culture – with a view to complying with the current plant health rules, which include requirements concerning 0-tolerance pests and pests that affect quality. Fungicides are used to prevent soil-borne diseases, for example, which can be very destructive in the establishment phase, but also for preventing mildew, grey mould, etc.

Most pot plants are treated with growth regulators several times during production to get the desired size and flowering structure.

6.5 Conclusion

Production within this sector is very varied and comprises many different cultures. The requirements concerning plant health within market-garden cultures are generally high and are governed by EU plant health directives, which also specify pests and levels of pests that cannot be accepted. In Denmark today there is a considerable degree of self-sufficiency in vegetables (60-90%), while self-sufficiency in fruit and berries varies between 25% for apples and 95% for cherries.

The supply of pesticides within the market gardening sector is already rather limited today because some products are no longer marketed and/or have been banned in connection with a review.

There are no studies with reliable figures for pesticide consumption within market gardening. There is therefore considerable uncertainty concerning the actual consumption, which makes it difficult to analyse scenarios.

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7 Present production in forestry

Private forests contra state forests

The sub-committee has only analysed production within private forestry, which covers an area of around 300,000 ha. There is already a plan for phasing out pesticides within state forestry before the year 2005, and the economic consequences of a ban on the of use pesticides on National Forest and Nature Agency Land have been analysed (Linddahl, 1996). State forests cover a total area of 108,000 ha. In this analysis, the economic loss in the case of ornamental greenery has been calculated to be 70% of the present profit, while the additional costs have been found to be 30%.

7.1 Present production and use of pesticides

Table 7.1 shows the distribution of land for production in private forestry. Approximately 11% of land in Denmark is forested.

Table 7.1
Distribution of land used for private forestry production, together with production value

Type of production	ha	Production value mill. DKK
Production of deciduous trees: beech, ash, oak, etc.	105,508	219
Production of coniferous trees: Norway spruce, Sitka spruce, etc.)	157,692	319
Production of Christmas trees and ornamental greenery (Norman fir)	24,000	750[1]
Production of Christmas trees and ornamental greenery *(Abies nobilis)*	8,600	133
Production of Christmas trees and ornamental greenery, other biomass	5,000	1,431
Total	300,800	

1) Covers both Norman fir and *Abies nobilis.*

Small pesticide consumption

Pesticide consumption in forestry has always been very low compared with farming, market gardening and fruit growing. In 1994/95, consumption in the entire forestry sector, including the State forests, was calculated to be as follows:

Herbicides	51,900 kg gs/year
Insecticides	3,500 kg gs/year
Fungicides	200 kg gs/year
Total	55,600 kg gs/year

This consumption amounted to approx. 1% of the total consumption in all sectors of agriculture.

Pesticide consumption is generally higher in private forestry than in state forestry because a larger part of the acreage is used for production of Christmas trees and ornamental greenery. In State forestry, average consumption is estimated to be 0.35 kg gs/ha/year for afforestation and 0.42 kg gs/ha/year for Christmas trees and ornamental greenery.

Pesticides are used in the establishment phase

Pesticides are mainly used in the culture phase in forests and in afforestation areas and areas with ornamental greenery. It is principally herbicides that are used in the establishment phase, when the main problem is controlling grass. Besides this, there is a small consumption of insecticides in ornamental greenery, principally to control common spruce aphid and periodical occurrences of moths. In the establishment phase of conifers, insecticides are also used against weevils.

In the past 20-30 years the production of Christmas trees and ornamental greenery has become of increasing importance for the entire forestry sector. Today, the economy of many forest properties depends on this production (Østergaard *et al.*, 1998).

Problems with grass weed

Grass weed is the predominant problem in forestry. Inadequate control, or none at all, would create a number of problems:

- Grass is a serious competitor for the available water, and in dry years and on poor soil, grass will always win the battle for water.
- Grass shades and lays itself on top of small plants when it dies down, thereby smothering them.
- Grass increases the risk of frost damage because it prevents heat from being given off from the soil. Some species of tree are killed by frost, while growth is retarded in others.
- Grass attracts mice, which can damage the trees by gnawing.
- Grass takes nutrition, which – all else being equal – means an increased need for fertilisation in cultures that are overrun by grass. Swardy soil causes yellowing of ornamental trees and Christmas trees.

7.2 Wood-producing forestry

This production is characterised by a long production time, with a rotation period of 50 to 150 years for deciduous trees and 40-70 years for conifers. This means that only around 5,000 ha have to be replanted per year. It is not known how much forest is established by natural reproduction or replanting, but we estimate that about 1/5 is established by natural reproduction and the rest by replanting. Pesticides are used particularly on land that is to be replanted and are normally applied 0-2 times in the first five years of the establishment phase. It is common practice to spray with glyphosate before felling so that weed is removed before replanting.

When establishing conifers it is sometimes necessary to take action against the seed pod weevil, which occurs frequently in Central and West Jutland. Other pests that can occur include the nun moth – a butterfly - although control measures are rarely needed for this. Pest problems in the form of insects are extremely rare in deciduous forests.

When establishing deciduous forests it is necessary to use repellents against mice. In areas under heavy pressure from game it is sometimes necessary to treat the top shoots of conifers or to set fences up to prevent biting.

Plan for afforestation

The Danish Parliament’s decision to double Denmark’s forested acreage within one tree generation means establishing 3-4,000 ha of new forest per year. Afforestation offers good possibilities of using mechanical methods of weed control and soil treatment, especially on even areas, while herbicides are used in less accessible areas. There is a particular need for pest control in new areas situated close to earlier forests, where pests have already become established.

7.3 Ornamental greenery

Scope of production

Ornamental greenery comprises Christmas trees and cut greenery. In the past 20 years this production has become of increasing importance to the economy of the entire forestry sector. Denmark is thus a country in which growers have specialised in this production. A substantial part of the production takes place on agricultural land. In the last 10 years exports have varied between 3 and 8 million Christmas trees, most of which are Norman fir. Exports of cut greenery vary between 12,000 and 22,000 tonnes. About 1.5 million Christmas trees and 10,000 tonnes of cut greenery are sold on the home market (Østergaard *et al.*, 1998).

Weed control

In ornamental greenery, weeds are normally controlled with herbicides. It is estimated that herbicides are used on about 70% of the acreage with these cultures, while a combination of mechanical methods and herbicides is used on the remaining 30%. Soil herbicides used to be widely used, but since a large number of these were banned, glyphosate has been used. However, treatment has to be more frequent than in the case of soil herbicides because glyphosate has a smaller long-term effect.

Pest attack

Areas used for production of ornamental greenery are constantly monitored for insect attacks because these can severely affect the quality of the trees. The main pests in this production are common spruce aphid and various species of moth, but severe attacks of seed pod weevil, gall mite and spider mite also occur. Chemical control is of great importance for preservation of the quality of the trees. Norman fir is particularly sensitive to insect attack, whereas *abies nobilis* needs less protection.

7.4 Conclusion

11% of Denmark is forested. The acreage is expected to increase in the future because of plans for afforestation of 3-4,000 ha per year. Pesticide consumption in forestry accounts for 1% of total agricultural consumption. Most of the consumption is used for weed control in the establishment phase and in the production of ornamental greenery.

Pesticides are used, particularly in the production of Christmas trees, to ensure quality and uniformity, on which sales depend.

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8 Alternative methods of controlling and preventing pests

The sub-committee was required to examine alternative, non-chemical methods of preventing and controlling diseases, pests and weeds as a basis for clarifying the consequences of totally or partially phasing out pesticides within a 10-year period. In this chapter we review existing knowledge in this area.

The methods examined are:

- prevention and control of fungal diseases
- control of seed-borne diseases
- prevention and control of pests
- prevention and mechanical control of weeds
- alternative methods for growth regulation
- biological control

The sub-committee has also considered measures that could help towards reduction in a scenario with partial phasing out of pesticides. The potential of the following measures has been examined:

- use of damage thresholds
- use of alternative spraying techniques to reduce pesticide consumption and environmental impacts
- use of genetically modified organisms
- the pesticides of the future

We can start with some general considerations concerning prevention in connection with choice of crop and crop rotation.

General considerations

Prevention of pests through choice of crops

Crop rotation is very important to the overall level of pests and their significance to crops. Thus, it is well-known that there is far less need for pesticides in crop rotations at dairy farms with a big production of coarse feed than at specialised arable farms with such productions as sugar beet and potatoes. There is generally a great need for research in order to assess the long-term perspectives of different crop rotations in which pests are to be controlled by alternative methods, as would be the case, for example, in a scenario without pesticides. Many technical changes could be made in the existing cultivation systems, such as adjustment of sowing time, fertilisation, quantity sown, etc., which would improve the possibilities of minimising problems with pests. These measures are discussed in chapter 8.1., 8.3 and 8.4.

We do not believe that there is any realistic possibility of changing the choice of crop to production of fodder and vegetables. We do, however, consider that there are certain viable alternatives in the use of wholecrop for sows and biomass production for non-food purposes. Both these types of production are estimated to have only a small need for pesticides (Olesen *et al.*, 1998). Intercropping, in the form of mixed seed, is not considered to offer any great crop-rotation potential in arable farming, although its potential could be greater in organic production, where the inclusion of nitrogen-fixing species affects the yield.

8.1 Prevention and control of fungal diseases

8.1.1 Possibilities with resistance and breeding

Resistance in agricultural crops

Breeding for resistance has been one of the main ways of reducing diseases in our cultivated species. Action in this field has to be long-term and continuous because resistance is not necessarily static. When species are cultivated on large areas of land, the fungal population's ability to attack the plants can change, whereby the resistance of the species becomes ineffective after some years' cultivation.

Cereal breeding is carried out in Denmark, but most of the species cultivated at the present time come from other countries. In the last few years, the acreage used for Danish varieties of spring barley and winter wheat has been between 5 and 10%. However, all the varieties of rye and winter barley grown have been of foreign origin.

2 kinds of resistance- race-specific and non-race-specific

When evaluating resistance in the present varieties it is important to differentiate between the different types of resistance, their genetic basis and the response of the pathogens to the resistance. Resistance is often classified as either race-specific or non-race-specific (partial) resistance. The two categories are defined on the basis of the effect of the resistance to specific pathogenic isolates. Race-specific resistance is characterised by a high effect on certain pathogenic isolates (those with avirulence against the resistance in question) and no effect on isolates with the corresponding virulence. The frequency of isolates with virulence/avirulence in the pathogen population thus determines the effect of race-specific resistance in field conditions. Race-specific resistance is normally inherited through one gene, whereas partial resistance depends on many genes.

Loss of resistance

The proliferation of virulent isolates in a pathogen population is expressed in practice by the resistance in question losing its effectiveness. The speed at which such proliferation occurs depends on the pathogen's biology and spreading pattern, but also the size of the area on which the variety in question is cultivated, whether as part of a mixed crop or a monoculture, whether the crop is grown in both spring and winter form and, last but not least, the level of partial resistance of the available varieties. Partial resistance has approximately the same effect on all pathogenic isolates. However, selection also takes place in the pathogen population to adapt to partial resistance, but this selection is less intense and partial resistance is therefore regarded as more "durable".

Good resistance in spring barley

Spring barley is the species of cereal that has been subjected to the most intensive breeding in the last 30-40 years and on which the most breeding-related research has been done in Denmark. It is also the species of cereal with the highest resistance to fungal diseases. The species cultivated already have effective resistance to mildew, brown rust and Rhynchosporium and moderately effective resistance to net blotch. Some of the most widely cultivated species combine good resistance to all four diseases. The relatively successful breeding for resistance in spring barley must be seen in the light of extensive use of ml-o resistance to mildew. There has thus been a distinct move towards cultivating more mildew-resistant species in the last 10 years. Ml-o resistance has thus given researchers time to incorporate good resistance to the other main fungal diseases.

Resistant species often have love yield losses

In spring barley, the level of yield of the most resistant varieties is equal to that of the highest yield varieties and, generally speaking, it does not pay to take measures to prevent and control fungal diseases in either the highest yielding varieties or the most resistant varieties (table 8.1). This is reflected in the present choice of varieties, especially within feeding barley. It can pay to use fungicides in wholly or partially sensitive varieties in localities and years with favourable conditions for epidemic development of fungal diseases.

Table 8.1
Yield relationships in the most resistant and the highest yielding varieties of spring barley with and without use of fungicides in 1995-97. The breakdown into 'most resistant' and ' highest yielding' varieties was carried out after the results from the underlying trials had been computed (Munk et al., 1999).

	The 5 most resistant varieties Yield hkg/ha*	*The 5 highest yielding varieties**. Yield. hkg/ha*
Treated with fungicides	*66.0*	*67.9*
Treatment costs	*2.5*	*2.5*
Net yield in treated cereals	*63.4*	*65.4*
Untreated	*65.2*	*65.8*
Net additional yield in treated cereals	*-1.7*	*-0.4*

*Resistant varieties: Meltan, Bartok, Heron, Tofta, Wren
**Highest yielding varieties: Henni, Bartok, Sultane, Cork, Paloma

Varieties with good mildew resistance generally give a smaller additional yield when fungicides are used than more sensitive varieties. This can be seen from table 8.2, which shows figures from 3 years in which disease attacks varied considerably. Variety mixtures generally have a low level of mildew and less need for disease control. Other diseases, such as brown rust, net blotch and Rhynchosporium cause a considerable loss of yield in some years if fungicides are not used. This was the case, for example, in 1998.

Table 8.2
Gross additional yields in hkg/ha for control with fungicides in different varieties of spring barley, with a breakdown by resistance and year. The mildew attack is given in brackets for each of the 3 years. All the figures are based on at least 15 trials. (Annual Reports of Field Trials, Supplementary Trials).

Varieties	1996	1997	1998
Resistant varieties	1.2 (0-0.1%)	3.8 (0%)	7.2 (0.2-0.3%)
Sensitive varieties	2.7 (1-6%)	3.8 (0.2-0.5%)	9.3 (3-9%)
Variety mixtures	1.3 (0.1-0.2%)	3.3 (0%)	6.0 (0.6-1%)

Feeding barley and malt barlev

In Denmark, varieties of feeding barley are grown on about half the acreage, and varieties of malt barley on the other half. Within feeding barley, great attention is paid to resistance in the choice of variety and cultural practices, with minimum use of fungicides. In the case of malt barley, farmers do not have the same possibility of choosing varieties with high resistance to disease because the malt industry in Europe only accepts very specific varieties that are of good quality, well known and well tried. To maintain Denmark's big export of malt (the additional value of malt barley compared with feeding barley in a normal season is often as much as DKK 10-30/hkg), resistance to disease must often be given lower priority than quality.

Low resistance to disease in winter barley

Winter barley has relatively low resistance to leaf diseases. The average loss in the five highest yielding varieties as a consequence of not using fungicides is about 2 hkg/ha after deduction of costs. Winter barley is attacked by the same diseases as spring barley, but in winter barley it is Rhynchosporium, net blotch and brown rust that cause most losses. The varieties exhibit considerable difference in the level of resistance, but only a single variety has had fairly high resistance to all diseases. Within the last few years, individual, new varieties have shown clearly improved resistance in trials, but none of them has shown a sufficiently high yield and resistance to winter conditions in Denmark. The varieties that best combine yield, winter resistance, stem characteristics and grain quality are normally grown on most of the acreage. As the variation in resistance among the varieties of winter barley is limited and no varieties combine sufficient resistance to all the main diseases, there is no possibility in the short term of further reducing the dependence on fungicides through choice of varieties (Hovmøller *et al.*, 1998).

No varieties of wheat with good resistance to all leaf diseases

Winter wheat's four most serious leaf diseases are mildew, yellow rust, leaf spot of wheat and glume blotch of wheat. It suffers severe attacks of these diseases, resulting in heavy loss of both yield and quality. There are varieties with moderate to good resistance, particularly to mildew and yellow rust, but no varieties on the market combine effective resistance to all the main leaf diseases (table 8.3).

Table 8.3
Frequency of damaging attacks of fungal diseases in winter wheat in Denmark, level of resistance of available varieties, and genetic basis and future potential for resistance (modified on the basis of Hovmøller et al., 1998).

	Mildew	Yellow rust	Leaf spot of wheat	Glume blotch of wheat
Years with attacks				
Strong	93,94,96	88-90	87,96-98	-
Moderate	88-92, 95, 98	92	88,91,94-95	97
Weak	97	91, 93-97, 98	89,90,92,93	88-96, 98
Resistance* (number of varieties)				
High	2	32	0	Not known
Medium	3	4	30	Not known
Low	34	2	8	Not known
Resistance basis	Few specific genes + partial resistance	Few specific genes + partial resistance	Partial resistance	Partial resistance
Evolution in pathogen	Rapid	Rapid	Moderate	Moderate
Future potential with conventional breeding	High	High	Moderate	Low

* Resistance is based on % coverage of leaf area in unsprayed observation plots, 1995-97.

Big annual fluctuations in yield losses after attacks by diseases

A simple breakdown of the varieties into sensitive and resistant, depending on the pressure of disease in the individual year shows that the loss of yields due to diseases varies between 6 and 21 hkg/ha (table 8.4). In the case of mildew, the varieties widely grown today are not fully resistant, although some of the very latest varieties appear to have effective resistance. For many years, the resistance of wheat to mildew has proved relatively short-term. Many of the varieties grown possess effective resistance to yellow rust, but here, too, the resistance lasts too short a time (Hovmøller et al. 1998). Leaf spot of wheat and glume blotch of wheat are diseases that could also cause serious problems in the future because the varieties worth cultivating today are insufficiently resistant. The strength of epidemic attacks depends greatly on the weather, and severe attacks can cause high yield losses.

Table 8.4
Gross additional yields in hkg/ha when fungicides are used in different varieties of wheat, with a breakdown by resistance and year. All the figures are based on at least 16 trials. (Annual Reports of Field Trials, Supplementary Trials).

Variety	1996	1997	1998
Resistant varieties	6.6	10.5	13.1
Sensitive varieties	9.2	13.7	21.6
Variety mixtures	7.4	10.8	16.9

**Resistant varieties: 1996-97: Terra, Lynx, Hunter, 1998: Lynx, Stakado, Cortez*
***Sensitive varieties: 1996-98: Ritmo, Versailles, Brigadier*

Resistant contra high-yielding varieties

As for spring barley, we have selected the five 'most resistant' and the five 'highest yielding' varieties of winter wheat in the period 1995-97 on the basis of the results from the underlying trials. In this connection it should be noted that the highest yielding varieties in one year are seldom highest yielding in the following year. A later analysis of the same material year by year shows that only one of the five highest yielding varieties in one year is to be found in the five highest yielding varieties in the previous year.

On average, in the period 1995-97, the use of fungicides resulted in an additional increase in yields in both the most resistant varieties (which were only partially resistant to leaf spot of wheat) and the highest yielding varieties. The most resistant varieties yielded 3.5 – 4.5 hkg/ha less than the highest yielding varieties, both with and without treatment with fungicides (table 8.5).

Subsequent trials in 1998, when most varieties suffered severe attacks of leaf spot of wheat and new fungicides were used, show that the net additional yields were of the order of 9-12 hkg/ha in the variety trials, with the highest additional yields in the group of highest yielding varieties (Munk *et al.*, 1999). It was also found that when the grouping of 'most resistant' and 'highest yielding' varieties for 1998 was based on results from 1997-98 there was no difference in yield between the two groups of varieties when treated with fungicides, while the most resistant varieties gave the highest yield without treatment.

Resistance does not cost yield from nature´s hand

The above results underline the fact that it is not the property 'resistance' that is the reason for a possibly lower yield than in varieties that are highest yielding for a period. We believe that with different breeding priorities the level of resistance can be raised while maintaining a high level of yield. However, since Danish plant breeders participate in international cooperation, the magnitude of the improvement in yield depends on the extent to which the same selection criteria are used and on how much material can advantageously be exchanged between the breeding companies. If Denmark concentrates unilaterally on resistance, it may mean that the improvement in yield of Danish varieties will have difficulty in keeping up with the expected improvement for foreign varieties. Conversely, increased focus on resistance in other countries as well could give Danish breeders a competitive advantage.

Table 8.5

Yield relationships in the most resistant and the highest yielding varieties of wheat with and without use of fungicides in 1995-97. On average, both groups produced additional yields of the same order of magnitude with treatment with fungicides. The classification into 'most resistant' and 'highest yielding' varieties was carried out after the results from the underlying trials had been calculated. (Munk et al., 1998).

	The 5 most resistant varieties Yield in hkg/ha*	*The 5 highest yielding varieties**, Yield in hkg/ha*
Treated with fungicides Treatment costs	*89.0 4.2*	*92,8 4,2*
Net yield in treated wheat Untreated	*84.8 84.1*	*88.6 87.0*
Net additional yield for treated wheat	*0.7*	*1.6*

**Lynx, Stakado, Sareste, Hunter, Pentium*
***Trintella, Ritmo, Flair, Record, Versailles*

Big breeding potential

Within the next 10 years the potential for breeding and use of varieties with effective resistance to mildew and to some extent to yellow rust is deemed to be relatively good because there are new effective resistance genes in breeding material and a comparatively high level of partial resistance in a number of well adapted varieties. However, if the population dynamic of the yellow rust fungus continues at the same rate in the years ahead, there may be a shortage of good resistance to yellow rust within 10 years. In the breeding material there is not at present fully effective, race-specific resistance to either leaf spot of wheat or glume blotch of wheat. There is a considerable difference in the level of partial resistance between new lines, but partial resistance is polygenetically determined and is therefore difficult to work with in breeding. The level of partial resistance can probably be increased in new varieties within 10 years, but it does not seem likely that a high enough level can be achieved to avoid epidemic attacks in weather conditions that are favourable to the two fungal diseases.

Many breeding aims

It must be stressed that wheat does not appear to have resistance comparable to the very durable Mlo resistance of spring barley. It will always be necessary to introduce new resistance to replace the specific genes that have lost their effectiveness. That means working to introduce new resistance to all four leaf diseases at the same time. New varieties must also have good winter hardiness, i.e. a high level of tolerance to frost and cold, combined with resistance to out-wintering diseases. We are therefore unlikely to see, within a 10-year horizon, the development of varieties that combine resistance to all four leaf diseases, let alone varieties with effective resistance to all the main diseases combined with good winter hardiness.

There is a considerable potential for reducing losses from leaf diseases genetically. In this connection it must be stressed that even though, in cereals for example, there is a possibility of remedying the problems within each of the areas leaf diseases, seed-borne diseases and weed competition, it is not given that all the problems can be solved at the same time by breeding within a short space of years. It is therefore necessary to carry out a combined assessment of unsolved tasks for each individual crop, while at the same time considering the level of yield and quality.

Resistance in rape, peas and seed grass

Only limited use is made of fungicides in rape, peas and seed grass. Too little is known about the significance of pathogens in rape, peas, seed grass and beets and about resistance genetics and the population dynamics of pathogens. There is generally a genetic basis for raising the level of resistance to diseases in rape, peas, seed grass and beets, but that calls for a major research and breeding effort. In the case of rape, peas and seed grass, breeding is primarily carried out for the export market, where one cannot expect any direct increase in demand for resistant varieties.

Potato blight

Potato blight is the principal disease in potatoes, and it occurs every year. The effect of attacks depends mainly on how early they occur and how severe they are, and on the receptivity of the potatoes cultivated, cf. figure 8.1. Losses from blight of 30-40% are common (Hansen & Holm, 1996). Good resistance to blight could considerably reduce the losses in potatoes.

Varieties with specific resistance genes to potato blight have been widely used for more than 40 years, but up to the present time all known, specific resistance genes lost their efficiency. Researchers have been working since the 1960s on non-specific resistance genes that act against different races of blight. Such varieties are attacked more weakly and the epidemic develops more slowly. However, in several varieties with non-specific resistance, the resistance has become partially or completely ineffective after many years' cultivation (Holm *et al*., 1998).

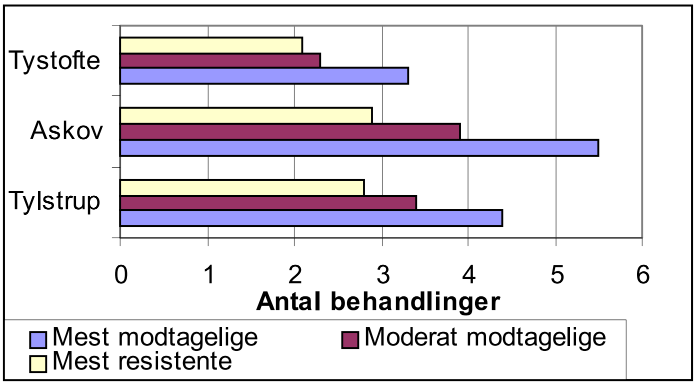
Present resistant varieties

Although there are some varieties with fairly good resistance to potato blight, it has not yet proved possible to transfer this resistance to all the varieties preferred by the consumers and the starch industry. Danva is an example of a late starch potato with good resistance. At the breeding stations there are several new, late starch and ware varieties with non-specific resistance on the way. However, in neither Danish nor foreign material are there any ware varieties with good resistance on the way. High resistance seems only to occur in late varieties (Holm *et al*., 1999). A common feature of resistant varieties is that nobody knows how long it takes for resistance to break down because of a change in the virulence of the fungus. Types that break down resistance develop faster in widely grown varieties.

None of the known resistances are strong enough to keep attacks of fungal diseases at bay and ensure against loss of yield. All varieties with non-specific resistance genes are strongly attacked towards the end of the growing season if the climatic conditions are favourable to blight. However, these varieties can manage with reduced spraying – especially early in the season (Holm *et al*., 1999).

Heavy consumption of fungicides in potatoes

Today, 40-50% of all fungicides, measured in kg active ingredient, is used to prevent this disease. The varieties' resistance to potato blight is not fully utilised because the risk of attack in the different varieties cannot be sufficiently differentiated at the present time. For that reason, varieties with some resistance are generally sprayed as though they have no resistance to attack.



(Antal behandlinger = Number of applications
Mest modtagelige = Low resistance
Moderat modtagelige = Moderate resistance
Mest resistente = Higt resistance)

Figure 8.1
Need-determined treatment frequency index against potato blight in 3 localities in Denmark up to 15 August, with a breakdown into 3 resistance levels. The figures are the average of the years 1988-95. With routine treatment, six applications are taken as the normal treatment level (Source: Hansen & Holm, 1996).

Strategic use of varieties, incl. variety mixtures

Besides direct use of resistant varieties, disease attacks can be reduced by *strategic* use of resistance, including use of mixed species and varieties and distribution of resistance over time, e.g. in winter and spring forms. Experience with the use of variety mixtures is good in spring barley, while there is only limited experience from other crops. The possibility of regulating and stabilising resistance by this means has often been advanced but has been of only limited practical importance owing to problems of regulation.

Resistance in market-garden cultures

The market gardening sector covers many cultures. Only a few of the most important will be mentioned. Most varieties within this sector come from other countries (particularly the Netherlands and the UK). In Denmark, very little breeding work is done in this area.

Problems in apples and strawberries

The biggest problem in pomes is fruit scab. The main varieties grown in Denmark today are not all the healthiest varieties. If pesticide consumption is to be reduced, the choice of varieties will have to be changed. That takes time (10-15 years) because the present production has to be written off before a new production can be established. There are varieties of apples with resistance to scab, but the resistance has become less effective in the same way as resistance in other crops. Choosing resistant varieties will reduce the problem of diseases but will not solve it (Lindhard *et al.*, 1998).

There are strawberry varieties with relatively good resistance to grey mould and mildew. Unfortunately, however, they do not meet the retail sector's requirement concerning a long shelf life. When planting strawberries it is important to ensure that the material is free of red rot, wilt and stem rot.

Vegetables cover many cultures and are grown both outdoors and, in many cases, indoors. One of the biggest problems in greenhouse vegetables is pythium, which attacks the plants' root system. There are at present no varieties that are resistant to this disease in, for example, cucumbers, although resistant wild types have been identified that could improve the level of resistance in the longer term (Thinggaard, 1998). In lettuce, downy mildew is a serious problem. Even though breeding is going on towards resistant varieties, the resistance is seldom particularly lasting.

Onions are a field culture that suffers severe attack from onion mildew. This fungal disease reduces both quality, yield and shelf-life. Screening of the varieties of onion cultivated has shown very little difference in their receptivity (Kjeldsen, Bjørn & Thinggaard, 1998).

The supply of ornamental plants is very varied, and as more than 400 different species are produced it is difficult to incorporate broad resistance in all cultures. Owing to rapid development in the choice of varieties it is thus difficult, with the present form of production, to ensure the cultivation of disease-resistant varieties (Ottosen *et al.,* 1998).

8.1.2 Possibilities offered by cultural practices

Agricultural crops

The crop rotation is of great importance to the total pressure of diseases and the reduction in yield caused by diseases. Table 8.6 shows some examples of crop-rotation diseases and nematodes and the number of years it normally takes before the crop is grown again on the land in question.

Generally, however, there is considerably less need for fungicides in dairy farm crop rotations with a big production of coarse fodder than in specialised arable farm crop rotations with, for example, cereals and potatoes. This is not due to attacks by specifically crop-rotation diseases but to the fact that cereals and potatoes are generally the crops that are most severely attacked by leaf diseases.

Not all these diseases can be prevented or controlled chemically. In Denmark, the general rule is a crop rotation that prevents proliferation of most of the crop-rotation diseases. Among other things, there is no tradition for controlling nematodes, which has been widely practised in Dutch agriculture, for example, in order to have a large proportion of potatoes and beets in the crop rotation.

There is some possibility of reducing the impact of diseases in winter cereals by postponing the sowing time. However, there can be a considerable reduction in yield with late sowing (5-7 hkg/ha), and late sowing also reduces the crop's N-absorption in the wintertime and increases the risk of leaching (Annual Report of Field Trials, 1997).

Table 8.6
Table showing crop-rotation diseases/nematodes and the number of years that normally have to elapse before the crop is again grown on the land in question (Source: Godt Landmandskab år 2000 (Good Agricultural PracticeYear 2000)).

Crop	Disease/pest	Also attacks	Resistant varieties	Number of years not cultivated
Wheat/rye	Take-all disease Eyespot	Grain Grain	No Some in wheat	1 2
Barley	Oat nematodes Typhula Take-all disease Eyespot	Grain Rye Grain Grain	Yes No No No	3 3 1 2
Oats	Oat nematodes	Grain	Yes	3
Beets	Beet nematodes Root rot	Cruciferous peas	No No	3 3
Potatoes	Potato nematodes Common scab Black scurf	- Carrots Grass, beets, Rape	Yes Some No	3 3 3
White/red clover	Stem nematodes Sclerotinia	- Lucerne	Some Some	3 3
Rape	Beet nematodes Clubroot Sclerotinia	Beets Cruciferous peas etc.	No No No	2-3 4 4
Peas	Root rot Wilt Sclerotinia	Beets - Rape etc.	No Some No	3-4 3-4 3-4

Effect of nitrogen

Increased quantities of seed and increasing quantities of nitrogen normally increase the risk of mildew in cereal crops (table 8.7), but the interaction between the cultural practices and the diseases, and thus the need for pesticides, is normally significantly less than the main effect (Jørgensen *et al.,* 1997).

Table 8.7
Effect of quantity of seed on percentage of plants with mildew in wheat in the first disease evaluation and the need-determined quantity of fungicide calculated by means of PC-Plant Protection (Jørgensen et al., 1997).

Grains per m2	Mildew, % of plants attacked		Total amount of fungicide used, l/ha	
	1993	1994	1993	1994
150	76	5	1.1	0.7
225/300	89	11	1.2	0.7
450	100	38	1.3	0.8

Attacks by diseases can therefore not be prevented simply by adjusting the cultural practices. The widespread practice of split application of the nitrogenous fertiliser helps to reduce the risk of severe mildew epidemics, compared with earlier strategies in which all the fertiliser was applied in one go.

Experience from organic potato production

In organic potato production, some cultural practices are used to minimise attacks of potato blight and their effect. The earlier the potatoes finish growing, the higher the yield that can be achieved. Growers not only select a variety with considerable resistance but also preheat and pre-germinate the seed potatoes and use spring ploughing, which results in warmer soil and faster germination (Holm *et al.*, 1999).

Second crops are deemed to be neutral with respect to attacks by diseases and pests provided unfortunate combinations of main and second crops are avoided.

Market-garden crops

In tree fruit, different methods are available for reducing attacks by diseases. However, none of them keeps the culture completely free of problems. For example, good orchard hygiene, including removal of old, mummified fruit, reduces the risk of monilia, while removal or good decomposition of old foliage, together with pruning that results in open trees, helps to reduce attacks of fruit scab in apples. Rapid decomposition of foliage also helps to reduce leaf spot in cherry trees and rust and leaf spot in blackcurrants. Good drainage and cutting out of wounds reduces the risk of fruit-tree canker, and clipping off of shoot tips infected with mildew, especially in young plantations, can reduce attacks (Lindhard *et al.*, 1998).

Grey mould is reckoned to be one of the diseases causing most losses in strawberries. Moist conditions during flowering encourage this fungus, which attacks through the flower. The risk of attack can be reduced by ensuring rapid drying of the plants – for example by reducing the supply of nitrogen – which results in smaller plant mass, cultivation of isolated plants and harrowing to remove old, died-down plant material (Lindhard *et al*., 1998).

8.1.3 Perspectives

Cultural practices

Many cultural practices can easily be incorporated in the present cultivation systems, such as adjustment of the sowing time, fertilisation, quantity sown, etc., whereby most problems can be reduced. However, several of these measures reduce the level of yield slightly or require extra work, especially in market-garden production.

Breeding

To utilise the potential for resistance, far more needs to be done in the way of breeding for resistance, and research and development are needed to support the primary breeding work. Besides this, more research and development are needed within resistance genetics and the epidemiology and population dynamics of pathogenic fungi, and testing of varieties and advisory services should be expanded. That applies to all crops and all pathogens (diseases) that are potentially harmful in the crop in question. Utilisation of the potential for resistance also requires close contact between the aforementioned players and activities and integration of the cooperation with agricultural advisers and seed producers so as to ensure the possibility of rapid adjustment of the varieties grown.

Strategic use of resistance

Strategic use of resistance should also be considered and more closely analysed. This would mean cultivating varieties with different resistance genes between each other (like a patchwork blanket) to reduce the risk of breakdown of resistance. Variety mixtures are another good strategy that reduces the risk of losses from diseases. Extensive use is already made of variety mixtures in spring barley (10%). Several years' trials in wheat have shown that there may also be a potential in this crop.

8.1.4 Conclusions

Breeding and cultural practices offer several options for preventing and controlling fungal diseases. However, the methods in question cannot at present make up for the losses that would result if fungicides were no longer used.

In most crops significant losses occur at intervals due to attacks by diseases. In agricultural crops the losses from diseases are potentially largest in potatoes and wheat. This is also clear from the fact that fungicide consumption is highest in precisely these two crops. Within market gardening, too, there is a risk of heavy losses in many crops – particularly pomes and strawberries. In the event of a total or partial phase-out of pesticides, greater use would have to be made of resistant varieties in order to reduce the loss of yield from attacks by fungal diseases.

There is a great potential for reducing the expected losses from leaf diseases genetically within the next 10 years. However, we do not think it possible for all the breeding objectives to be achieved simultaneously within a 10-year period. Besides resistance to leaf diseases in cereals, work is also needed on resistance of seed-borne diseases and better weed competition. It will therefore be necessary to prioritise the breeding activities. There is a great need for a major intensification of work on breeding and of research on breeding if we are to see any noticeable change in the range of resistant varieties, compared with the range that is available today.

Foreign plant breeding is of great general significance to the Danish range of varieties and production; there is also close collaboration between Danish and foreign breeders. The feasibility of changing Danish breeding priorities in favour of breeding for resistance would thus depend on the interests of foreign breeders.

There is a significant potential for reducing losses from fungal diseases through strategic use of resistance (including variety mixtures).

Many cultural practices can be incorporated in the present cultivation systems, such as adjustment of the sowing time, fertilisation, amount of seed sown, etc., to improve the possibility of minimising pest problems. However, diseases can neither be prevented nor minimised only by adjusting cultural practices. Several of the changes in cultural practices would reduce the level of yield.

Within market gardening there are also different methods that can reduce attacks by diseases. However, none of them can keep cultures free from all problems. For example, good orchard hygiene, which includes removal or good decomposition of old foliage, together with pruning that results in open trees, helps to reduce attacks. Several of these methods are associated with an increased need for manpower.

8.2 Seed-borne diseases

8.2.1 Present situation

Current practice

Thanks to effective and systematic seed-dressing of most Danish seed for drilling, serious, loss-producing, seed-borne diseases have been kept at a very low level. Today, a large proportion of all seed for drilling (85-90%) is dressed, while seed-dressing of other crops varies somewhat, depending on the actual occurrence of diseases. It is absolutely essential to treat infected consignments. Other consignments can be left untreated, but with our present-day resources and technology, it is not always possible to determine which consignments need dressing. The total consumption of seed-dressing agents corresponds to around 3% of total pesticide consumption. Several seed-borne diseases can proliferate and spread relatively rapidly, so continued action is needed to keep these diseases down. In the worst event, lack of control and prevention would result in serious losses of yield and very serious impairment of the quality of seed for drilling and cereals in general produced in Denmark (Nielsen *et al.,* 1998). The principal diseases/pests, damage thresholds and loss levels that could occur in connection with the establishment of the main agricultural crops are shown in table 8.8. The quantities in the different generations of seed are given in table 8.9.

Table 8.8
Table showing the principal agricultural crops and their need for treatment with seed-dressing agents against diseases and pests. Indication of damage thresholds and expected losses from severe attacks (Nielsen et al., 1998).

Crop	Need for seed-dressing when	Expected loss in severe attack
Wheat		
Fungal diseases that damage shoots	Over 15% of grains attacked	Approx. 5%
Glume blotch	Over 5% of grains attacked	Approx. 5-10%
Stinking bunt	When present	Up to 70% (unsuitable for bread and fodder)
Barley		
Fungal diseases that damage shoots	Over 15-30% of grains attacked	Approx. 3-5%
Barley strip/leaf spot	Over 5% of grains attacked	Just under 1% per percentage of plants attacked
Naked smut	Over 0.2% of grains attacked	Approx. 0.75% per percentage of plants attacked
Rye		
Fungal diseases that damage shoots	Over 15% of grains attacked	Approx. 5%
Stripe smut	When present	Just under 1% per percentage of plants attacked
Beets		
Phoma/soil-borne fungal diseases and pests	No guideline damage threshold	Severe attacks cause plant death. Additional yields achieved in trials: 68 hkg/ha or 971 feed units. Latest pesticide produces 113 hkg/ha or 1614 feed units because of better long-term effect.
Peas		
Leaf and pod spot	When present	Average additional yield in trials: 1.2 hkg/ha
Fungal diseases that damage shoots	Over 25% of grains attacked	Largest losses measured 8.3 hkg/ha
Rape		
Alternaria/grey mould/etc.	No guideline damage threshold	No importance attached to attacks
Thrips/flea beetle	Attacks vary from year to year	Average additional yield in trials: 2-4 hkg/ha.

If seed-dressing agents were not used, we would expect the biggest problems to be stinking bunt in winter wheat, leaf stripe and naked smut in barley and, possibly, stripe smut in rye. These fungal diseases multiply unusually rapidly, and even a small amount of inoculum on the grains can result in heavy attacks in the same growth season. Insect attacks and soil-borne diseases can cause very serious losses in beets and moderate losses in peas and rape.

Table 8.9
Quantity of certified seed for drilling in tonnes. Breakdown by seed and categories, together with estimate of the farmer´s use of own seed in 1996/97. Cert. 1. Generation and Cert. 2 Generation.: Certified seed for drilling of 1st and 2nd generation, respectively. The certified breeding acreage is also shown. Source: The Danish Plant Directorate

Quantity of certified seed for drilling in tonnes						
Species	Pre-basis	Basis	Cert. 1 generation	Cert. 2 generation	Total	Quantity of farmer´s own seed
Winter cereals	175	2,070	7,812	111,967	**122,024**	
Winter barley	41	369	1,594	28,759	**30,763**	
Rye	0	481	9,012	0	**9,493**	
Triticale	0	211	105	936	**1,252**	
Winter cereals total	***216***	***3,131***	***18,523***	***141,662***	***163,532***	***29,000***
Spring barley	336	1,558	7,767	83,390	**93,051**	
Oats	0	149	441	3,632	**4,222**	
Spring wheat	12	15	102	781	**910**	
Spring cereals, total	***348***	***1,722***	***8,310***	***87,803***	***98,183***	***11,000***
seed for drilling	**564**	**4,853**	**26,883**	**229,465**	**261,715**	**40,000**
Certified acreage, ha	**1,347**	**4,506**	**18,035**	**58,157**	**82,045**	

8.2.2 Possibilities of prevention and control without pesticides

Alternative methods not fully developed

The possibility of regulating seed-borne diseases without seed-dressing agents is very limited in the short term because there are no alternative methods that would have sufficient effect. The risk, particularly in cereals, of directly phasing out seed-dressing agents is so serious that we suggest that treatment with seed-dressing agents be retained where alternatives have not been developed and faster methods of analysis in winter cereals have not been implemented. We know too little today to be able to say whether these methods could entirely replace chemical seed-dressing agents within a 10-year period. Alternatively, we would expect this breeding work to take place abroad, where use of seed-dressing agents would still be permitted.

The only possibility in a 0-scenario would be disease analysis of consignments of seed for drilling and subsequent rejection of infected consignments. This would depend entirely on fast, effective and representative analysis in the period from harvest to sowing. Since the quantities of seed for drilling are very large, a very big bottleneck would occur in winter cereals. The time needed to analyse a sample is between 2 and 10 days, depending on what the sample is being analysed for. The present systems of analysis would not be able to cope with the tasks in the short term. If each sample were to cover 50 tonnes, that would correspond to having to build up capacity for handling about 30,000 samples. The analysis capacity would thus have to be increased considerably from the present level of about 1,000 samples (Bent Nielsen, Pers. com.). We would expect large quantities of seed for drilling to be rejected, which would necessitate a substantial increase in the breeding acreage. There would be a real risk of uncontrolled proliferation of the diseases and large yield losses. The problems would be greatest in winter wheat, spring barley and rye, while they are difficult to predict in spring wheat. In triticale, the varieties investigated up to the present time have had few problems with seed-borne diseases. Triticale varieties with a large "proportion of wheat" would, however, be at risk of attack by stinking bunt.

Problems in rape, peas and beet

Today, there are no alternatives to treatment with seed-dressing agents for rape, peas and beets, and there would be very large losses in the case of beets and moderate losses in the case of rape and peas. The risk – particularly in the case of cereals – of directly phasing out seed-dressing agents is so great that we suggest retaining seed-dressing of the first generations of seed up to and including C1. With 1.5 hkg seed/ha, the C1 generation of 26,833 tonnes, could be sown on 175,000 ha, but the C2 acreage is only 58,157 ha (table 8.8), which means that only about one third of the C1 quantity could be sown. Since a larger breeding acreage than actually used would be needed, it might be necessary to dress a larger area in order to ensure sufficient supplies of varieties.

Intermediate

In the intermediate scenarios it is assumed that the breeding generations up to and including certified seed for drilling C1 are treated with very effective seed-dressing agents, while the large commonly used generation (C2, 80% of the seed for drilling) are analysed for seed-borne fungal diseases and only dressed if the damage thresholds are exceeded. Owing to serious capacity problems in analysing winter cereals, it would be necessary to determine whether a sufficiently extensive need analysis could be carried out. On the face of it, the model appears usable in spring-sown cereals, where the need for analysis would be of manageable size if the resources were increased. In Denmark, seed for drilling is produced at a relatively small number of very large facilities. If the consignments of seed were to be separated according to the need for seed-dressing, considerable restructuring (of silos, containers, etc.) would be required at the grain merchants.

8.2.3 Perspectives

Research in alternative methods

Chemical seed-dressing, which is the only method used to prevent and control seed-borne diseases in seed for drilling, has been practised since the beginning of this century. There are other possibilities, however, but only limited research and development have been done in this area up to the present time. Prevention of seed-borne diseases by means of resistant varieties is possible, particularly in the case of stinking bunt and leaf stripe, for which effective genes are available. However, that calls for a continuous and systematic breeding programme and monitoring to check whether the resistance lasts. The last few years have brought some development in biological control and prevention of plant diseases, and several products are also suitable for dressing seed. However, the products in question have not been fully developed and must also be tested for effect and usefulness in practice. Other alternative methods of prevention and control include the use of hot water, hot air, swabbing (in the case of diseases like stinking bunt, which sit on the surface of the seeds). However, these alternative methods will rarely have sufficient effect against high-level attacks. The alternative methods are far from usable in practice. The technology and methods need testing, and the investment requirement and capacity must be investigated. It is thus necessary to review control and prevention strategies and to look at possibilities of combining different measures.

10-year perspective

As described in the foregoing, there are some prevention and control measures with a considerable potential against seed-borne diseases. They include, particularly, resistance and biological prevention and control. However, too little is known today to be able to say whether these methods could replace chemical seed-dressing agents altogether within a 10-year period. Analyses of the incidence of diseases are of vital importance in this scenario as well, and work is going on to determine whether a system can be established that can handle the very large quantities of winter cereals in question within a very short space of time. Larger breeding acreages will be needed than today because more areas/consignments must be expected to be rejected than at present. Furthermore, a requirement concerning resistance to seed-borne diseases would mean a reduced choice of varieties, so it would not always be possible to use the varieties with the highest yield potential.

8.2.4 Conclusions

Problems in a 0-scenario

Today, 85-90% of all seed for drilling and the seed of a large proportion of other crops in Denmark are dressed. If dressing were generally omitted, we would expect rapid proliferation of several of the seed-borne diseases that cause losses. The risk of phasing out seed-dressing agents is so great, especially in the case of cereals, that we propose that dressing be retained where alternatives have not been developed and faster methods of analysis in winter cereals have not been implemented. Too little is known today to be able to say whether these methods could entirely replace chemical seed-dressing agents within a 10-year period. Alternatively, one would have to expect this part of breeding to take place in countries where such agents could still be used. Continued dressing of the first generations of cereals, followed by an assessment of the need of subsequent consignments of seed, would be one way of reducing fungicide consumption - a way that should be examined more closely and tested. The need assessment would demand fast, reliable analytical methods, the separation of seed consignments and probably the discarding of significant quantities of grain for multiplication. In beets, too, there could be substantial losses due to uncertain establishment if seed-dressing agents were banned.

Alternative methods

Today, work is in progress on several alternative methods of combating seed-borne diseases, including resistant varieties, the use of biological agents and technical methods involving the use of hot water/air or brushes. None of these methods has been fully developed, and much research and development work needs to be done before it can be judged whether these methods can directly replace chemical methods. For this reason, we propose that, in the event of a phase-out of pesticides, dispensation be granted for prevention of seed-borne diseases in the early generations of seed, since the consequences of an uncontrollable proliferation of seed-borne diseases are incalculable.

In spring barley, we believe that dressing of the first generations, combined need assessment of the C2 generation, could be practised, whereas for winter cereals a more detailed evaluation would be needed to determine whether need assessment of C2 was practicable owing to the short time elapsing between harvest and sowing.

8.3 Control of pests

8.3.1 Pest-resistant varieties

Pest-resistant varieties – unknown

Insect resistance in plants is seldom an “on/off” phenomenon. The resistance is usually partial. Insect resistance is reflected in different ways: for behavioural reasons, the pests in question choose a different species or variety because the plant is impossible to colonise, lay eggs in, is repellent, etc., or for physiological reasons, the pests do not ‘thrive’ well on the plant and therefore do not do much damage to it. In extreme cases, the insects die (Hansen, 1998).

However, partial resistance is of great importance because even small differences in varieties can have major effects with respect to population dynamics. Another form of partial insect resistance is tolerance. Here, the plant has developed a ‘system’ that enables it to continue growing and produce a largely normal yield despite an insect attack.
As far as concerns resistance in existing varieties, it can be concluded that there are no pest-resistant varieties of cereals in Denmark with the exception of some varieties of barley and oats, which are resistant to the cereal cyst nematode. Similarly, there are no pest-resistant varieties of grass, beets, rape and peas, whereas many varieties of potato are resistant to both kinds of potato cyst nematode.

8.3.2 Alternative methods

Agricultural crops

Many cultural practices affect the quantity of insects in fields. That applies to both harmful insects and useful animals. Some of the difference is due to natural variation and influence from adjoining habitats, while some depends on the cultural practices. The choice of crop, crop rotation, sowing time, application of fertiliser, soil preparation and use of pesticides all have an influence (Hald & Reddersen, 1990, Goldschmidt, 1995, Petersen *et al*., 1996). There are at present no clear directions on how to promote the population of useful animals as an element of the strategy to keep pests down in the field. A study from 1994 and 1995 showed that harrowing had no distinctly negative effect on the number of ground beetles, which play an important role as aphid predators (Petersen *et al.,* 1996).

Effect of nitrogen

Aphid attack in cereals is affected by nitrogenous fertiliser. Increasing amounts of nitrogen and, especially, late applications promote the proliferation of aphids. That is because the crop stays green and thus attractive to aphids for a longer period and the aphids are looking for protein. The current levels of nitrogen are deemed to have only a limited effect on the aphid population. The effect of the level of nitrogen on the need to spray against aphids and on the additional yield from insecticide spraying is unclear (Nielsen & Jensen, 1998).

Pest attacks are also affected by the sowing time. For example, oats sown late are attacked most by frit flies, and winter cereals sown early are attacked more by barley yellow virus because the aphids have more time in the autumn to transfer the virus (Nielsen & Jensen, 1998).

In recent years, field slugs have been a growing problem in many autumn-sown fields. The attack depends not only on the climate and the type of soil but also very much on the method of cultivation. Ploughing reduces the number of slugs, while direct sowing promotes attacks because the slugs are not disturbed. Black soil that is harrowed repeatedly for as long as possible before sowing of winter cereals/winter rape impedes the slugs because they are disturbed and starved (Nielsen & Jensen, 1998). Neither frit flies nor slugs are of any great significance for the present level of pesticide consumption.

Market-garden crops

Within fruit growing, work is going on abroad on alternative methods of controlling moths based on the development of confusion techniques using sex hormones. With this method, a large number of dispensers containing pheromones are set out per ha. In IPM production, predatory mites are set out to control spider mites and rust mites. Within blackcurrants, bud gall mites are the main pest. Attacks can be prevented to some extent by using healthy plant material in new plantations, keeping distance from infected bushes and removing infected buds by hand. Usable varieties with resistance to bud gall mites are expected on the market within 10 years (Lindhard *et al.*, 1998).

Attacks by several kinds of pest on outdoor vegetables can be reduced by practising good crop rotation. This applies, for example, to carrot flies and cabbage flies. Attacks can also be reduced by adjusting the sowing in relation to the lifecycles of the pests. Attacks by cabbage flies, carrot flies and thrips can also be partially kept down with netting, while cutworm attacks can be reduced by watering (Friis *et al.*, 1998).

Within the greenhouse sector, great efforts are being made to ensure that biological prevention and control is the main alternative method. It is that already in the production of greenhouse vegetables. Another method that is now undergoing pilot trials is gassing with mixtures of environment-friendly gases. In the case of pot plants, this could, for example, be done just before sale to rid the plants of pests and useful animals (Ottosen *et al.*, 1998).

8.3.3 Perspectives

Pest problems are limited in Denmark

Research in insect-resistant plants has primarily taken place in countries with economically serious pest problems. There, some use is made today of insect-resistant varieties. The reason for the low input in this area in our part of the world is that pest attacks are rarely all-destructive, and in severe attacks farmers have been able to spray with insecticides, which is a very cheap and effective measure. Genetically modified plants with resistance to pests in maize, among other crops, are becoming widely used in the USA and other countries. The possibilities offered by these methods are discussed in section 8.9.

Screening of the varieties used in Denmark would probably reveal differences between varieties with respect to host-plant properties in relation to their respective pests. Preliminary screening in this area could create the basis for incorporation of factors concerning insect resistance in breeding work. The results of such breeding activities have a long time horizon (10 years or more).

Biological prevention and control and the

With respect to the use of biological control of pests in the field, there are deemed to be certain possibilities, which are described in detail in section 8.6. The sub-committee believes that there is a potential for utilising the natural fauna to regulate pests in agricultural crops, but it cannot be utilised immediately.

8.3.4 Conclusion

Pest resistance

Little is known about the resistance of Danish varieties to pests. Simple screening for receptivity to pests could prove this to be an unused resource. The use of genetically modified plants with resistance to, for example, pests in maize is rapidly gaining ground in the USA and some other countries. The same thing could happen in other crops. However, the sub-committee does not think that serious progress, and thus use in Denmark in this area, could be achieved within a 10-year period.

Only very limited use is made of biological control of pests in fields at present, and further development and trials are needed before biological control can become a realistic alternative to chemical control.

It is a well known fact that natural field fauna, e.g. ground beetles and spiders, affect the pest population. In some years, they make a significant contribution to controlling, e.g., aphids, whereas they are insufficient in other years owing to high proliferation rates. We lack specific knowledge of the effects in this area.

Major attacks at interval of years

The development of pest attacks depends greatly on the climate. Severe, loss-producing attacks that cannot be prevented occur at regular intervals, usually in seasons with hot weather, when the proliferation rate is high.
Cultural practices, such as sowing time, fertilisation and soil preparation, affect the population of some pests. Methods involving such factors should be used where they can reduce losses from pests.

Within market gardening there are several alternative methods that can be used to control certain pests. They include placing crops in satisfactory crop rotations, adjusting sowing times, use of netting and watering.

8.4 Prevention and mechanical control of weeds

8.4.1 Present knowledge

Experience from mechanical control

In all current crops, trials have shown that weeds can be controlled with non-chemical methods, but in most cases the effect is not quite as good as with chemical agents. Therefore, more weeds must be expected in the crops if one only looks at the effect of the direct methods. To achieve an acceptable effect, both preventive and direct control methods would have to be used in a planned combination. Relevant methods are shown in table 8.10 for a wide range of crops, while the general principles are illustrated in figure 8.2, which shows that it would be necessary to use both crop rotation, various preventive methods and direct control. In localities with a high pressure of weeds or particularly aggressive species of weeds, weeds that could not be controlled sufficiently effectively with non-chemical methods would cause yield losses and harvesting problems.

Table 8.10
Table showing relevant non-chemical methods of controlling weeds in important crops. The table expresses typical processes in mechanical weed control and the number of applications (Tersbøl et al., 1998).

Crop Low and high pressure of weeds	Blind harrow-ing	Normal harrow-ing	Selective harrow-ing	Inter-row culti-vation	Hoe-ing	Gas-burn-ing	Hand-hoe-ing	Number of applicati ons, total	Control effect, %	Import-ance of quality of seed bed	Yield loss compared with chemical control
Spring cereals, low	0-1	(1)						(0-2)	70-95	***	0-5%
Spring cereals, high	1	1-2	1					2-3	50-80	***	5-15%
Winter cereals, low	0-1		1					0-2	>70	**	0-5% 1)
Winter cereals, high	1	(1)	2-3					3-4	40-70	**	0-10% 1)
Field peas	1	2-3						3-4	80-95	***	5-15%
Maize	1	2	1-2	2	2	(1)		8	70	***	10-20%
Winter rape		(1)	(1)	2-3				2-4	?	**	0%
Beets			(1-2)	3		(1)	1-2	3	95-100	**	0%
Potatoes		1-3			3			4-6	90-100	*	0%

Figures give number of applications ( ) indicates possible treatment
***Indicates great importance 1) yield loss due to late sowing not included
**Indicates importance
*Indicates slight importance

Methods of prevention

Postponing the sowing time in winter cereals offers good possibilities of reducing the importance of weeds. However, late sowing can result in a considerable loss of yield, reduce the crop's absorption of nitrogen during the winter and increase the risk of leaching.

A number of methods of prevention, including cultural practices, have a regulating effect on the relationship between crop and weeds. In addition, they can act in interaction with the direct, mechanical methods of control. Preventive methods would have to be used in a situation without access to herbicides. Only limited use is made of these methods today.

Strategy for prevention and control of weeds

Crop rotation

⇓

Prevention

- **Choice of crop and variety**
- **Quantity and quality of seed**
- **Soil preparation and quality of seed**
- **Sowing time and false seedbed**
- **Soil preparation in the dark**
- **Supply of nutrients**
- **Application of fertilizer**
- **Row spacing**

⇓

Control

- **Harrowing**
- **Flaming**
- **Inter-row cultivation**
- **Brush-weeding**
- **Hoeing**
- **Manual hoeing**

⇓

Result

Figure 8.2
Principles for weed control without pesticides, where the overall result depends on the crop rotation, the prevention measures used and the direct control measures used. (based on Michael Tersbøl).

Increasing the quantity of seed and the amount of nitrogen applied normally increases the weed competitiveness of cereal crops. Applying fertiliser seems to increase the competitiveness. The interaction between the cultural practices and weeds is normally significantly less than the main effect. Adjusting cultural practices would not make up for the losses that would occur if herbicides were no longer used.

The effect of second crops on seed-propagated weed is not known, but serious problems must be expected with root weeds such as couch grass.
The success of the direct mechanical methods depends very much on the timing of the action and adjustment of the treatment intensity to the sensitivity of the crop. It also depends on the quality of the seed bed and the weather conditions around the time the control measures are carried out. In current cultivation practice, extensive and successful use is made of mechanical control in rape, where the methods are able to compete with chemical methods.

Experience from rape, maize and peas

Table 8.11 shows figures for mechanical control in rape and maize sown in rows. As will be seen, in rape, a result similar to that with chemical control is achieved. In peas, harrowing produced rather good results in 1998. The number of plants and the additional yield have been smaller with harrowing, but harrowing two or three times has produced competitive net yields compared with chemical agents, which are relatively costly in peas (Annual Report of Field Trials, 1998). The long-term effect and the consequences of the lower effect for the subsequent crops are not known.

Harrowing can make it difficult to carry out measures aimed at preventing wind erosion, such as applying liquid manure, which is done on light soils.

Table 8.11

Comparison of weed control and additional yields in different crops with chemical and mechanical control methods (Annual Report of Field Trials, 1997).

	Method (number of trials)	Weed/cover-age at harvest	Yield and additional yield, hkg(crop units)/ha
Winter rape	8 trials		
Untreated		54	25.7
Chemical control	Broad spraying	39	1.4
Mechanical control*	3 x inter-row cult.	33	0.4
Maize	3 trials		
Untreated		-	-
Chemical control	Broad spraying	1	116.8
Mechanical control	Harrowing + Hoeing	18	-8.8

* 50 cm row spacing + reduced quantity of seed

Table 8.12

Comparison of weed control and additional yields in peas with different quantities of weed and chemical and mechanical weed control (Annual Report of Field Trials, 1998). The result of the control measures depends greatly on the amount of weed.

	Number of weeds at harvest	Yield hkg/ha	Net additional yield hkg/ha
Trials with under 100 plants/m2 (6 trials)			
Untreated	43	3.2	
2 x harrowing	34	-1.2	-2.7
3 x harrowing	28	0.3	-1.9
Chemical control	9	1.2	-4.9
Trials with over 100 plants/m2 (6 trials)			
Untreated	61	34.8	-
2 x harrowing	28	4.0	2.5
3 x harrowing	25	3.2	1.0
Chemical control	11	7.2	1.1

In potatoes, too, provided the control measures are carried out at the right time and in the right way, there is no appreciable difference between chemical and mechanical control. Without chemical control, root and grass weed can cause serious problems in certain circumstances (Holm *et al.*, 1999).

Capacity problems

In some situations, the capacity of the mechanical methods is deemed to be generally lower than that of chemical methods. In potatoes, for example, it is estimated that mechanical control would take 2-3 times as long as chemical control. That might cause problems for the approximately 300 large potato producers, who account for 40% of the total production. Without the use of chemical agents it is doubtful whether the present structure – with potato production concentrated in large and specialised farms – could be retained (Holm *et al.*, 1999).

In rainy periods it can be extremely difficult to carry out mechanical control, let alone achieve a good effect. Some fields and crops might therefore have to be abandoned in some years.

In certain periods the capacity of the mechanical methods is greater than that of spraying because, at some stages (blind harrowing and some late harrowing), harrowing takes less time than spraying and time is not spent on filling, washing and cleaning. Neither spraying nor harrowing can be done in rainy weather or just after it. Unlike spraying, harrowing can be carried out in windy weather. For a good result, harrowing must be carried out at the right time because the weather can be a limiting factor. Harrowing is much less effective than pesticides and the effect that can be achieved depends greatly on the quality of the seed bed.

8.4.2 Effect on the seed pool

The effect on the seed pool is not known

There are no trials that throw any light on weeds' production of seeds with mechanical control measures. Trials with reduced dosages of herbicides indicate that the seed pool will not increase when the weeds' production of biomass is significantly reduced. The goal for all non-chemical control of weeds must therefore be to keep the quantity of weeds at such a low level that the weeds do not cause yield losses, do not increase the weed-seed population or develop vegetative reproductive organs, do not impair the quality of the crop and do not cause unnecessary harvesting problems. We have no reliable basis today for predicting the development of the seed pool on the basis of crop rotation and control methods (Tersbøl *et al.,* 1998).

The possibilities and limitations of non-chemical control measures against weeds have been evaluated and described within different types of crop rotation, in which the prevention and control methods are integrated. The types represent a selection of typical agricultural productions on relevant types of soil. With the reservations mentioned, concerning especially root weeds and special situations with respect to pressure of weeds and aggressive species of weeds, it is believed that the systems described could regulate weeds satisfactorily in the main crops. However, this evaluation is based on a very slender body of research. In the event of heavy pressure of weeds or aggressive species of weeds, the crop rotation/choice of crops would have to be adjusted still further. It might be necessary to grow some crops (cereals and rape) in rows to make room for row cultivation and, on certain soils and in some localities, it would probably be necessary to switch to grass.

8.4.3 Weed problems in vegetable production

Poisonous species of weed

With the present cultivation conditions, the occurrence of poisonous plants in Danish farm produce presents no health problems for humans. There are occasional cases of poisoning of livestock, but there are no data indicating the magnitude of the problem. There are reports of fatal poisoning of livestock, but most cases are less serious. In Denmark, spring groundsel and deadly nightshade are considered to be the two most significant poisonous species.

Spring groundsel

In the period 1994-98, spring groundsel spread to a rapidly growing number of set-aside fields and fields under grass, especially in Jutland. Species of groundsel contain toxic alkaloids. Horses, cattle, sheep and pigs can be poisoned. The toxicity of the species of groundsel in question is not destroyed by ensiling and drying. Few cases of poisoning of animals or humans by spring groundsel have been described. This is due partly to the fact that there is no usable Danish survey of cases of plant-poisoning of animals and humans. Spring groundsel can be controlled by mowing set-aside fields, the banks of ditches and other natural ecosystems when flowering commences to prevent the plants from setting seed and by establishing the best possible grass cover on set-aside fields and newly established grass meadows. Preventive measures alone cannot prevent the threshold of 35-40 spring groundsel plants per 100 m2 from being exceeded where there is a lot of air-borne seed

(Jensen *et al.*, 1998a). The problem has been aggravated by the ban that has been introduced on the use of chemical agents on set-aside land.

Deadly nightshade

Deadly nightshade is widespread in Danish fields in which crop rotation is practised. The fruit of deadly nightshade has the same colour, size and specific gravity as green peas and can therefore not be discarded during harvesting and processing of tinned peas. The crop is therefore rejected if deadly nightshade is found during a field inspection. To avoid the problem of deadly nightshade, it is necessary to prevent its fruit from reaching a size at which it can be confused with peas by sowing early or late in the growing season. Cultivation without pesticides would therefore imply a considerable reduction of the production period, which would call for a larger production capacity if the same production were to be maintained (Jensen *et al.,* 1998a).

In the event of restructuring for pesticide-free farming, a proliferation of the above-mentioned poisonous plants could therefore not be excluded. In Denmark, there would hardly be any question of an increased risk of poisoning of humans, but there could be more cases of poisoning of livestock, which would cause some loss of production in the form of a reduced milk yield, reduced growth rates and similar.

Control of wild oat

As a consequence of the Act on Wild Oat, seed-bearing wild oat must not occur during the growing season. When producing cereals without pesticides, it would be necessary to replace chemical control of wild oat with manual weeding. This is a realistic method of controlling relatively small populations of wild oat, but it is not realistic for large populations. Here, the crop rotation would have to be changed towards production of coarse fodder to reduce the population (Jensen *et al*., 1998a).

Grass and clover seed, as well as vegetable and flower seed, cover a broad range of cultures. Some of the cultures could be cultivated without serious consequences for the gross seed yield. Common to the cultures is the fact that the production is used as seed, that the main settling criterion is high purity and germination capacity, and that the seed is free of or has a very low content of seeds of other cultures and weeds. The seeds of many cultures are the same size as those of common species of weed, which in some cases makes seed-cleaning impossible or very costly. Therefore, to meet the high quality requirements, the raw material the farmer grows in the field must largely fulfil the criteria. That means high requirements concerning cleaning of the crops. With our existing expertise and the alternative methods available today, it would be difficult, if not impossible, to maintain most of the production without herbicides. We estimate that pesticide-free production of grass seed would make the export-oriented part of seed production in Denmark unprofitable (Jensen *et al.*, 1998a). 92% of production from the 61,000 ha cultivated is exported. Strenuous efforts are being made to develop a production of organic seed, but experience from this is limited. Denmark also has a substantial production of vegetable and flower seed. This production covers a wide range of cultures, most of which are exported. Here, we would expect serious problems in meeting the purity requirements and with profitability.

Organic soil

On organic soil, which often has special species of weeds that are difficult to control, problems could be expected with mechanical control methods. Denmark has 660,000 ha of organic soil. Estimated on the basis of individual municipalities, about 75% of this land is used for cereals (Hjort Caspersen, Pers. com.). Weighing this up in relation to the fact that not all organic soil is cultivated, we estimate the probable total acreage on which rotation is practised to be at least 150,000 ha.

8.4.4 Control of Couch grass without pesticides

Mechanical control of couch grass

Comparative analyses of the need to control couch grass with mechanical stubble-harrowing or spraying with glyphosate have been carried out by (Melander, 1993, Permin, 1990, Høstmark, 1990). According to Permin, stubble-harrowing would be needed every year to avoid proliferation. This is close to the figure indicated by Høstmark (1.2-year interval), whereas, according to Melander, stubble-harrowing each year would not, on its own, suffice in certain crop rotations. Høstmark gives a treatment interval of 2 – 3.2 years with chemical control of couch grass in a cereal crop rotation in order to maintain the status quo. The 2 years are for a control effect of 85%, while with a control effect of 95%, the interval can be increased to more than 3 years. In 1994, sales of glyphosate products corresponded to treatment of 480,000 ha with normal dosage, and the average for 1995 and 1996 was just under 600,000 ha. This consumption accords well with the need for control of couch grass according to the above sources if the weed is primarily controlled with chemical agents.

Control of couch grass at organic farms

At organic farms couch grass occurs in 15% of the observations, judged a short time after earing (Kristensen, 1998). On average, 13 couch-grass shoots/m2 were counted. It should be noted that the time of observation was not ideal for evaluation of a couch-grass population because a small stand of couch grass can easily be overlooked beside small cereal shoots. Thistles occurred in 5% of the observations, with an average of 2 thistles/m2. For comparison, thistles were not found at conventional dairy farms, while couch grass also occurred in 10-15% of the observations (953 nos.). On average, there were only 6 couch-grass shoots/m2 at these farms. It is thus possible to control both couch grass and thistles without herbicides. On the other hand, the variation from field to field would become greater because it can take several years to achieve effective control of a large population of root weeds.

Negotiations are in progress on a voluntary agreement between the milling trade and farmers on discontinuation of "pre-harvest treatment" with glyphosate in the production of bread cereals.

8.4.5 Perspectives

New machines for mechanical control

The existing mechanical methods could be made more efficient through development for more targeted use, and the development of autonomic cultivators could provide the necessary greater capacity. The need for manual weed control could be reduced using existing technology, and hand-hoeing could possibly be dispensed with in planted-out crops grown in rows, although this would at the same time mean higher costs for establishment. Similarly, a number of new technologies could in time be made operational, thereby obviating the need for hand-hoeing in sown crops grown in rows. The greatest potential lies in the use of sensors to identify crops and weeds with automotive machines. Effective detection, together with a low speed, would enable the use of a number of non-chemical technologies that have not yet been used. Whether the technologies will be developed for practical use depends on the demand for them and on support for product development.

Success requires restructuring

For successful non-chemical weed control, the whole of the way in which weed is controlled today would have to be changed. That would involve costs in connection with a changed choice of crops, higher direct energy consumption, loss of yield and quality in special situations in which the weed is not effectively controlled, investments in new tools, development and research in farm-oriented weed control, and retraining and supplementary training of farmers and agricultural advisers.

8.4.6 Conclusion

Prevention and mechanical methods

If pesticides were totally or partially phased out it would be necessary to combine preventive methods, cultural practices and mechanical methods to achieve sufficient control of weeds. Research results have shown that mechanical control is feasible in almost all crops. However, owing to a generally lower effect, it is not yet clear how the transition to mechanical weed control would affect the soil's seed pool. In crops like rape and potatoes, mechanical methods are already equal to the chemical methods used.

Problem situations

In certain situations with, for example, special types of soil, unstable weather and poor establishment of crops, mechanical control could be problematical. Crop damage after harrowing and a generally lower level of weed control would mean increased losses and adjusting crop choice and cultural practices in order to control weeds would involve increased costs. The capacity of mechanical methods is generally less than that of chemical methods, which could be problematical in conjunction with unstable weather. It is believed that there is plenty of potential for improving the existing mechanical methods to replace hand-hoeing. Switching to non-chemical methods would require considerable retraining and supplementary training, and most farms would have to invest in new machines.

Poisonous plants

Under present cultivation conditions, the occurrence of poisonous plants in Danish farm produce presents no health problems for humans. There are occasional fatalities among livestock. In Denmark, spring groundsel and deadly nightshade are considered to be the two most significant poisonous species. Restructuring for pesticide-free farming might therefore result in proliferation of the poisonous plants in question. It is hardly likely that there would be any increased poisoning risk for humans, but there could be more cases of poisoning of livestock, which would cause some production loss in the form of lower milk yields, reduced growth rates and suchlike.

Wild oat

Pursuant to the Act on Wild oat, seed-bearing wild oat must not occur during the growing season. If cereals were to be produced without pesticides, chemical control of wild oat would have to replace manual weeding. This is a realistic method in the case of relatively small populations of wild oat, but not in the case of large ones. Here, it would be necessary to change the crop rotation towards production of coarse fodder in order to reduce the population.

Problems in seed production

Grass and clover seed, as well as vegetable and flower seeds, cover a wide range of cultures. Over 90% of our production is exported. All the cultures are grown for seed. The main price criteria are high purity and germination capacity, in addition, the seed must be free of or have only a very low content of other cultures and weed seed. These criteria set very high requirements concerning the purity of the crops - requirements that, for the greater part of production, would be difficult to meet without the use of herbicides, given our present level of expertise.

Control of couch

Couch grass can be controlled without herbicides on most soils. In several studies of the crop rotations practised at arable farms, the need for mechanical harrowing after harvesting has been compared with the need for glyphosate treatment. Mechanical stubble-harrowing is required every year to avoid proliferation of couch grass in certain crop rotations, as replacement for glyphosate treatment approximately every four years. We have reasonably good experience of controlling couch grass in organic dairy farming, but the crop rotations practised in that form of farming are very different from those practised at the various types of arable farm. Experience from organic farming shows that thistles can be a major problem. Variations in the quantities of root weeds from field to field would become greater without access to pesticides, as it can take several years to attain effective control of large stands of such weeds.

8.5 Alternative methods for growth regulation

Growth regulation prevent lodging

Some use is made of growth regulation in cereals to prevent lodging. The cereals are typically treated during elongation and the agents used have a shortening effect on the internodal length and strengthen the stem itself. Experience shows that the spraying is done to safeguard against lodging. The use of growth regulators has decreased in recent years in step with the cultivation of stiff-stemmed varieties and use of less nitrogen. The results of trials on varieties with strong stems have shown that it seldom pays to spray. Growth regulators are used almost exclusively in winter cereals. The treatment frequency index was reduced from 0.6 in the period 1981-85 to 0.1 in 1997. (Environmental Protection Agency statistics on pesticide consumption). The highest level of consumption is in rye, where the varieties cultivated have relatively poor straw strength, and where lodging can greatly reduce the baking quality of the rye. There is also a small consumption in certain species of seed grass, including cock's foot. On average, 11% of the seed acreage was treated in 1997.

8.5.1 Growth regulation in cereals

Alternatives in cereals

As mentioned, there are good strong-stemmed varieties of wheat that have only a slight tendency towards lodging. In addition, the risk can be reduced by sowing fewer grains per m2 – 200-250 instead of 280-350 and using less nitrogen (10-30 kg/ha).

The disadvantage with some of the strong-stemmed varieties is that they generally have difficulty competing with weeds. Terra is a good example of a tall, relatively soft-stemmed variety of wheat with good resistance to disease and good competitiveness with weeds. To minimise problems with lodging in such a crop it is necessary to reduce the amount of nitrogen applied.

In 26 trials in 3 varieties representing different types, carried out by the Danish Agricultural Advisory Centre in 1995-97, reliable additional yields for growth regulation were not achieved (Petersen *et al.*, 1997). The varieties in question included Terra. The lack of yield increase was due in part to the fact that there was no serious, long-term lodging of the crop in the trials.

Problems in rye

In rye there is a generally greater risk of lodging. Rye from fields affected by lodging is usually of a poorer baking quality than rye from standing crops owing to moister conditions during ripening close to the soil. There are also practical problems in the form of increased harvesting difficulties when the ears of rye have to be combined from lodging. Crops affected by lodging have a greater risk of a lower cereal yield, a higher water content, a lower falling number, which impairs the baking quality of the grain, a lower grain weight, more stones in the product harvested, a reduced harvesting capacity, higher drying costs and a risk of total rejection as bread rye at falling numbers lower than 100 (Anon., 1998). Generally speaking, there are more trials in rye than in wheat that show positive additional yields for growth regulation (table 8.13). Trials with different, current varieties of rye have shown some difference in the varieties' response to growth regulation - something that is to some extent reflected in the assessment carried out of the lodging of varieties (table 8.14). However, positive additional yields have been achieved in several varieties with growth regulation. There are thus no varieties that can definitely be recommended if one wants to avoid lodging.

Due to consumer demand for bread from cereals that have not been growth-regulated, increasing attention is being paid to ways of cultivating rye without growth regulators. One of the problems focused on here is how to avoid lodging via cultural practices and what costs this involves.

Alternatives in rye

In rye, trials are in progress to determine the effect of alternative methods on growth regulation. Elements that have an effect and that are being studied are postponed sowing, reduced quantity of seed and reduced application of nitrogen. Too large a reduction in the quantity of seed (<150 plants/m2) increases the risk of ergot. In an open stand many side shoots form, which flower unevenly, increasing the chance of ergot infecting the flower formations. On good soil, sowing would have to be postponed until the beginning of October and the quantity of nitrogen would have to be reduced to 80 kg/ha to reduce the risk of lodging. It is estimated that that would reduce the net yield by 6-7 hkg/ha, necessitating an additional price of DKK 7-8/hkg to compete with growth regulated production (Anon., 1998).

Table 8.13
Additional yield in different years with growth regulation of rye (2 applications: Cycocel at gs 30-31 and Terpal at gs 37-39),with a breakdown into trials with and without lodging (Annual Reports of Field Trials).

Year	Yield, untreated	Additional yield after growth regulation, hkg/ha
1985 5 trials with lodging	60.3	6.1
1985 2 trials w/o lodging	46.2	1.8
1986 6 trials with lodging	47.1	3.5
1986 2 trials w/o lodging	49.9	0.9
1990 4 trials with lodging	55.5	4.2
1990 5 trials w/o lodging	48.8	0.2
1995 5 trials with lodging	54.9	5.8
1996 3 trials with lodging	28.2	8.9
1996 1 trials w/o lodging	38.8	1.4
1997 6 trials with lodging	30.9	3.9
1997 1 trials w/o lodging	53.3	1.1

Table 8.14
Additional yield in different varieties of rye treated with growth regulators (1.5 l Cycocel + 0.5 Cerone). Annual Report of Field Trials, 1996-97)

Variety of rye	4 trials in 1997 and grade for lodging ()	3 trials in 1996 and grade for lodging ()
Dominator	3.6 (4)	4.5 (5)
Rapid	4.4 (4)	4.7 (4)
Motto	3.4 (2)	4.2 (3)
Apart	2.5 (4)	4.4 (4)
Esprit	6.1 (5)	7.2 (4)
Hacado	3.4 (5)	5.0 (5)

2-year trials with a reduced quantity of seed sown and reduced application of nitrogen have shown that it is possible to avoid the use of growth regulators in rye (Petersen *et al.*, 1998). However, multi-year trials are needed to get a clear idea of what that implies for stability of cultivation and yield.

On very light soil without irrigation, where rye has traditionally been grown, there is less risk of lodging. The risk is thus greatest on better soils. Only 20% of the present rye production of approx. 500,000 tonnes is used for bread. The remainder is exported or used in mixed fodder. The demand for rye for bread can be covered with about 22,000 ha.

Voluntary agreements

Efforts are being made to get a voluntary agreement established between the milling trade and farmers on discontinuation of the use of growth regulators in the production of bread cereals.

8.5.2 Growth regulation in seed grass

Growth regulation is used in certain species of seed grass to minimise the risk of lodging and straw breakage, thereby reducing the risk of harvesting losses and problems. Trials with cock's foot grass and red fescue show that a better yield can be achieved with one or two applications of the growth regulator Cycocel (table 8.15).

Table 8.15
Growth regulation of seed grass with two applications of Cycocel during stem elongation. Trials from Annual Reports of Field Trials (1986 and 1990).

Crop	Yield, untreated	Additional yield with treatment
Cock's foot grass (7 trials 1984-86)	794 kg	142 kg
Red fescue (17 trials 1988-90)	1,093 kg	64 kg
Red fescue (7 trials 1986)	899 kg	57 kg

In a trial series in red fescue, the interaction between the amount of fertiliser applied (40 or 60 kg/ha) and growth regulation has been investigated. The results show no certain interaction or greater need for growth regulation at the highest amount of nitrogen.

8.5.3 Growth regulation in pot plants

Growth regulation is widely used in pot plant cultures to create compact plants with greater flower density. There are seven approved agents for growth regulation in greenhouse cultures. The most widely used is Cycocel. In many cultures, a combination of chemical and alternative methods is used today. One extensively used method is "negative dif", which is based on regulation by means of light and temperature.

Research in alternative methods

Current research focused on reducing growth by various methods, including applying less phosphorus, indicates that there are methods that could in time be used to reduce the use of chemical growth regulators (Hansen & Nielsen, 1999). At the present time, a combination of "negative dif" at the beginning of the growing period and chemical regulation is used in many cultures, but it has not been determined whether the agents can be omitted altogether or whether the use can be reduced dramatically (Ottosen *et al.*, 1998).

8.5.4 Conclusion

Winter cereals

Growth regulators are used in about 10% of winter cereals – particularly in rye. A little is also used in seed grass and ornamental plants. There are good prospects for the use of alternative methods in winter wheat, to minimise the risk of lodging. The risk is thus small when cultivating varieties of good stem strength and reduced plant counts. If less strong-stemmed varieties are grown, it might be necessary to reduce the amount of nitrogen applied by 10-30 kg/ha. There is a considerable risk of lodging in rye on good soils, but less risk on sandy soil. There are no varieties of rye that can completely eliminate the risk of lodging, although some varieties can contribute to reducing this risk. The risk could also be reduced by postponing sowing until the beginning of October and reducing the amount of seed sown and the amount of nitrogen applied. Together, these measures would reduce the net yield by 6-7 hkg/ha.

Seed grass

The use of alternative methods of growth regulation in seed grass has only been clarified to a limited extent. We can expect a reduction of stability of cultivation in certain soils until alternative methods of growth regulation have been developed.

Pot plants

In pot-plant production, growth regulators are used mainly to promote the especially richly-blossoming and compact plants that have the best sales value. No methods of replacing chemical growth regulators are immediately available for pot plants. Considerable research would be needed to determine whether there are alternative methods for the many different pot plant cultures.

8.6 Biological control

Here, biological prevention and control in agriculture is defined as placing living organisms in the crop. The methods include use of both "macrobiological" animals and microorganisms.

8.6.1 Present use and potential in greenhouses

Biological control of pests in greenhouses

Biological and microbiological control of pests is widely used in greenhouses today. At present there are products of 50-60 species of useful organisms for use against the main greenhouse pests in Denmark (table 8.16). In greenhouse vegetables, biological pest control is routinely practised on largely the entire acreage, while it is used on about 30-35% of the acreage used for greenhouse-grown ornamental plants.

Potential in greenhouses

The present scope of biological pest control in greenhouse vegetables is largely equal to the potential, while in greenhouse-grown ornamental plants, it is below the potential, given our present level of knowledge and experience. That is due to special factors concerning ornamental plants – including the fact that ornamental plants include many species that are attacked by a wide variety of pests and that the damage threshold is low. Some other special factors are also involved – for example, that biological control can be costly, that it is new, so growers are unaccustomed to it, and that it may be associated with bad experience. In addition, the requirement made by countries importing pot plants concerning complete freedom from pests plays a role, and there is a lack of essential knowledge and experience in a number of areas (Enkegaard *et al.*, 1998).

Microbiological prevention/control and diseases

Microbiological prevention and control of plant diseases in greenhouses: Internationally, there are now about 30 microbiological organisms (MBOs) for prevention and control of plant diseases in agriculture. Of these, around 20 have been developed for use in greenhouses. Only a few agents are marketed in Denmark today. The use of MBOs in Denmark is at present restricted (table 8.17).

Work is in progress on the establishment of an approval procedure for MBOs in Denmark and the EU, but no organisms are at present officially approved. Dispensation has been granted for the time being for sale of the organisms that are marketed.

Table 8.16

Pests in Danish greenhouse crops and the useful organisms that can at present be used to control them – depending on the species of pest, the species of plant and specific cultural practices. It should be noted that each category of pest and useful animal (e.g. aphids and ichneumon) comprise up to several species. In all, there are 46 different useful organisms.

CROP	PEST	BIOLOGICAL CONTROL AGENT
Greenhouses		
Tomatoes	Aphids	Parasitic wasps, aphid gall midges, lacewing, ladybirds
	Leaf-miner fly	Parasitic wasps
	Spider mite	Predatory mites, predatory gall midge
	White fly	Parasitic wasps, predatory mites
Cucumber	Aphids	Parasitic wasps, aphid gall midge, lacewing, ladybirds
	Leaf-miner fly	Parasitic wasps
	Spider mite	Predatory mites,
	Thrips	Predatory mites, predatory bugs
	White fly	Parasitic wasps
Beans/peppers	Aphids	Parasitic wasps, aphid gall midges, lacewing, ladybirds
	Spider mite	Predatory mites, predatory gall midges
	Thrips	Predatory mites, predatory bugs
	White fly	Parasitic wasps
Ornamental plants	Aphids	Parasitic wasps, aphid gall midges, lacewing, ladybirds, predatory bugs, flower fly, insect-pathogenic fungi
	Spider mite	Predatory mites, predatory bugs, lacewing, insect-pathogenic fungi
	Thrips	Predatory mites, predatory bugs, predatory thrips, insect-pathogenic fungi
	White fly	Parasitic wasps, predatory bugs, ladybirds, insect-pathogenic fungi
	Leaf-miner fly	Parasitic wasps
	Mite	Predatory mites
	Top-shoot mites	Predatory mites
	Sciarid fly	Nematodes, predatory mites, *Bacillus thuringiensis*
	Butterflies	Predatory bugs, parasitic wasps, *Bacillus thuringiensis*
	Weevils	Nematodes
	Scale-bug complex	Parasitic wasps, ladybirds
	Mealy-bug complex	Parasitic wasps, ladybirds

Table 8.17
Diseases in Danish greenhouse crops that are at present controlled with microorganisms and the acreage on which the organisms are used. A detailed breakdown by disease is not possible because MBOs are often used prophylactically by adding them to the growth medium on the basis of an assumption that they have an effect on one or more of the diseases mentioned.

CROP	PEST	BIOLOGICAL CONTROL AGENT	ACREAGE
Tomatoes	*Pythium spp, Botrytis cinerea*	*Trichoderma* spp.	about 50% of the tomato acreage
Cucumber	*Pythium spp.*	*Trichoderma* spp.	about 30% of the cucumber acreage
Ornamental plants	*Fusarium spp., Pythium spp., Phytophthora spp., Rhizoctonia solani, Thielaviopsis basicola, Botrytis cinerea*	*Trichoderma* spp.	about 30% of the ornamental-plant acreage
Herbs	*Pythium spp.*	*Trichoderma* spp.	minimal

8.6.2 Future perspectives in greenhouses

Considerable potential in greenhouses

The future potential for biological pest control in greenhouse vegetables is thought to be limited, whereas the potential in greenhouse-grown ornamental plants is considerable. It is difficult to say how much of this potential can be realised within a 10-year period.

In greenhouses, we expect to see specially developed MBOs for controlling some selected, serious root pathogens and some few leaf pathogens, such as mildew and grey mould. MBOs are unlikely to be developed specifically for control of pathogens of limited economic importance in small cultures or for control of so-called 0-tolerance pests.

Realisation of the potential for biological prevention and control of diseases and pests in Danish agricultural and market-garden crops within a 10-year horizon will depend on several factors, including the price and availability of the biological organisms, the availability of pesticides, the situation with respect to pests, political measures and the scope of research in Denmark and elsewhere.

8.6.3 Biological and microbiological prevention and control in fields

Very limited use in fields

Very little use is made of biological control in fields. *Bacillus thuringiensis* is used against butterfly larvae, nematodes are used against weevils, virus is used against cutworm, and predatory mites are used against mites. The acreages on which these methods are used are very small (table 8.18).

In fields, MBOs are at present being tested against seed-borne diseases in cereals. We expect it to be possible for microbiological control measures to be used in fields against these types of diseases in both vegetables, flowers and agricultural crops within the next few years.

Table 8.18
Pests in Danish field crops that are at present controlled with useful organisms, and the acreage on which these are used. Readers are referred to table 1 for the full names of species.

	PEST	**BIOLOGICAL AGENT**	**ACREAGE**
Carrots	Turnip-moth larvae (cutworm)	Virus (AsGV)	< 10 ha
Cabbage (several varieties)	Small cabbage white butterfly	***Bt kurstaki***	a few ha
	Large cabbage white butterfly	***Bt kurstaki***	a few ha
	Turnip moth	***Bt kurstaki***	a few ha
Fruit trees	Fruit-tree spider mite	Predatory mites	a few ha
Nurseries	Greenhouse spider mite	Predatory mites	a few ha
Strawberries	Greenhouse weevil	Nematodes	a few ha
	Strawberry mite and other mites	Predatory mites	a few ha

8.6.4 Perspectives for field use

Uncertain potential in fields

In the short term, the sub-committee expects some expansion of biological control of pests in fields, using agents that are at present marketed abroad and under development in Denmark. In particular, there will be products against aphids, butterfly larvae, mites and soil-borne insects. This expansion of biological control will mainly be directed towards high-value crops: specialised crops, ornamental greenery and nurseries. In the long term, more possibilities could be realised. Potentially, all pests can be controlled biologically – outdoors as well as indoors. Biological control of a single pest affects many of the main crops, e.g. aphids in cereals, or different forms of biological control against all pests in a single crop could probably be achieved with an intensive R&D effort in Denmark and abroad, combined with other political measures.

The sub-committee estimates that development of MBOs for outdoor prevention and control of other diseases than the seed-borne diseases and fungal diseases that affect germination would, except in a very few cases, require a longer time horizon than 10 years. The use of MBOs will depend on continued intensive research and close cooperation between researchers, producers of MBOs, agricultural advisers and farmers.

8.6.5 Possibility of using plant extracts and similar

Limited experience and knowledge

Plant extracts and non-synthesised natural substances are attracting renewed interest as alternatives to chemical control agents. However, very little is known about their effect spectrum and use, so detailed studies under relevant conditions are needed before their use can be recommended. Extensive research and trials are necessary in order to be able to evaluate continuously products introduced in this field (e.g. pyrethum, garlic extracts, stinging-nettle extracts, neem, etc.).

There are at present 10 approved active ingredients that occur naturally, including five extracted from plants (soaps, pyrethrin, soya oil, rotenon and citronella oil). Four of these are used as plant protection agents, although outside the actual agricultural sector. Two ingredients are extracted from the mineral kingdom (sulphur and paraffin oil) and two from the animal kingdom (gelatine and blood meal), while one is microbiological (toxin of *Bacillus thuriengensis*). With the exception of blood meal and citronella oil, these substances are used for controlling insects (Memorandum from the Danish Environmental Protection Agency, 17 December 1998).

8.6.6 Conclusion

Biological pest-control methods, which include both useful animals and microbiological agents, have great potential within greenhouse production. They are already used extensively in vegetable production, while there is still an unexploited potential within greenhouse production of ornamental plants. Effective methods of preventing and controlling diseases in greenhouses are still limited. Outdoors, biological pest-control methods are deemed to have some potential within specialised crops, whereas biological prevention and control of diseases within a short time horizon is only deemed to have a potential in the case of seed-borne diseases and fungi that affect germination.

There is a need for a major research effort in this area, aimed at developing methods for outdoor use. Besides that, there is a need to improve the use of biological control of diseases and pests in ornamental plants cultivated in greenhouses and to spread the use of this method of control.

8.7 Effect of alternative methods on the need for nutrients

Lower yield means reduced need for nitrogen

With a reduced yield as a consequence of weeds, diseases and pests, changes in optimal nitrogen of 1-1.25 kg N/hkg cereal (Olesen *et al.*, 1998) must be expected. In the event of deviations from normal yields, the sub-committee recommends use of the Plant Directorate's fertiliser guidelines, where a 1 hkg change in cereal yield in winter cereals gives a 1.3 kg change in the need for nitrogen, and in spring cereals, a 1 kg change in the need for nitrogen. If a lower yield is largely due to weeds and pests, the need for nitrogen might actually not fall as indicated because both weeds and pests absorb nitrogen and can contribute to reduced nitrogen utilisation.

Effect of nitrogen on pests

Reducing and splitting-up of the amount of nitrogen applied could to some extent reduce the risk of both pests and diseases. The fertiliser should also be used strategically to strengthen the crop's competitiveness to weeds. This is an area in which the sub-committee believes that there is a clear advantage over organic production.

Mechanical control of couch grass in the autumn is thought to have a negative side-effect in the form of increased leaching of nitrogen in winter owing to increased nitrogen-mineralisation, while mechanical weed control in spring is also known to increase nitrogen metabolism. This is often seen as a positive effect on the crops, which have good possibilities of utilising the quantities of nitrogen released during their growing season.

An increase in the acreage with second crops to replace winter cereal, such as winter-green fields, can help to reduce leaching of nitrogen in the winter-time.

8.8 Use of damage thresholds

Growing attention has been paid to damage thresholds up through the 80-90s because such thresholds are essential for need-adjusted use of pesticides.

8.8.1 Weeds

Use of reduced dosages

Preliminary trials have also shown that use of a crop's competitiveness and other preventive measures can reduce the use of herbicides still further. However, only limited data and experience are available concerning this. That also applies to the combination of preventive measures and need-based, non-chemical weed control.

PC-Plant Protection

In Denmark, the most widely used decision-support system for weed control is PC-Plant Protection/weeds. This is a robust system that is targeted on recommendation of herbicides and dosages. The program is generally based on economic optimisation. Despite relatively widespread use of PC-Plant Protection/weeds, the treatment frequency index has not fallen in the last few years due in part to growing acreages with winter cereals and consequently increased proliferation of annual grass weed, which has often meant a need for two herbicides – one for monocotyledonous weed and one for dicotyledonous weed. In systems under development, greater importance is being attached to preventive measures and need analyses. We do not have a decision-support system or guidance system for non-chemical weed control at present; nor do we have damage thresholds or a decision-support system for weed control in outdoor vegetables or forestry.

8.8.2 Diseases and pests

Warning models

Over the years, economic damage thresholds have been developed and used as the basis for need analyses of several important diseases in the main agricultural crops. In a cooperation between the Danish Agricultural Advisory Centre and the Danish Institute of Agricultural Sciences, agricultural advisers pass on results from a number of weather-based warning models and from monitoring of certain diseases and pests in important crops. Table 8.19 lists monitoring and warning systems in Denmark. Most of the systems are also communicated by means of the Internet-based system Planteinfo.

Registration system for diseases and pests

Since 1992, the Danish Agricultural Advisory Centre has operated a registration system (Nielsen & Juhl, 1996). Here, the occurrence of the principal diseases and pests is monitored in the part of the growing season in which treatment may become necessary. Occurrence is monitored in untreated plots throughout the growing period and in a broad selection of varieties.

In cereal crops, the different damage thresholds are combined in PC-Plant Protection/diseases and pests. Results from four years' trials with PC-Plant Protection are shown in table 8.20.

PC-Plant Protection

As will be seen, there are equal net yields after all treatments. In accordance with PC-Plant Protection, the principles of plant protection in surrounding fields and the recommendations from the farmers' groups, a considerably lower treatment frequency index was used than according to the standard treatment and also reduced dosages of fungicides but full dose of insecticide. The very similar results from the last three treatments are due to the fact that principles from PC-Plant Protection are often also used by the farmers' groups and in the general principles on which many farmers base their treatments.

In the disease area, PC-Plant Protection/diseases in cereals has contributed towards a more targeted use of fungicides. Among other things, it has supported the use of reduced dosages (Secher *et al.*, 1995). For example, the treatment frequency index for cereal fungicides has been reduced by 50% compared with the reference period in the first pesticide action plan.

Table 8.19
Monitoring and warning systems used in agricultural crops in Denmark

Pest and crop	Method
Leaf fungi and pests in cereals	Agricultural advisers' registration system
Eyespot in cereals	Agricultural advisers' registration system
Virulence-monitoring of mildew and stripe rust	Catch plants in nurseries
Sclerotinia rot in rape	Laid-out samples of sclerotinia
Cabbage gall midge in rape	Weather-based risk model and catch trays
Cabbage stem flea beetle	Catch trays
Pea moth	Pheromone traps
Pea aphid	Agricultural advisers' registration system
Aphids in sugar beet	Weather-based risk model and registration
Leaf fungi in sugar beet	Registration in fields
Potato blight	Weather-based risk model
Leaf fungi in potatoes	Catch trays
Frit flies	Weather-based model and catch trays
Cabbage flies	Felt traps
Turnip moth	Pheromone traps
Carrot flies	Glue plates

Table 8.20
Treatment frequency index and yield with PC-Plant Protection for diseases and pests. 26 trials in wheat from 1995-1998 with comparison of PC-Plant Protection with standard treatment (2 x 0.5 l Tilt top+sumi alpha in 1995-97 and 0.33 l Tilt top/0.33 l Amistar in 1998), the treatment in surrounding fields and the recommendation from a local Farmers' group (Source: Annual Reports of Field Trials, 1997-98).

Treatment	TFI	Yield and additional yield hkg/ha	Net yield hkg/ha
Untreated	-	71.6	
Standard treatment	1.6	9.3	2.6
PC-Plant Protection	0.8	8.1	3.5
Treatment in surrounding fields	0.9	7.9	3.2
Farmers' groups	0.7	7.9	3.8
LSD_{95}		2.5	

Warning against potato blight

PC-based decision-support systems (Negfry) are being developed within potato blight, where there is a large consumption of fungicides. Negfry's calculations of the need for treatment with fungicides are based on knowledge about the fungus's biology; temperature and moisture also play a role (Hansen & Holm, 1996). Negfry has shown promising results with possibilities of reducing the number of applications by 2-3. In a few seasons, delayed application has been recommended in some localities, which reduces the confidence in a high-value crop like potatoes, where an early attack of potato blight results in substantial yield losses and reduced quality. Negfry is still under development.

In the case of pests there are several operational warning systems and damage threshold models. In many crops these tools have been very targeted and have led to a marked change in the use of chemical control. There are warning systems for a number of pests in the main agricultural crops with the exception of rape.

8.8.3 Potential for use of damage thresholds

15% of farmers use PC-Plant Protection today

Increasing use has been made of decision-support systems, warning systems and damage thresholds for plant protection in recent years, primarily because of greater awareness of and interest in more environment-friendly farming, but also because the systems offer farmers the possibility of saving on spending on chemicals. Today, about 15% of Danish farmers use PC-Plant Protection directly or indirectly (Svendsen *et al*., 1997).

Wider use of decision-support systems depends on several factors. The main ones are:

- the systems' technical foundation and further development
- the farmer's professional interest and training in the use of decision-support systems and the time he has available for using them
- feasible and reliable detection and monitoring methods and the cost of using them
- the value of the additional yield from control and the costs involved.

Aversion to risk

Another and perhaps equally important factor in the spread and use of decision-support systems is the farmer's willingness to take risks. For many years it has been "good farming practice" to keep fields clear of weeds, diseases and pests. This ensures a stable and high yield that is not necessarily economically optimal because farmers do not like admitting to an over-consumption of pesticides. Under-consumption, on the other hand, is visible and directly measurable in the yield. In most years less treatment is often sufficient, but in unfortunate circumstances things can go wrong. Seen over a span of years, need-based control will be economically optimal.

8.8.4 Perspectives

Major future potential

The sub-committee believes that there are good possibilities of reducing herbicide consumption still further, partly through greater use of mixed herbicides that are adjusted to the composition of weed species and the total pressure of weeds. In the case of diseases and pests, we think that further knowledge concerning the relationship between cultural practices and climate could help towards further reduction of consumption. Assumptions for reduced consumption fall into the following categories (Christensen *et al*., 1998):

A. widespread dissemination and use of existing damage thresholds and warning and decision-support systems
B. further development of existing damage thresholds and warning and decision-support systems and development of new systems that take account of the following factors:
    - development of robust, simple and effective monitoring methods
    - strengthening of the data and experience base for need-based planning and decisions
    - adjustment of consumption to falling prices for plant products as a consequence of the EU's dismantling of subsidy schemes and increased taxes on pesticides
    - use of site-specific plant protection, with control measures limited to those areas of a field in which there is a need for prevention and control of pests
    - integration of preventive methods, including choice of crop rotation, soil preparation, competitiveness and resistance properties, in damage threshold models and warning and decision-support systems
    - development of robust warning systems that combine use of chemical and non-chemical/biological control.

Considerable potential for reduction

In the opinion of the experts, if several or all of the above-mentioned assumptions can be fulfilled, pesticide consumption in many crops, including cereals, could be reduced by 20-25% in relation to what is possible with the present computer-based decision-support systems (Christensen *et al*., 1998).

8.8.5 Site-specific plant protection

Possibilities of patchwise treatment

Research is now in progress on site-specific plant production and plant protection, with control measures limited to those areas of a field in which there is a need for prevention or control of pests. The sub-committee believes that the development of methods for handling such a system would help to reduce consumption considerably. Trials and research have shown that purposeful use of fertiliser, pesticides and other factors related to the phase-out can contribute to satisfying environmental requirements and simultaneously optimise production economically. Also under development is advanced spraying equipment that operates on the basis of a treatment map and in which one or more herbicides are only mixed with water when this is pumped out into the pipe system. Spraying systems of this kind, in which the water and the pesticide(s) are kept apart, could eliminate problems with spray residue. The new technology also offers the possibility of automatically storing data on location-specific conditions and treatments that can be used as an experience/database in subsequent years and as documentation for the treatment carried out. A prerequisite for wide use of site-specific plant protection is automation of pest registration. Several technologies that could be used for that purpose are expected to become available in the next few years.

8.8.6 Conclusion

In recent years, decision-support systems have been developed for several of the main agricultural crops as support for the farmer when evaluating the need for prevention and control measures. Such decision-support systems have contributed significantly to reduction and adjustment of dosages, not only through direct use of the programs, but also through advisory services and newsletters from the Danish Agricultural Advisory Centre. Although the use of damage thresholds and decision-support systems has spread, it has not been possible to reach all farmers.

Damage threshold systems still need to be developed for a large number of crops and there is plenty of room for improvement of several of the existing systems.

In a number of crops it is believed that a 20-50% reduction could be achieved by combining decision-support systems and chemical and non-chemical control methods.

8.9 Use of genetically modified organisms (GMOs)

Reduction potential in beets

In connection with the desire for greater use of resistant varieties, it is interesting to determine whether new breeding techniques based on molecular-biological methods can be expected to produce more and faster progress. The question is whether these methods can decisively reduce the losses from diseases and thus change the need for pesticides. It is also of interest to determine whether plants with built-in herbicide resistance can significantly change the present consumption.

8.9.1 Present situation

Only a few genetically modified plants are ready for immediate introduction on the Danish market. They include herbicide-resistant varieties of beet and rape and insect-resistant maize. Only limited official studies of the effect they will have on pesticide consumption have been carried out. However, it is believed that:

- Cultivation of glyphosate-resistant and glyphosinate-resistant sugar beet and mangolds could lead to a significant reduction in herbicide consumption compared with present-day consumption in the cultivation of these crops. As a cautious guess, there could be a saving of about 2 kg active ingredients per ha with glyphosate-resistant varieties of beet. Trials have shown that it is possible to achieve a reduction from the present level of 2800 g traditional beet herbicides to 540 g glyphosate/ha (Elbæk-Jensen, 1998).
- Cultivation of herbicide-resistant rape is not expected to result in a significant reduction in herbicide consumption. Today, only a few herbicides are available for this crop and there is a trend toward increasing use of mechanical weed control. However, if this trend spreads, there might be a risk of increased herbicide consumption if and when the herbicide-resistant varieties are widely used.
- Cultivation of glyphosate-resistant or glyphosinate-resistant maize in Denmark would mean that the agents used today could be replaced with glyphosate or glyphosinate. This would probably not result in any significant change in total consumption.

8.9.2 Future perspectives

Limited effect within 10 years

In Denmark, the general view is that genetically modified plants with good resistance to disease could have a significant effect on the present need for pesticides. Genetic modification to achieve improved resistance to fungal diseases still seems to be at a preliminary stage. A great deal of knowledge has been built up concerning the basic mechanisms of attacks by fungal diseases and fungus-plant interactions, but relatively few field trials have yet commenced. The first varieties with effective resistance to fungal diseases will definitely not appear on the market for another 10 years.

Widespread use of GMO in the USA

In North America and elsewhere, vast areas of land (several million ha) are used for cultivation of genetically modified soya beans, maize and rape that are resistant to herbicides or that have had pest-resistant genes built into them. This has reduced the consumption of herbicides and insecticides.

Possible disadvantages in connection with the cultivation of genetically modified plants are evaluated in the Sub-committee on Environment and Health’s report.

8.9.3 Conclusion

In the GMO field in Denmark, most progress has been made in the development of herbicide-resistant plants that have a possibility of being marketed within a few years. The introduction of genetically modified, herbicide-tolerant varieties of beet is expected to result in a significant reduction in herbicide consumption - about 1 kg active ingredient per ha. Herbicide-tolerant rape and maize are not expected to result in any major reduction. With our present knowledge, it is not possible to predict how much genetically modified plants will affect the consumption of pesticides in Danish agriculture in a coming 10-year period. Intensive research is going on in this field all over the world and will undoubtedly in time greatly change our cultivated plants. Particularly if methods were developed for rapid breeding of genetically modified, disease-resistant plants, we would expect the basis to be created for reducing losses from disease.

8.10 Possibility of new spraying techniques reducing pesticide consumption and undesirable environmental techniques

8.10.1 Use of new spraying technology to reduce pesticide consumption

Sprayers and reduced dosages

There are different types of sprayer on the market, including hydraulic sprayers with and without air assistance and air-assisted sprayers. Over the years a number of trials have been carried out to determine whether a better biological effect that makes it possible to use lower dosages can be achieved by using different types of nozzle, quantities of water and pressure. These trials have generally shown that, in relation to the most widely used spraying system (hydraulic sprayers with flat sprinkler nozzle, about 100-200 l water and a pressure of 3-5 bar), there are only limited possibilities in Denmark of further reducing present-day dosages.

A technology that combines site-specific application of pesticides via GPS (Global Positioning System) is being developed that will open the way for more varied application on a field basis on the basis of a need analysis (Christensen *et al*., 1998).

8.10.2 Possibility of reducing drift by the choice of spraying method

A spraying technique that combines good effect with minimum drift can be used is some situations but not in others.

Effect of drift

Various factors affect the extent of drift. In calm weather, most of the liquid sprayed reaches the crop/the weed. In windy weather or periods with atmospheric instability, some of the liquid is transported out of the areas treated. The amount that drifts depends on:

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

The climatic conditions – particularly the wind velocity – are critical for the extent of drift. The practitioner cannot affect this. He can, on the other hand, ensure that there is sufficient spraying capacity on the property – also in peak-load periods. Spraying in unfavourable conditions can thereby be avoided or limited in years with significantly fewer favourable spraying hours than normal. In Denmark, strong wind is the most limiting factor for the kind of spraying that enables use of the lowest dosages (Jensen *et al.,* 1998b).

Morning spraying causes least drift

Spraying conditions are normally best in the hours of morning, when the relative humidity is at its highest and wind velocity is at its lowest. Climatic conditions that are favourable with respect to effect also reduce drift. Air assistance on the basis of Hardy's Twin Principle is another example of the fact that drift during field spraying can be reduced without reducing the biological effect.

New low-drift nozzles minimize drift

On the other hand, the choice of nozzle, and thus the drop size, is a point where there will be a conflict in some cases between the two objectives: effect and drift. That is because small drops settle and cover crops best during spraying with leaf agents, but small drops also involve the highest risk of drift. Trials carried out so far with small, low-drift nozzles have shown that it is possible to maintain the biological effect and at the same time reduce the risk of drift compared with the traditional flat-sprinkler nozzles that are otherwise used. It has not yet been documented whether low-drift nozzles and coarse-atomising air-injection nozzles can replace the traditional flat-sprinkler nozzles in all situations without serious loss of effect.

8.10.3 Possibility of reducing point-source contamination with pesticides

Problems during filling and cleaning

During filling and cleaning of sprayers there is a risk of contaminating the surroundings – the groundwater, the farmer's own wells, other wells and watercourses – via drainage systems from the farm. There is not much documentation showing that washing water or pesticide spills cause serious groundwater pollution, but a few sources suggest that farm wells and other wells can be seriously contaminated with pesticides (Anon., 1995). Although there is very little documentation showing that washing yards and pesticide spills cause serious groundwater pollution, there are a number of factors that mean that the said areas may be particularly critical because the pesticides reach the surroundings in very concentrated form. In addition:

- The area load is high because the same washing/filling yard is often used regularly for many years.
- Washing/filling yards are often surfaced with gravel and stone without any topsoil, which considerably increases the risk of pollution. With topsoil, microorganisms that can cause biological degradation are removed and the potential for bonding and retention is reduced. That means that the rate of transportation of water and pesticides is relatively high.
- For the same reason, weed control on farmyards and lanes involves a risk to well water and groundwater.
- Remnants of pesticide are led to the soil with a relatively large quantity of water increases the risk of percolation.
- Some yards are connected with drainage pipes or waste pipes, which means that watercourses and drain water can be affected.
- Handling often takes place close to wells and drilled holes.

Need for information campaign

All in all, we expect increased focus on the use and handling of pesticides, together with information and guidance, to help to minimise point-source contamination of groundwater, farmers' own wells, other wells and watercourses. This will result in improved conditions (Jensen *et al.*, 1998b).

The following points should be impressed on farmers:

- Filling of concentrated pesticide and washing of spraying equipment should be done on an area with soil covered with vegetation, a bio-bed or a concrete-surfaced yard with drainage to a separate tank – possibly a liquid-manure tank. A grass-covered area is very suitable. The grass prevents run-off and the formation of flow channels in the soil.
- Residual spraying liquid should never be disposed of by emptying it out on topsoil or a surfaced area or into a liquid-manure tank. The right way to dispose of it is to dilute it and spray it on the crop. The heavily diluted washing liquid should be sprayed over as large an area of the field as possible. The diluted liquid can also be discharged into a liquid-manure tank.
- Washing and filling should never be done on areas surfaced with gravel or concrete, where the washing water and waste can percolate to sewers, drains or watercourses. In addition, washing and filling should never be done near wells.
- Packaging from pesticides must be disposed of via the municipal waste collection scheme.

It is important for users of pesticides to be aware that even very small, accidental spills can cause pollution of groundwater and water courses.

EU-standards for sprayers

At European level, common standards are being prepared for field sprayers. Work is in progress on:

- obligatory rules for mounting of a clean-water tank on sprayers so that the sprayer can be washed through before it leaves the field.
- In addition to a clean-water tank, there must be an extra water tank for washing hands.
- common codes for filling equipment and equipment for cleaning chemical packaging.

Compliance with a standard is normally voluntary, but in some countries it will form the basis for approval of spraying equipment. In Denmark there is already a trend towards voluntary installation of clean-water tanks on sprayers. Clean-water tanks can be added to most sprayers without serious technical problems (Jensen *et al.*, 1998b).

8.10.4 Conclusion

Compared with the spraying technology used at present, the introduction of alternative, known spraying technologies offers only a limited possibility of reducing the quantities of pesticides used. There is, however, an exception to this in the form of site-specific application, which will in time enable varied application at field level by means of GPS technology.

Possibilites of reducing drift

The risk of drift can be reduced by using new nozzles that minimise the proportion of drops that are particularly exposed to drift. Some of the new types of nozzle increase the capacity in relation to earlier sprayers, which at the same time improves the possibility of getting spraying done in calm weather. Within fruit growing, we also think that new screened equipment, which collects spray residue, offers good possibilities of reducing the impact on the surrounding environment.

Information on the risk of point-source contamination

We consider that, with intensified information and guidance for farmers on filling and cleaning sprayers, there are good prospects for minimising point-source contamination of groundwater, farmers' own wells, drilled holes and water courses in connection with the filling, washing and cleaning of sprayers. These possibilities require only a limited investment.

8.11 New pesticides

Development of low-dose agents

New pesticides are constantly being developed for use in agriculture. It is difficult to judge whether new pesticides will in the future change significantly the present consumption of pesticides. There has been a general trend towards agents containing a smaller quantity of the active ingredient. For example, the average content in agents developed in the 1940s corresponded to 1.5 kg/ha, while the average content of those used today is just over 100 g/ha. The cost of developing new agents has risen very greatly in the last 20 years, in step with the increasingly stringent requirements concerning the agents' environmental profile. This has at the same time reduced the success rate for finding new agents.

Today, there are some pest/crop combinations for which there are no pesticides. Traditionally, there has, for example, been no means of preventing or controlling take-all disease in cereals. Recently, however, seed-dressing agents have been introduced that can reduce the risk of take-all disease (Beale *et al*., 1998, Löchel *et al*., 1998).

As resistance to many products is constantly increasing, constant development of products that act through other mechanisms is vital if we are to ensure continued effective pest control.

Some trends can, however, be described.

8.11.1 Herbicides

In the last few years some very effective agents have been developed that are active in very small dosages (<100g active ingredients per ha). In the same period there has been some focus on the development of herbicides from naturally occurring chemical substances, although success has so far been limited. Up to the present time, only one of these herbicides has been marketed: Bialafos in Japan. Glyphosinate (Basta) is a synthetic copy of this agent. In addition, there has been a development towards herbicides that affect processes that are specific to plants, which has resulted in falling toxicity to humans and animals. As a result of these developments, there are now fewer different modes of operation than there used to be, which increases the risk of weeds developing resistance.

8.11.2 Fungicides

Strobilurines

In connection with the development of fungicides, attention has similarly been focused on utilising naturally occurring active substances from fungi and bacteria. Of the new types, strobilurines, in particular, have proved to be very effective, and at the same time broadly acting, against some of the principal pathogenic fungi that attack cultivated crops. Compared with fungicides used earlier, the strobilurines have proved to increase additional yields significantly – for example, by 4-10 hkg/ha in wheat. The reason for this is that, unlike earlier agents, the strobilurines already attack the fungi at the spore stage and thus do not trigger the plants' own defence system. The new agents have improved the economy of control of fungal diseases and mean that it will remain financially advantageous to combat fungal diseases in cereals despite lower cereal prices.

Other new fungicides act by mobilising the crop's own defence mechanism. The agents do not in themselves have any toxic effect on fungi but have proved able to impede certain fungi after the plant's defence system has been activated. An example of this group is benzothiazol (Bion), and a substance extracted from a brown alga (Joubert *et al*., 1998). Bion is marketed in Germany and some other countries as a "plant activator".

8.11.3 Insecticides

More seed-dressing agents

New types of insecticide are characterised by the fact that they are also active in very small quantities (5-20 g/ha) and that agents are being developed with action mechanisms that differ from those previously used. Examples are triazamat (Aztek) and imidaclopride (Confidor). These make it possibly to control species of pest that have developed resistance to the agents used previously. Within pest control in beets, for example, increasing use is being made of seed-dressing agents that are able to replace 1-2 applications of, e.g. pyrethroids. Seed-dressing agents are generally thought to have a minor environmental impact because less than 1% of the acreage is directly exposed to the pesticide.

Another innovation within insecticides is the development and use of attractants (including pheromones), which have the effect of stopping proliferation of the insects or means that they are caught in a kind of trap with pesticides, where they are killed. These methods are believed to be considerably more environment-friendly because the agents are not applied broadly in the culture (Jones & Langley, 1998).

8.11.4 Conclusion

New pesticides are being constantly developed to replace old agents, and agents are being developed that offer new means of controlling diseases, including take-all disease. The agents are generally used in smaller quantities than previously and there is a trend towards increased use of certain insecticides as seed-dressing agents. The search is being intensified for active ingredients derived from nature's own substances, although significant modification is often needed to achieve stable and suitable pesticides. The success rate for finding new agents has decreased owing to more stringent environmental and health requirements concerning the agents.

As resistance to many products is continuously increasing, constant development of products that act through other mechanisms is vital if we are to ensure continued effective pest control.

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9 Total phase-out of pesticides in agriculture - 0-scenario

Basically, for the 0-scenario, as many alternative methods of control as possible have been incorporated, including experience from organic farming. Microbiological methods are not used in the 0-scenario – a factor that would not have any practical implications in farming but that would reduce the possibility of controlling certain pests in greenhouse production. Immediate omission of dressing of cereals against seed-borne diseases could result in large and uncontrollable losses. Since it has not been possible to evaluate the consequences of a total phase-out of seed-dressing agents for cereals, we have assumed in the 0-scenario that use of these agents is still permitted up to and including the C1 generation of cereals.

In continuation of the 0-scenario proposed on the basis of agronomic considerations, we have set up a 0-scenario based on economic optimisation of production. In the following, the 0-scenario described by the sub-committee will be discussed first. This will be followed by a short description of the 0-scenario based on economic optimisation, although subjected to various assumptions concerning maximum proportions of winter cereals, crop sequences, etc.

9.1 Assumptions

Adjustment of crop rotations

On the basis of present production, we have set up farms in a 0-scenario in which the choice of crops is adjusted to mitigate the greatest problems with pests. In these agronomic scenarios a production of special crops has been maintained, even though this can be expected to create problems in the shape, for example, of weeds in sugar beet, weed seed in seed grass and potato blight. The proposed crop rotations have a generally lower yield level, including a 23% reduction of the average cereal yields. The following elements have been included in the crop rotations in order to mitigate the yield losses to some extent:

- The crop rotations must contain fewer fields with winter cereals - max. 40%.
- More rye and triticale must be grown because these crops compete well with weeds and are less susceptible to diseases.
- Winter wheat, rye and winter barley must be sown later than is done to day in order to reduce the pressure of weeds.
- The crop rotations must include second crops in order to comply with the requirement concerning 65% green fields.
- Extensive use must be made of mechanical weed control to keep weeds under control.
- Disease-resistant varieties must be used if available and possibly variety mixtures.

Besides the agronomic crop rotations set up in the 0-scenario, economically optimised regimes have been set up (Ørum, 1998). A number of agronomic restrictions have been set in these regimes, but it is largely economic considerations that have determined the crop composition. This optimisation is described in greater detail in chapter 9.5. In the analyses carried out by the Sub-committee on Production, Economics and Employment, use was made of data from 2000 farms in 1995/96, for which expanded accounting statistics are available

(Ørum, 1998). These farms have been broken down into 10 types, for each of which the contribution margins can be calculated.

For 10 of the 12 present types of farm described in chapter 5 (table 5.2), we suggest how the crop rotations can be adjusted in a situation without access to pesticides (table 9.1). Besides the specific crops, a certain proportion called “other crops”, which cover crops with small acreages, is described. The two crop rotations describing other farms of less than 20 ha have not been analysed in this material. A more detailed picture of the crop rotations in the 0-scenario is given in appendix 1.

Maintaining livestock units and special crops

The proposed crop rotations are based on the assumption that the present production and structure at the farms is largely retained in the 0-scenario with respect to livestock units and types of crop. The total livestock production is maintained. To compensate for a reduction in coarse-fodder production, the acreage used for this purpose has been increased slightly, at the expense of the acreage used for cereals. Crop rotations with potatoes, sugar beet and seed grass are retained without clarifying whether they would be realistic in a 0-scenario in which weeds in beets would have to be controlled mechanically and manually, and in which it is very uncertain whether it would be possible to continue meeting the purity requirements for seed grass and thus ensure a saleable product. It is also uncertain how large a part of the potato production could be maintained without measures against potato blight. However, the crop rotations are deemed to be so important that both an agronomic and an economic analysis should be carried out to evaluate the full consequences of a total phase-out of pesticides for these crop rotations.

Table 9.1

10 types of farm on clayey and sandy soil have been selected, as described in present production in a proposed agronomic 0-scenario, in which account is taken of how pest problems can be reduced. Economically optimised crop rotations have also been created for the 0-scenario. In the 0-scenario, yield and percentage loss are given in relation to present production. Contribution margin 2 is given as an average for the types of farm in present production and the 0-scenario. The figures for treatment frequency index (TFI) include set-aside land but not control of couch grass.

Arable farms without pigs on clayey soil Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario (economically optimised)	
Crop	TFI	Yield hkg/ha	% acre-age	Crop	% loss of yield	Yield hkg/ha	% acre-age	Crop	% acre-age
Winter rape	2.5	28	5	Winter rape and/or	7	26	9	Rape/peas	0
Winter wheat, 1st yr.	3.2	78	14	Peas	21	30	9	Spring cereals	41
Winter wheat, 2nd yr.	3.2	68	20	Oats	16	43	17	Winter cereals	29
Spring cereals	2.0	51	21	Winter cereals	29	55	17	Special crops	0
Winter barley	1.9	58	13	Spring barley				Feed crops	1
Winter rye	1.4	53	4	(second crop)	19	42	13	Set-aside	28
Set-aside	-		13	Winter barley	18	48	9		
Miscellaneous	2.9	-	10	Triticale/rye	12	47	9		
				Set-aside	-	-	13		
				Miscellaneous			4		
Average CM 2 DKK/ha (av. TFI)		3,231(2.2)	100			1,704	100		2,439

Arable farms with pigs on clayey soil Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario, (economically optimised)	
Crop	TFI	Yield hkg/ha	% acre-age	Crop	% loss	Yield Hkg/ha	% share	**Crop**	% share
Winter rape	2.5	9	5	Winter rape and/or	7	27	9	Rape/peas	16
Winter wheat, 1st yr.	3.2	81	14	Peas	21	31	9	Spring cereals	33
Winter wheat, 2nd yr.	3.2	71	20	Oats	16	45	18	Winter cereals	39
Spring cereals	2.0	54	20	Winter cereals	29	57	18	Feed crops	2
Winter barley	1.9	61	13	Spring barley				Set-aside	10
Winter rye	1.4	56	4	(second crop)	19	43	13		
Set-aside	-	-	11	Winter barley	18	48	9		
Miscellaneous	1.5		13	Triticale	12	47	9		
				Set-aside	-	-	11		
				Miscellaneous			4		
Average CM 2 DKK/ha(av. TFI)		2,781 (2.1)	100			1,991	100		2,204

Arable farms with sugar beet on clayey soil Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	% share
Sugar beet	4.3	480	23	Sugar beet	14	413	23	Sugar beet	0
Winter wheat, 1st yr.	3.2	88	8	Spring barley	19	48	39	Spring cereals	72
Winter wheat, 2nd yr.	3.2	78	34	Winter wheat,				Winter cereals	0
Spring cereals	2.0	59	22	1st yr.	29	63	6	Grass	2
Set-aside	-		9	Winter wheat,				Grass seed	0
Miscellaneous	1.8		4	2nd yr.	27	57	21	Set-aside	26
				Set-aside			9		
				Miscellaneous			2		
Average CM 2 DKK/ha(av. TFI)		4,184 (2.8)	100			302	100		2,801

Arable farms with seed grass on clayey soil; Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	%share
Seed grass	1.5	9.5	19	Seed grass	50	4,8	22	Sugar beet	0
Sugar beet	4.3	480	6	Sugar beet	14	413	6	Seed grass	4
Winter wheat, 1st yr.	3.2	86	22	Winter cereals	29	61	22	Spring cereals	39
Winter wheat, 2nd yr.	3.2	76	20	Triticale	12	52	13	Winter cereals	34
Spring cereals w.				Spring barley				Feed crops	0
undersown crop	2.0	57	11	w. undersown	19	46	25	Set-aside	23
Set-aside	-		10	crop					
Miscellaneous	2.2		12	Set-aside			10		
				Miscellaneous			2		
Average CM 2 DKK/ha (av. TFI)		3,928 (2.3)	100			1,967	100		2,822

Dairy farms on clayey soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				0-pesticide scenario, (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	% share
Winter wheat, 1st yr.	3.2	75	13	Winter cereals	29	54	17	Beets/maize	0
Winter wheat, 2nd yr.	3.2	66	8	Spring barley				Rape/peas	10
Spring cereals	2.0	50	17	(second crop)	19	40	17	Spring cereals	19
Wholecrop	1.0	64	17	Wholecrop	14	55	17	Winter cereals	10
Grass	0.08	68	21	Grass	3	66	40	Wholecrop	27
Mangolds	4.0	120	6	Set-aside			6	Set-aside	9
Maize	1.3	66	5	Miscellaneous			3	Grass	25
Set-aside	-		6						
Miscellaneous	2.8		7						
Average CM 2 DKK/ha (av. TFI)		2,217 (1.7)	100			1,684	100		1,846

Arable farms on sandy soil Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario, (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	% share
Spring rape or	2.0	20	3	Winter rape or	7	22	8	Grass seed	9
Winter rape or	2.5	24	4	Peas	21	32	8	Rape/peas	0
Peas or	3.3	40	5	Seed grass	50	4	4	Spring cereals	39
Seed grass	1.5	8	4	Winter cereals	27	52	17	Winter cereals	20
Winter wheat, 1st yr.	3.6	71	16	Spring barley	17	40	24	Feed crops	3
Winter wheat, 2nd yr.	3.6	56	9	Winter barley	19	44	8	Set-aside	29
Rye	1.4	54	8	or					
Spring cereals	1.5	49	20	Winter rye	12	48	8		
Winter barley	1.9	54	8	Set-aside	-	-	13		
Set-aside	-		13	Miscellaneous			10		
Miscellaneous	2.0	-	10						
Average CM 2 DKK/ha (av. TFI)		2,254 (2.0)	100			1,565	100		1,847

Pig farms on sandy soil Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	% share
Spring rape or	2.0	19	3	Winter rape or	7	22	8	Special crops	5
Winter rape or	2.5	23	2	peas	21	30	9	Rape/peas	11
Peas or	3.3	39	4	Grass	3	62	6	Spring cereals	45
Grass	0.08	64	5	Winter cereals	27	50	17	Winter cereals	22
Winter wheat, 1st yr.	3.6	68	16	Spring barley	17	39	21	Feed crops Set-	6
Winter wheat, 2nd yr.	3.6	53	6	Winter barley	19	41	8	aside	11
Rye	1.4	52	6	or winter rye	12	46	8		
Spring cereals	1.3	47	21	Set-aside	-	-	12		
Winter barley	1.9	52	12	Miscellaneous			11		
Set-aside	-	-	12						
Miscellaneous	1.0		13						
Average CM 2 DKK/ha (av. TFI)		2,106 (1.8)	100			1,646	100		1,835

Arable farms with potatoes on sandy soil Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario, (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	% share
Potatoes Peas winter cereals Spring cereals Set-aside Miscellaneous	6.9 3.3 3.6 1.3 - 1.3	367 35 63 43	24 6 18 31 11 10	Potatoes Triticale/Rye Spring barley (second crop) Set-aside Miscellaneous	42 12 17	219 42 36 -	24 21 40 11 4	Potatoes Spring cereals Winter cereals Set-aside Miscellaneous	3 41 23 32 1
Average CM 2 DKK/ha (av. TFI)		3,778 (3.0)	100			1,282	100		2,035

Dairy farms on sandy soil <1.4 LU dairy cows per ha Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	%share
Winter wheat, 1st yr. Spring cereals Wholecrop/maize Grass Mangolds Set-aside Miscellaneous	3.6 1.3 1.0 0.08 4.1 - 1.9	61 41 59 64 100	10 21 18 31 6 8 6	Spring barley w. undersown crop Wholecrop (maize) Grass winter cereals Set-aside Miscellaneous	 17 14 3 27	 34 51 62 45	 23 18 41 9 8 1	Wholecrop Rape/peas Spring cereals Winter cereals Feed crops Set-aside Miscellaneous	14 8 32 0 37 8 1
Average CM 2 DKK/ha (av. TFI)		2,012 (1.2)	100			1,859	100		1,942

Dairy farms on sandy soil >1.4 LU dairy cows per ha Crop rotation in present production				0-pesticide scenario (agronomically optimised)				0-pesticide scenario (economically optimised)	
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield Hkg/ha	% share	Crop	% share
Winter wheat, 1st yr. Spring cereals Wholecrop/maize Grass Mangolds Maize Set-aside Miscellaneous	3.6 1.3 1.0 0.08 4.1 1.5 - 3.2	62 42 60 64 100 62	8 11 26 39 7 3 3 3	Spring barley with undersown crop Wholecrop Grass Set-aside Miscellaneous	 17 14 3	 34 51 62	 12 28 56 3 1	Spring cereals Winter cereals Grass Wholecrop Maize Set-aside	1 5 65 25 0 4
Average CM 2 DKK/ha (av. TFI)		1,986 (1.2)	100			1,913	100		2,257

9.2 Loss sizes in a 0-scenario

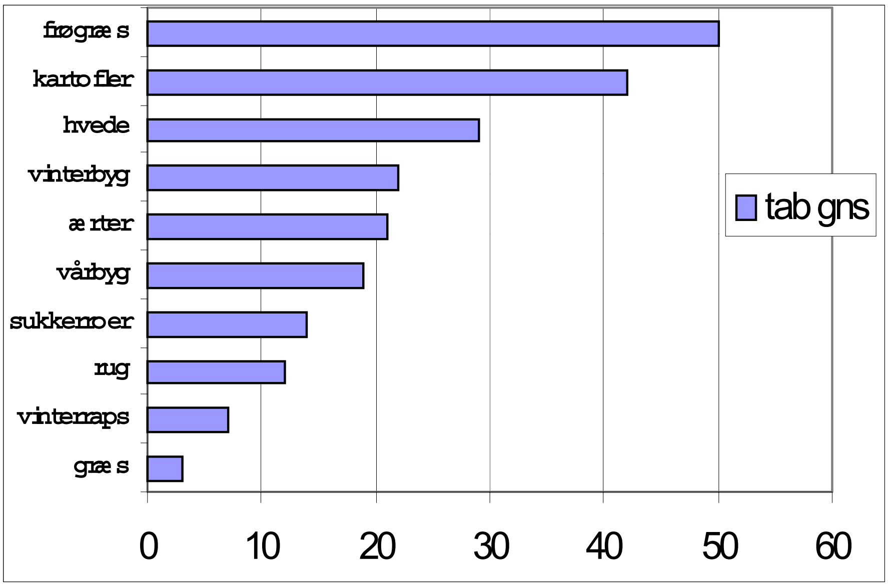
For each crop a percentage loss as a consequence of cultivation without pesticides has been calculated (see section 5.5.2). The total average production loss for different crops varies between 3 and 50% (see figure 9.1).

23% reduction in cereal yield

For the total cereal production a weighted change in production has been calculated as shown in table 9.2. In this weighted average allowance has been made for the fact that a large part of the 2nd year's wheat would be replaced with other species of cereal and for the fact that some species would change from one type of farm to another.

Table 9.2
Grain yield in present production and the 0-pesticide scenario. Weighted average of all farms (Mikkelsen et al., 1998).

Grain hkg/ha	Present production	0-scenario	% change
Winter wheat on sandy soil	63	47	25
Winter wheat on clayey soil	75	57	25
Spring cereals on clayey soil	53	44	17
Spring cereals on sandy soil	44	37	16
Cereals for maturity, total	58	45	23



(frøgræs= seed grass
kartofler = potatoes
hvede = wheat
vinterbyg = winter barley
ærter = peas
vårbyg = spring barley
sukkerroer = sugar beet
rug = rye
vinterraps = winter rape
græs = grass)

tab gns = average loss

Figure 9.1
Percentage losses in different crops in a 0-scenario

Some of the most problematical crops with serious yield losses are discussed in the following.

Experience from organic potato

In potatoes the average losses from diseases and pests are estimated to be just over 40% (table 5.6), although this covers a considerable annual variation. In evaluating the yield from organic productions there is a yield loss of 42% compared with the present production (table 9.3).

Seed potatoes

It is almost impossible to sell seed potatoes that have been attacked by potato blight, so the production would be unprofitable. In years with early attacks, potato blight could reduce the quality and shelf life of ware potatoes, and producers of starch potatoes could not maintain a reliable supply that would enable them to compete with similar foreign producers.

Table 9.3
Acreages and yields for potato production, with a breakdown into 3 main types. The figures are gross figures (Holm et al., 1998)

Type of potatoes	TFI	Acreage, 1997 ha (av. 92-96)	Present production hkg/ha*	Organic production hkg/ha**
Seed potatoes	3-4	7, 350	300	no figures
Ware potatoes	4-5	11, 760	400	233
Starch potatoes	6-7	25, 800	450	300 (estimated)
Total		44, 900		

* General levels given by the Plant Directorate in connection with nitrogen supply
** Organic potatoes are from monitoring of organic farming 1991, 1996-97

Starch potatoes

The biggest problems in a 0-scenario are expected for starch potatoes, which have the longest growing season and are generally sprayed most against blight. With the present quota schemes for starch potatoes in the EU, a considerable variation in the production would make it impossible for Denmark to achieve stable utilisation of its national quota. This would affect both the individual producer and the potato-starch manufacturers. Potato starch is made at 5 factories. Most of the production is exported. A 40% loss would make production unprofitable. The manufacturers would be unable to increase the price paid to the farmers because it seems unlikely that a premium could be obtained for starch produced without chemicals since most of the starch products are used for industrial applications. We would therefore expect a 0-scenario to result in closure of the factories and the end of starch-potato production (Holm *et al.*, 1999).

It is believed that greater use could be made of the potato varieties' resistance, but even though there are varieties with considerable resistance, it is not given that they can be used for all types of cultivation. The starch potato Danva, for example, is not suitable as a ware potato, and Sava, which is the variety most widely grown by organic farmers because of its resistance to mould in the tubers, cannot be used as an early potato for chips and crisps. An attack of potato blight in Sava usually develops epidemically and defoliates the field within 2-3 weeks. This rapid desiccation often results in less tuber attack than in conventional fields, where weak attacks without significance for the quantitative yield can result in spores getting washed down to tubers over a lengthy period and thus cause relatively more tuber mould (Hansen & Holm, 1996). Experience from Foulum indicates that there could be very big yield losses in 2 out of 9 years in potatoes cultivated without pesticides. In a situation without chemical control of blight, we would expect the pressure of infection to increase drastically after mid-July and thus impose a heavy pressure of attack on all varieties.

In the EU there is tough price competition on seed and ware potatoes. It would therefore be difficult to achieve a higher price for Danish potatoes. Experience shows that the price of ware potatoes in Denmark cannot be many percentage-points over the price in Germany and the Netherlands before the retail trade starts importing (Holm *et al.,* 1999).

Other problems in potatoes

The following problems could also arise in potatoes if pesticides were not used:

- With the acreage used for potatoes at present, capacity problems could occur if weed control had to be carried out at the right times - typically 3-4 times during the season - which could lead to poorer weed control.
- The increased risk of mould in potato tubers could reduce the starch quality of starch potatoes, which would impair Danish competitiveness in this area.
- Without chemical desiccation methods, there would be an increased risk of viral infection, particularly in seed potatoes. Without pre-harvest desiccation before the arrival of aphids, the seed potatoes would be infected with virus and would not be approved for sale. The alternative topping methods are generally more time-consuming.

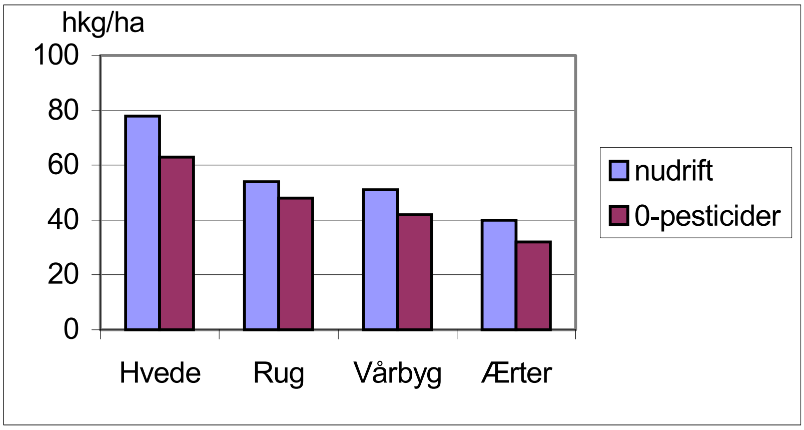
- Discontinuing dressing of seed potatoes against certain diseases during storage (Phoma, Fusarium, etc.) would reduce the quality of Danish seed potatoes compared with seed potatoes produced elsewhere.

Problems in seed grass

In seed grass there would also be substantial losses due to weed problems and problems with removing weed seed. An estimate has been made of the loss because there are no real data that can be used to substantiate its magnitude. The great uncertainty in fixing the percentage loss is also due to the fact that the production covers many different species and types. To meet the current rules on purity (max. 1% content of a single other plant species and a total content of other plant species of 1.5-2%), which have to be met for certification and an EU subsidy, the seed consignments would have to be cleaned much more thoroughly. This would reduce the individual farmer's settlement. It is very difficult to get rid of some species. Denmark is at present the leading global producer of grass seed, due in part to the fact that we produce seed of high quality. Denmark is thus the world's biggest exporter of grass seed. If the production in Denmark were to be associated with great uncertainty, many of the seed firms would probably move their production to other countries.

Problems in wheat

In wheat we estimate that the total loss would be 27-29%, made up of a 7-9% loss from leaf diseases, 14% because of weeds and damage to the crop in connection with harrowing and approx. 3% from pests, while other factors, such as postponement of the sowing time and choice of resistant varieties would result in a loss of 7-8%. Losses from diseases vary considerably from year to year. In moist growing seasons – as in 1987 and 1998, for example – it is common to see losses of 20-30% from diseases (especially septoria), while in other years, the losses are insignificant. Even if the most resistant varieties were cultivated, it would be impossible, with today's choice of varieties, to avoid some of the losses that are caused by septoria and other diseases.



(nudrift = present production
0-pesticider = 0-pesticides)
Hvede = Wheat Rug = Rye Vårbyg = spring barley Ærter = peas)

Figure 9.2
Yield in 4 crops, with present production compared with zero use of pesticides.

We estimate that the crops with the smallest losses – 3 and 7%, respectively – would be grass and winter rape.

Problems in beets

The losses in beets would be relatively low provided the crop could be weeded mechanically and manually. Manual weeding is a costly process that would make the production much more expensive. For example, the time consumption for hoeing is estimated to be 100 hours per ha. It is also uncertain whether sufficient manpower would be available. Postponing the sowing time or planting out the beets could reduce the problems with weeds. However, the first solution would reduce the yield and the second would increase the cost of cultivation.

Problems with seed-borne diseases

Losses from seed-borne diseases are not included in the described losses for cereals because of great uncertainty in determining their magnitude. A severe attack of stinking bunt, for example, in wheat would mean total loss of the crop. Therefore, in the 0-scenario, we have assumed dressing of the first generations of seed (up to and including C1). Subsequent consignments of cereal would have to be analysed to determine the degree of attack, followed by an assessment of whether the consignment can be used or whether the attack necessitates rejection. In spring barley we think there would be a good possibility of carrying out a need assessment, while, in wheat, a detailed analysis would have to be carried out of the extra capacity needed to handle a very large number of analyses within the 14-30-days between harvest and sowing.

Economic analyses of contribution margin 2 for whole types of farm if the present proportion of special crops were maintained show an average reduction, compared with present production, of 4-8% for dairy farms on sandy soil, 39 and 48% for arable farms on sandy and clayey soil, respectively, and 50 and 93%, respectively, for arable farms with a large proportion of seed and sugar beet, and 66% for potato producers (table 10.9).

9.3 Total crop changes in a 0-scenario

In the proposed 0-pesticide scenario we have reduced the proportion of green fields but have compensated for this by including second crops. The total acreage with sugar beet, potatoes and seed grass has been maintained, which, taken together, means a reduction in production as a consequence of the calculated yield losses (table 9.4).

Changes in cultivated acreages

Mangolds have been omitted because we estimate that the cost of manual weeding in a 0-scenario would make the crop less competitive than other coarse fodder. The wheat acreage is reduced by 250,000 ha because 2nd year wheat is generally not included. The rye and triticale acreage is increased by 110,000 ha, and the oats acreage by 70,000 ha. Rye, triticale and oats have an advantage because they compete well with weeds and are generally less vulnerable to leaf diseases. We would expect problems with selling the large quantities of rye and oats. However, it should be possible to include rye in cattle-feed mixtures, whereas this might be more difficult in the case of oats. The increased acreage with oats would mean an increased risk of proliferation of cereal cyst nematodes and thus a risk of yield losses in oats and spring barley.

Dynamic changes

Altogether, we estimate that the proposed crop rotations would reduce the need for nitrogen by 12,000 tonnes as a consequence of lower yield levels and a different crop composition.

We have described different crop rotations that could be relevant in a scenario without pesticides. In practice, however, the crop rotations would by no means be static.

Depending on market conditions and problems with pests and, particularly, with weeds, adjustments would be needed from time to time in order to optimise the farm's economic output. The possibility of selling the increased quantities produced has not been specifically assessed by the Sub-committee on Agriculture, but the Sub-committee on Production, Economics and Employment has included in its report calculations for both economically and agronomically optimised crop rotations on the basis of crop and production prices.

Table 9.4
% changes in cultivated acreage in the proposed 0-scenario compared with present production

	Acreage calculated on basis of figures from farm accounts 1000 ha	Acreage calculated in a 0-scenario (agronomic)	% change in 0-scenario
Winter rape	51	121	+137
Spring rape	42	0	-100
Peas	69	121	+75
Seed grass	58	61	+5
Sugar beet	76	74	-3
Potatoes	45	42	-7
1st yr. wheat	344	342	-1
2nd yr. wheat	271	35	-87
Rye/triticale	77	185	+140
Oats	27	101	+274
Spring cereals	546	514	-6
Winter barley	176	121	-31
Wholecrop/maize	149	153	+3
Grass	200	302	+51
Mangolds	46	0	-100
Set-aside	261	261	0
Permanent grass	184	184	0
Total	2,622	2,616	0
Cereals for maturity, total	1441	1298	-10
Coarse fodder, total	578	639	+11
Winter cereals	868	683	-21
Spring cereals (incl. wholecrop)	722	768	+5
Broad-leafed crops + seed grass	387	419	+8

9.4 Overall changes in production quantities

Table 9.5 shows the main production figures as a basis for evaluating the general consequences for production in a 0-scenario.

In the scenarios described we do not think that production would be reduced so much that it would affect livestock production. This assumption is based on the fact that the farms' total acreage would be the same in operation without pesticides as in present production. Similarly, the level of coarse fodder per livestock unit (LU) would be maintained without pesticides (constant total coarse-fodder production). There would thus be a reduction in the proportion of cereal corresponding to the fall in yield in wholecrop and grass. Farms with livestock would need to purchase more primary cereals because their own production would no longer cover their need for fodder. This would be offset by an increased production of rape and peas, which would reduce the need for bought-in supplementary fodder.

In the years 1993-96 net cereal exports averaged 1.7 mill. tonnes (Agriculture in Denmark, 1998). In a pesticide-free scenario a net import of cereals of just under 1 mill. tonnes (8.4-1.7 – 5.8) would thus be needed to maintain livestock production at the present level.

Table 9.5
Main productions in 1000 hkg (crop units) – figures in present production and the 0-scenario (Sillebak Kristensen, Pers. com.).

	Present calculated	the 0-scenario	the 0-scenario % change
Total cereal production	83,986	58,398	-30
Winter cereals for maturity	56,943	33,712	-41
Spring cereals for maturity	27,042	24,686	-9
Total coarse-fodder production	30,441	30,378	0
Total rape production	2,178	2,809	+29
Production of seed potatoes	1,536	614	-60
Production of ware potatoes	3,963	2,774	-30
Production of starch potatoes	10,861	7,168	-34
Production of peas	2,617	3,624	+38
Production of seed	518	274	-47
Production of sugar beet	35,787	30,154	-15

The Sub-committee on Production, Economics and Employment has evaluated the total production figures in the optimised 0-scenario on the basis of the analysis in the economic model. With respect to production of sufficient feed units to maintain our present animal production, a production that would do this is planned at dairy farms in the 0-scenario. In the case of pig production, it is estimated that importing from other countries could make up for a reduction in cereal production. The economic consequences of such a change have been taken into account in the economic analyses.

9.5 Evaluation of the economically potimised 0-scenario

Model for optimisation of crop rotations

Besides the purely agronomic crop rotations described in the foregoing, some types of farm have been set up on the basis of both agronomic and economic factors (see table 9.1 and appendix 1). Some agronomic restrictions have been set up, but it is largely the economic factors that have determined the crop composition. If a crop gives a large financial yield, the model increases the proportion of these crops in the crop rotation. If a crop is less profitable, it is omitted from the rotation. A pesticide ban would change the relative yield of the crops, cf. the losses set up by the Sub-committee on Agriculture. Some would be slightly changed, whereas others would be changed considerably. The consequences of a pesticide ban would thus in reality be a different crop rotation, and the changes would be caused by a mixture of agronomic and economic factors. The economic reactions have been modelled in an optimisation model (Ørum, 1998), which has to some extent been checked to determine whether the types of farm arrived at comply with the necessary agronomic restrictions. The economic analyses have been based on the Danish Institute of Agriculture and Fisheries Economics' accounts statistics, which are expanded accounts statistics based on 2,000 farms, in which costs and prices are broken down between the 10 different types of farm. In the 0-scenario use has been made of the Sub-committee on Agriculture's proposed substitutions, including, for example, mechanical instead of chemical weed control. Restrictions are imposed on the proportion of winter cereal and the crop sequence in the crop rotations.

Special crops omitted

Unlike the crop rotations proposed by the Sub-committee on Agriculture, in which the present proportions of special crops (sugar beet, seed and potatoes) are retained, with the existing price relations, these crops are almost totally phased out in the economic model. This accords well with the concerns expressed about these crops, in which the cost of weed control and losses – from potato blight, for example – is expected to be high. That means that other crops in a 0-scenario would outprice these crops.

Increased proportion of set-aside land

The substantial losses in many crops would impair the economy of farms to such an extent that set-aside would become advantageous. The proportion of set-aside acreage would rise (from 10% to 20-30%), particularly at pure arable farms, where the handling of liquid manure and harmonisation rules do not have to be considered. The scenario envisaged by the Sub-committee on Agriculture includes the same set-aside acreage as in present production practice. Whether such large set-aside acreages as those that are economically optimal would be allowed, politically, would depend on the effect this would have on production and economically in the agricultural sector.

The Sub-committee on Agriculture's 0-scenario includes some rape and peas in several crop rotations. These crops have not been found competitive where farms are economically optimised, but have been replaced by rotation set-aside, which is also assigned a previous-crop value. Spring cereals also gain ground at the expense of winter cereals.

For a more detailed presentation of the different types of farm in the various scenarios, readers are referred to appendices 1 and 3.

10 optimised crop rotations

In the following we comment briefly on each of 10 types of farm described in a 0-scenario as a basis for evaluating whether the model's propositions are realistic:

1.0 Arable farms on clayey soil: The proportion of set-side rises from 10 to approx. 30% and the proportion of spring barley from 19 to 41%. Wheat is reduced to 0 and, instead, the rye/triticale acreage is increased to approx. 30%. Spring barley and rye/triticale are increased considerably because they have lower loss functions than wheat in the 0-scenario. Rape and peas are not competitive.

2.0 Pig farms on clayey soil: Owing to the harmonisation rules, it will not be possible to have more than 10% set-aside. Oats and wheat are grown as the largest cereal crops due to the changed price relations because the cereal has to be grown for pigs, and also because the contribution margin in the base situation is more favourable to oats and wheat than to spring barley and rye. There is also a small production of peas and rape and a little winter barley.

3.0 Arable farms with beets on clayey soil: The set-aside acreage is increased to 30%; sugar beet is not grown at all because of the high cost of weed control. The cereal acreage consists only of spring barley because the beet producers traditionally get a higher settlement (about 10% higher) for barley that is used for malting.

4.0 Arable farms with seed production on clayey soil: Seed production is discontinued altogether because of the heavy losses caused by the fact that the seed cannot live up to the purity requirements. Wheat is dropped, while rye/triticale is increased to about 30% of the acreage and spring barley from 19 to 39%. This change is due to the lower losses in rye/triticale and spring barley than in wheat. Set-aside takes up 25% of the acreage.

5.0 Dairy farms on clayey soil: Here, too, the set-aside acreage is only 10% in order to meet the harmonisation rules. Wheat is dropped almost entirely in favour of more wholecrop, which increases from 9% to 26%. This crop must replace mangolds and maize, which are difficult to grow without using pesticides. There is about 6% with winter barley followed by winter rape. Combined, these two crops compete well with the other crops.

6.0 Arable farms on sandy soil: The set-aside acreage is close to 30%; wheat is omitted, being replaced by rye/triticale. Spring barley is still grown on about 1/3 of the acreage. There is about 9% with seed grass, which, despite the heavy losses of about 50%, can compete with the other crops. There is already approx. 5% seed production at these farms in present production – mainly rye grass, which thrives on sandy soil.P

7.0 Pig farms on sandy soil: The set-aside acreage remains at 10% to enable the farms to meet the harmonisation requirements. Wheat is replaced by rye/triticale, while the acreage with spring cereals is increased by about 10%. Here, too, wheat is dropped because of the heavy losses in this crop. There are about 15% with rape, peas and seed grass.

8.0 Potato producers on sandy soil: The set-aside acreage rises to approx. 30%. Wheat is omitted, being replaced by winter barley on about 22% of the acreage. The spring-barley acreage rises from 28 to 41%. Potatoes are dropped apart from a small production of ware potatoes (3.3%), which we estimate can be sold to consumers with a preference for Danish potatoes who are willing to pay a higher price for them. Winter barley also does well in present production compared with wheat and rye/triticale.

9.0 Dairy farms with low intensity on sandy soil: The set-aside acreage is kept at 8%. Mangolds and maize are dropped because it would be costly to keep them in a 0-scenario. Instead, coarse fodder is produced from wholecrop and rotation grass. Wheat is dropped and the spring-cereal acreage is kept at around 1/3 of the acreage.

10.0 Dairy farms with high intensity on sandy soil: The set-aside acreage is reduced from 6% to 3.5%. Mangolds and maize are no longer grown because of the high cost of growing them in a 0-scenario. They are replaced by coarse fodder produced from wholecrop and rotation grass. Cereal for maturity are grown on only 5% of the acreage compared with 16-20% at present.

9.6 Use of alternative methods of control

Mechanical weed control

In a 0-pesticide scenario treatment with herbicides would be extensively replaced by mechanical weed control. It is estimated that this, together with preventive measures, would result in an acceptable level of weed control. However, it severely restricts what can be grown in the different crop rotations. The level of control would generally not reach the level achieved with chemical measures. We would therefore expect the quantity of weed in many fields to rise, contributing to crop losses and increased harvesting and drying costs. We estimate that the weather, in particular, would regularly limit the success of the control measures, which might mean that some fields and crops would have to be abandoned. The long-term proliferation of weeds in the proposed crop rotations is not known either. Particularly on certain types of soil, including organic soil, major problems could arise with weed control, which might mean having to take the acreages in question out of cultivation and putting them under grass. The capacity of the mechanical control methods is generally lower than that of chemical control methods, so phasing out pesticides could have consequences for the size and structure of farms - especially farms with a large production of potatoes.

Resistant varieties

In the scenario without pesticides, the cultivation of resistant varieties would become of increasing importance. However, even if the most resistant varieties were chosen, it would be impossible to avoid attacks by diseases because the existing assortment does not include varieties with good resistance to all major diseases in, for example, cereals and potatoes. The long-term effects and any losses as a consequence of increased pressure of infection when control measures are omitted cannot be determined from the existing plot trials.

There are descriptions of several alternative methods that are being developed to replace dressing agents (Nielsen *et al.*, 1998). However, none of the methods have reached a stage of development at which they could replace the chemical methods.

For this reason, the sub-committee has incorporated an assumption that control of seed-borne diseases would be sufficiently ensured by the necessary dispensation schemes in order to minimise the losses.

With our present level of knowledge, there are very few possibilities of reducing pest attacks by alternative methods. Attacks will regularly cause significant crop losses and reduce security of cultivation.

Cultivation without growth regulators is widely practised today through the use of short and strong-stemmed varieties. If tall and more competitive varieties were used, there would be an increased risk of lodging if the nitrogen level was not reduced at the same time (by about 30 kg N). A 30-kg reduction of nitrogen would mean a generally lower yield potential.

9.7 Uncertainties and difficulties in a O-scenario

Annual fluctuations in yield losses

The losses that could occur must be expected to fluctuate considerably from year to year. That would reduce the existing security of cultivation. Similarly, there would be considerable fluctuations between the different farms, depending on various factors, including the type of soil and the existing weed flora. This would probably increase the differences already seen today. The success of the individual crops and crop rotations would largely depend on how well the individual production manager tackled problems with pests, among which weeds are deemed to be the biggest problem.

We estimate that the crop rotations described could be practised, although typically with 10-25% yield losses compared with present production. Their course is very uncertain, particularly at farms with large proportions of special crops, where the losses can be expected to be closer to 50%. Success would depend on more farsighted planning of production, with pests “controlled” to a far greater extent than at present by a combination of crop rotation, preventive, indirect treatment and direct action. The manager’s decision would therefore necessarily be based on controlling pests rather than only on optimising production on the basis of traditional, economic considerations. This change would require considerable input with respect to training and supplementary training.

Security of cultivation would thus very much depend on how farsighted the individual production manager was because the 0-pesticide solution depends on cultivation elements that are ahead of their time as far as recognition of the problems is concerned. The present security of cultivation rests largely on the fact that pesticides can be used to minimise damage.

Risk of heavy losses

Table 5.8 gives average losses for different crops, together with an estimated maximum loss to illustrate the magnitude of the losses that could occur in individual years countrywide. In situations in which a pest developed to a high level, the losses for commercial crops would lie between 22% and 100%, which can be taken to mean a reduction in the security of cultivation. It is extremely difficult to say anything about how often these maximum years occur, mainly because they depend very much on the weather. For fungal diseases in cereals, there were almost max. outcomes in the years 1987, 1989, 1990, 1996 and 1998 – in other words, in 5 out of 14 years, corresponding to approx. every third year. The attacks in 1989 and 1990 were particularly severe in wheat as a consequence of cultivating a variety that was sensitive to yellow rust on large acreages. In a situation without fungicides, one would expect such a variety to be discarded. In rape there are major attacks of disease approximately every 5 years in a considerable part of the crops. Stapel (1983) has calculated the variations in the degree of attack of both diseases and pests for a 100-year period on the basis of records from monthly reports. This material shows the large annual variations.

However, it is important to stress that there are also considerable fluctuations in yield from year to year in the present, conventional production, due mainly to variations in precipitation, see figure 5.2 (Kjær, 1998).

Mycotoxins

An assessment has been carried out of the risk of an increased occurrence of mycotoxins in harvested crops (Elmholt, 1998). The principal mycotoxins produced in Denmark come from Fusarium and Penicillium fungi. There are no clear indications that the present use of fungicides significantly reduces attacks on cereals by these fungi. It can therefore not be inferred that a phase-out would increase the attacks. Increased quantities of mycotoxins could occur indirectly. In connection with increased occurrences of weeds and the increased risk of lodging, getting the harvested cereals dry could thus become increasingly problematical. This would lead to increased costs for drying cereals and could affect the quality of the cereal, including the content of mycotoxins. Studies of ochratoxin A in flour and grain carried out by the Danish Veterinary and Food Administration showed a tendency towards a higher content in the products from organic farms (Anon., 1998). This could have been due to a higher water content in the harvested grain, combined with inadequate drying.

Soil preparation and mineralisation

Increased mechanical soil preparation, as a significant weed-control factor, can, if a lot of the work is done in the autumn, cause increased leaching of nitrogen. Autumn ploughing results in leaching of approx. 15 kg more nitrogen than spring ploughing. Stubble-harrowing in the autumn, which would be needed to keep couch grass down, also results in increased leaching of nitrogen, the increase being about 10-15 kg/ha (Møller Hansen & Djurhuus, 1996). On the other hand, cultivation of large acreages with second crops must be expected to reduce the risk of nitrogen leaching. The risk in the different scenarios has been analysed by the Sub-committee on Environment and Health.

Reduced need for nitrogen

The smaller cereal yields in the proposed 0-scenario imply a reduced need for nitrogen of 33,000 tonnes for cereals, while an increased acreage with grass and winter rape implies an increased need for nitrogen in relation to fertilisation in present production. Without pesticides, the need for nitrogen would be reduced by a total of 12,000 tonnes.

In the 0-pesticide scenario it would similarly be possible to reduce the amount of phosphate and potassium fertiliser applied. The change in the need for fertilisation has been calculated as the difference in removed commercial product. The increase in rape and pea acreage implies an increased need for phosphate of 4,000 tonnes and a smaller need for potassium of 36,000 tonnes.

9.8 Results of trials without pesticides

There have been very few trials showing the effect of a 0-pesticide scenario compared with conventional cultivation in conditions in which allowance is also made for incorporating alternative control methods. In the following two trial series the cultural practices have been adjusted, but the crop rotation has not been changed.

One year's result from Køge-Ringsted farmers association

In 1998, two trials commenced in two localities in which crop rotations without use of pesticides are being evaluated in comparison with a crop rotation with a low-input level of pesticides (Kjærsgaard *et al.*, 1998). The crop rotation comprises peas, wheat (1st yr.), wheat (2nd yr.) and spring barley on clayey soil, while on sandy soil it comprises peas, wheat, rye and rye. The trials are multi-year trials and, where possible, include cultural practices in the 0-scenario (mechanical weed control, resistant varieties, late sowing, lower nitrogen level, etc.). The pressure of weed on the land used for the trials is relatively limited.

The results from the first trial year showed in an average of all crops a lower yield level of 23 hkg/ha, which, after inclusion of variable costs and crop earnings, results in a reduced average income of DKK 1,420/ha. The yield losses in the trial year were large owing to severe attacks of septoria and aphids in wheat, brown rust in spring barley, thrips in rye and pea weevil and pea moth in peas. The weed problems are not thought to have been particularly serious in the trial year. This first year's trial does not tell much about the degree of proliferation that can be expected in the trials. The yield losses in 1998 are estimated to have been higher than in an average year but are a very good indicator of realistic losses in a year with severe pest attacks. Compared with the calculated losses in the 0-scenario, in which the total cereal loss is 23%, the level from Køge-Ringsted is over 30%.

0-pesticide cultivation of malting barley

In the period 1992-96, DIAS carried out 24 trials with 0-pesticide cultivation of malting barley. In the trials, the only adjustment made to cultivation practice was the introduction of mechanical instead of chemical weed control. The yield loss compared with conventional cultivation averaged 11%. Where a more resistant variety was grown, the reduction in yield was approximately halved (Rasmussen, 1998). The trials were not sited in crop rotations with permanent 0-pesticide cultivation. It can thus not be judged from these trials whether weeds would proliferate to such an extent over the years as to cause major losses. The losses in these trials lie 5-7% below the level fixed in this work.

9.9 Conclusion concerning 0-scenario

10-25% yield loss

This chapter suggests what a 0-scenario could be like for 10 different types of farm. It is estimated that the crop rotations described could be practised, although typically with a 10-25% loss in yield compared with present production. There is great uncertainty about its course, particularly at farms with large proportions of special crops, where the loss of yield is expected to be closer to 50%.

Changed crop rotations

In practice, a 0-pesticide scenario would require considerable restructuring of the farms, including crop rotations with a significantly smaller proportion of winter cereals (max. 40% of the crop rotation) in order to reduce the problem of grass weeds. To continue meeting the requirement concerning 65% green crops, second crops have been incorporated in connection with the cultivation of spring cereals. Also incorporated is a wide range of cultural practices that would be needed to minimise pest problems.

Loss in individual crops

Percentage losses as a consequence of 0-pesticide cultivation have been estimated for all crops. The percentage losses for the individual crops have been broken down between different pests. The total average production loss for different crops varies between 7% and 50%. In potatoes, the loss from potato blight, for example, would be about 38%, while the yield from seed grass would be halved due to weed problems and problems with removing weed seed. In wheat, the total loss is estimated to be 27-29%,. Of this, 7-9% is due to leaf diseases, 14% to weed and damage to the crop in connection with harrowing, about 3% is due to pests, and about 7-8% is due to other factors such as postponement of the sowing time and use of resistant varieties.

The smallest losses estimated are in grass and winter rape, which would be affected only minimally. Considerable fluctuations can be expected in the losses that could occur, which would reduce the existing security of cultivation. It must be expected that certain productions with strict requirements concerning purity and freedom from disease would have to be abandoned. Estimating the percentage losses in a 0-pesticide scenario is encumbered with considerable uncertainty because of a significantly different epidemiology and population dynamics for the pests. For example, there is at present only very limited trial documentation on which to base an evaluation of a 0-scenario.

Dispensation for treatment with dressing agents

In the event of pesticides being phased out the sub-committee proposes that dispensation be granted for prevention and control of seed-borne diseases in the early generations of seed because the consequences of an uncontrollable proliferation of seed-borne diseases are incalculable and could result in heavy losses. In fields with severe attacks of stinking bunt, the crop would be worthless as food for either animals or humans. In spring barley we estimate that the combination of treatment of the first generations with a dressing agent and need assessment of the C2 generation could be practised, whereas for winter cereals a more detailed evaluation would be required to determine whether a need assessment of C2 was feasible with the very short time between harvesting and sowing. If treatment of the first generations up to and including C1 with a dressing agent were retained and were followed by a need assessment of C2, the treated acreage could presumably be reduced to less than 10% of the present figure. Such a strategy would have to be followed up by information and advice to ensure that farmers changed their sowing material.

Change in contribution margin II

For the crop rotations used at dairy farms, restructuring would be relatively easy and cause only limited losses, while the biggest loss would be suffered in connection with specialised arable farms, which have a substantial production of, for example, seed, potatoes and sugar beet. It is not deemed realistic to maintain these specialised productions if pesticides are banned altogether. Economic analyses of contribution margin II for whole types of farm, if the present proportion of special crops is maintained, thus show, in relation to present production, an average reduction of 4-8% for dairy farms on sandy soil, 39% and 48%, respectively, for arable farms on sandy soil and clayey soil, and 50% and 93%, respectively, for arable farms with seed production and sugar beet, while the loss for potato producers would be 66% (table 10.9).

Economically optimised crop rotations

Besides the crop rotations proposed with a view to reducing the level of pests and maintaining the present acreage with special crops, we have set up some types of farm based on a mixture of agronomic and economic factors in an economic optimisation model. In a 0-scenario, these farms would almost totally phase out special crops. That accords well with the misgivings expressed about these crops, for which heavy costs can be expected for weed control, together with losses from, for example, potato blight. It is therefore natural that other crops would oust these crops in a 0-scenario. Owing to the substantial losses in many crops, the economy of the farms would be impaired to such an extent that set-aside would become advantageous. The proportion of set-aside would increase to about 30% at pure arable farms, where handling of liquid manure and harmonisation rules do not have to be considered. That would give a total of 18% set-aside, which is in excess of Denmark's total quota of 15%. In the purely agronomic 0-scenario, some rape and peas have been proposed in several crop rotations. These crops would not be found competitive where economic optimisation was practised but would be replaced by rotation set-aside, which is also assigned a previous-crop value. Spring cereals would similarly generally gain ground at the expense of winter cereals.

CM II in economically optimised crop rotations

Economic analyses of contribution margin II for these optimised farms, where there are largely no special crops, show, in relation to present production, an average reduction of 21-24% for dairy farms on sandy soil, 26% and 34%, respectively, for arable farms on sandy and clayey soil, and 35% and 39%, respectively for arable farms with seed production and sugar beet, while the loss for potato producers would be 51% assuming 1995/96 prices. The losses would be significantly lower at the optimised arable farms with special crops compared with the more agronomically optimised crop rotations (table 10.9).

Meeting quality requirements

The success of a 0-pesticide scenario would depend to a great extent on being able to meet current quality requirements concerning, for example, seed, seed potatoes, starch potatoes and similar. In the case of crops grown in rows, manual weeding would be necessary until new methods were developed. Whether it would be possible to procure sufficient manpower for such very seasonal work is another question that remains to be answered – and one that could make continued production of sugar beet difficult. The lower yields and, in some cases, higher additional costs for, say, weed control and drying, must be judged in relation to whether a premium could be obtained for crops that had not been treated with pesticides.

The percentage losses given in the 0-scenario are deemed to be relatively optimistic. The reasons for this view are as follows:

- The expected losses from weeds have been put at half the losses observed at organic farms today. On the other hand, larger losses have been added as a consequence of expected increased activity with mechanical control compared with existing organic farms.
- It is not known whether epidemics of diseases in a situation without control measures would result in faster proliferation rates and faster reduction of the effect of the incorporated resistant genes.
- Adjustments have not been made for situations in which the assumptions used do not hold good – in the case of heavy pressure of weeds and species of weed that are difficult to control on, for example, organic soil.
- Account has not been taken to any great extent of the fact that the production management would not be optimal in all situations.

Unused alternatives

The sub-committee believes that there are several unused alternatives to chemical control methods that could improve the cultivation conditions in a 0-pesticide scenario. Together with better utilisation of disease resistance, broader distribution and further development of methods of mechanical weed control are among the most obvious. Adjustments to crop rotations would have a powerful effect when pest prevention becomes more important than direct pest control. We consider that the demand for alternative methods would, in itself, promote and stimulate the development of alternative methods.

The Sub-committee on Production, Economics and Employment has evaluated the total production figures in a 0-scenario on the basis of a socioeconomic model. Concerning the production of sufficient feed units to maintain the present livestock production, in the 0-scenario a production is planned at the dairy farms that would maintain the necessary production of feed units. In the case of pig farms, it has been estimated that a reduction in cereal production could be made up for with imports from other countries. The economic consequences of such restructuring have been included in the economic analyses.

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10 Partial phasing out of pesticides in agriculture

10.1 Description of intermediate scenarios

3 intermediate scenarios

The main committee decided that the following 3 scenarios were to be analysed:

- **the 0+scenario (almost total phase-out):** A scenario that permits sufficient use of pesticides to enable compliance with the current phytosanitary rules (the Danish Plant Directorate's regulations). The scenario is very similar to the 0-scenario.
- **the +scenario (limited use):** A scenario that describes areas in which it is known from experience that heavy losses occur if pesticides are not used. Basically, the areas included are those in which yield losses have, on average, exceeded 15%. The crop rotations used are similar to those practised in the described 0-scenario.
- **the ++scenario (optimised use):** In this scenario, the aim is to avoid all serious economic losses from pests. The production is deemed to be close to present production. The scenario assumes use of all available damage thresholds and harrowing, where these methods can compete with the chemical methods.

Agronomic scenarios

The content of the different scenarios is mainly described by means of tables. In the + and ++scenarios, the losses are expressed as crop-percentage losses at national level. The losses are then evaluated agronomically and economically and expressed in relation to the contribution margins of the crops and the types of farm. A total treatment frequency index is calculated for the different scenarios.

Economically optimised scenarios

Besides purely agronomically defined scenarios, the Danish Institute of Agricultural and Fisheries Economics has set up economically optimised intermediate scenarios for the 0-scenario with a view to showing the consequences for the economy of farms and the socioeconomic consequences. The economically optimised scenarios include a large number of agronomic restrictions as substitution for pesticides.

In the following, a description is given of both the purely agronomic scenarios and the scenarios set up on the basis of both agronomic and economic principles. The intermediate scenarios also form the basis for the Sub-committee on Environment and Health's evaluation of the environmental consequences of changing from the present production to a total or partial phase-out of pesticides.

A list has been prepared of the pesticides that would probably be used in the 0+ and +scenarios. The list for the ++scenario is expected to be identical with the agents approved at present.

10.2 0+scenario (almost total phase-out)

Complicance with plant health rules

The crops that would be unable to meet specific, statutory requirements concerning purity or that are subject to requirements concerning prevention and control of pests covered by the quarantine rules are defined in notices from the Danish Plant Directorate. The list in table 10.1, in which the specific areas covered by the 0+scenario are described, has been checked with the Danish Plant Directorate.

Table 10.1
Situations in which dispensation would be granted for continued use of pesticides in a 0-scenario

Crop areas	Reasons for dispensation
1. Treatment of all seed with a dressing agent to and including 1st generation.	1. There are no reliable methods at present for controlling stinking bunt, leaf stripe and stripe smut. Treating the pre-basis, basis and 1st generation would ensure against major proliferation in the large 2nd generation (max. 60,000 ha).
2. Control of problematical species of weed in seed grass.	2. Seed grass cannot be certified if sufficient freedom from weed seed cannot be achieved. Most of the seed produced is exported (61,000 ha).
3. Seed potatoes. Use of desiccation agents and agents against potato blight.	3. Rapid pre-harvest desiccation of seed potatoes is important for ensuring a virus-free product. Permission to use chemical agents against potato blight is needed to ensure that the quality requirements concerning seed potatoes are met (6,000 ha).
4. Control of wild oat in stands where hoeing is not possible.	4. Wild oat has to be controlled by law. Where there is such a serious problem with this weed that hoeing is impossible, dispensation should be granted for chemical control (65,000 ha).
5. Prevention and control of Colorado beetles in seed potatoes.	5. Farmers are required by law to prevent and control Colorado beetles (rarely needed).
6. Prevention and control of specific pests in pot plants and nursery cultures.	6. Pot plants and nursery cultures may only be sold in the EU and exported provided they are completely free of specific pests (including leaf-miner fly and tobacco white fly), cf. the Danish Plant Directorate's notices). The products are also required to be to all intents and purposes free of common pests (including thrips and aphids).

The scenario is generally reckoned to be very close to a 0-scenario. In relation to 0-pesticide production, there would only be consequences for cultivation and yields in the case of seed grass, seed potatoes and pot plants/nursery cultures. Because of the dispensation granted for these crops, it is estimated that the productions in question could be maintained and would meet the requirements concerning purity and quality.

The permitted treatment of cereals with dressing agents corresponds to that proposed in the 0-scenario and is therefore not expected to change the production (table 10.9). Similarly, it is not considered that the permission to control wild oat would have any serious effect on the overall production, except that a serious problem with wild oat in a 0-scenario would require restructuring of the crop rotation and involve heavy costs for weed control if the requirements concerning control were to be met. These changes could be avoided in a 0+scenario.

Very limited use

The treatment frequency index would be very low in a 0+scenario. For most of the types of farm, it would be almost 0, while for potato and seed producers it would be less than 5% of the present level. As the scenario lies very close to the 0-scenario, its economic consequences have not been analysed.

10.3 +scenario (limited use)

Limiting large yield loss

In this intermediate scenario, slightly more use of pesticides is permitted than in the above-mentioned 0+scenario. The sub-committee has evaluated combinations of crops and pests to find the combinations for which it would be most difficult to avoid control with pesticides. The areas included (table 10.2) depend on the yield losses that can be expected as a consequence of attacks by pests. Basically, the sub-committee has included areas where there would be large yield losses or where it is estimated that a profitable production of specific crops could not be maintained.

There would have to be a) substantial average losses from pests (>15-20%) or b) the production would be discontinued or would be impossible to fit into the crop rotation.

The basic assumption is a crop rotation in the +scenario that is similar to the 0-scenario, with not more than 40% winter cereals and with mechanical weed control and resistant varieties as important elements. Considerable monitoring would be needed to determine when there was an attack that would result in large yield losses. Where possible, account has been taken of the fact that these serious losses can occur in some years, but the scenario does not generally allow for the fact that losses greater than 15-20% can occur in a crop in individual localities and in individual years. That is because, for most crops, it is not possible to predict how often such a situation will occur.

The areas included in the +scenario are described in table 10.2. The scenario also includes the areas already described in the 0+scenario. Appendix 2 shows in greater detail the losses that can be expected if pesticides may not be used and provides a little background for the individual problem areas.

Application areas in the +scenario

Table 10.2

Crop/pest combinations for which pesticides are included to avoid very serious losses, and which are included in the +scenario

1. Seed-dressing and band spraying in beets and sugar beet.
2. Control of specific weeds in cereals (e.g., camomile and charlock).
3. Control of weeds in peas.
4. Patch-control of perennial species of weed, such as thistles etc.
5. Control of grass weed on severely infested acreages.
6. Control of severe attacks of leaf diseases in wheat and winter barley.
7. Control of pollen beetle in spring rape in conditions in which the crop cannot compensate for attacks.
8. Band spraying with herbicides in maize.
9. Chemical control of couch grass in 1 out of 10 years, combined with mechanical control.
10. Control of poisonous species of weed, e.g. spring groundsel in coarse fodder.
11. Control of aphids when the damage threshold has been exceeded in cereals and peas.
12. Control of snails and flea beetles in rape when the damage threshold has been exceeded.
13. Control of clover weevil in clover-seed production.
14. Control of diseases and pests in fruit growing.
15. Control of diseases and pests in vegetables.
16. Pre-harvest desiccation and control of fungal diseases in certain garden-seed crops.

TFI of 0,5 in the +scenario

Table 10.3 shows the pesticides proposed for the various crops in the +scenario, measured in TFI, while table 10.4 shows how much the applications described would reduce the losses in relation to the 0-scenario.

The scope of the pesticide treatment in the +scenario gives a treatment frequency index of slightly less than 0.5, corresponding to an approx. 80% reduction compared with a level of 2.45 in 1997. About half the consumption in the +scenario would be in the form of herbicides. The treatment frequency index would vary between 0.2 for dairy farms on sandy soil and 1.1 for potato producers on sandy soil.

Change in CM II

Economic analyses of contribution margin II for the different types of farm in a +scenario show a total reduction of 0% for dairy farms on sandy soil, 15% and 36%, respectively, for arable farms on sandy and clayey soil, and 13% and 22%, respectively, for arable farms with seed production and sugar beet, while the reduction for potato producers would be 36% (see appendix 2 and table 10.9).

In the economically optimised +scenario, the treatment frequency indices are generally of the same order of magnitude as in the purely agronomic scenarios, but the reductions in contribution margin II are expected to be smaller. The reduction is

14-15% for dairy farms on sandy soil, 6% and 19%, respectively, for arable farms on sandy and clayey soil, and 15% and 23%, respectively, for arable farms with seed production and sugar beet, while the reduction for potato producers would be 15%.

Table 10.3

Present pesticide consumption measured in treatment frequency indices. The consumption in the described +scenario is based on the acreages in the 0-scenario, while the ++scenario is based on the acreage figures from present production (1994 production). The figures do not include set-aside.

	Herbicides			Fungicides			Insecticides			Growth regulator			Pesticides, total		
	1994	+	++	1994	+	++	1994	+	++	1994	+	++	1994	+	++
Winter wheat, clay	1.2	0.1	1.0	0.93	0.25	0.6	0.65	0.09	0.5	0.4	-	0.1	3.2	0.44	2.3
Winter wheat, sand	1.6	0.1	1.0	0.93	0.25	0.5	0.65	-	0.2	0.4	-	0.1	3.6	0.35	1.8
Winter rye	1.0	0.1	0.7	0.5	-	0.2	0.1	-	0.1	0.6	-	0.2	2.4	0.1	1.2
Winter barley	1.3	0.1	0.9	0.6	0.1	0.4	0	-	-				1.9	0.2	1.3
Spring barley, clay	0.8	0.1	0.5	0.5	-	0.3	0.7	0.11	0.5				2.0	0.2	1.3
Spring barley, sand	0.8	0.1	0.5	0.25	-	0.2	0.3	0.05	0.2				1.3	0.15	0.9
Winter rape	1.3	-	0.6	0.07	-	0.05	1.0	0.05	0.2				2.5	0.05	0.85
Spring rape	0.9	-	0.6	0.05	-	0.05	0.9	0.25	0.8				2.1	0.25	1.25
Other seed	0.8	0.8	0.4	0.10	-	0.10	0.7	-	0.4				1.5	-	1.3
Peas	2.1	-	1.3	0.4	-	0.25	0.8	0.2	0.8				3.3	0.2	2.35
Oats	0.7	0.1	0.44	0.3	-	0.25	0.4	-	0.2				1.25	0.1	0.89
Seed potatoes	1.5	-	1.0	3.0	1.0	3.0	-	-	-				4.5	1.0	4.0
Starch potatoes	1.5	-	1.0	8.5	4.5	6.5	0.3	-	0.1				10.6	4.5	7.6
Ware potatoes	1.5	-	1.0	4.5	2.0	3.5	0.3	-	0.1				6.6	2.0	4.6
Beets	2.2	1.3	1.3	0.10	-	0.10	1.9	dress	1.3				4.1	1.3	2.7
Maize	1.0	0.5	0.7	-	-	-	0.3	-	0.3				1.3	0.35	1.0
Grass	0.03	-	0.03	-	-	-	0.05	-	0.05				0.1	-	0.1
Vegetables	2.5	2.4	2.4	3.4	2.5	2.5	1.7	1.5	1.5				7.6	4.5	6.5
Control of couch grass	0.2	0.1	0.2	-	-	-	-	-	-				0.2	0.1	0.2
Av. TFI	1.28	0.24	0.9	0.53	0.12	0.36	0.54	0.05	0.38	0.12	0	0.04	2.5	0.41	1.7

Table 10.4

Percentage losses in the described scenarios – the 0-, + and ++scenarios. The total losses in the 0-scenario correspond to those shown in table 5.8. The losses in the + and ++scenarios are a best estimate in relation to the permitted use of pesticides. The economic analyses have been based on these losses.

	Herbicides			Fungicides*			Insecticides			Pesticides, total		
	0	+	++	0	+	++	0	+	++	0	+	++
Winter wheat, clay	17	10	0	12	5	0	4	3	0	29	17	0
Winter wheat, sand	17	10	0	11	4	0	2	2	0	27	15	0
Winter rye	6	5	0	4	4	0	3	3	1	12	12	1
Winter barley	13	10	0	10	6	0	0	0	0	22	15	0
Spring barley, clay	8	4	0	7	7	1	6	4	0	19	14	1
Spring barley, sand	8	4	0	6	6	1	3	2	0	17	12	1
Winter rape	0	0	0	2	2	1	5	4	0	7	6	1
Spring rape	5	5	0	2	2	1	17	11	0	23	17	1
Other seed	50	0	0	1	1	0	3	1	0	50	2	0
Peas	12	5	0	2	2	0	9	6	0	21	12	0
Oats	9	5	0	5	5	2	3	3	0	16	12	2
Seed potatoes	0	0	0	41	5	0	3	3	0	43	8	0
Starch potatoes	0	0	0	37	5	0	8	8	0	42	13	0
Ware potatoes	0	0	0	40	5	0	6	6	0	43	11	0
Beets	0	0	0	2	2	1	12	2	0	14	4	1
Maize	13	4	0	0	0	0	3	3	0	16	7	0
Grass	0	3	0	0	0	0	0	0	0	3?	3	0

*includes pre-harvest desiccation in potatoes

Relevant pesticides in the 0+ and + scenarios

Table 10.5 shows a section of the pesticides that would be used in a 0+ and +scenario. The agents cover herbicides, fungicides and insecticides and represent broad section of the agents that are available today.

Table 10.5
Chemicals that can be used for the applications mentioned in a 0+scenario.

Seed-dressing agents for cereals	Stinking bunt etc. in wheat, stripe smut in rye Stripe smut in barley Loose smut in barley	Bitertanol+fuberidazole, fenpiclonil Imazalil, maneb Carboxin, tebuconazole
Weeds in seed grass	Mono- and dicotyledonous weeds	Clopyralid, fluroxypyr, MCPA, ioxynil, methabenzthiazuron, isoxaben, thifensulfuron methyl, difenzoquat
Seed potatoes	Potato blight Pre-harvest desiccation	Maneb, Mancozeb, Propamocarb, Fluazinam ??
Wild oat	In cereals In broad-leafed crops	Fenoxaprop-p-ethyl, Flamprop-M-isopropyl, Difenzoquat, Fluazifop-p-butyl, haloxyfop
Colorado beetle	Seed potatoes	Pyrethroids, dimethoate,
Specific problems in greenhouses	Pests	Pyrethroids, pyriproxyfen, mercaptodimethur, carbuforan, azinphos-methyl
Specific problems in nursery cultures	Pests	Carbofuran, dimethoate, pyrethroids, chlorfentezine, fenbutatin-oxyd,

Chemicals that can be used for the applications mentioned in a + scenario

Disease control in potatoes	Potato blight	Maneb, mancozeb, propamocarb, fluazinam
Band-spraying and seed-dressing in beets	Seed-dressing Weed control	Thiram, imidacloprid Phenmedipham, ethofumesatw, thifensulfuron-methyl, metamitron
Control of specific species of weed in cereals	Camomile Charlock	Thifensulfuron-methyl
Patch-control of perennial species of weed	Thistles	MCPA
Prevention and control of diseases in cereals	Mildew, stripe rust and septoria	Propicoazole, fenpropimorph, azoxystrobin, prochloraz, tebuconazole
Pollen beetle in spring rape, pests in peas, aphids in barley and wheat	Assessed on basis of damage threshold	Pyrethroids, pirimicarb, dimethoate
Band-spraying in maize	Weeds	Pyridat, bentazone , terbuthylazin, pendimethalin
Control of couch grass in 1 in 10 years	Couch grass	Glyphosate
Specific problems in fruit growing	Diseases Pests	Bitertanol, maneb, chlorothalonil, triforin, Diflubenzuron, dimethoate, pyrethroids, clofentezine
Specific problems in greenhouse production	Diseases Pests	Prochloraz, triforine, propamocarb, iprodione Pyrethroids
Specific problems in outdoor vegetables	Diseases Pests	Maneb, mancozeb, chlorothalonil, iprodione Chlorfenvinphos, carbofuran, dimethoate

10.4 ++scenario

Basically, serious economic losses from pests in agriculture are not expected in this scenario, see table 10.4. The production is largely the same as in the present production. The scenario is based on a proposal from DIAS, which, in 1996, estimated what could be a realistic reduction of the treatment frequency index (Anon., 1997) without affecting the present production economy.

Use of damage thresholds and mechanical weed control

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. More time will have to be spent on monitoring and need-based control than in present production – typically a half to a whole day per 100 ha per week in the growing season (14 days in all).

10.5 Evaluation of intermediate scenarios that are economically optimised

Cost of monitoring

Intermediate scenarios that are economically optimised are based on the options indicated in the 0+, + and ++scenarios. Table 10.4 shows the expected reduction in loss for each of these options. Costs for monitoring pests have been included (DKK 150/ha per year), together with costs for mechanical weed control and agronomic limitations on, for example, the proportion of winter cereal, crop sequences, etc. (Ørum, 1998).

Special crops and set-aside

As a natural reaction to the options in the 0+ and the +scenarios, special crops would be included in the crop rotations if the way were opened for use of pesticides for controlling the most problematical pests in those crops. Seed grass would return fully in the 0+scenario, while sugar beet would feature in the +scenario. In the case of potatoes, only ware potatoes would be included in the +scenario, whereas starch potatoes could only compete in the ++scenario. The winter-cereal acreage would increase considerable in many crop rotations in the +scenario, while the set-aside acreage would fall compared with the 0-scenario. However, in the case of arable farms on sandy soil, there would still be almost 30% set-aside and still no rape or peas in the crop rotation. Except in the case of potato producers, there would be no difference in the +scenario between the treatment frequency index at production units operated on the basis of agronomic considerations and those that were economically optimised (table 10.8).

TFI in intermediate scenarios

In the economically optimised ++scenario, the distribution of the acreage lies very close to the distribution in present production. There would, however, be a small reduction in the proportion of winter cereals, which would be made up for by more spring cereal. This would be a natural consequence in order to limit the growing problems with grass weed. The acreages with set-aside and special crops would be similar to present production in the optimised ++scenario. Exceptions to this are arable farms on sandy soil and potato producers on sandy soil, where there would still be a substantial proportion of set-aside in the ++scenario because peas and rape would not be able to compete in the price situation in question.

The TFI figures largely correspond to the types of farm described by the sub-committee (Mikkelsen *et al*., 1998). The figures have been arrived at by using the average consumption figures from the statistics in 1994, followed by a breakdown between the respective crops. Table 10.8 shows the treatment frequency index from two different starting points. In the +scenario, there is a reduction in TFI of between 90 and 80%, while in the ++scenario, there is a reduction of 43-71%.

10.6 Documentation from field trials and experience from farmers' groups show that a 50% reduction is possible

Trials carried out with PC Plant Protection over a number of years indicate that it would be possible to reduce the treatment frequency index by 30-50% compared with present production (Secher, 1997).

Trials with af TFI of 1.3

Moreover, trials carried out with a low input of pesticides in Køge-Ringsted Farmers' Association have shown that it would be possible for farms growing mainly cereals to approach a treatment frequency index of 1.3 without any reduction in contribution margin (table 10.6).

However, these low treatment frequency indices depend on intensive monitoring during the entire growing season, and special crops, such as sugar beet, seed grass and potatoes, were not included in the crop rotations (Anon., 1998).

A crucial question when judging these results is whether the results from small plot trials can be transferred to similar success at field level.

Table 10.6

Results of trials with different treatment frequency indices in cereals, from which it appears that even though the grain yield falls with falling pesticide input, the contribution margin (CMI)remains much the same, indicating a considerable potential for reducing pesticide input provided the crop is closely monitored. The reduction in TFI is not due to spraying less but to reduced dosages. Correspondingly, the nitrogen supply is typically reduced by 10 kg N/ha (Køge-Ringsted Farmers' Association, 1998).

Crop	Grain yield kg/ha	Variable costs DKK 1	CM 1 DKK	TFI	Number of trials
Winter barley/–25% Winter barley/normal Winter barley/+25%	63.1 65.5 67.9	1,290 1,550 1,785	4,150 4,110 4,080	1.0 1.5 2.0	1995-98 8 trials
Winter wheat/-25% Winter wheat/normal Winter wheat/+25%	87.0 90.1 91.2	1,400 1,600 1,850	5,150 5,150 5,000	1.2 1.6 2.0	1995-98 Lynx 9 trials
Winter wheat/-25% Winter wheat/normal Winter wheat/+25%	96.0 99.0 102.0	1,475 1,775 2,220	6,200 6,150 5,950	1.6 2.5 3.4	1995-98 Ritmo 9 trials
Spring barley/-25% Spring barley/normal Spring barley/+25%	61.4 62.9 63.3	1,020 1,140 1,275	5,285 5,315 5,215	0.4 0.8 1.1	1995-98 8 trials

Experience from farmer's groups

In connection with the first pesticide action plan, many farmers' groups were established to exchange experience on plant protection. The groups consist of 8-10 farmers and an agricultural advisers. At the farms represented in these farmers' groups, the consumption of herbicides and fungicides is lower than the national average, whereas the consumption of insecticides is slightly higher. Participation in the groups has resulted in an overall fall in pesticide consumption. The groups have had a major influence on the choice of pesticides and the dosages (Danish Environmental Protection Agency Report No. 296, 1995). In 1996-1998, the treatment frequency indices used for crops by the members of the farmers' groups in Ringkøbing and Videbæk Farmers' Associations were calculated. The results show that indices in line with the action plan's goals can perfectly well be achieved (table 10.7). (Ringkøbing County's Arable Farming Report 1998). Generally, however, cereals suffer fewer attacks from diseases in West Jutland than, say, on the Danish islands.

Table 10.7
Statistics showing the treatment frequency index (TFI) used in practice by members of farmers' groups in Ringkøbing and Videbæk Farmers' Associations in the period 1996-98

Crop		1996	1997	1998
Winter wheat	acreage ha TFI	1,300 1.47	1,589 1.37	1,353 1.27
Winter barley	acreage ha TFI		431 1.19	358 1.26
Rye/triticale	acreage ha TFI		105 0.73	286 0.61
Spring barley	acreage ha TFI	1,100 0.62	1,679 0.72	825 1.01
Peas	acreage ha TFI		445 1.58	348 1.40
Couch grass	acreage ha TFI			4,100 0.21

10.7 Control of application in different scenarios

Use of damage thressholds

It lies outside the sub-committee's mandate to indicate non-technical instruments for controlling pesticide consumption in the three scenarios. Both the +scenario and the ++scenario incorporate the use of damage thresholds and data from the registration system. Compared with present-day practice, all spraying would be carefully considered before being carried out. In the +scenario, for example, there would have to be a well-founded suspicion of an attack of great economic importance. In the ++scenario, farmers would use damage thresholds together with a combination of alternative and chemical methods of controlling weeds etc.

No damage thresholds for some pests

We do not at present have reliable damage thresholds for all the main pests. The development of the pests depends greatly on the weather, and this, together with the fact that treatment has to take place relatively early in the life-cycle of the pests in order to achieve the optimum effect with reduced dosages, means that it is not possible to predict reliably a fixed percentage loss for a given treatment. The needs and percentage losses indicated have therefore, in several cases, been based on experience from control trials in a given growing season. Within certain crops, this makes it difficult to operationalise scenarios that are based on a partial phase-out of pesticides.

In the 0+scenario, it is assumed that dispensation would be granted for the use of pesticides in accordance with specific rules. The treatment frequency index would thus be very limited in this scenario.

10.8 Overall evaluation of the scenarios for total and partial phase-out

Key figures for the intermediate scenarios

As a basis for evaluating the general consequences of the different scenarios for production, table 10.8 shows the respective treatment frequency indices in the intermediate scenarios in relation to present production. Table 10.9 shows key figures for changes in contribution margin II for 10 different types of farm, while table 10.10 gives the total production figures.

Contribution margin II

Contribution margin II is a good measure of the consequences of the different intermediate scenarios for the different types of farm. The contribution margin expresses the economy/ha since this quantity adjusts for loss of yield and extra yields, changes in the cost of purchasing and applying pesticides, together with changes in the cost of mechanical weed control. The value of the costs saved on application of pesticides and the increased costs for mechanical weed control have been determined by using machine station rates. It will be seen that reductions in CMII of 4-93% have been measured for the 0-scenario, 0-36% for the +scenario and 0-17% for the ++scenario. Looking at the individual types of farm, the consequences would thus be least for dairy farms and greatest for farmers with a substantial production of special crops. This accords with the economic analyses at farm level carried out by the Sub-committee on Production, Economics and Employment (Ørum, 1998). The losses at dairy farms are relatively high in the ++scenario because mangolds and maize have been retained in this scenario, but not in the 0 and +scenarios, which gives a better contribution margin.

Table 10.8

Treatment frequency index in 3 scenarios shown for 10 different types of farm on clayey and sandy soil.

Scenario	Present production * DIAFE	Present production ** Crop rotation	++scenario		+scenario	
			Opti-mised ***	Agro-nomic ****	Opti-mised ***	Agro-nomic ****
Clayey soil						
Arable farms	2.4	2.6	1.5	1.5	0.4	0.4
Pig farms	2.5	2.4	1.3	1.4	0.4	0.4
Beet production	2.8	3.1	1.8	1.9	0.7	0.7
Seed production	2.4	2.6	1.5	1.6	0.7	0.6
Dairy farms	1.9	1.8	0.9	1.2	0.3	0.3
Sandy soil						
Arable farms	1.8	2.3	1.0	1.2	0.3	0.3
Pig farms	1.9	2.0	1.3	1.2	0.3	0.3
Potato production	3.9	3.4	2.6	2.6	0.5	1.1
Dairy farms, ext.	1.4	1.3	0.6	0.8	0.2	0.3
Dairy farms, int.	1.0	1.2	0.3	0.7	0.2	0.2
Average *****	2.44	2.5	1.45	1.7	0.47	0.41

*DIAFE's accounts statistics 1995/96. The figures do not include set-aside or control of couch grass.
** Based on the crop-rotation group's work on pesticide consumption from 1994. The figures do not include set-aside or control of couch grass
*** Economically optimised scenarios are dynamic model scenarios. The figures include set-aside.
****Agronomic scenarios are static scenarios with fixed crop rotations. The figures include set-aside.
***** Average figures for the whole of Denmark, excl. set-aside but incl. control of couch grass.

Where economic optimisation is used, the reduction in CMII for the 0-scenario is generally smaller and more evenly distributed than in the agronomic scenarios. The model-optimised CMII for present production is improved by DKK 50-400/ha compared with the actual present production, which indicates that there may be a potential for improving the economy of present-day farms.

The reason for the differences between the agronomically and economically optimised farms is that the agronomic 0- and +scenarios include a crop rotation that is based on the described 0-scenario, in which production of special crops is maintained, whereas a distribution based on the present production is assumed in the ++scenario and present production. The economically optimised crop rotations express the optimised land consumption with production with or without permission for limited use of pesticides and with the yield losses and crop-rotation restrictions set by the Sub-committee on Agriculture. In the 0-scenario production of special crops is reduced almost to zero and the set-aside acreage is increased considerably in several of the optimised scenarios, although with a maximum upper limit of 30%.

Table 10.9
Percentage change in contribution margin II for 10 different types of farm with and without economic optimisation in the case of total and partial phasing out of pesticides

Types of farm	CMII Present produc-tion agro-nomic DKK /ha*	0 sce-nario agro-nomic	+ sce-nario agro-nomic	++ sce-nario agro-nomic	CMII Present produc-tion opti-mised DKK /ha**	0- sce-nario opti-mised	+ sce-nario opti-mised	++ sce-nario opti-mised
Clayey soil								
Arable farms	3231	-48	-36	-1	3420	-34	-19	+0
Pig farms	2781	-29	-24	-1	3070	-34	-18	+0
Beet production	4241	-93	-22	-1	4310	-39	-23	-1
Seed production	3903	-50	-13	0	4080	-35	-15	+1
Dairy farms	2217	-25	-4	-10	2580	-34	-26	-11
Sandy soil								
Arable farms	2254	-31	-15	0	2290	-26	-8	-1
Pig farms	2106	-22	-15	0	2320	-28	-16	+0
Potato production	3778	-66	-36	0	3860	-51	-15	+3
Dairy farms, ext.	2012	-8	+2	-11	2240	-24	-15	-8
Dairy farms, int.	1986	-4	+3	-17	2420	-21	- 14	-12

**Contribution margins II in present production are determined on the basis of the crop composition based on the 13,000 farm accounts. The agronomic scenarios are evaluated in relation to these contribution margins.*
***The economically optimised contribution margins II are evaluated in relation to an optimised, calibrated present-production scenario determined by DIAFE.*

Change in production

Total cereal production would fall by around 30% in both the agronomic and the optimised 0-scenario, which would mean importing grain in order to maintain the present pig production (table 10.10). Production of potatoes and seed would be approximately halved in the agronomic scenario, while there would be an approximately 30% increase of both rape and peas. This rise would reduce the need for bought-in supplementary fodder. In the economically optimised scenario, this production would be largely replaced by set-aside, and both potato production and beet production would be reduced by more than 90% and seed production by 60%.

Unchanged livestock production

In none of the described scenarios is it thought that production would be reduced to an extent that would affect livestock production This accords with the economic analyses at farm level carried out by the Sub-committee on Production, Economics and Employment (Ørum, 1998). The level of coarse fodder per livestock unit (LU) would be similarly maintained without pesticides (total coarse-fodder production would remain constant). The proportion of cereals would thus be reduced by the proportion needed to substitute the reduction in yield in wholecrop and grass. Farms with livestock would thus need to purchase more primary cereal because they would no longer be able to grow enough themselves to maintain their fodder consumption. In the optimised scenarios with a large proportion of set-aside, the sub-committee has not considered the question of whether, with the reduced cereal yields and increased set-aside acreage, it would be possible to sell liquid manure to neighbouring farms. Nor has the sub-committee considered whether there would be a shortfall in straw production in relation to the current requirements.

Need for grain imports

Net grain exports averaged 17,222 hkg in the years 1993-96 (Agriculture in Denmark 1998). Whereas, in the 0-scenario, a net import of just under 10,000 hkg would be needed (83,986-17,222 – 58,398), in the +scenario, the figure would fall to just under 3,000 hkg (83,986-17,222-63,858) to maintain livestock production at the present level.

In the 0+scenario, there would be changes only in the production of seed potatoes and grass seed, whereas, in the +scenario, there would be an increase in the production of almost all crops in relation to the 0-scenario. Specific production figures are not given for the ++scenario because it is estimated that, in this scenario, there would be only a small change in the yield level in relation to present production, according to the definition of this scenario.

The socioeconomic consequences of a restructuring are included in the analyses from the Sub-committee on Production, Economics and Employment.

Table 10.10
The main productions in 1000 hkg (CU) for present production in whole DKK. For the scenarios, the percentage change in production is given. The figures are based on figures from the economic analyses at farm level.

Crops	Present *	0 opti-mised	0 agro-nomic	0+ agro-nomic	+ opti-mised	+ agro-nomic
Total cereal production	90,584	-26	-31	-31	-16	-24
Winter cereals for maturity	62,522	-	-41	-41	-	-34
Spring cereals for maturity	28,062	-	-9	-9	-	-4
Coarse-fodder production	39,320	0	0	0	0	+2
Rape	2,388	-58	+29	+29	-62	+30
Seed potatoes	1,658	-100	-43	-13	-100	-13
Ware potatoes	3,695	-92	-43	-43	-75	-11
Starch potatoes	9,537	-100	-42	-42	-100	-13
Peas	2,588	-58	+38	+38	-62	+50
Seed	557	-60	-50	-5	0	-2
Sugar beet	33,592	-98	-16	-16	-22	-4

- Danmarks Statistik

10.9 Conclusions concerning the intermediate scenarios

The sub-committee has considered three intermediate scenarios: a 0+scenario, a +scenario and a ++scenario.

Treated acreage in the 0+scenario

The 0+scenario (almost total phase-out) covers a scenario in which the only aim is to comply with the current phytosanitary legislation and regulations. As in the 0-scenario, this includes treatment of cereals with dressing agents in all early generations (up to and including C1) and, where a need assessment shows that treatment is necessary in the C2 generation (10,000-20,000 ha), field-spraying of about 70,000 ha with seed and seed potatoes, and of land infested with wild oat. Spraying of greenhouse and nursery cultures with pesticides is also permitted in order to comply with rules for export and home sale. In a 0-scenario, the treatment frequency index would be very low – almost zero for most types of farm and less than 5% of the present level in potato and seed production. With respect to total production in Denmark, there would be an increase only in production of grass seed and seed potatoes compared with the 0-scenario.

The +scenario (limited use) covers a scenario in which continued use of pesticides is permitted for control of pests of very great economic importance – treatment, for example, to ensure continuation of a profitable production of special crops. Altogether, the treatment frequency index would be around 0.5 in this scenario, which is a reduction of about 80% compared with the present consumption. The index ranges from 0.2 for dairy farms on sandy soil to 1.1 for potato producers on sandy soil.

CM II in agronomic +scenario

Economic analyses of contribution margin II for the different types of farm in a +scenario show a total reduction of 0% for dairy farms on sandy soil, 15% and 36%, respectively, for arable farms on sandy and clayey soil, and 13% and 22%, respectively, for arable farms with seed production and sugar beet, while the loss for potato producers would be 36%.

This reduction is based on an assumption of largely the same restructuring of production as described in the 0-scenario. The chosen input is deemed sufficient to retain the present production of sugar beet, seed-producing crops and potatoes. The scenario permits the use of pesticides where pests result in an average yield loss of more than 15%. The scenario thus does not calculate the consequences in individual localities and at individual farms in some years because, for most crops, it is not possible to predict how often such a situation will arise. The scenario also permits the use of pesticides in outdoor vegetables, fruit and berries and ornamental greenery to the extent needed to maintain production (approx. 20,000 ha with market-garden crops and 35,000 ha with ornamental greenery).

CM II in economically optimised +sceanario

In the economically optimised +scenario, the treatment frequency indices would generally be of the same order of magnitude as in the agronomic scenarios, except in the case of potato producers. The reduction in contribution margin is 14-15% for dairy farms on sandy soil, 8% and 19%, respectively, for arable farms on sandy and clayey soil, and 15% and 23%, respectively, for arable farms with seed production and sugar beet, while the reduction for potato producers is 15%.

In **the ++scenario (optimised use)**, pesticides may still be used to the extent needed to avoid economic losses. The scenario assumes the use of all available damage thresholds, together with harrowing and other mechanical weed-control methods where these can compete with the chemical methods. Crop rotations are expected to be as at the present time, with economic optimisation, but also optimisation with respect to using as little pesticide as possible. Compared with present production, more man-hours would have to be spent on monitoring pests and using damage threshold programmes.

Treatment frequency of 1,5-1,7 in the ++scenario

The total treatment frequency index (TFI) in the pure agronomic scenario would be approx. 1.7 if set-aside were omitted. This corresponds to a 31% reduction compared with the treatment frequency index in 1997 and 36% compared with the treatment frequency index in the reference period 1981-85. This covers a range from 0.7 for dairy farms on sandy soil to 2.6 for potato producers on sandy soil. In the corresponding economically optimised scenario, TFI ranges from 0.2 at intensive dairy farms on sandy soil to 2.6 at farms with a large production of potatoes. The average TFI for the optimised ++scenario is 1.45. Contribution margin II for all farms would not differ significantly from present production, although in some of the optimised crop rotations there are indications that it would be possible to improve on the present contribution margins for certain types of farm. The average reduction in contribution margin II would be 2%.

Need for better warning systems

In all, the intermediate scenarios would reduce considerably the losses expected in the 0-scenario. In the +scenario, the yield losses would typically be reduced by 25-50%, while there would be practically no losses at all in the ++scenario. In the case of diseases and pests, damage thresholds and warning systems would have to be used in order to reduce the percentage losses. However, we do not have reliable damage thresholds for all areas at present and, for reliability, long-term weather forecasts would be needed. Therefore, there is considerable uncertainty, particularly with respect to the amount of spraying needed to ensure against yield losses of more than 15%. Compared with present production, many more man-hours would have to be spent on monitoring pests, and to avoid attacks of diseases, a lot of breeding work would be needed in step with the breakdown of "resistance".

Experience from trials with intermediate scenarios

Experience from trials and farmers' groups with intensive input from agricultural advisers indicates that a treatment frequency index of around 1.3 for vegetable production is realistic. Similarly, experience with a TFI of 0.5, corresponding to the +scenario, is not available.

References

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11 Total or partial phase-out of pesticides in market gardening

Experience from organic production has been used

As in the case of the agricultural sector, there is very little experimental material on which to base an evaluation of the consequences of a total or partial phase-out of pesticides in market gardening. Firstly, there is no usable experimental material that can be used as a basis for estimating loss sizes and, secondly, untreated plots in trials do not always give a true picture of any loss because they do not include possible other preventive measures or other possible forms of prevention and control, including different cultural practices. Therefore, in some areas, the yield losses in a 0-scenario have been estimated on the basis of estimates from organic growers. These estimates are deemed to be the most reliable, particularly since special crops would often be placed where the fertilisation conditions are optimum. The level of fertilisation is therefore not expected to be far from the conditions in conventional cultivation.

11.1 Outdoor vegetables

11.1.1 0-scenario

Yield reductions

It is estimated that a ban on pesticides would have major consequences for the present production of outdoor vegetables and garden seed. The reduction in yield would be approx. 30% for onions, 25% for cabbage, 15% for carrots and 35% for peas. Production of such vegetables as cauliflower and broccoli would be very uncertain, as reflected, for example, by today's very limited organic production of these vegetables (table 11.1). Table 11.2 shows the main reasons for the yield losses.

Table 11.1
Production of different outdoor vegetables in conventional market gardening compared with estimated figures for a 0-scenario, which are based partially on experience from organic production (Friis et al., 1998).

Crop	Present production per ha	Production per ha. in 0-scenario
Onions	30-36 tonnes	20-22 tonnes
Cabbage/red cabbage	40 tonnes	30 tonnes
Cauliflower/broccoli	20-22,000 nos.	16-17,000 nos.
Carrots	44 tonnes	37 tonnes
Table peas	6.5 tonnes	3.0 tonnes

Need for additional price for products

It is estimated that most of the production would have to be abandoned because the estimated yield losses and/or additional costs would be so great that a very considerable premium would have to be charged to keep the same contribution margin. Prices would have to be increased by 30-120%, corresponding to the prices obtained today for organic produce (Friis *et al.,* 1998). The production would be even more exposed than it is already to large annual fluctuations, and this, together with the high establishment costs for crops of this type, would make heavy requirements with respect to the producers' liquidity. A fluctuating production would be unfortunate in relation to the retail trade and could lead to increased foreign imports.

More costly weed control

For some crops, such as onions and carrots, control of weeds is of great importance for the size of the yield. Weeds could be controlled either mechanically or manually, at great cost, and it is also uncertain whether enough manpower could be obtained for this work.

Rational and effective methods would have to be developed for controlling weeds in rows mechanically or by means of cover materials.

11.1.2 Intermediate scenarios for outdoor vegetables

For the different main cultures, an evaluation has been carried out of relevant pests to determine which can be expected to present the biggest problems, and where producers could therefore least do without pesticides in a scenario for a partial phase-out. The areas in question are listed in table 11.2 (Friis *et al.,* 1998).

Main problems in intermediate scenarios

In onions, it would be most difficult to do without agents against onion mildew. For the part of the production (about 1/3) that is sold after March/April, germination-impeding treatment with maleinhydrazide is at present of vital importance to the production. Trials are now going on to determine whether there are alternative methods of slowing down germination in onions. It is also estimated that band-spraying of onions could save about 60-70% of the present consumption of herbicides in onions.

Major pests in several crops

In the event of a partial phase-out of pesticides, it would be important, particularly in the case of cabbage, to have agents available for controlling pests because there are several pests that could have a critical impact on yield and quality. In the case of weeds, there are largely no chemical control agents available today for use in cabbages, so it can be said that a phase-out has already taken place in this areas.

Table 11.2
Areas in which producers could least do without control measures in a scenario for partially phasing out pesticides.

Onions	Cabbage	Carrots	Peas	Garden seed
1. Agents against onion mildew 2. Band-spraying of weeds 3 Germination-impeding treatment in parts of the culture where layered storage is required	1. Pesticides to control cabbage whites, cabbage fly and aphids	1. Band-spraying of weeds 2. Insecticides to control cutworm and carrot fly	1. Agents to control moths and aphids	1. Herbicides to control weeds 2. Agents for control and prevention of pests and diseases

In the event of a partial phase-out of pesticides in carrots, it would probably be impossible to control some species of weed. That is a situation that could be just as difficult to deal with as a non-chemical solution because there would be the same or a greater need for manual weeding. In a partial phase-out, the focus should be on band-spraying, which would reduce the present herbicide consumption by 60-70%. It would also be necessary to be able to control cutworm and carrot fly. The latter, in particular, could cause large yield losses and give rise to a need for extra man-hours for sorting.

In pea production it is mainly pests, including pea moths, that are the cause of the large yield loss. The loss is based on three years' experience from organic production. A partial phase-out would therefore mainly have to ensure that agents were available for controlling moths.

Garden–seed production

In the case of garden seed, most of which is exported, strict requirements are made concerning the quality of the seed. For Denmark to be able to compete in this area, the seed must meet very high requirements concerning purity and germination capacity, and the seed must be free of disease. In a partial phase-out, herbicides and fungicides would be important in order to maintain the present quality.

11.2 Fruit and berries

11.2.1 0-scenario

It is generally considered that a ban on pesticides in fruit and berry production would have serious consequences for future production of these cultures in Denmark.

On the basis of all present-day knowledge, the sub-committee has tried to give its best estimates of the yield from unsprayed fruit and berries. The estimates are based on the Danish Fruit Producers' economic analyses at farm level, average of yields from 1994-96. Organic and unsprayed yield levels have been estimated on the basis of unsprayed trials and telephone-interviewing of organic fruit and berry growers (see table 11.3).

Yields with 0 pesticides

Table 11.3
Production of different fruit and berry cultures in conventional production compared with figures from organic producers and trials in which pesticides have not been used (Lindhart et al., 1998)

Crop	Tonnes in conventional production	Tonnes/ha organic produc-tion***	tonnes/ha unsprayed	% reduction when unsprayed
Apples	20 tonnes (av. of varieties)	2.8 tonnes	-	80
Pears	11 tonnes (av. of varieties)	2.5-7 tonnes	0.8-5.8	41-84
Cherries	6 tonnes	-	4.4 *	27*
Blackcurrants	4.3 tonnes	1.9 tonnes**	3.6*	16-75
Strawberries	9.6 tonnes	5-6 tonnes	6.6	40

*figures from recently commenced trials at DIAS
**figures from economic analyses at farm level for organic producers
*** sprayed with sulphur

Reduced self-sufficiency

Owing to the heavy losses in a 0-scenario, it is believed that a pesticide ban would result in a considerable reduction of fruit and berry production in Denmark and thus to reduced self-sufficiency and increased imports of foreign products. It would probably be impossible to obtain Danish apples after Christmas owing to impaired keeping qualities. The consumers would thus increasingly have to buy foreign fruit, which is treated with more pesticides than Danish fruit (Anon., 1995). Since cultivation security would be significantly reduced, one would have to expect a reduction in new plant of cultures and fewer newcomers to the industry.

Long restructuring period for pomes

With the varieties of apple grown today, it would take a long time to restructure the acreage in question for cultivation with a minimum of pesticides. At the same time, it must be stressed that cultivation of the present varieties, which are produced with a view to storage, could not continue without use of pesticides. Without substantial premiums, most of the production of fruit for sale to consumers (apples, pears and strawberries) would be discontinued. A very reduced production of industrial fruit (sour cherries and strawberries) might be maintained if a considerable premium were achieved (Lindhard *et al.,* 1998).

Evaluation of existing quality requirements

If production of apples and pears was to be maintained without use of pesticides, a reduction of the quality requirements might improve the possibility of selling the fruit. However, the sub-committee does not consider that the present quality requirements should be reduced very much. The consumers can be expected to choose fruit that does not have a lot of deformities and surface defects. However, this theory should be tested by means of consumer surveys before any changes are made to the present quality requirements.

11.2.2 Intermediate scenarios for fruit and berry production

If agents for controlling the pests listed in table 11.4 were available, a production of a substantial size could be maintained.

Table 11.4
The most serious pests, in order of priority. It is for these pests that fruit and berry producers could least do without control methods.

Apples	Pears	Sour cherries	Blackcurrants	Strawberries
Apple scab Gloesporium Moths Apple saw fly Water Voles/mice	Pear scab Pear gall midge Moths Jumping plant aphids	Grey monilia Leaf spot	Bud gall mite Mildew Discomycetes	Grey mould Mildew Moths/bugs

Alternative methods

Extensive research is needed to identify alternative, non-chemical control methods. However, with the present level of knowledge, it is already considered possible to achieve some reduction in the present use of pesticides. Weeds in fruit and berry cultures can be controlled without herbicides, but only at considerably greater cost. In some of the cultures there is a possibility of cultivating more resistant varieties, but a change in the assortment would in many cases – apples, for example, take 10-15 years. There are various cultural practices that can reduce disease and pest attacks, but many of them are rather costly (removing old foliage, cutting out infected shoots, etc.) and would add considerably to the cost of production.

Problems with common scab

If pomes are to be produced organically/without pesticides, it is important to get a product approved for combating scab on apples and pears overwintering on the bough. Scab has been a growing problem since 1995, when the use of agents containing copper was banned in Denmark. Organic producers in many other EU countries are allowed to use cuprous agents.

IP; production is practised today

A large part of the Danish production of apples and pears is carried out in accordance with IPM rules. The main purpose of IPM production is to promote good cultivation practice and reduce significantly the use of pesticides and fertilisers. The system has been used in Denmark since the beginning of the 1990s, and producers are inspected by the Danish Plant Directorate. A list of pesticides for IPM-production is issued each year. The pesticides listed are those that are least harmful to the environment and useful animals (IPM working group for pomes, 1997).

11.3 Greenhouse production

11.3.1 The 0-scenario

Generally speaking, very little is actually known about the consequences of a 0-scenario. Everything is therefore in the nature of estimates that can only give an indication of what the consequences could be.

Greenhouse vegetables

A very rapid phase-out of pesticides would result in a considerable fall in the production value of vegetables, although the fall could gradually be reduced. There is a great deal that can go wrong in vegetables, and for this and other reasons, it is estimated that there would be a greater need for replanting of cultures (cucumber, for example). However, if one gets towards late summer, it becomes impossible to achieve a new planting with a reasonable yield. There would therefore be a big spread in the yield losses, both at the individual market gardens and between years at the individual market garden. A loss of up to 50% is not unrealistic, while the average yield would probably be reduced by 5-15%. There are examples of organic production of tomatoes and cucumber, but the yield is lower. In the case of edible products it would be difficult to meet the quality standards for fruit and vegetables in the EU's market scheme, one of the requirements of which is no pests or damage from pests.

Cultivation in soil instead of a growth medium, which is practised by organic producers today, sometimes causes serious problems with fungal infections. Cultivation in soil would require greater use of disinfectants, which are no longer available on the market, and would give rise to problems with leaching of nutrients.

Pot-plants cultures

Pot-plant production covers about 400 different cultures, which makes it extremely difficult to estimate the overall consequences for all areas. For each culture there are a number of diseases and pests that can impede or damage the production. The tolerance level in greenhouse cultures is very low due partly to the current plant health rules, which include a 0-tolerance rule for certain pests, and partly to the fact that the consumers demand pot-plants of very high quality.

The fall in production of ornamental plants would be between 0 and 100%, depending on the culture and the season (Ottosen *et al.,* 1998). The reason for this large variation is to be found in the legislation, which permits not more than 2% common pests (aphids and thrips). It might be possible to ensure this percentage in periods of the year using biological agents. It is estimated that there would be 5-10 cultures (certain bulb cultures) that would rarely have problems with these so-called dangerous common pests.

Biological control methods are an obvious option for spring cultures, but a massive invasion by thrips, for example, after the grain harvest would prevent effective biological control. This is a factor that could impair the quality of the plants and make it difficult to sell them.

Problems with 0-tolerance pests

The visual quality of ornamental plants is of great importance to their saleability. For example, compact and uniform ornamental plants, which are major quality requirements in the export market, would be difficult to achieve without the use of growth regulators. The existence of pests could also mean direct rejection of plants and make it impossible to export them. This would happen particularly in the case of pests covered by 0-tolerance rules.

11.3.2 Intermediate scenarios for greenhouse production

IPM production of greeenhouse vegetables

Vegetables: Basically, in a scenario with the partial phase-out of pesticides, it would be possible to use many of the methods used in integrated production, the rules for which include rules for vegetables (Ottosen *et al*., 1998). The conditions for approved integrated production of greenhouse vegetables, covering all cultures, are as follows:

- The greenhouses must be cleaned before the culture is started.
- The varieties grown must be chosen from among the varieties that are best able to resist plant diseases.
- The climatic control must meet the needs of the culture and limit the risk of plant diseases.
- Plant health must be based on biological plant protection measures and cultural practices.
- The pesticides used must be those that are least harmful to useful organisms in the biological plant protection system.

Biological control of pests

In a partial pesticide phase-out scenario, the sub-committee considers that there would be good prospects for continuing the production of vegetables. This is not least because biological methods of control are already widespread. Biological control can keep pests down in most situations, but a market garden is not static. Biological control sometimes fails due to changes in the surroundings that allow the pest to gain the upper hand. In such situations it is necessary to control the pest chemically in order to reestablish the balance between pest and useful animal.

With a partial phase-out there would also be a need for pesticides for combating disease. In market gardening that means particularly pythium in propagation plants, powdery mildew in cucumber and grey mould in tomatoes. The last-mentioned can often be dealt with by swabbing sore faces and removing leaves. Problems with diseases could probably be reduced through improved hygiene, although this would mean increased use of disinfectants, which are also in the nature of control agents even though they do not figure as plant protection agents.

The current situation in Denmark is that most vegetable production is carried out in accordance with the IPM rules. According to the industry, this, together with the fact that producers in Denmark have very few plant protection agents at their disposal compared with other EU countries, means that the present situation can already be regarded as critical with respect to maintaining the production.

Increased potential for biological control

Ornamental plants: The sub-committee considers that there is a big potential for expanding the use of biological control to ornamental plants. That means that chemical agents could in time mainly be reserved for compliance with 0-tolerance and the 2% rule for pests. However, it is estimated that growth regulators and certain fungicides would still be needed for up to 10 years to ensure stable production.

For the production of ornamental plants to be maintained it is crucial that the producers be allowed to continue using agents that enable them to meet the requirements concerning 0-pests and the quality requirements concerning maximum 2% of common pests.

11.4 Nursery cultures

11.4.1 The 0-scenario

Problems in connection with propagation of cultures

It is estimated that, in a 0-scenario, large parts of the production would be closed down because the cultures would be ruined or become so expensive that they would be unable to compete with other countries' products. The experts' cautious estimate indicates that 30-50% of the production would stop because of competition problems and problems in supplying plants without pests (Brander *et al.*, 1998). Nursery cultures are extremely sensitive in the propagation phase, whether propagated from seed or from cutting. For this reason, there is today only a very limited organic production of nursery cultures.

The sub-committee considers that, where insecticides and fungicides are concerned, the 0-scenario would have a devastating effect on the production of many cultures. Particular problems are predicted for fruit trees and ornamental trees, fruit bushes, roses and many other ornamental plants if alternative methods are not available.

In the case of herbicides, a 0-scenario here and now would have a ruinous effect on production, particularly in the propagation phase, because the additional cost of mechanical control, including manual weeding, would make it difficult for Danish producers to compete with foreign producers.

Problem with 0-tolerance pests

The quality rules for all productions would have to be changed if pesticides were no longer available because producers would have difficulty in complying with the phytosanitary rules for pests (Order No. 128, 1997). There are 0-tolerance values for certain pests, while for others, a small number is acceptable.

11.4.2 Intermediate scenarios for nursery cultures

It is difficult to analyse the consequences of a partial phase-out for the cultivation of nursery-garden cultures.

For some cultures – roses, fruit trees and ornamental trees, fruit bushes and some ornamental plants - big problems could be expected, particularly with scab and various mites.

It would be almost impossible to do without control agents in the propagation phase, which often takes 1-2 years. Once this phase is over, there are fewer pest attacks and the plants are more resistant. After planting out in forest, park or garden, there is rarely any need for control measures, except for fruit trees and fruit bushes.

Alternative methods

The sub-committee considers that technical changes could to some extent be implemented to cope with weed control. This means different cultural practices that facilitate mechanical control and the use of cover crops or organic materials such as wood chips to help keep weeds down. Many of these alternative methods are still at the development stage. Another alternative method is to use steam to control root rot and weed seed, but with present-day methods and technology, the method is very energy-intensive.

It is estimated that some nursery production could be maintained even if pesticide consumption were reduced, but agents would have to be available for combating acute, severe attacks of pests (Brander, 1998).

11.5 Conclusions concerning total and partial phasing out of pesticides in market gardening

Outdoor vegetables and garden seed

The yield losses in a 0-scenario have been estimated on the basis of estimates from organic growers. This has been done because there is no usable material from trials on which to base a calculation of loss sizes. The yield losses have only been estimated for the main crops. The reduction in yield would be about 30% for onions, 25% for cabbage, 15% for carrots and 35% for peas. The production of such vegetables as cauliflower and broccoli would become very unreliable. This is obvious from the fact that there is only very limited organic production of these vegetables today. Production of Chinese cabbage for winter sale would also be impossible. The production would probably suffer even more than it does today from large annual fluctuations owing to severe attacks of pests in some years. The sub-committee therefore estimates that a 0-pesticide scenario would have very serious consequences for the production of outdoor vegetables and garden seed and that most of the production would be abandoned because the estimated yield losses and/or additional costs are so great that a very substantial premium would be needed to keep contribution margins at their present level. In organic production today, a premium of 30-100% is obtained, depending on the crop. It is considered that similar premiums would be needed for products in a 0-scenario. For some crops, e.g. seeded onions and carrots, weed control is of great importance to the size of the yield. Mechanical and manual weeding could be used, but the costs might be high and it is very uncertain whether sufficient manpower could be procured for the work.

In a scenario with a partial phase-out of pesticides, some areas are indicated where there are not deemed to be alternative methods that could replace the chemical methods for combating diseases and pests. Within weed control, the possibility of band spraying is pointed out, which could reduce consumption by 60-70%. There would be a big need to develop rational and effective methods for controlling weeds in rows by mechanical means or by means of cover material.

In the case of garden seed, it is estimated that increased costs for weed control would affect the production and that cultivation security would be considerably reduced as a consequence of a greater risk of pollution with weeds and fungal attack on the seeds. Most of the production is exported, and it is estimated that it would be difficult to maintain this market if the quality could not be maintained.

Production of fruit and berries

The yield losses in a 0-scenario have mainly been estimated on the basis of estimates from organic growers because there is only a limited amount of material from trials on which to base a calculation of loss sizes. The yield losses have only been estimated for the main crops. With the current quality requirements, the losses in apple production would be more than 86% of the harvest yield. The yield in unsprayed pears would be reduced by 40-80%, depending on the variety. It is estimated that the losses in sour cherries would be approx. 30%, in blackcurrants approx. 50%, and in strawberries 40% of the traditional production. It is thus estimated that there would be a very big fall in production. It is hardly likely that apples that keep until after Christmas could be produced. The sub-committee believes that this would have serious consequences for the amount of fruit produced in Denmark. The consumers would thereafter increasingly have to buy foreign fruit, which is treated with more pesticides than Danish fruit. A big reduction would have to be expected in new plantings and in new players in the sector because cultivation security would be greatly reduced. With significant price increases, by far the greater part of fruit and berry production would become unprofitable if the fruit were to be produced without the use of pesticides.

In a scenario for a partial phase-out of pesticides, some pests have been indicated for which it is not estimated that there are alternative methods that could directly replace the chemical methods of combating diseases and pests. Much of the production could be expected to be maintained if there were means of combating these pests. In particular, it is regarded as important to have agents for combating scab on apples left on the bough over the winter. Support for this view is provided by the fact that organic producers have experienced growing problems with fruit on the bough since the use of cuprous agents was banned in Denmark.

Weed control without herbicides is possible in fruit and berry cultures, but the solutions are considerably more costly. In some of the cultures it is possible to cultivate more disease-resistant varieties, but a change in the assortment – in the case of apples, for example – often takes 10-15 years. There are various cultural practices that can reduce attacks of disease and pests, but many of them are rather costly (removal of old foliage, cutting off infected shoots, etc.) and would add considerably to the cost of production.

There would be a great need to develop rational and effective alternative methods of controlling pests and weeds if pesticides were phased out. It might also be necessary to consider whether the quality rules for the products should be changed.

Greenhouse production

Since greenhouse production comprises a very large number of cultures – both edible cultures and ornamental plants – it is very difficult to generalise about the consequences of a 0-scenario. However, it is estimated that a 0-pesticide scenario introduced over a short time horizon would have a very negative impact on present greenhouse production, with producers unable, for example, to meet the international requirements concerning prevention and control of pests in connection with exports. The visual quality of ornamental plants is of great importance to their saleability. For example, compactness and uniformity are major quality requirements for ornamental plants on the export markets – and would be difficult to achieve without the use of growth regulators. The presence of pests can also mean direct rejection of plants. This applies particularly to pests covered by 0-tolerance rules.

The reduction in the production of ornamental plants would be between 0 and 100%, depending on culture and season. The reason for this large variation is to be found in the legislation, which permits max. 2% common pests such as aphids and thrips. It might be impossible to achieve this percentage with biological agents in some periods of the year. A pesticide ban would be unfortunate for all the main cultures. The reason for putting the loss at between 0 and 100% is that there are very big variations from one season, culture and year to another. Biological control is an obvious option for spring cultures, but a massive invasion by thrips, for example, after the grain harvest often makes effective biological control impossible. This is a factor that could impair the quality of the plants and the possibility of selling them.

In a partial pesticide phase-out scenario, we consider that there would be good prospects for continued production of vegetables. This is due particularly to the fact that biological control methods are already widely used for pests. Biological control can keep pests down in most situations, but a market garden is not static. Biological control sometimes fails due to changes in the surroundings that allow the pest to gain the upper hand. In such situations it is necessary to control the pest chemically in order to reestablish the balance between pest and useful animal.

With a partial phase-out there would also be a need for pesticides for combating disease. In market gardening that means particularly pythium in propagation plants, cucumber mildew and grey mould in tomatoes. The last-mentioned can often be dealt with by swabbing sore faces and removing leaves. Problems with diseases could probably be reduced through improved hygiene, although this would mean increased use of disinfectants, which are also in the nature of control agents even though they do not figure as plant protection agents.

The current situation in Denmark is that most vegetable production is carried out in accordance with the IPM rules. According to the industry, this, together with the fact that producers in Denmark have very few plant protection agents at their disposal compared with other EU countries, means that the present situation can already be regarded as a "partial phase-out" scenario.

The sub-committee considers that there is a big potential for expanding the use of biological control to ornamental plants. That means that chemical agents could in time mainly be reserved for situations in which biological control fails and for compliance with 0-tolerance and the 2% rule for pests. However, it is estimated that growth regulators and certain fungicides would still be needed for up to 10 years to ensure stable production.

Nursery cultures

It is estimated that, in a 0-scenario, large parts of the production would disappear because the cultures would be ruined or become so expensive that they would be unable to compete with other countries' products. It is estimated that 30-50% of the production would disappear because of competition problems and problems in supplying plants without pests. Nursery cultures are extremely sensitive in the propagation phase, whether propagated from seed or from cutting. The sub-committee considers that, where insecticides and fungicides are concerned, the 0-scenario would have a devastating effect on the production of many cultures. Particular problems are predicted for fruit trees and ornamental trees, fruit bushes, roses and many other ornamental plants if alternative methods are not available. In the case of herbicides, a 0-scenario here and now would have a ruinous effect on production, particularly in the propagation phase, because the additional cost of mechanical control, including manual weeding, would make it difficult for Danish producers to compete with foreign producers.

The quality rules for all productions would have to be changed if pesticides were no longer available because producers would have difficulty in complying with the phytosanitary rules for pests. There are 0-tolerance values for certain pests, while for others, a small number is acceptable.

It is difficult to analyse the consequences of a partial phase-out for the cultivation of nursery cultures. We consider that some nursery production could be maintained even if pesticide consumption were reduced but that this would demand the availability of products for controlling acute, severe pest attacks. For some cultures – roses, fruit trees and ornamental trees, fruit bushes and some ornamental plants - big problems can expected, particularly with scab and various mites. It is in the propagation phase, which often takes 1-2 years, that it would be most difficult to do without control agents. The sub-committee considers that technical changes could to some extent be implemented to cope with weed control. This means different cultural practices that facilitate mechanical control and the use of cover crops or organic materials such as wood chips to help keep weeds down. Many of these alternative methods are still at the development stage.

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12 Total or partial phasing out of pesticides in forestry

It is generally estimated that a total ban on pesticides in forestry would cause serious problems despite the small quantity used in this sector today. In old woodlands, a fall in profit of 30-40% can be expected, while in the case of moorland forestry, it is doubtful whether any profit at all could be achieved. Production would go down, both quantitatively and qualitatively, and the choice of species of tree would be reduced, which would affect the forests' value as a recreational amenity (Østergaard *et al*., 1998). Forestry has been divided into three segments for the purpose of evaluating the consequences:

- Wood-producing forestry
- Afforestation
- Ornamental greenery

12.1 Wood producing forestry

Difficulties in establishing cultures

If the use of pesticides were not permitted in wood-producing forestry, it could be difficult to establish cultures, particularly in heavy soils in Eastern Denmark. It is generally considered that it would take longer for the cultures to become established and that there would be an increased need for replacement planting.

It is also estimated that there would be a change towards more robust species, with spruce, for example, gaining ground at the expense of other species. That would conflict with the desire for a larger proportion of deciduous trees (Østergård *et al.*, 1998).

Another consequence of a ban might be an attempt to make greater use of natural reproduction. This would mean that birch as a pioneer tree species would replace such species as beech, oak and ash. Such a development is not considered desirable.

Today, there are mechanical means of controlling competing weeds. However, the methods in question are not sufficiently robust for use in forests, and the weed closest to the plant cannot be removed in this way. The problem is particularly serious on the heavy clayey soils in Eastern Denmark, where the pressure of weeds can be very heavy, and where machines can only be used with difficulty in moist periods and on hilly land.

It is estimated that weevil would be a problem in connection with the replanting of conifer cultures in light soil. This might prevent regeneration.

12.2 Afforestation

Mechanical weed control

There would probably be rather good possibilities of controlling weeds mechanically on light arable land used for afforestation. In recent years subsoiling (ploughing to a depth of up to 80 cm) has become common practice, particularly in connection with afforestation on light soils, because it considerably reduces the weed population – for five years in the best event. Subsoiling can be problematical with respect to culture-historical traces. However, there are several mechanical methods of controlling weeds after planting. The main problem is weed control around the plants themselves, whereas control between the rows is easy with, for example, inter-row cultivation.

Mechanical weed control is technically feasible today, but is more difficult on hilly land with clayey soil than on lighter soils. In practice, it is often necessary to use pesticides as an emergency solution in situations in which weeds have got out of control.

Insects rarely cause problems in connection with afforestation, so a pesticide ban would cause only limited problems. The exception is the pine weevil, which can occur when afforestation is carried out near established coniferous forests.

12.3 Ornamental greenery

High quality requirements

Today, production of ornamental greenery and Christmas trees contribute significantly to the economy of many forest properties. Turnover on Christmas trees and ornamental greenery is approximately the same as on timber (DKK 600 million).

The quality requirements for Christmas trees are high. Even minor damage caused by either pests or weeds can thus make a tree or ornamental greenery unsaleable. It is therefore considered that a total pesticide ban would ruin the present profitable production – and particularly the production of Norman fir. Controlling weeds by mowing would increase the cost of production and impair the quality of the trees.

Pests

Pests – particularly chermes in Norman fir – are also a serious problem in some parts of the country, which makes it very uncertain whether the desired quality could be achieved. The uncertainty concerning production of Norman Christmas trees is so great that a large part of the production would probably be discontinued. Just a few, small insect attacks can ruin a whole culture with Christmas trees, so the financial yield would fall considerably. Production of ornamental greenery is an economically accumulating process, so a pest attack in a culture that is 7-8 years old has a far greater economic impact than in the case of an annual agricultural crop.

It is considered that ornamental greenery from *Abies nobilis* could perfectly well be produced without pesticides, although with a considerable reduction in yield, mainly due to the problem of controlling weeds in the establishment phase.

Alternative methods in forest cultures

There are at present no realistic technical means of controlling weeds in all types of forest cultures in existing forests.

In the case of afforestation, there are good possibilities of using various mechanical methods of the kind developed for mechanical control on farm land.

Mechanical weed-control methods

Mowing machines are already on the market but are considerably more costly than using pesticides. Furthermore, mowing only helps with a couple of the problems caused by weeds, namely, competition for light and damage to cultures. There will still be the risk of frost and the competition for water, which are the main problems caused by weeds (Østergaard *et al.*, 1998). Mowing was used in the old days, when there was also a large number of plants per m2 (40,000/ha), which, in itself, meant better competition with weeds. Today, fewer plants are grown per m^2.

Another old method used to control weeds was horse-harrowing. Unlike a tractor, a horse can work between the rows and the method also enables harrowing between stumps and stones. For both financial and practical reasons, it is unrealistic to imagine the horse as a solution for the forestry sector in general, although it could perhaps be that on individual properties.

Other methods that have been tried out include soil coverage and the use of livestock. Here, sheep for example have proven an option in coniferous cultures. The drawback with grazing sheep is that one cannot avoid damage from frost.

Alternative methods of controlling pests

In the case of pests, there are as yet no real alternatives to pesticides. Up to the present time, research aimed at the development of alternatives to pesticides has been limited. That also applies to trials of more environment-friendly pesticides (insect soap) and biological control. The main problem with a ban on insecticides would be replanting in moorland and dune plantations, where the seed pod weevil is often encountered.

12.4 Furture perspectives

The sub-committee believes that research and development in the next 10 years are likely to result in the development of improved and more effective methods of mechanical control in fields and in connection with afforestation. In the case of weeds in forest cultures, on the other hand, the possibilities of finding alternative methods of control that can compete with pesticides are deemed to be more limited – also within a 10-year horizon.

In the case of pests, the possibility of developing alternative methods seems limited. In the cultivation of *abies nobilis*, the producers could perhaps be persuaded to accept a certain level of damage, but pests that attack Norman fir are hardly likely to allow themselves to be kept at a moderate level and level of damage.

12.5 Conclusions concerning total/partial phasing out of pesticides in forestry

Wood-producing forestry

A ban on the use of pesticides would in many cases result in a longer establishment phase, less complete cultures and increased costs for replanting, which would impair the economy of forestry and change the forest scene. It is estimated that one consequence of phasing out pesticides would be a shift away from deciduous trees. Replanting of conifers would give rise to problems with the seed pod weevil in Western Denmark and the other core areas for growing conifers, and deciduous trees would generally suffer problems with grass, which would in turn cause problems with frost and mice. All in all, this would increase the cost of reestablishment and result in a lower rate of growth in the first years of growth.

Afforestation

Unlike replanting in forests, afforestation offers good possibilities of mechanical prevention and control of weeds. A considerable development effort is being made in mechanical control, and a number of practicable machines have been designed for use on easy, flat land. However, the development of machines for difficult, hilly land is going more slowly. If the use of herbicides were banned in the good localities for deciduous trees, one would have to expect the already slow afforestation to be braked still further. In the case of afforestation near existing coniferous forests, there could be problems with weevils. If afforestation took place far from old forests, there would only exceptionally be damage as a consequence of pests.

Ornamental greenery

The quality requirements for Christmas trees are high. Even minor damage caused by either pests or weeds can thus make a tree or ornamental greenery unsaleable. It is therefore considered that a total pesticide ban would ruin the present production of ornamental greenery. Controlling weeds by mowing would increase the cost of production and impair quality.

Pests

Pests – particularly chermes in Norman fir – are also a serious problem in some parts of the country, which makes it very uncertain whether the desired quality could be achieved. The uncertainty concerning production of Norman Christmas trees is so great that a large part of the production would probably be discontinued. Just a few, small insect attacks can ruin a whole culture with Christmas trees, so the financial yield would fall considerably. Production of ornamental greenery is an ongoing investment, so a pest attack in a culture that is 7-8 years old has a far greater economic impact than in the case of an annual agricultural crop.

It is considered that *Abies nobilis* ornamental greenery could perfectly well be produced without pesticides, although with a considerable reduction in yield, mainly due to the problem of controlling weeds in the establishment phase.

The possibilities of a partial phase-out, which were not specifically considered by the sub-committee, depend on how quickly alternative methods of controlling weeds and pests are developed. A great deal of research covering many alternatives is needed if usable alternatives are to be found. If the spruce aphid is to be controlled without insecticides, research will also be needed to determine whether biological or other methods can be used. The sub-committee does not believe that all the problems relating to alternative control of weeds and pests can be solved within a 10-year period.

Reference

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13 Perspectives and conclusions

Today, pesticides are of great importance for sustainable arable farming. At the same time, the use of pesticides is in the spotlight because of the risk of pesticides getting into the food chain and the environment, including groundwater. It is not possible to stop using pesticides from one day to the next, but action against pesticides can be intensified with a view to gradually reducing their use.

A reduction in pesticide consumption can be expected as a consequence of the falling product prices seen since 1998 and the increased pesticide tax introduced in November 1998. Economic analyses indicate that the optimum treatment frequency falls considerably when these two factors are incorporated in the scenarios (Ørum 1999).

13.1 Present level of knowledge

The ++scenario is possible

The sub-committee considers that, with our present level of knowledge, there is a good possibility of reducing the present consumption of pesticides without serious economic losses. The following means are already available for reducing consumption:

- Band-spraying in crops grown in rows, including beets; this would more than halve herbicide consumption in these crops.
- Use of mechanical weed control can be increased in some crops, including rape and potatoes, and is also a possibility in cereals and peas.
- Band-spraying of crops grown in rows with fungicides and insecticides.
- Introduction of need-based dressing of spring barley.
- More extensive cultivation of resistant varieties and variety mixtures could reduce the use of fungicides in spring barley for fodder and other crops.
- The use of insecticides for controlling aphids in cereals could be reduced simply by using existing damage thresholds and reducing dosages. The same applies to pests in winter rape.
- General use of decision-support systems could reduce the dosage in individual situations, depending on the development stage, pests and climate.

A further reduction could be achieved, especially in control of grass weed, by reducing the proportion of winter cereals in the crop rotation and postponing the sowing time, since this would reduce the population of annual species of grass weed and also allow more time for mechanical control of couch grass. However, postponing sowing would at the same time reduce the yield.

Decision-support systems have only been developed for the main crops. It is therefore considered vital to get the existing knowledge concerning special crops gathered together in decision-support systems to make it easier for farmers to adjust their spraying to the actual need.

With our present level of knowledge, the sub-committee considers it possible to reduce pesticide consumption to a level corresponding to the ++scenario in agriculture. Where production of special crops is maintained and the proportion of set-aside remains unchanged, that corresponds to a reduction of the treatment frequency index to 1.7. In the corresponding economically optimised crop rotation, an average treatment frequency index of 1.45 has been calculated. For these reductions to be achieved, all existing knowledge must be incorporated and systematised.

It is thus considered realistic to reduce consumption at pure arable farms and pig farms to a treatment frequency index of 1.2-1.7, as demonstrated in trials and farmers' groups. At specialised arable farms with a substantial production of seed, sugar beet and potatoes, the treatment frequency index could be reduced to between 1.7 and 2.8, while at dairy farms it could be reduced to between 0.5 and 1.4.

Lack of knowledge about the 0- and + scenarios

There is no experience from trials or practice from which to determine the possibilities of farming without pesticides or with pesticide consumption at a level corresponding to the +scenario, with a treatment frequency index of around 0.5. In this area, we thus know too little at the present time.

Since 1987, work at organic all-year research farms has produced experience and production level measurements that give a picture of yield situation in organic farming. However, the situation with a total or partial phase-out of pesticides would be significantly different. The crop rotations would be different and the crops' ability to compete with weeds could be improved through increased fertilisation. The results, which provide a basis for a realistic evaluation of the possibility of cultivation without pesticides, have in almost all cases been based on single-factor trials – normally with no attempt to describe the prehistory, the significance of which has therefore not been analysed in relation to the results achieved. It is a well-known fact that the prehistory can be of greater importance to the result than the individual levels of experimental treatments.

Before any total phase-out or limited use of pesticides is recommended, demonstration farms should be established to throw light on the consequences in their entirety under conditions that are comparable to practice.

The work of the sub-committee has revealed a serious lack of data on the development and potential of pests in different crop rotations. Particularly in the case of weeds, we have very little data at present describing the development of weeds in different crop rotations. The sub-committee has made some use of experience from organic farming in its work, but many projects are in their initial phase and cannot be used yet. This applies particularly to the more specific crop rotations used in arable farming. As a consequence of this lack of data, many of the evaluations have had to be based on estimates, particularly in the 0-pesticide scenario.

13.2 Research and development

Technological development

Within the next 10 years, continued technological development can be expected to help towards further reduction of pesticide consumption. Several current development areas have, where possible, been discussed in this report, partly on the basis of consultants' reports. Many initiatives have been launched. The sub-committee finds that the following have particular potential and should be supported:

Preventive and non-chemical control methods:

- Research in the population dynamics of pests in different cultivation systems/farms
- Research in preventive strategies via choice of crop and cultural practices, including the effect of the level of fertilisation on pests

- Development of new technologies for mechanical weed control could improve control. For example, there is a good possibility of weed-control robots being developed as a replacement for manual weeding
- Development of more resistant varieties and research in the mechanism behind resistance
- Research and development of alternative methods of controlling seed-borne diseases.

Areas related to chemicals:

- Intensified development of warning and decision-support systems that can predict situations in which serious attacks will develop, and in which action should be taken in the form of spraying
- Development of decision-support systems for special crops, incorporating both prevention and chemical control
- Development of improved chemical control methods for use together with mechanical control in row-sown crops
- Development and use of information technology for passing on knowledge and advice on plant protection
- Development of site-specific cultivation and plant protection, where control measures are limited to those parts of the field in which there is a need for control or regulation of pests
- Greater focus on the handling of pesticides in connection with the filling and cleaning of spraying equipment; here, there are deemed to be good possibilities of reducing the risk of point-source contamination around farms.
- Intensified focus on spraying techniques that reduce the risk of drift
- Evaluation of the relationship between yield loss, time of spraying and residual concentrations in food products with a view to minimising ingestion of pesticides.

Breeding potential

The sub-committee considers that, within a 10-year horizon, there are only limited possibilities of reducing pesticide consumption through the use of new, genetically modified plants. In the longer term, however, there could be a big possibility of varieties with better resistance to disease.

The sub-committee does not think it possible at present for breeders to meet all the demands concerning varieties at one and the same time. It is therefore unlikely that the next 10 years will bring varieties that combine resistance to all serious diseases with good winter hardiness, good competitiveness, good stem stiffness, high yields and good quality characteristics.

More basic knowledge on the biology and development of pests is needed as a basis for guidelines on prevention and control.

Research within market gardening

Many of the above-mentioned research and development measures apply to both farming and market gardening. In view of the relatively high spraying intensity in market gardening, there is a particularly great need in that sector to find alternatives to the chemical methods. However, even with our present level of knowledge, some reduction in the present use of pesticides in this area can already be achieved. Weeds can be controlled without herbicides in fruit and berry cultures, but the solutions are considerably more costly. In some cultures, more resistant varieties can be grown, but in the case of apples, for example, it would take 10-15 years to change the assortment. There are various cultural practices that can reduce, although not eliminate, pest attacks. However, many of them are rather time-consuming (removal of old foliage, cutting out of infected shoots, etc.) and would make production considerably more costly.

Within greenhouse production, biological and microbiological control is possible and should be developed still further. Similarly, work on alternative methods of regulating growth should be supported.

Both on the home market and the export markets, increasing demand can be expected for products with certified production methods. Such certification depends on the development of the necessary tools, procedure and rules, including IPM rules.

13.3 Advice and training

Advice

In order to get research results passed on to farmers, coordinated action is needed to ensure that all available information goes out. The following elements are important:

- advice on strategic planning in connection with the choice of varieties and crop rotation
- Establishment of local and national warning systems
- Communication of warnings of diseases and pests
- Demonstration farms illustrating problems relating to different levels of protection and crop rotations
- Establishment of farmers' groups focused on low pesticide consumption. Both farmers and agricultural advisers will benefit from this.
- Training must be provided in the use of decision-support systems, and the systems should, for example, be available on the Internet.

Training

In line with the supplementary training required for a spraying certificate, follow-up courses must be organised on ways of minimising the use of pesticides. This is essential to reach the level of optimised use described as the ++scenario.

Considerable training will be needed for a change from the present form of cultivation to cultivation without pesticides or with only limited use of them. Since a major restructuring of production will be necessary, the production management effect is deemed to be very important. Success will depend to a large extent on farmers learning how to handle mechanical weed control in practice and about the interaction between production management decisions and consequences for weeds and diseases.

For farmers to be receptive to such advice, they must be able to transfer the results to their own farms and practice.

13.4 The Sub-committee's conclusions

Present body of knowledge

The Sub-committee on Agriculture has come to the conclusion that it is within farm crops that most is known about the useful effect and consumption of pesticides, whereas knowledge is limited in the case of forestry and market gardening. For this reason, the sub-committee has not carried out a detailed evaluation of scenarios for a partial phase-out in these sectors.

The estimation of average crop losses and the variation in these if pesticides are phased out is encumbered with considerable uncertainty because there is only limited documentation from trials.

In several areas, too little is known to be able to indicate the treatments that would be needed to avoid serious yield losses, as assumed in one of the intermediate scenarios (the +scenario).

Knowledge must be built up as a basis for increased application of the principles for integrated control, including better warning systems, decision-support systems, together with knowledge concerning methods of prevention and mechanical weed control.

Consequences of a total-phase out of pesticides

To minimise losses resulting from pest attacks, a total phase-out of pesticides would require significant restructuring of present crop rotations, including a reduction of the acreage used for winter cereals from 60% to 40%.

Large parts of the present production of special crops, including potatoes, seed grass and sugar beet, would disappear or become unprofitable.

With a total phase-out of pesticides, agricultural production would fall by 10-25%, despite the use of alternative methods of pest control. Livestock production could be maintained because grain would be imported.

This fall in production would affect earnings at the different types of farm. Without crop adjustments, it has been estimated that contribution margin II would be reduced by 4 to 93 %. The average reduction would be 31-48% for arable farms, 4-25% for dairy farms and 50-93% for arable farms with a large proportion of special crops.

If farmers carried out an economic optimisation of their production, earnings would be reduced by 21-51%.

For several types of farm, the contribution margin would fall below the EU's hectare payment, which would lead to increased interest in set-aside.

With the present prices for market-garden products, a total phase-out of pesticides in this sector would have major production consequences because large parts of the production of vegetables, pot plants, fruit and berries, and nursery cultures, would become unprofitable because of low yields. There would also be serious problems with meeting the present quality requirements.

A total phase-out of pesticides can also be expected to have serious consequences for forestry production of ornamental greenery and for the establishment of forests. A large proportion of Christmas tree production would probably be discontinued.

Consequences of partial phase-out of pesticides

The sub-committee concludes that the present pesticide consumption in agriculture could be reduced by about 30% to a treatment frequency index of 1.7, corresponding to the ++scenario, without any significant change in the existing crop composition. In the economically optimised crop rotations, where the choice of crops is adjusted, pesticide consumption could be reduced to a treatment frequency index of 1.45 without serious consequences for agriculture and society. This corresponds to a reduction of 43% in the present treatment frequency index. The reduction potential is highest for dairy farms and lowest for specialised arable farms.

At pure arable farms and pig farms, a reduction of pesticide consumption to a treatment frequency index of 1.2-1.7 is deemed realistic. This has also been demonstrated in trials and farmers' groups. At specialised arable farms, the treatment frequency index could be reduced to 1.7-2.8, while at dairy farms, it could be reduced to 0.5-1.4.

Use of all available damage thresholds and mechanical control methods is assumed where these methods can compete with chemical methods.

In the evaluations, account has not been taken of the fact that it may be difficult to meet the stated treatment frequency indices on certain soils (including organic soil and land with large weed populations) or of the fact that in some years with severe pest attacks it would be difficult to avoid economic losses in a ++scenario.

Given the present level of knowledge, a reduction of pesticide consumption to a treatment frequency index of around 0.5 (the +scenario) in agriculture is not deemed to be a realistic scenario. It would imply considerable yield losses, in part because there are no adequate tools at present for determining treatments that would keep yield losses below 15%.

The sub-committee has not carried out specific evaluations of how the intermediate scenarios would affect production in market gardening and forestry. However, there are deemed to be several alternative methods that could be used to reduce the consumption of pesticides and that would be a natural extension of the IPM production already widely practised today in market gardening.

Instruments

The sub-committee has not decided which instruments can or should be recommended in connection with a total or partial phase-out of pesticides.

Reduction of pesticide consumption to a level corresponding to the ++scenario would require the implementation of known methods of prevention and control and further development of these methods. There are several ways in which integrated prevention and control in the agricultural sector can be promoted, including incorporating information and guidelines in decision-support systems.

Advisory and training activities would have to be increased considerably to achieve the reduction.

To be receptive to this advice, farmers would have to be able to transfer the results to their own farms and practice.

Appendix 1: 10 types of farm on clayey and sandy soil have been selected. They are described in present production, a proposed agronomically optimised 0-scenario, where account is taken of how pest problems can be reduced, and economically optimised crop rotations have been created for the 0-scenario, the +scenario and the ++scenario. The figures for treatment frequency index (TFI) include set-aside and exclude couch grass.

Arable farms without pigs on clayey soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss %	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Winter rape	2.5	28	5	Winter rape and/or peas	7	26	9	Rape/peas	0	0	17
Winter wheat, 1st yr.	3.2	78	14	Oats	21	30	9	Spring cereals	41	26	15
Winter wheat, 2nd yr.	3.2	68	20	winter cereals	16	43	17	Winter cereals	29	44	55
Spring cereals	2.0	51	21	Spring barley (second crop)	29	55	17	Special crops	0	2	2
Winter barley	1.9	58	13	Winter barley	19	42	13	Feed crops	1	1	1
Winter rye	1.4	53	4	Triticale/rye	18	48	9	Set-aside	28	27	10
Set-aside	-		13	Set-aside	12	47	9				
Miscellaneous	2.9	-	10	Miscellaneous	-	-	13				
							4				
Average TFI/ CMII DKK/ha	2.2	3,231	100			1,704	100		2,439 (0)	2,788 (0.2)	3,445 (1.3)

Arable farms with pigs on clayey soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% of acreage 0-scenario	% of acreage +scenario	% of acreage ++scenario
Winter rape	2.5	9	5	Winter rape and/or Peas	7	27	9	Rape/peas	16	10	12
Winter wheat, 1st yr.	3.2	81	14	Oats	21	31	9	Spring cereals	33	39	28
Winter wheat, 2nd yr.	3.2	71	20	Winter cereals	16	45	18	Winter cereals	39	39	48
Spring cereals	2.0	54	20	Spring barley (second crops)	29	57	18	Feed crops	2	2	2
Winter barley	1.9	61	13	Winter barley	19	43	13	Set-aside	10	10	10
Winter rye	1.4	56	4	Triticale	18	48	9				
Set-aside	-	-	11	Set-aside	12	47	9				
Miscellaneous	1.5		13	Miscellaneous	-	-	11				
							4				
Average TFI/ CMII DKK/ha	2.1	2,781	100			1,991	100		2,204 (0)	2,549 (0.2)	3,093 (1.2)

Arable farms with sugar beet on clayey soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	+scenario	++scenario
Sugar beet	4.3	480	23	Sugar beet	14	413	23	Sugar beet	0	25	22
Winter wheat, 1st yr.	3.2	88	8	Spring barley	19	48	39	Spring cereals	72	39	35
Winter wheat, 2nd yr.	3.2	78	33	Winter wheat, 1st yr.	29	63	6	Winter cereals	0	25	32
Spring cereals	2.0	59	22	Winter wheat, 2nd yr.	27	57	21	Grass	2	2	2
Set-aside	-		9	Set-aside			9	Grass seed	0	1	1
Miscellaneous	1.8		5	Miscellaneous			2	Set-aside	26	8	8
Average TFI/ CMII DKK/ha	2.8	4,184	100			302	100		2,801(0)	3,321 (0.5)	4,291 (1.6)

Arable farms with seed grass on clayey soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Seed grass	1.5	9.5	19	Seed grass	50	4.8	22	Seed grass	4	18	18
Sugar beet	4.3	480	6	Sugar beet	14	413	6	Spring cereals	39	28	28
Winter wheat, 1st yr.	3.2	86	22	winter cereals	29	61	22	Winter cereals	34	38	39
Winter wheat, 2nd yr.	3.2	76	20	Triticale	12	52	13	Feed crops	0	0	0
Spring cereal with undersown crop	2.0	57	11	Spring barley with undersown crop	19	46	25	Set-aside	23	9	9
Set-aside	-		10	Set-aside			10	Sugar beet	0	7	6
Miscellaneous	2.2		12	Miscellaneous			2				
Average TFI/ CMII DKK/ha	2.3	3,928	100			1,967	100		2,822 (0)	3,493 (0.5)	4,158 (1.3)

Dairy farms on clayey soil Crop rotation in present production				Crop rotation in 0-scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Winter wheat, 1st yr.	3.2	75	13	Winter cereals	29	54	17	Beets/maize	0	0	6
Winter wheat, 2nd yr.	3.2	66	8	Spring barley with second crops	19	40	17	Rape/peas	10	11	10
Spring cereals	2.0	50	17	Wholecrop	14	55	17	Spring cereals	19	16	3
Wholecrop	1.0	64	17	Grass	3	66	40	Winter cereals	10	12	24
Grass	0.08	68	21	Set-aside			6	Wholecrop	27	27	25
Mangolds	4.0	120	6	Miscellaneous			3	Set-aside	9	9	7
Maize	1.3	66	5					Grass	25	25	25
Set-aside	-		6								
Miscellaneous	2.8		7								
Average TFI/CMII DKK/ha	1.7	2,217	100			1,684	100		1,846 (0)	1,935 (0.1)	2,313 (0.7)

Arable farms on sandy soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Spring rape or	2.0	20	3	Winter rape or	7	22	8	Grass seed	9	4	4
Winter rape or	2.5	24	4	Peas	21	32	8	Rape/peas	0	0	0
Peas or	3.3	40	5	Seed grass	50	4	4	Spring cereals	39	26	26
Seed grass	1.5	8	4	Winter cereals	27	52	17	Winter cereals	20	40	36
Winter wheat, 1st yr.	3.6	71	16	Spring barley	17	40	24	Feed crops	3	3	3
Winter wheat, 2nd yr.	3.6	56	9	Winter barley or	19	44	8	Set-aside	29	27,9	31
Rye	1.4	54	8	Winter rye	12	48	8				
Spring cereals	1.5	49	20	Set-aside	-	-	13				
Winter barley	1.9	54	8	Miscellaneous			10				
Set-aside	-		13								
Miscellaneous	2.0	-	10								
Average TFI/ CMII DKK/ha	2.0	2,254	100			1,565	100		1847 (0)	2115 (0.1)	2286 (0.8)

Pig farms on sandy soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Spring rape or	2.0	19	3	Winter rape or	7	22	8	Special crops	5	3	3
Winter rape or	2.5	23	2	Peas	21	30	9	Rape/peas	11	8	15
Peas or	3.3	39	4	Grass	3	62	6	Spring cereals	45	50	44
Grass	0.08	64	5	Winter cereals	27	50	17	Winter cereals	22	22	22
Winter wheat, 1st yr.	3.6	68	16	Spring barley	17	39	21	Feed crops	6	6	6
Winter wheat, 2nd yr.	3.6	53	6	Winter barley or	19	41	8	Set-aside	11	11	10
Rye	1.4	52	6	Winter rye	12	46	8				
Spring cereals	1.3	47	21	Set-aside	-	-	12				
Winter barley	1.9	52	12	*Miscellaneous*			11				
Set-aside	-	-	12								
Miscellaneous	1.0		13								
Average TFI/ CMII DKK/ha	1.8	2106	100			1646	100		1835 (0)	1979 (0,1)	2345 (1,1)

Arable farms with potatoes on sandy soil Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Potatoes	6.9	367	24	Potatoes	42	219	24	Potatoes	3	9	29
Peas	3.3	35	6	Triticale/Rug	12	42	21	Spring cereals	41	30	38
winter cereals	3.6	63	17	Spring barley with	17	36	40	Winter cereals	23	29	11
Spring cereals	1.3	43	31	second crops			11	Set-aside	32	29	18
Set-aside	-		11	Set-aside		-	4	Miscellaneous	1	3	4
Miscellaneous	1.3		10	Miscellaneous							
Average TFI/ CMII DKK/ha	3.0	3,778	100			1282	100		2035 (0)	3323 (0.3)	3995 (2,4)

Dairy farms on sandy soil <1.4 LU (dairy cows) per ha Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Winter wheat, 1st yr.	3.6	61	10	Spring barley with				Wholecrop	14	14	13
Spring cereals	1.3	41	21	undersown crop	17	34	23	Rape/peas	8	8	4
Wholecrop/maize	1.0	59	18	Wholecrop (maize)	14	51	18	Spring cereals	32	32	34
Grass	0.08	64	31	Grass	3	62	41	Winter cereals	0	0	3
Mangolds	4.1	100	6	Winter cereals	27	45	9	Feed crops	37	37	36
Set-aside	-		8	Set-aside			8	Set-aside	8	8	8
Miscellaneous	1.9		6	Miscellaneous			1	Miscellaneous	1	1	1
Average TFI/ CMII DKK/ha	1.2	2,012	100			1,859	100		1,942 (0)	1,997 (0.05)	2,170 (0.4)

Dairy farms on sandy soil >1.4 LU (dairy cows) per ha Crop rotation in present production				Crop rotation in 0-pesticide scenario (agronomically optimised)				Crop rotation in 0-pesticide scenario, +scenario and ++scenario (economically optimised)			
Crop	TFI	Yield hkg/ha	% share	Crop	% loss	Yield hkg/ha	% share	Crop	% share 0-scenario	% share +scenario	% share ++scenario
Winter wheat, 1st yr.	3.6	62	8	Spring barley with				Spring cereals	1	4	5
Spring cereals	1.3	42	11	undersown crop	17	34	12	Winter cereals	5	2	3
Wholecrop/maize	1.0	60	26	Wholecrop	14	51	28	Grass	65	62	61
Grass	0.08	64	39	Grass	3	62	56	Wholecrop	25	24	23
Mangolds	4.1	100	7	Set-aside			3	Maize	0	4	4
Maize	1.5	62	3	Miscellaneous			1	Set-aside	4	4	4
Set-aside	-		3								
Miscellaneous	3.2		3								
Average TFI/ CMII DKK/ha	1.2	1,986	100			1,913	100		2,257	2,260 (0.05)	2,305 (0.1)

Appendix 2

Crops where, for economic reasons, continued permission for use of pesticides in a +scenario should be considered. (This scenario includes 0+.)

Problem	% loss and effect on contribution margin	Background
16. Minimum control of potato blight in ware and starch potatoes	24% in ware potatoes 2 TFI increases CMII by DKK 7,500/ha 28% in starch potatoes 4 TFI increases CMII by DKK 2,700/ha	Starch potatoes have a long production period, and it would be difficult to maintain the high yields that are needed to ensure profitability if some control of blight were not permitted (25,000 ha). Due to high prices for ware potatoes, some blight control could generally be defended on economic grounds (10-15,000 ha).
17. Seed-dressing and band spraying in beets and sugar beet	Seed-dressing reduces losses by 10%=DKK 1,500 Band-spraying would give an advantage of DKK 9,000 compared with hand-hoeing.	Manual weeding of beets is very costly and it is extremely uncertain whether the necessary manpower for a satisfactory result could be obtained. Band-spraying combined with inter-row cultivation could, at a cautious estimate, halve the need for herbicides. Beet seed would have to treated with a dressing agent to ensure reliable, uniform establishment and minimise pest problems in the establishment phase (111,000 ha with beets in all).
18. Controlling specific weeds in cereals (e.g. camomile and charlock)	The additional yield from controlling dicotyledonous weeds in cereals is low. The return per ha is relatively low – DKK 190-250/ha with a low dosage.	Some of the species that are difficult to control mechanically are very sensitive to herbicides, e.g. charlock and camomile. Chemical control would increase cultivation security and reduce the need for mechanical weed control, which is the most risky form of control for this crop.
19. Controlling weeds in peas	Peas are a crop that has difficulty in competing with weeds, and the way pea plants grow makes mechanical control difficult.	It is estimated that the entire acreage with peas would need weed control – typically split application with reduced dosages. The sub-committee suggests using the smallest possible quantity of herbicide - corresponding to the ++scenario.
20. Controlling patches of perennial weeds such as thistles etc.	3 % of the cultivated acreage is deemed to need this. It is estimated that all crops benefit from this form of control.	Control of certain perennial varieties is difficult and makes it impossible, for example, to grow second crops. Patch control of thistles etc. could obviate this problem.
21. Controlling grass weed on particularly contaminated land	The loss from grass weed in winter cereals is often more than 15-20%. Full TFI must be used on acreages needing this.	On some land there are serious problems with grass weeds such as loose silky bent and blackgrass. Experience with mechanical control is very uncertain. Particularly in the transitional phase, the changes in crop rotations are not expected to be adequate on contaminated land.
22. Controlling severe attacks of leaf disease in wheat and winter barley on the basis of warnings	In wheat, losses of more than 15 % are common every other year, and a TFI of 0.5 is recommended. In winter barley, losses of more than 15% are common every 4th year, and a TFI of 0.4 is recommended.	Even if varieties with the best available resistance were grown, there could be years in which severe attacks of leaf diseases in cereals caused losses of more than 15-20 %. Heavy losses would be particularly likely in rainy growing seasons.
23. Controlling pollen beetle in spring rape in conditions in which the crop cannot compensate for attacks	It is estimated that there is a loss of 25% on one quarter of the acreage.	In drought conditions, among others, spring rape might not be able to compensate for attacks of pollen beetle. Control measures should therefore be taken to safeguard the crop.
24. Band-spraying with herbicides in maize	With mechanical weed control, the crop loss will in many cases be more than 15-20%.	The experience with mechanical weed control is uncertain. A combination of band-spray and inter-row cultivation would ensure a more stable coarse-fodder yield (45,000 ha).

25. Chemical control of couch grass in 1 in 10 years, combined with mechanical control	Without effective control of couch grass, the yield loss can exceed 15% in crops that have difficulty in competing with this weed.	Mechanical control of couch grass is very much less reliable than chemical control and is also dependent on the weather. Winter cereals, green fields and second crops reduce the options. Limited chemical treatment combined with mechanical control would increase cultivation security.
26. Controlling poisonous weeds, such as spring groundsel, in coarse fodder	If the population of poisonous spring groundsel is large, the crop cannot be used for silage and hay.	Spring groundsel has become an increasing problem since the introduction of set-aside acreage. On grassland, control may be necessary to prevent poisoning of cattle.
27. Controlling aphids in wheat and peas when the damage threshold has been exceeded	The crop loss from aphids in peas is expected to exceed 15% on about 20% of the acreage. The crop loss from aphids in spring barley is expected to exceed 15 % on about 12% of clayey soil and 6% of sandy soil. The crop loss from aphids in wheat is expected to exceed 15% on around 10% of clayey soil.	In some parts of the country – mainly on the islands - aphids can cause serious losses in cereals and peas. Control is recommended where it is certain that the damage thresholds have been exceeded.
28. Controlling snails and flea beetle in rape when the damage threshold has been exceeded	Severe attacks can cause losses of more than 15% on around 5-10% of the acreage. There is only limited documentation of the need.	In winter rape, snails and flea beetle cause serious problems in some seasons that might warrant the use of spraying to avoid the need to resow.
29. Controlling clover weevil in clover-grass production	Attacks in clover-seed fields can often halve the clover-seed yield. The need is expected to be great on the entire acreage with clover.	Clover weevil can be a serious problem that reduces still further the cultivation security of an already unreliable crop.
30. Prevention and control of diseases and pests in fruit growing, evaluated on the basis of the level of attack		Prevention and control of diseases and pests in fruit (apples, strawberries, blackcurrants, etc.) are needed to ensure a continued, good and stable Danish production.
31. Prevention and control of diseases and pests in vegetables, evaluated on the basis of the level of attack		Prevention and control of diseases and pests in vegetables on the basis of a need evaluation are needed to ensure continued, stable and competitive production.
32. Pre-harvest desiccation and prevention and control of fungal diseases in garden-seed crops		For stable production of species of garden seed, prevention and control of fungal diseases are needed, together with pre-harvest desiccation, to ensure uniform maturation, which is often a condition for good-quality seed.

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