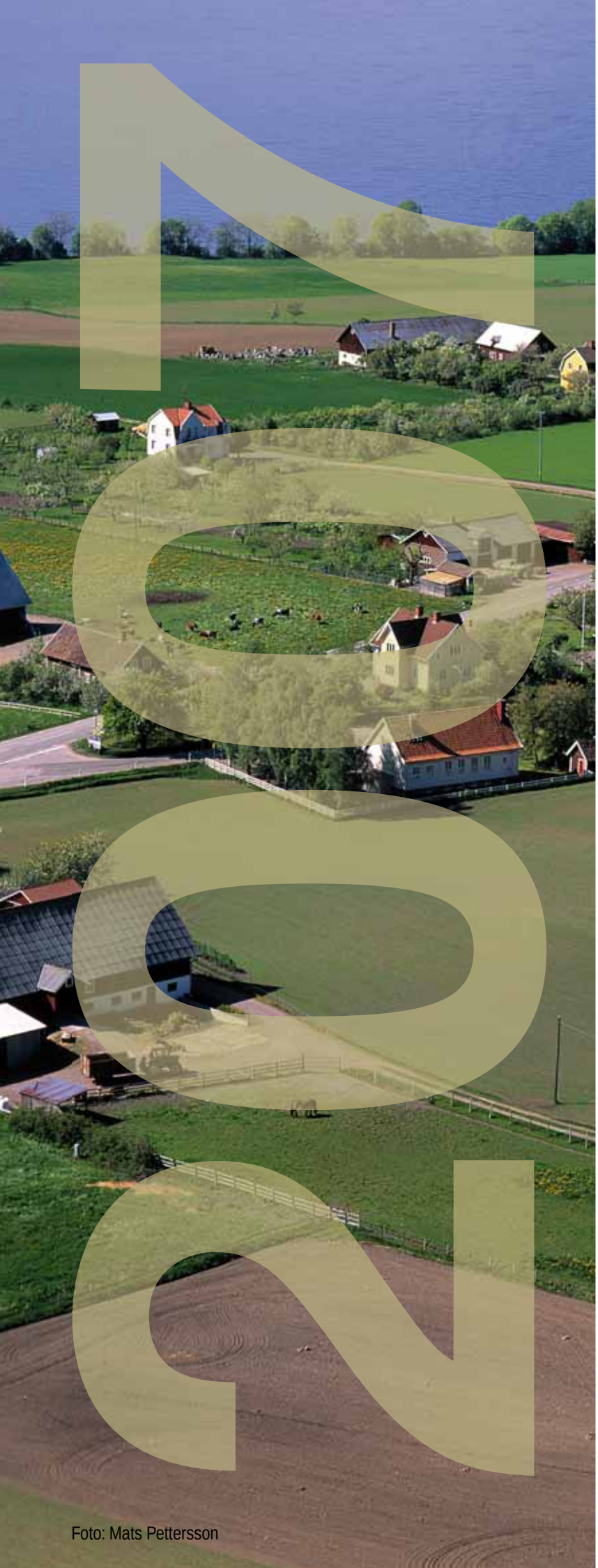

Foto: Mats Pettersson

The impact of herbicide tolerant crops on some environmental quality objectives

– Report from the Swedish Board of Agriculture and the Swedish Environmental Protection Agency

JORDBRUKS VERKET

Report 2007:21

The impact of herbicide tolerant crops on some environmental quality objectives

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The report has been developed by the Swedish Board of Agriculture in collaboration with the Swedish Environmental Protection Agency and after consultation with the Swedish Chemicals Agency.

Contents

Summary

This report presents the findings of the Swedish Board of Agriculture, in collaboration with the Swedish Environmental Protection Agency, in their investigation as commissioned by the Swedish government. The subject of the investigation was how possible cultivation of genetically modified crops with introduced herbicide tolerance will affect the following environmental objectives in the short and long term: *A non-toxic environment*, *A varied agricultural landscape* and *A rich diversity of plant and animal life*. The investigation was carried out after consultation with the Swedish Chemicals Agency and other relevant authorities and players.

During the 20th century, agriculture in Sweden and the rest of Europe has changed radically. An increased level of mechanisation, development of technology and increased international competition have led to rationalisation and intensification of agriculture. This has contributed to increasing agricultural output significantly while also weakening biodiversity. The introduction of herbicide tolerant crops should therefore be seen as a continuation of an ongoing process of rationalisation in modern agriculture.

Herbicide tolerant crops that are approved for cultivation within the EU may, depending on factors such as the hardiness of the crop, also be cultivated in Sweden. This is why it is important to investigate and identify the effects that this type of cultivation would have on our environment and on the health of people and animals. We must also investigate the options for minimising any negative effects that are identified. In this report, cultivation of crops with herbicide tolerance is compared with conventional cultivation of the same crops.

The genetically modified crop with herbicide tolerance that is closest to being approved for cultivation within the EU, which as a result may be a possibility for commercial cultivation within the next ten years, is maize. The cultivation of maize is expected to be given a relatively limited scope, around 25,000 hectares. This report also discusses the cultivation of herbicide tolerant sugar beet and rape, although this will probably be in a slightly more distant future.

The active ingredient in herbicide may change to glyphosate in cultivation of herbicide tolerant maize, sugar beet and rape. From the perspective of the environmental quality objective *A non-toxic environment*, it is judged that this will bring about a decreased risk for sugar beet and rape and an increased risk for maize. Changing the active ingredient to glufosinate ammonium is judged to cause increased risks in all three crops. However, it is unlikely that glufosinate ammonium will be approved for this type of usage in Sweden. Cultivation of herbicide tolerant crops will involve use of herbicides and as such will lead to an increased dependence on plant protection products in agriculture. This may have a negative effect on our chances of achieving this objective.

The lack of knowledge of the ecological effects of herbicide tolerant crop cultivation in Swedish conditions is apparent. It is possible to construct theories on the effects of cultivation of such crops in Sweden, based on basic ecological theory and experience and studies from similar cultivation in other countries. If herbicide tolerant crops were cultivated in the same way as in the most extensive study thus far – farm-scale evaluations in the UK – this could have negative effects on biodiversity and the environmental quality objectives *A varied agricultural landscape* and *A rich diversity of plant and animal life*. However, there is no way of making safe assessments of the effects of commercial cultivation of herbicide tolerant crops in Sweden based on generalisations from this study and other similar ones. The effects of this kind of cultivation depend on a number of factors, including type of crop, type of

tolerance, method of use, strategy for use of plant protection products, the type of ground and the size of the cultivation area. As such, the need for research in Sweden is great.

However, the negative effects that may come about as a result of cultivation of herbicide tolerant crops can to a certain extent be counteracted by adapting cultivation methods and using plant protection products, thereby minimising the negative effects on the environmental quality objectives.

Various control mechanisms may be needed in order to apply measures that counteract unwanted environmental effects and boost the positive environmental effects of this kind of cultivation. The available control mechanisms include legislation (in the form of regulations and supervision) economic measures (including charges and support for environmentally friendly farming), informative measures (using information and advice to change behaviour and practice). National action programmes, certification and sectoral agreements can also encourage farmers to implement certain measures. Decisions on which control mechanisms to use should be made based on the measures and results sought.

This report points out the following options for limiting environmental impact:

- Improving the bank of knowledge available that is specific to Swedish conditions.
- Sweden should work to ensure that the assessments according to the various regulatory frameworks for genetically modified organisms and plant protection products are carried out in parallel. This would provide a basis for more comprehensive and complete evaluations in future decisions regarding approval or rejection of cultivation of herbicide tolerant crops.
- Sweden should work to ensure that issues that fall into a no-man’s land between different regulatory frameworks, such as impact on non-target organisms, are dealt with.
- In the event of an introduction of herbicide tolerant crops, their development should be monitored and measures such as the following should be put into place wherever necessary:
    a) Develop guidelines for cultivation of herbicide tolerant crops that include strategies to avoid resistance and the appearance of herbicide tolerant crops as weeds in later crops.
    b) Measures to regulate the size of the seed bank, for example changing treatment times, using band spraying, and applying conservation tillage.
    c) Compensatory measures such as intermittent fallow, untreated field margins, uncultivated field margins and non-chemical methods in crop rotations to create better conditions for reaching the environmental quality objectives.

1 Description and limits of the investigation

The directive commissioning this investigation is detailed in appendix 1 (only in the Swedish version), government decision 8 from 15 February 2007. In summary, the government commissioned the Swedish Board of Agriculture to work together with the Swedish Environmental Protection Agency to investigate what impact the possible cultivation of genetically modified crops with introduced herbicide tolerance in Sweden would have on the environmental quality objectives *A non-toxic environment*, *A varied agricultural landscape* and *A rich diversity of plant and animal life*, in the short and long term.

In particular, the investigation was to show how these types of crops could be cultivated in such a way as to ensure that the environmental quality objectives mentioned above are reached. The investigation was to focus on crops that could be cultivated commercially and was to include an analysis of various scenarios for cultivation of genetically modified herbicide tolerant crops in Sweden, compared to conventionally cultivated crops. The positive and negative effects of these two forms of cultivation were to be reviewed. Measures to counteract unwanted environmental impact and boost positive environmental effects were to be discussed. Other aspects judged to be relevant by the agencies were to be included.

The investigation was to be presented by the two agencies by 31 October 2007, and carried out following consultation with the Swedish Chemicals Agency and other relevant authorities and players.

Certain more comprehensive delimitations have been made concerning the investigation. The project has been limited to the crops that may be relevant for cultivation between now and 2020, which is the deadline for reaching the environmental quality objectives. These crops are maize, sugar beet and oil crops. The basis of this delimitation is explained in part 4.4. In addition, the investigation has been limited to effects that are directly linked to the introduction of herbicide tolerant crops. Where comparisons arise, these have been limited to cultivation of the equivalent conventional crop with the use of herbicides. Gene spread to soil-dwelling organisms may occur, but the extent of this gene spread under natural circumstances is unclear and there is a lack of knowledge of this issue (Snow et al, 2005). As a result, this issue is not discussed in the report.

The environmental objective *A non-toxic environment* is one of the more difficult environmental quality objectives to reach. According to a report from the Swedish Chemicals Agency, ’Basis of information for the second in-depth evaluation of the environmental quality objective *A non-toxic environment*’, major measures are required in order to reach the objective. The ongoing work on the environmental objectives can therefore be expected to affect the use of pesticides in various ways. However, it is as yet unclear in what way and to what extent. The assessments made in this report are therefore based on the assumption that it will be possible to use the affected plant protection products to the extent to which they are currently used. However, there is some uncertainty in this assumption, as it depends on the strategies used to reach the environmental objectives in the future.

The investigation has been completed through the creation of this report. It was drawn up by a working group consisting of the following people.

Magnus	Franzén	Swedish Board of Agriculture
Kersti	Gustafsson	Swedish Chemicals Agency

Henrik	Hallqvist	Swedish Board of Agriculture
Lena	Niemi	Swedish Board of Agriculture
Camilla	Thorin	Swedish Chemicals Agency
Johan	Wallander	Swedish Board of Agriculture
Peter	Örn	Swedish Environmental Protection Agency

Other relevant authorities and players have had the opportunity to submit their points of view in referral carried out in September 2007. The table below (only in the Swedish version) shows the people who have had the opportunity to submit opinions. A large number of responses were submitted. Both overall and detailed opinions were submitted, and some changes have been made to the report on the basis of these. In several cases, these responses raised issues that are not judged to be within the scope of this investigation. In order for these responses to be available for use in future investigations and assessments concerning herbicide tolerant crops, these responses are attached (only in the Swedish version). A compilation of the referrals is attached in appendix 3 (only in the Swedish version).

(In this place in the Swedish version of the report you will find a list of authorities and organisations given the opportunity to submit points of view.)

When the report was referred to the above authorities and organisations, it was also published on the website of the Swedish Board of Agriculture in order to give other parties the opportunity to submit points of view.

2 Introduction/background

The increased specialisation and demand for profitability in today's agriculture have led to a greater need for effective methods for reducing the occurrence of weeds. Weeds compete with the crop and as such have a negative effect on production. The positive effects of effective weed control have led to extensive usage of herbicides in crop cultivation. The total usage of selective herbicides for use with different crops has nonetheless decreased in recent years, but if we also include non-selective herbicides (total herbicides), the total usage of herbicides has increased over the last decade (SCB, 2007). On the basis of the economic and effect-related advantages of herbicides compared with other weed control methods, it is realistic to assume that herbicides will continue to be used in conventional crop cultivation.

At the same time, the use of herbicides and other plant protection products involve a series of risks for the operator, the consumer and the environment. Since the mid 1980s, there has been an attempt to reduce these risks. This work now forms part of the national environmental quality objectives. Initially, the work was directed towards reducing the quantities of active substances used. This has been successful, and usage today is at around 39% of the level of usage between 1981 and 1985 (Swedish Chemicals Agency, 2007). This is largely as a result of reduced dosage, increased usage of low-dose products, and decreased and changed usage of agricultural area. In recent years, the focus of the work has shifted towards reducing the risks of usage. The following diagram shows how the risk index has changed since 1988. Since 1988 the health risks and environmental risks, expressed as risk indicators, have been reduced by 69 and 28 percent respectively (Swedish Chemicals Agency, 2007). The greatest transformations occurred during the first 10 years of the period.

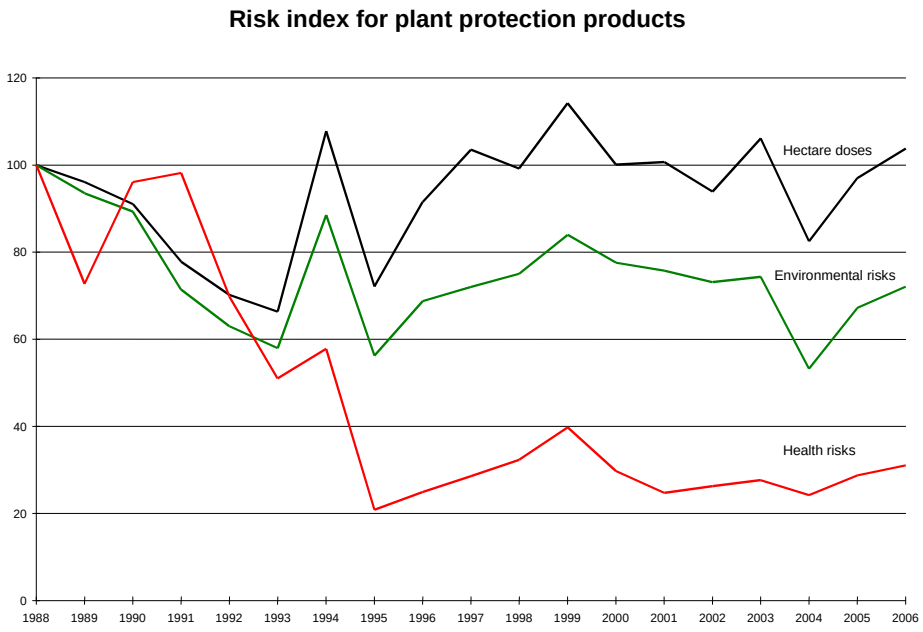

Figure 1. Risk index for plant protection products 1988-2006 (Swedish Chemicals Agency 2007)

Usage of herbicide tolerant crops could have both positive and negative effects on the chances of reaching the environmental objectives. The long and short-term effects depend to a great extent on the crops cultivated, the area of land cultivated, the herbicide used and the cultivation methods used. For example, if the cultivation of a herbicide tolerant crop brings about reduced herbicide usage or a transition to use of less risky herbicides, this would be a positive development in terms of the *A non-toxic environment* objective. If it involves a reduction in the earth's seed bank and in the frequency of weed growth, this could lead to negative consequences for biodiversity and the environmental objectives *A varied agricultural landscape* and *A rich diversity of plant and animal life*. Since the same crop can have several different effects on the environmental quality objectives, it may be problematic to determine whether the overall effect is positive or negative.

2.1 Current strategies for weed control and the size of the seed bank versus herbicide usage

The reasons for weed control may be quantitative, such as to increase the harvest, or qualitative, for example, to increase the protein content, decrease waste and/or increase nutritional value. Weed control can also lead to reduced risks for lodged stand of cereals, lower drying costs and easier harvests.

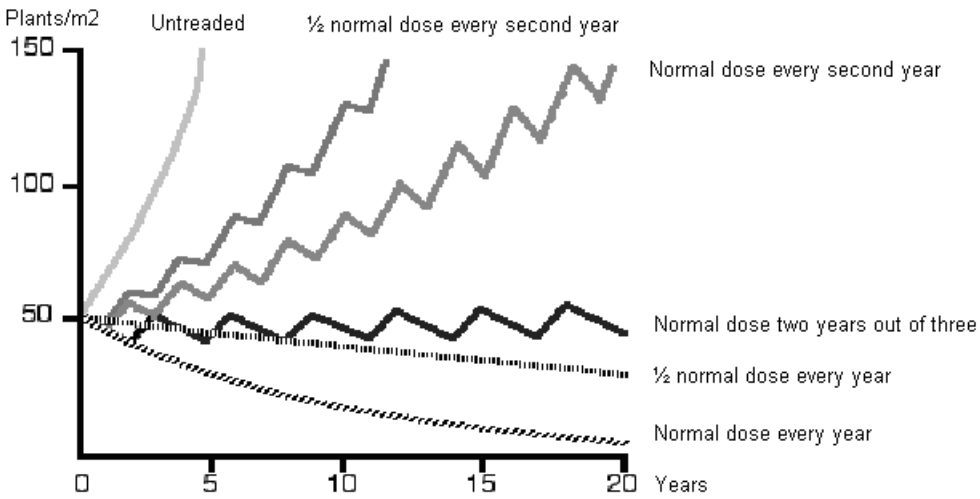

Figure 2. Estimated development of the amount of weeds under different strategies for weed control in one-sided cultivation of spring barley (after Kryger Jensen, 1990)

In order to preserve the high production potential of arable land, the weed seed bank must be kept at a level that means that the weeds do not multiply after their occurrence has been reduced to a level that does not have a negative effect on the crop. The objective of weed control must therefore be to prevent as many as possible of the weed seeds bank in the soil from growing. If the level of weed control is too low, there will be a need for more extensive treatment in the future.

The increase in yield following chemical treatment varies widely depending on factors such as the crop, the yield level, the types of weeds and the quantities thereof. A few examples can be noted, according to a compilation of studies carried out at the Swedish University of Agricultural Sciences. The increase in yield after treatment with herbicide averages between 3 and 7% in grain, oil crops and peas. The increase in yield after treatment to prevent growth of silkybent-grass averages around 45% in winter grains (Swedish Board of Agriculture, 2002).

In crops such as sugar beet, potato and seed cultivation, weed control may be entirely necessary in order to cultivate a successful crop. In the case of potato cultivation, chemical and mechanical prevention methods are often combined. In this context, it is important to point out that all cultivation and all kinds of weed control do, in different ways, come into conflict with one or several of the environmental quality objectives.

2.2 Herbicides and herbicide tolerance

An important characteristic of effective weed control products is that they are effective against weeds but do not have a negative effect on the crop. It is also important to be able to use as low dosage as possible. Partly to keep costs down, but also to minimise negative effects on the environment.

There are several different categories of herbicides. Some only work against a certain category of plants, called selective herbicides, and others that have an effect on all plants, called total herbicides. Traditional methods for chemical prevention of weeds also include a method where another substance is applied along with the active herbicide, known as safeners, which activate a protection mechanism in the crop in order to ensure it is not damaged by the substance.

2.2.1 Development towards broad spectrum herbicides

Selective herbicides have been extremely important, since they can be applied to growing crops. Total herbicides affect the natural metabolic process of the plants to which they are applied, and as such they prevent the growth of all kinds of plants, including the crop in question. As a result, total herbicides have to be applied to the fields before the crop has begun to grow. In order to use a total herbicide on a growing crop, the crop must be tolerant of that herbicide.

There are currently several genetically modified crops available on the international market, which are tolerant of glyphosate, glufosinate ammonium and the active ingredients in other herbicides. Herbicide tolerance and usage of herbicides with broader effects could lead to a reduction in the number of active substances used, since these are extremely effective against all kinds of weeds. Herbicide tolerant crops could also increase the flexibility in terms of how and when chemical control is used and make it possible to reduce the number of treatments used on a crop. Overall, this could lead to a reduction in the usage of herbicides.

In contrast, fears have also been expressed that the use of herbicide tolerant crops could lead to an increase in the use of herbicides. Tolerance makes it easier to use herbicides and makes herbicide tolerant crops more competitive on the market. This could decrease the need for, and development of, alternative forms of weed control. As such, herbicides would become an increasingly important tool for cultivation.

2.2.2 What is herbicide tolerance?

Herbicide tolerance means that a plant has genes that give it the characteristics necessary for an ability to withstand herbicides that would otherwise kill it.

Agriculture has made use of different plants' varying tolerance of herbicides for a long time. Such characteristics can occur naturally, through mutations in the genes that regulate the plant's response to a herbicide. By using particular varieties, or wild-growing plants from the same family, that have this kind of mutation, it is possible to cross the desired crop with a herbicide tolerant variant. It is also possible to introduce mutations that lead to herbicide tolerance using chemical methods. However, when referring to herbicide tolerance in crops,

the most common method is via gene technology. These crops are called genetically modified, since the methods for developing herbicide tolerant plants using gene technology may involve 'switching off' a particular gene or introducing a new gene into the plant.

Herbicide tolerance was one of the first characteristics that were introduced into agricultural crops with the help of gene technology. Of the genetically modified crops cultivated all over the world in 2005, crops with herbicide tolerance were the most common, making up 76 % of the total arable land sown with genetically modified crops (Brookes & Barfoot, 2006). The remaining 24 % consisted of crops that had been given characteristic making them resistant to insects. In 2006, 68 % of genetically modified crops were herbicide tolerant, 19 % were insect resistant and 13 % were crops with both characteristics, herbicide tolerance and insect resistance (James 2006).

Herbicide tolerant genetically modified crops are usually resistant to glyphosate (N-(phosphonometyl)glycin) or glufosinate ammonium (phosphinothricin).

2.2.2.1 Tolerance of glyphosate

Glyphosate works by binding and blocking the enzyme EPSP synthase, which is necessary for plants' production of the aromatic amino acids tyrosine, phenylalanine and tryptophane (Boocock & Coggins 1983). Without these amino acids, the plant's protein synthesis will stop and the plant will die. The genetically modified plants with glyphosate tolerance that exist today have been given this characteristic by transferring a gene from the soil bacteria *Agrobacterium* sp. strain CP4 to the plant. The gene occurs naturally in soil bacteria and has the genetic code for a version of EPSP synthase that is not sensitive to glyphosate.

As well as being present in plants, EPSP synthase exists in fungi and bacteria, but not in animals. Herbivores take in a number of variants of this enzyme every day through their fodder. The EPSP synthase that is created in genetically modified plants does not differ significantly from the EPSP synthase in non-modified plants (Nap & Metz 1996).

2.2.2.2 Tolerance of glufosinate ammonium

Glufosinate ammonium stops the creation of the enzyme glutamine synthetase, which is needed in order for the plant to be able to transform ammonia to less harmful nitrogen compounds (Kvaløy et al, 1998). Ammonia is produced in green plants via the plant's normal metabolism and quickly accumulates to fatal levels if it is not made harmless. The soil bacteria *Streptomyces hygroscopius* and *S. viridochromogenes* produce an enzyme called PAT that inactivates the active substance in glufosinate ammonium. By transferring the gene from the earth bacteria that have the code for this enzyme from soil bacteria to plants, the plants become resistant to glufosinate ammonium.

Both the enzyme PAT and glufosinate, as well as their metabolites are new molecules for herbivores and could, theoretically, have undesired effects on the consumer. In the case of PAT, biochemical studies have shown that the enzyme has high specificity for glufosinate (OECD 1999, FSANZ 2003). It is therefore unlikely that its activity in the modified crop would result in any unknown secondary metabolites and no allergic or toxic reactions have been shown on consumption thereof (OECD 1999, FSANZ 2003). The enzyme itself loses its activity and is quickly broken down by the body's metabolic processes (Privalle 1994, OECD 1999, FSANZ 2003). In the herbicide tolerant crop, glufosinate is broken down primarily into N-acetyl-glufosinate, which is less toxic than glufosinate.[1,2]

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[1] http://ec.europa.eu/food/fs/sc/scp/out15_en.html

2.3 Cultivation of genetically modified plants

Before a genetically modified crop can be used and cultivated in Sweden and elsewhere in the EU, the crop must be approved. Herbicide tolerant crops that have been developed using gene technology will therefore be subjected to a thorough investigation of the effects they may have on the health of people, animals, and the environment, before they are approved for cultivation.

2.3.1 Regulations

There is common EU legislation governing the use of genetically modified plants for commercial use, consisting of directive 2001/18/EC on the deliberate release into the environment of genetically modified organisms and regulation (EC) no 1829/2003 on genetically modified food and feed. Directive 2001/18/EC has been introduced into Swedish legislation through chapter 13 of the Environmental Code and regulation (2002:1086) on release into the environment of genetically modified organisms.

According to the provisions of directive 2001/18/EC, applications for permission to import and cultivate these crops can be approved. According to the provisions in regulation (EC) no 1829/2003, applications for both import and cultivation and use in food products and feed can be approved.

All kinds of use of genetically modified crops must then also be approved according to seed legislation before the seeds can be sold.

2.3.2 Approval process

The majority of applications relating to cultivation now come in under 1829/2003 since this regulation allows all aspects of use of the crop to be dealt with. Risk assessment of these cases is handled by the European Food Safety Authority (EFSA). The EFSA carries out a complete assessment of the application and also makes the application available to the relevant authorities in all the EU countries. The Swedish Board of Agriculture is Sweden's relevant authority for import and cultivation of genetically modified plants and for their use as fodder. The National Food Administration is the relevant authority for use of genetically modified crops in food products. All EU countries are allowed to comment on the application to the EFSA, which then takes these points of view into consideration in its assessment of the application. For applications that are submitted under 2001/18/EC, the relevant authority in the country where the application is submitted is responsible for writing an assessment report. In both cases, the EFSA publishes a statement, after which the Commission makes a decision proposal.

Both directive 2001/18/EC and regulation (EC) no 1829/2003 specify a time limit for each stage of the decision-making process. For example, the relevant authority or EFSA have a certain length of time in which to write their assessment report and the member states have a certain length of time in which to submit objections or questions. Every time supplementary information is requested from the applicant, or when the EFSA, the Commission or a member state submits a question or objection, the clock is stopped. It starts again when the supplementary information or response has been submitted.

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[2] http://www.efsa.europa.eu/etc/medialib/efsa/science/praper/conclusions/895.Par.0008.File.dat/praper_ej27_conclusion_glufosinate_summary_en1.pdf

When the EFSA has published its statement, the Commission has a certain period of time in which to write a decision proposal. Then the member states vote on the proposal. For applications submitted under 2001/18, the minimum length of time between submission of the application and the voting procedure is approximately 14 months. For 1829/2003, this period is approximately 9 months. In both cases, this is assuming that the application is judged to be complete at the time of submission and that neither the EFSA nor other member states have objections or questions that demand a response.

In order for the Commission's proposal to be accepted or rejected in the voting process, a qualified majority is required. This is currently 255 votes out of 345. If there is not a qualified majority for acceptance or rejection of the proposal, the matter goes to the Council of Ministers, who have three months in which to vote and make a decision. If a qualified majority vote against the product, it is not allowed to enter the market. If a qualified majority of the Council of Ministers vote for the product, or if the Council of Ministers does not manage to reach a decision, the Commission's decision is adhered to. Therefore, a decision in a matter concerning cultivation of genetically modified crops could take around 12-18 months.

In reality, the entire process takes much longer, as the clock is usually stopped several times during the process when the applicant is asked to submit supplementary information and respond to various questions. The process is also slowed down by objections based on the strong opposition to cultivation of genetically modified crops that exists in many EU member states.

An example of the process is an application on cultivation of genetically modified potatoes with altered starch quality. This application was submitted in 1996 and is now under 2001/18. The voting process took place in the spring of 2007 and the Commission is now making its decision.

2.3.3 The current situation

Currently only one type of genetically modified maize has been approved for cultivation in the EU. It is an insect resistant maize that is grown in Spain, Portugal, Germany, France, the Czech Republic and Slovakia.

At the time of writing this report, nine applications have been submitted relating to the cultivation of crops with introduced herbicide tolerance. There is one maize application that was submitted under directive 2001/18/EC. It was submitted in 2001 and is now awaiting the voting process. Under regulation (EC) no 1829/2003, eight applications have been submitted. Seven of these concern types of maize and one concerns soya beans. The soya bean application and five of the maize applications were submitted in 2005. The other two maize applications were submitted in 2006 and 2007. One of the maize applications submitted in 2005 and the one submitted in 2007 are still incomplete. The clock has been stopped for the other applications as they wait for the EFSA to publish its statement. That means that they still have a long way to go before reaching the stages of voting and decision-making.

2.3.4 Assessment of environmental risks

The assessment and investigation to which genetically modified crops are subjected before they can be approved for cultivation in the EU seeks to identify and assess all the risks of negative effects on the health of humans and animals, and on the environment, that could be linked to cultivation of the crop. The environmental risk assessment is carried out by the EFSA's GM panel and follows the regulations contained in directive 2001/18/EC, which means that all the characteristics that may cause negative effects must be identified, the

consequences of any possible effects must be evaluated, and the likelihood of the effects occurring must be assessed. In the context of risk assessments, the genetically modified plant is compared with a similar non-modified crop, since the effects of conventional crops on people's health and the environment are seen as acceptable.

The assessment focus on how the plant and its properties may affect its surroundings. Aspects relating to the use of herbicides are not covered by 2001/18/EC, but are regulated by EC directive 91/414. Issues relating to the effects of herbicide use are therefore managed under a different piece of legislation and the Panel for Plant Protection Products and their residues (PPR) is responsible for these issues within the EFSA.

There are no examples of how an assessment by several different panels within the EFSA works in practice, as the EFSA has not yet made any statement in a matter regarding the cultivation of herbicide tolerant crops. In regulation 178/2002 on general food law, there is a description of how the EFSA is to be structured and what kind of work it should undertake and how. It is made clear here that the EFSA's scientific committee is responsible for making statements in cases that are relevant to more than one panel. This is the case in the example of cultivation of herbicide tolerant genetically modified crops, which would fall within the competence of both the GM panel and the PPR panel.

The possible effects of cultivation of herbicide tolerant crops on human and animal health and on the environment are the same regardless of whether the crop has gained its herbicide tolerance as a result of gene technology or through a different method. However, only genetically modified crops must be approved before they can be cultivated within the EU. Cultivation of crops that have been made herbicide tolerant with methods other than those that, according to the definition in the current legislation, result in genetically modified organisms, is allowed and does not require permission. Such crops are not subjected to an investigation of their effects on their surroundings.

2.3.5 Coexistence

In 2003, the Commission decided that no form of agriculture should be excluded in the EU and that farmers should be able to choose between production of conventional, organic or genetically modified crops while also following the laws that exist in relation to labelling and standards for varietal identity[3]. This has been termed coexistence and ensures the farmer the right to cultivate a non-genetic modified crop without risk of economic losses because of the possible consequences of admixture from nearby fields containing genetically modified crops.

The Commission has also published recommendations and guidelines on the best way for the member states to develop national strategies or regulations for coexistence. It has not been judged to be possible to have common regulations for the entire EU, since conditions vary so widely between different member states. As a result, all member states have been allowed to develop their own regulations.

In Sweden, at the end of May 2007, regulation (2007:273) was passed on cautionary measures in cultivation, transport and other handling of genetically modified crops.[4] The regulation also contains provisions on registration of cultivation with the relevant authority as well as providing information to other entrepreneurs with nearby agricultural land. There are also provisions on measures to be taken to prevent admixture and financial damage for others, as well as an authorisation that gives the Swedish Board of Agriculture the opportunity to

[3] http://www.sjv.se/download/18.145934e108234077158000823/KOMs+rekommendation.pdf

[4] http://www.notisum.se/rnp/sls/lag/20070273.htm

prescribe further cautionary measures. The Swedish Board of Agriculture is currently developing these regulations, which are expected to enter into force in the spring of 2008.

A special investigation of the issue of responsibility in the cultivation of genetically modified crops was completed in spring 2007 (SOU 2007:46). The investigation included an analysis of the need for special compensation rules in the case of financial damage as a result of the spread of genetically modified organisms to non-genetically modified crops.

2.4 How is a plant protection product approved?

Regulations for review and approval of a plant protection product before it can be released onto the market are harmonised within the EU. In order for a plant protection product to be released on the Swedish market, it must be approved for a specific area of use by the Swedish Chemicals Agency. Information on testing and approval of plant protection products is available on the Swedish Chemicals Agency's website[5].

Plant protection products are regulated in EC directive 91/414/EEC, which has been included into national legislation in Sweden. There is a joint process for assessment of the active ingredients in plant protection products within the EU[6]. Ingredients that fulfil the requirements of the directive and are judged to be acceptable from a health perspective and an environmental perspective, following a vote among the member states, are listed in appendix 1 to EC directive 91/414/EEC. After the active ingredient has been added to appendix 1, there is a process of product approval in order for use of the plant protection product to be approved in each member state. Plant protection products that are judged by the Swedish Chemicals Agency to be acceptable and to fulfil the conditions in annex 1 and annex 6 of EC directive 91/414/EEC are approved for the Swedish market for a maximum of 10 years. Thereafter, a further assessment of the plant protection product must be carried out before its period of approval can be extended.

For the purpose of assessment of the active ingredient within the EU, substances are divided into new and existing substances. Existing substances are those that were available on the European market in 1993 and new substances are those that have appeared since then. Supervision of existing substances has been divided into four stages and is divided between the different member states. There are EC regulations that give provisions outlining how this work should be carried out. There are strict requirements for substances to be well investigated and documented. Existing substances that lack complete documentation may not exist on the European market after 2003. These substances are listed in EC regulation 2076/2002. Detailed and extensive information must be submitted to the documentation on the substance, including its chemical and physical properties, its effects on health and the environment as evaluated according to tests that conform to certain protocols (eg the OECD Guidelines for Testing of Chemicals), selectivity, effectiveness, resistance and planned area of use with calculations for exposure affecting people and the environment. Assessments of people's exposure to the substance must include those who spread the substance, those in the surroundings of the area to be sprayed, and consumers who may take in residue and/or metabolic products of the herbicide via food products.

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[5] www.kemi.se / Bekämpningsmedel / Växtskyddsmedel, 2007-08-22

[6] http://ec.europa.eu/food/plant/protection/evaluation/index_en.htm , 2007-08-22

2.4.1 Risk, spread and sustainable use of pesticides

Even if a plant protection product is approved, there may still be risks connected with its use. For example, it could be spread over a wider area than planned, through carelessness or transport via wind or water. Test results show that remnants of plant protection products are found in surface water and ground water. In Sweden, legislation for pesticides has been supplemented by special national action programmes to achieve reduced risks. Elements of these programmes agree with the proposed framework directive for sustainable use of pesticides that the Commission submitted to the Council and the Parliament in July 2006. Tightening of the regulations, alongside voluntary measures within the framework for national action programmes for plant protection products are extremely significant for risk reduction in Sweden.

Within the EU, seven prioritised environmental problems have been highlighted in connection with the implementation of the 6th environmental action programme. One of these is the risks associated with pesticides. Joint guidelines will now be drawn up in order to reduce these risks. In 2002, the EU Commission submitted its proposals in the report ”Towards a thematic strategy on the sustainable use of pesticides”. The Commission’s report includes the following proposals:

- All member states shall develop national action programmes. These must include descriptions of how particularly sensitive areas are to be protected, as well as technical improvements in equipment for spreading and protection.
- Increased control of usage and spread.
- The substitution principle shall be included in the current regulatory framework. This principle states that hazardous substances are to be replaced with less hazardous ones.
- Forms of cultivation with limited or no use of pesticides are to be promoted.
- Regular reporting.

Within the EU at the moment, a framework directive containing these points is being drawn up for sustainable use of pesticides.

2.5 Environmental quality objectives

In 1999, the Swedish parliament decided on a new structure for its work with environmental objectives, involving the establishment of 15 environmental quality objectives. A decision on a 16th environmental quality objective was taken by the parliament in 2005. These objectives are in turn divided into a total of 72 targets. The aim of the environmental quality objectives and the overall work on environmental issues is to give the next generation a society where the major environmental problems in Sweden are solved. The environmental quality objectives have been drawn up on the basis of the environmental impact that nature can sustain, and they define the environmental state that this environmental work should be aiming for (Government proposition 2004/05:150).

2.5.1 A non-toxic environment

Work to create *A non-toxic environment* is based on preventing damage to human health or to the environment caused by chemical elements, products (including plant protection products), and goods. Knowledge of the properties of chemical elements is essential if we are to understand the ways in which these elements could damage human health and the environment, and to prevent this damage from being done. This means that chemical elements

and products must be well investigated in terms of the health and environmental risks they present, and that this information must be passed on those who use these chemical elements and products. In addition, as harmless products as possible must be selected, and substances that are hazardous to health or the environment must, wherever possible, be replaced with less hazardous and if possible harmless substances or other methods. Health and environmental risks presented by use of chemicals must also be removed through safe handling.

The environmental quality objectives are described on the environmental objectives portal[7]. According to the government's assessment (proposition 2004/05:150) and from a generational perspective, the *A non-toxic environment* objective should include the following:

- The levels of elements that occur naturally in the environment are close to the background levels.
- The levels of elements that do not occur in nature are close to zero and their effects on the ecosystem are negligible.
- All fish in Sweden's seas, lakes and waterways are suitable for human consumption in terms of their content of elements that do not occur in nature.
- Overall exposure to particularly hazardous elements in the working environment, the outdoor environment and indoors is close to zero and any exposure to other chemical elements is not hazardous to humans.
- Polluted areas are investigated and where necessary appropriate measures are taken.

There are nine targets for *A non-toxic environment* objective. Herbicide tolerance is dealt with primarily in targets 1-4. Targets 1 and 2 are fulfilled as plant protection products must be investigated and dangers and risks in their area of use must be known before they can be used. As such, the knowledge and information objective is built in to the testing of plant protection products.

When the plant protection products directive came into force in the early 1990s, there were approximately 900 active substances on the market[8]. Now more than half of these have been recalled by their manufacturers and around 450 substances/organisms remain. Of the 219 active substances/organisms that have been assessed jointly by the EU, 59 have been banned. The reasons for these bans may be risks for consumers, operators, pollution of groundwater, etc. However, 13 substances that have previously been banned in Sweden have, despite Swedish opposition, been added to the directive's list of approved substances. Of the 160 active substances/organisms that have been accepted within the EU for use in plant protection products, around half are available on the Swedish market.

Target 1, before 2010/2020. Knowledge of the properties of chemical substances in terms of health and the environment. By the year 2010, information must be available on the properties of all deliberately produced or extracted chemical substances that are available on the market.

Target 2, 2010. Health and environment related information for products. By 2010, all products must be supplied with health and environment related information on the hazardous substances that they contain.

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[7] www.miljomal.nu, 2007-08-22

[8] Basis of information for the second in-depth evaluation of the environmental objective *Non-toxic environment*, 2007-09-28.
http://www.miljomal.nu/las_mer/rapporter/myndigheter/malrapporter/4_giftfri_miljo/Underlag_till_fordjupad_utvardering2_Giftfri_miljo 2007-10-16.

Target 3, 2007/2010. Phasing out of hazardous substances

In terms of phasing out hazardous substances, the following apply. New products shall, as far as possible, be free from:

- new organic substances that are long-lived (persistent) and bioaccumulating, new carcinogenic and mutagenic substances and substances toxic for reproduction, and mercury as soon as possible and by 2007 at the latest,
- other carcinogenic and mutagenic substances and substances toxic for reproduction, and all hormone disrupting and allergy causing substances, by the year 2010 if the products are designed for use in such a way as to enter the ecosystem,
- other organic substances that are long-lived and bioaccumulating, as well as cadmium and lead, by the year 2010.

These substances should not be used in production processes either, unless the company can prove that there is no risk of damage to human health or the environment.

Existing products that contain substances with the properties detailed above shall be handled in such a way as to prevent release of these substances into the environment.

Spread of substances covered by this objective to Sweden via air and water shall be reduced on an ongoing basis.

This objective covers substances that are produced or extracted from nature by human hand. The objective also covers substances that give rise to substances with the properties mentioned above, including those that are produced unintentionally.

Target 4, 2010. Continuous reduction of the health and environment related risks of chemicals. The health and environment related risks of production and use of chemical substances shall be reduced on an ongoing basis until the year 2010, according to indicators and key figures that are to be set up by the appropriate authorities. During the same period, the occurrence and use of chemical substances that hinder the recycling process are to be reduced.

2.5.3.1 Phasing out – target 3

'Particularly hazardous substances' include the following: i) substances that are persistent and bioaccumulating; ii) substances that are carcinogenic or mutagenic or toxic for reproduction; and iii) hormone disturbing substances or substances that provoke strong allergic reactions.

The Swedish Chemicals Agency have worked together with the Nordic and Baltic countries to submit a joint proposal to the Commission regarding the establishment of criteria for phasing out particularly hazardous substances in plant protection products[9]. Much of this proposal was reflected in the official proposed plant protection product regulation presented by the Commission in June 2006. The criteria now proposed are in close agreement with target 3. The government and the Swedish Chemicals Agency are now involved in negotiations on the new regulation to ensure the criteria are not weakened.

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[9] Basis of information for the second in-depth evaluation of the environmental objective *Non-toxic environment*, 2007-09-28.
http://www.miljomal.nu/las_mer/rapporter/myndigheter/malrapporter/4_giftfri_miljo/Underlag_till_fordjupad_utvardering2_Giftfri_miljo 2007-10-16.

The Swedish Chemicals Agency proposes that a national action programme for plant protection products be developed with support from the EU strategy for sustainable use of plant protection products, in order to counteract the use of plant protection products that contain particularly hazardous substances.

2.5.3.2 Risk reduction – target 4

In an evaluation[10] of *A non-toxic environment*, indicators of the levels of plant protection products show that the estimated health and environment related risks have decreased significantly over a fifteen-year period. However, despite the reduction in risks, developments in certain areas are still going in the wrong direction. The intensity of use of plant protection products (measured in number of hectare doses) has not decreased over the same period, which is partly the result of a move towards cultivation of crops that require more intensive usage of plant protection products. It is also possible that products or areas of use that are currently prohibited in Sweden may become approved again as a result of joint EU legislation. From a more long-term perspective (one generation), comprehensive changes will be needed in order to move away from the current chemical dependence of the food production process. This will require initiatives to develop and implement alternatives to chemical pest control. Use of pesticides involves the intentional spreading of chemical substances with hazardous properties. Significant developments of pesticides and pest control methods are needed in order to reach this target within a reasonable time frame.

The Commission has proposed that the product choice principle should be included in a future plant protection product regulation. This proposal means that candidate substances for substitution will be established at an EU level and that the product choice principle will be applied to plant protection products that contain these substances, following a comparative assessment of different plant protection products. The government and the Swedish Chemicals Agency are now involved in council negotiations to ensure that the regulations remain in line with this target.

2.5.2 A varied agricultural landscape

The environmental quality objective *A varied agricultural landscape* entails protection for the value of agricultural landscape and agricultural land for biological production and food production, as well as retention and strengthening of biodiversity and natural and cultural heritage. This environmental quality objective consists of six targets.

The agricultural landscape is home to a large proportion of our flora and fauna. These species are primarily found in haymaking and grazing land but also on the edges of fields and roads, field copses, wetlands and other small biotopes. Many of these living environments also have a cultural historic value that helps us to recreate a picture of early agricultural methods used in the agricultural landscape. In order for this objective to be reached, it is important that there is involvement and commitment both from the affected farming community and the general public. We also need solid knowledge of the necessary measures. This environmental objective is affected by the Common Agricultural Policy (CAP) of the EU and many measures are now implemented with the help of support for environmentally friendly farming.

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[10] Basis of information for the second in-depth evaluation of the environmental objective *Non-toxic environment*, 2007-09-28. http://www.miljomal.nu/las_mer/rapporter/myndigheter/malrapporter/4_giftfri_miljo/Underlag_till_fordjupad_utvardering2_Giftfri_miljo 2007-10-16.

From a generational perspective, *A varied agricultural landscape* should include the following, according to the government's assessment:

- Arable land should have a well-balanced nutritional state, good soil structure and topsoil content, and as low levels of pollutants as possible, so that there is no threat to the ecosystem and human health.
- The agricultural landscape is farmed in such a way as to minimise negative environmental effects and favour biodiversity.
- The land is farmed in such a way as to maintain its long-term production capacity.
- The agricultural landscape is open and rich in variation, with significant elements of small biotopes and water environments.
- The biological and historical value of the agricultural landscape, which is the result of its long history of traditional management, should be maintained and improved.
- Any buildings and settlements of particular value on the agricultural landscape should be preserved and developed.
- Threatened species, types of natural environments and environments of historical and cultural value should be protected and preserved.
- The agricultural landscape's non-domesticated plant and animal species should have their habitats and propagation routes guaranteed.
- Genetic variation among domesticated animals and plants should be protected. Cultivated plants should be preserved as much as possible in their historic places.
- Foreign species and genetically modified organisms that may threaten biodiversity should not be introduced.

These targets are primarily expressed as a *quantitative* measure of how many (or what size of) arable areas of different types are to exist by 2010. In terms of the effects of herbicide tolerant crops on the environmental objectives, it is primarily the *qualitative* aspects of the types of natural environments that are affected and it is this aspect that discussions will focus on.

2.5.3 A rich diversity of plant and animal life

The aim of the environmental quality objective *A rich diversity of plant and animal life* is for biodiversity to be preserved and utilised in a sustainable way, for current and future generations. The living environments and ecosystems of all species, as well as their functions and processes, should be protected. Species must be able to survive in the long term, with a robust population and sufficient genetic variation. People must have access to a healthy natural environment with rich biodiversity, as the basis of health, quality of life and welfare. This environmental objective covers all the biodiversity we have in our country, not only the biodiversity that is of particular importance for quality of life and welfare.

This environmental objective is the sixteenth, and was added as a supplement to earlier environmental objectives, primarily objectives relating to different natural environments (*Sustainable forests, A balanced marine environment, Flourishing coastal areas and archipelagos, A varied agricultural landscape, A magnificent mountain landscape,* and *Thriving wetlands*). The objectives or measures that affect biodiversity in a particular type of environment are mentioned under the objective for that type of environment. Horizontal issues and objectives relating to biological resources are dealt with under *A rich diversity of plant and animal life*. This environmental quality objective seeks to establish more effective,

focused and better-coordinated work to ensure preservation and sustainable use of biodiversity. In this government investigation, we have chosen to carry out a combined assessment of the possible effects on the two environmental objectives *A varied agricultural landscape* and *A rich diversity of plant and animal life*.

The environmental objective *A rich diversity of plant and animal life* contains three targets:

Target 1. Loss of biodiversity must be stopped by the year 2010.

An international commitment covering diversity at all levels, from a gene level to a species level to an ecosystem level. At a gene level, genetically valuable and distinctive populations must be retained until 2010. Parallel to this, we need to improve our insufficient knowledge of genetic variation in order to be able to care for it as part of the work to fulfil the environmental objectives. At a species level, this target involves breaking the downward trend in the preservation status of certain species, and ensuring that species that currently have a favourable status maintain that status. At an ecosystem level, the target involves maintaining the functions and processes of the ecosystem and as such their capacity to cope with change and to develop in order to be able to supply goods and services. The objective also involves putting a stop to the loss of types of environment and living environments that have been in decline in recent years.

Target 2. Decrease the proportion of threatened species by the year 2015

By improving the status of threatened species in all ecosystems (seas, forests, agricultural landscapes etc), the proportion of species that are classified as threatened should be reduced by 30% by the year 2015, and no further species should die out. This objective is to be reached by actual improvements for all relevant groups of species. This target should be seen as a continuation of the targets that have already been established on action programmes.

Target 3. By the year 2007, there should be methods in place to ensure that biodiversity and biological resources, on land as well as in water, are utilised in a sustainable way.

By the year 2010, biodiversity and biological resources, on land as well as in water, are utilised in a sustainable way, so that biodiversity is maintained at a landscape level.

The aim of this target is to gain a landscape perspective on biodiversity, which earlier environmental quality objectives dealing with biodiversity and biological resources only deal with to a limited extent, as they focus primarily on the various separate ecosystems such as forests, agricultural landscape, lakes and seas. This objective supplements the sustainable utilisation mentioned in the other environmental quality objectives and at the same time creates a better balance between preservation and utilisation. The objective on sustainable utilisation is a prerequisite for achieving targets 1 and 2.

From a generational perspective, *A rich diversity of plant and animal life* should, according to the government's assessment, include the following:

- Societal initiatives for preservation of biodiversity should be managed from a landscape perspective on ecosystem management. The ecosystems' ability to act as buffers, i.e. their ability to cope with changes and develop further, should be maintained so that they can continue to be productive and deliver goods and services.
- The landscape, lakes and seas are constituted in such a way as to ensure that species have their habitats and propagation routes ensured.
- There are sufficient living environments for the preservation of robust species populations in the long term (favourable preservation status).

- In areas where important types of environment have been damaged, they should be restored, thus improving the conditions for biodiversity.
- Species are spread out in their natural spreading areas in the country, so that there is sufficient genetic variation within and between populations.
- Foreign species or genetically modified organisms that may be a threat to the health of humans or threaten or deplete biodiversity in Sweden shall not be introduced.
- Biodiversity is preserved primarily through a combination of sustainable use of biological resources, preservation of species and their living environments, and measures to minimise the effects of pollution and limit the effects of climate change.
- People have access to nature and areas of natural and cultural heritage with a rich diversity of plant and animal life, which in turn contributes to a healthy population.
- Our biological heritage is managed to ensure that important natural and cultural elements remain.
- Society and its citizens have wide knowledge and understanding of the importance of biodiversity. Traditional and local knowledge of biodiversity and utilisation thereof is preserved and used where appropriate.

The government's proposal in relation to the environmental objectives (Prop. 2004/05:150 Svenska miljömål - ett gemensamt uppdrag) states that biodiversity should also include normal species and that the important aspects of biodiversity are at ecosystem level.

The ongoing work to evaluate this environmental quality objective has established that target 1 will be extremely hard to fulfil, even if different control mechanisms and measures are put in place. This is partly due to the fact that in some areas it is unclear which measures are needed (such as ensuring genetic variation). The trend towards more threatened species is still negative. These include birds in the agricultural landscape. Reporting according to article 17, the species and habitat directive, showed that around three quarters of types of environment and around half of all species, do not have a favourable preservation status. Naturally, these results are of great importance for target 2 also.

Target 2 is thought to be within reach on the condition that the action programmes for threatened species are carried out, and that areas of great natural value are taken care of in accordance with the content of the objectives on types of environment.

Target 3 is judged to be extremely difficult to reach. One indication is the first decline in common species and in several species and types of environment from the species and habitat directive. It is judged to be extremely difficult to reach a situation of sustainable utilisation of biodiversity and biological resources, on land and in water, by 2010. This is primarily because the transitions in agriculture, forestry and fisheries, and society in general, take time to implement. In order to fulfil this target, it is judged to be important that the landscape perspective permeates all this work, to ensure that attention is paid to the effects of actions taken outside the area that is directly relevant.

In the context of the in-dept evaluation and in the government investigation 'GM and the environmental quality objectives (Swedish Nature Preservation Society)', the importance of including genetically modified organisms in the sectoral authorities' own government investigations of sustainable utilisation of biological resources was emphasised.

3 Current knowledge

3.1 History and where herbicide tolerant crops are grown

The commercial introduction of genetically modified crops took place in 1996 on 1.7 million hectares in 4 countries. In 2006, genetically modified crops were cultivated on 102 million hectares in 22 countries. The predominant countries are the USA, Argentina, Canada and Brazil. Herbicide tolerant crops are grown on around 80 percent of the acreage, and the remaining 20 percent are insect resistant crops (James 2006, Brookes & Barfoot 2006). The dominant crops are soya, maize, rape and, to a certain extent, cotton.

- Herbicide tolerant soya beans are grown on 64 percent of all soya bean acreage in the world. The largest producers are the USA, Brazil and Argentina.
- Herbicide tolerant rape is grown on 18 percent of the total global acreage of rape. Herbicide tolerant rape is only grown in the USA and Canada where it makes up more than 80 percent of the total rape acreage.
- Herbicide tolerant maize is grown on roughly 50 percent of the maize acreage in the USA. In Canada this figure is around 35 percent. South Africa and Argentina have recently introduced herbicide tolerant maize, so far only on a minor scale.
- Herbicide tolerant cotton is grown on around 60 percent of the cotton acreage in the USA. Other countries with extensive cultivation of herbicide tolerant cotton are Australia, Argentina and South Africa.

The EU accounted for only 0.2 million hectares of the total of 102 million hectares of genetically modified crops that were grown in 2006. In 2006, genetically modified maize with insect resistance, known as Bt-maize (*Bacillus thuringiensis*), was grown in Spain, Portugal, France, the Czech Republic, Slovakia and Germany. In Romania, around 100,000 hectares of herbicide tolerant soya was grown. As of 2007, Romania is a member of the EU and as such must now follow EU legislation. Herbicide tolerant soya is not approved for cultivation in the EU and as such its cultivation is not permitted, neither in Romania nor in any other member state.

3.2 Experience

During the 20th century, agricultural practice changed radically, both in Sweden and in the rest of Western Europe (Donald et al, 2001). An increased level of mechanisation, development of technology and increased international competition have led to rationalisation and intensification of agriculture. Small farms have either been closed down or merged with others to form larger units, obstacles to farming have been removed and marshlands have been drained (Aronsson and Matzon 1987). This process, in combination with more effective fertilisation and pest and weed control, has contributed to increasing agricultural output significantly while also depleting biodiversity. The introduction of herbicide tolerant crops should therefore be seen as a continuation of an ongoing process of rationalisation in modern agriculture.

Cultivation of genetically modified herbicide tolerant crops can affect biodiversity both directly and indirectly (Dale et al, 2002). Direct effects mean that the crop itself causes problems via undesired pollination of wild plants that are reproductively compatible, or by spread of the genetically modified crop beyond the boundaries of the cultivated area where it alters conditions for other species. Indirect effects mean that the crop causes changes in the

use of plant protection products or in cultivation technique, which in turn affect biodiversity (table 1).

Table 1. Summary of possible effects of cultivation of herbicide tolerant crops (HT crops) on biodiversity. The table deals only with herbicide tolerant crops but the same effects can be caused by conventional crops. The table concerns herbicide tolerant forms of maize, winter rape, spring rape, and sugar beet. The direct effects of genetically modified maize are negligible, since no wild relatives of maize grow in Sweden. The table is a modified version of the one in Sanvido et al, 2006, and is read by column, from top to bottom.

	Direct effects		**Indirect effects**	
Possible effects on biodiversity with introduction of herbicide tolerant crops:	Gene flow from HT crops to wild relatives (pollination) and other crops.	HT crops are established and reproduce outside the areas where they are cultivated.	Weeds develop resistance (via natural selection or hybridisation).	Changed behaviour of farmers in cultivation of HT crops.
Leads to:	Appearance of herbicide tolerant hybrids outside the cultivated fields and in other crops	HT crops compete with wild species.	Specific herbicides lose their effect.	Changes in methods of weed control and farming.
Leads to:	Increased or decreased viability compared with wild relatives. Genetically modified organisms are mixed in with conventional crops.		Changes in weed control strategies.	Effects on the soil's physical, chemical and biological composition.
Effect:	Effect on wild relatives and their survival. Negative effects on other crops.	May affect other species and ecosystems including effects at gene level.	More intensive weed control, affecting other species, not just weeds.	Effect on the occurrence and species composition of weeds and insects and higher trophic levels.

3.2.1 Direct effects

The direct effects of cultivation of herbicide tolerant crops include the spread of the modified properties to related wild species or to fields containing conventional variants of the same crop. Gene spread includes everything from the physical spread of individuals, seeds, pollen etc, to introduction of the genes through hybridisation, subsequent recrossing and incorporation into the wild population's gene pool (known as introgression) (Swedish Environmental Protection Agency, 2006). The result is hybrid species that may carry the modified gene. If the hybrid gains a property that gives it a competitive advantage in relation to its wild relatives and other wild plants this may imply that the hybrid spreads at the expense of the wild species, bringing a negative effect on biodiversity. The property could also give the hybrids a competitive disadvantage in relation to its wild relatives. Repeated hybridisation between genetically modified and wild species could therefore reduce the average fitness of wild species, which may have a negative effect on these species' long-term survival. Greenhouse studies of hybrids of genetically modified rape (*Brassica napus*) made tolerant of glufosinate ammonium with wild turnip (*Brassica rapa*) showed a reduced fitness on the part of the hybrid plants with the herbicide tolerance property (Snow et al, 1999). As such, it seems there is no increased cost for the property of herbicide tolerance. However, it should be pointed out that greenhouse studies do not always adequately reflect the selection pressure that exists in natural conditions, and as such, the hybrids may harbour costs that are not visible in the context of greenhouse studies. It is also extremely important to point out the lack of basic research in this area, particularly in Sweden. It is also difficult to say whether the results of short-term empirical fitness studies are suitable for use in predicting long-term effects. For example, the fitness of the hybrid may be modified over time as a result of evolutionary changes in the recipient population (Swedish Environmental Protection Agency, 2006).

In terms of herbicide tolerant crops, it is primarily sugar beet (*Beta vulgaris*) and rape (*Brassica napus)* which may, under Swedish conditions, hybridise with related wild species. Hybridisation with wild relatives is a limited problem in sugar beet since they are not usually allowed to bloom. The only wild relative that a blooming sugar beet could hybridise with in Sweden is the rare subspecies sea beet (ssp. *maritima*). Hybridisation could also take place with cultivated beet varieties, such as beetroot, mangelwurzel and mangold.

The cultivated strains of rape are sexually compatible with other cultivated or wild rape plants. In addition, they could cross with other *Brassica* species and a small number of wild species of other types within the family *Brassicaceae*. These include wild turnip (*Brassica rapa*), mustard greens (*Brassica juncea*) and wild radish (*Raphanus raphanistrum*). Wild radish is now red-listed and categorised as a near threatened species. Mustard greens are also red-listed and establishes itself temporarily on ruderal land. Wild turnip used to be a common weed but it has become less and less common on the agricultural landscape. Hybrids of rape and wild turnip have been found in fields and in their immediate vicinity. Rape can also hybridise with field mustard (*Sinapis arvensis*) but the offspring has not been found to be fertile.

Maize does not have any close wild relatives in Sweden. This eliminates the risk of hybridisation and spread of the introduced property, and as such eliminates the threat to biodiversity.

Although hybridisation can occur between herbicide tolerant crops and related wild species, herbicide resistance probably does not give the hybrid a selective advantage outside the area that is regularly treated with herbicide (Dale et al, 2002, Squire et al, 2003). There may be an effect on the border areas of the cultivated area, to the extent that spray drift of pesticides

from the treatment of the cultivated area occurs. As such, herbicide tolerance can, in the majority of cases, be seen as a neutral characteristic for hybrids, and thus it has no direct effect on their fitness or on biodiversity outside the cultivated area.

Spread and establishment of herbicide tolerant crops in areas outside the cultivated area probably would not imply any direct effect on biodiversity either. The competitive advantage that herbicide tolerance brings to plants in areas that are regularly treated with weed killer disappears if the plants manage to establish outside these areas. Areas outside fields that are regularly treated with herbicide or that may be treated with herbicide are primarily railway embankments. There is a possibility that herbicide tolerant plants establish and spread in these environments, which may have a negative effect on the original flora and fauna.

Hybridisation between herbicide tolerant crops and closely related wild species may result in a weed that is difficult to control, but this is primarily an agronomic problem and as such it is not discussed in connection with the *direct* effects of herbicide tolerance on biodiversity. However, more intensive methods of combating these kinds of weeds may lead indirectly to negative effects on biodiversity and this is discussed in more detail below. Hybridisation between cultivated crops and close wild relatives does occur and may present a threat to biodiversity, but in the above review, only the hybrid's characteristic of herbicide tolerance has been analysed. A detailed review of gene spread and the possible ecological effects thereof is given in the Swedish Environmental Protection Agency's report *Ekologiska effekter av GMO* (Ecological effects of GMOs, Palm & Rydan 2006).

The spread of pollen from fields containing genetically modified herbicide tolerant crops to fields containing conventional varieties may, if the spread is sufficiently extensive, put the conventional crop at a disadvantage, as the crops must then be marked and handled as genetically modified crops. An Australian review of gene spread from commercially cultivated, genetically modified, herbicide tolerant rape to fields containing conventional equivalents, at different distances, showed that gene spread from the genetically modified rape had appeared in 63% of the fields, as far as 3 km from the field containing the herbicide tolerant rape (Rieger et al 2002). However, the contamination level was extremely small (< 0.03%). A meta analysis of Damsgaard and Kjellson (2005) points to the conclusion that 50 m is a sufficient distance between conventional and genetically modified rape in order to keep the contamination level under 0.3%.

3.2.2 Indirect effects

In this context, indirect effects are the effects on biodiversity that result from a change in cultivation technique in connection with the change from conventional crops to herbicide tolerant ones. For example, changes in cultivation technique may include use of new plant protection products, changing the quantities of plant protection product used and changing the time of treatment. Alterations in the cultivation method as a result of cultivation of herbicide tolerant crops also constitute a changed cultivation technique.

The indirect effects that may result from cultivation of herbicide tolerant crops are the effects that have the most significant impact on biodiversity and as such the analysis in this report will focus primarily on these effects.

3.2.3 The herbicides concerned

There are currently seven products containing five active substances (bentazone, thifensulfuron-methyl, chlopyralid, fluroxypyr and rimsulfuron) that are approved for use in the cultivation of maize, seven products for rape also with seven active substances (metazachlor, quinmerac, cycloxydim, clomazone, clethodim, chlopyralid and propyzamide)

and for sugar beet, there are ten products that are approved for use against weeds, and these contain nine different active substances (tepraloxydim, phenmedipham, quinmerac, cycloxydim, metamitron, ethofumesate, diquat bromide (only for cultivation of sugar beet seeds) and triflusulfuron-methyl). The substances occur in the products both alone and in combination. Of the active substances, phenmedipham, metamitron and ethofumesate are used the most for sugar beet, metazachlor, quinmerac and chlopyralid are used the most for rape, and rimsulfuron, bentazone and thifensulfuron-methyl are used the most for maize. With the introduction of herbicide tolerant maize, sugar beet or rape, two more active substances could be used: glufosinate ammonium and glyphosate.

In order to assess whether there would an increase, decrease or no change in the health and/or environmental risks with the use of the two 'new' active ingredients, the most commonly used substances have been compared with glyphosate and glufosinate ammonium (appendix 2). For these substances, a modified risk index has been carried out using a method developed by Bergkvist (2004).

3.2.3.1 Bentazone

Bentazone is a selective contact herbicide that inhibits photosynthesis. It is absorbed primarily by the leaves and there is very little transport of the substance into the plant. Bentazone is also absorbed by the roots, and primarily transported in the plant's sieve tubes.

In animal tests bentazone has moderately high acute toxicity. Bentazone has also caused notable but non-lasting eye irritation. After repeated delivery of high doses, bentazone has had effects on the kidneys and liver. There are indications that high doses of bentazone reduce foetal weight in pregnant rats and rabbits. However, at a dosage that represents the equivalent of the recommended level, there is no indication that bentazone causes chronic damage.

Bentazone has extremely high mobility in the ground. The results of lysimeter field studies do show a considerably lower elution than the results of laboratory studies, but tests taken in waterways show that bentazone is of frequent occurrence there. Bentazone has moderate acute toxicity for water borne organisms. In Sweden, bentazone has found in groundwater, in water from drinking wells and in flowing waterways.

3.2.3.2 Thifensulfuron-methyl

Thifensulfuron-methyl is a systemic herbicide that is absorbed through leaves and roots. Cell division and growth come to a stop at the plant's growth points, as a result of inhibition of the function of the enzyme acetolactate synthase (ALS), which is active in the creation of two vital amino acids.

The toxicity of thifensulfuron-methyl is low, with single dose treatment of laboratory animals and with repeat treatment over a long period. The substance is not judged to be carcinogenic or to damage the genetic make-up. In tests on rats, there was a slight negative effect on ossification in the foetus when high doses were applied. Thifensulfuron-methyl does not cause irritation or sensitisation of the skin, nor does it cause irritation of the eyes.

Thifensulfuron-methyl has high mobility. Its mobility is increased in soil with a high pH value and low organic matter content. The high mobility can constitute a risk that the substance may be transported to groundwater and surface water. It has been found in drinking water, but not in groundwater. The primary degradation mechanism involves hydrolysis. The rest of the degradation process is slow. Thifensulfuron-methyl has a low acute toxicity for birds, fish and water fleas. Toxicity is extremely high for free-floating aquatic plant duckweed (*Lemna minor*) and for algae. This should be placed in context by saying that with normal

dosage, the amounts of thifensulfuron-methyl that escape into the environment are extremely small.

3.2.3.3 Rimsulfuron

Rimsulfuron is a systemic herbicide and is absorbed by leaves and roots. It is transported to the plant's active parts, where acetolactate synthase (ALS), the key enzyme in the synthesis of branched amino acids, is inhibited. This stops the growth of the plant's roots and shoots.

Long-term exposure to relatively high doses of rimsulfuron caused reduced growth and increased liver and kidney weight in the laboratory animals. Apart from this, the health risks are judged to be minor, as the substance is designed for use in low concentrations.

Rimsulfuron is converted relatively quickly, primarily through hydrolysis, to two stable metabolites. Rimsulfuron has a high expected mobility in soil, and the two metabolites have shown the potential for mobility in soil column tests. The mobility and persistence of rimsulfuron and its two primary metabolites bring an increased risk of spread in the environment. Rimsulfuron has a moderately high acute toxicity for algae and an extremely high toxicity for *Lemna*. Contamination of surface water may therefore constitute a risk of negative effects on water borne plants. Levels of rimsulfuron above the acceptable limit have been found in surface water in the last sixteen years, but not in groundwater.

3.2.3.4 Phenmedipham

Phenmedipham is a selective contact herbicide that is absorbed in the plant's leaves and inhibits photosynthesis in most dicotyledonous plants.

The animal tests carried out show that phenmedipham has low acute toxicity. There is no evidence that phenmedipham causes allergies, skin irritation, tumours, damage to genetic material, or reproductive or foetal effects. In sub-chronic and chronic studies, changes have been observed that indicate that phenmedipham can cause anaemia. There is no information available concerning its effects on humans.

Phenmedipham is relatively immobile in soil, as a result of strong adsorption to soil, low vapour pressure and low solubility in water. Since phenmedipham creates a strong bond with soil particles, particle-bound substance transport should be possible, with wind transport and drainage of surface water. MHPC, the product of hydrolysis, is significantly more mobile, but as a result of its rapid breakdown the risk of leakage is still judged to be low. Hydrolysis of phenmedipham to MHPC is the dominant degradation process, especially in basic conditions. The acute toxicity is low to moderate for land-living organisms (birds, bees and earthworms) and moderately high to extremely high for water-borne organisms (*Lemna*, water fleas and algae). The effects on the latter group are particularly serious as phenmedipham also shows bioaccumulative properties. It is also worth noting that the effects on green algae can appear even with very low levels of phenmedipham in the water.

3.2.3.5 Metamitron

Metamitron is a triazine derivative and is absorbed by roots and leaves. It inhibits photosynthesis.

Metamitron is absorbed quickly and almost entirely with both low and high dosage, and the highest concentrations are found in the liver and kidneys. Metamitron has a moderately high acute oral toxicity and a low acute dermal toxicity. The substance does not irritate the skin or the eyes, and it does sensitise the skin. Metamitron is not mutagenic, genotoxic or carcinogenic. It has not shown any properties that are toxic to reproduction.

Metamitron shows high mobility in several studies, and spread beyond the target area is probably primarily caused by leakage through soil and surface drainage. In monitoring investigations, metamitron has been found in surface and drainage water situated beside the sprayed area and after heavy rain. This risk is highest for sandy soil types. Metamitron has also been found in groundwater. The relatively fast degradation process reduces the risk of residual effects. Its toxicity for algae and *Lemna* is high. The risk of bioaccumulation, toxic effects on soil organisms and poisoning of birds and other land-living vertebrates is considered to be small.

3.2.3.6 Ethofumesate

Ethofumesate is a selective and systemic herbicide that is absorbed by the roots and sprouting shoots and transported to the plant's leaves. Once there, it is though to work partly by inhibiting the development of the waxy covering of the leaf (cuticle).

Ethofumesate is absorbed from the intestinal tract to a high degree, and is distributed to the organs from which it is converted and secreted – the liver and kidneys. The doses used in studies of acute toxicity have been too low in most of the animal tests carried out. Nonetheless, the combined assessment is that the acute toxicity of the substance is low for all types of application. The substance has been found to be mildly irritating for the skin. The liver enlargement that has been observed with repeated application of high doses may be able to be explained by the fact that the substance is broken down in the liver. Ethofumesate is not judged to damage genetic material, or to be toxic to reproduction or to the foetus.

The speed of its primary degradation in soil varies widely. It is slowest under anaerobic conditions (lacking in oxygen), for example in sediment, and with high doses. Complete degradation is probably extremely slow. The toxicity for the majority of organisms tested was moderate to low. Ethofumesate also shows a tendency to accumulate in living organisms. Compounds containing ethofumesate are mostly used to combat troublesome weeds on all soil types. However, there is a risk of leaching in light soil, since the substance is loosely bound to this kind of soil. It has been found in groundwater, above acceptable levels. Ethofumesate has also been found in drinking water.

3.2.3.7 Metazachlor

Metazachlor is a selective herbicide that is absorbed by the hypocotyl and the roots and inhibits germination.

Metazachlor has low acute oral, dermal and inhalation toxicity and does not irritate the skin or eyes. It does, however, have skin sensitisation properties. Animal tests show that in high doses, metazachlor can cause damage to the liver, kidneys and blood. Long-term studies have shown increased frequency of hepatic adenoma and tumour of the thyroid in rats, and cell tumour of the bladder in mice. Metazachlor has not exhibited any effects that are toxic to the reproductive system.

Degradation of metazachlor in soil is moderate to fast. Lysimeter studies suggest that it does not have particularly high mobility, possibly because of its fast degradation. Earlier evaluations suggest a low adsorption to soil particles and as such, a high expected mobility. Metazachlor has been found in groundwater over the acceptable level of 0.1 µg/l. It has also been found in drinking water. Its effects on terrestrial micro-organisms and animals are low to moderate. Toxicity for the aquatic organisms tested is also low to moderate. However, toxicity is extremely high for green algae.

3.2.3.8 Quinmerac

Quinmerac is a systemic herbicide that is absorbed by the plant's roots and leaves. It works by disrupting the function of the roots, causing growth to stop. The remainder of the plant then decomposes.

Quinmerac has low acute toxicity in terms of consumption and exposure of the skin. Tests carried out on animals show that quinmerac does not irritate the skin or eyes and has not been shown to sensitise the skin. The substance is not judged to be carcinogenic, nor to affect genetic material. Based on studies carried out, quinmerac is not thought to have effects on reproduction or on foetal health. However, with extremely high doses, which were toxic for the mother animal, the offspring was also affected.

Quinmerac has high mobility in soil, which could increase the risk of spread beyond the target area via surface drainage and seepage through the soil. Quinmerac has been found in groundwater, surface water and drinking water. Its toxicity for land-living and water-borne organisms is low to moderate. The risk for bioaccumulation of quinmerac in organisms is small, as it has a low solubility in fats.

3.2.3.9 Chlopyralid

Chlopyralid is a systemic herbicide that is absorbed by the plant's leaves and roots and can be transported both upwards and downwards within the plant. Chlopyralid causes effects similar to auxin and works on both the cell elongation and respiration.

Chlopyralid can cause serious damage to the eyes, such as permanent opacity of the cornea. However, preparations containing up to 40% chlopyralid have not caused the serious eye injuries that have been seen using the pure technical product. The acute oral and dermal toxicity is moderate. A clear mother toxicity has been shown, but with no significant effects on the embryo, foetus, litter size or litter itself.

The degradation of chlopyralid is slow under Swedish conditions. The substance has a high mobility in soil, which is also shown by the fact that it has been found in groundwater and surface water. Levels over 0.1µg/l have been found in groundwater but none of the levels in surface water have been over the acceptable levels. The substance has also been found in drinking water. The substance degrades with difficulty in water-sediment conditions and in anaerobic conditions. As a result, chlorpyralid can accumulate in waterways, constituting an environmental risk. Its toxicity for algae, *Lemna* and *Daphnia* is moderately high.

3.2.3.10 Glufosinate ammonium

Glufosinate ammonium is a contact herbicide that is absorbed via the plant's leaves and inhibits the activity of glutamine synthetase in photosynthesis. As a result of the inhibition of the ammonium metabolism, ammonia accumulates in the plant cells. Ammonia is phytotoxic and kills the leaves within a few weeks.

Glufosinate ammonium has moderate acute toxicity. There is no evidence to suggest that the substance is sensitising, or irritating for the skin or eyes, but it can cause serious health risks when consumed and can also seriously damage health in the case of long-term inhalation. There is also good reason to suppose that the substance can cause foetal damage and that there is a risk of reduced reproductive capacity.

Glufosinate ammonium occurs naturally in the soil. Its degradation in soil is moderate. The degradation process is highly temperature-dependent and to some extent pH-dependent. Glufosinate ammonium is extremely water-soluble and its adsorption to sandy soil is low. As

such there is a risk that the substance may be transported to the surface water or groundwater in unfavourable conditions, such as heavy rain. Its toxicity for *Daphnia* is low and moderate for algae and *Lemna*. Glufosinate ammonium has a low bioaccumulative potential.

3.2.3.11 Glyphosate

Glyphosate is a broad spectrum systemic herbicide. It is primarily absorbed by the parts of the plant that are above ground, and it spreads quickly throughout the plant thereafter. Glyphosate works on at least one of the plant's enzyme systems and its effects include inhibition of the creation of certain amino acids.

Glyphosate has a low acute toxicity in test animals. No serious effects have been noticed after chronic treatment with glyphosate in low doses. As it is an acid, Glyphosate can cause serious damage to the eyes. The toxic effects on reproduction shown with higher dosage must be seen from the perspective that even the mother animal was harmed. No genotoxic or carcinogenic effects have been observed. Reported effects on humans are limited to nausea in milder cases of poisoning, and skin irritation in the case of spillage.

Glyphosate binds readily to the soil and its low vapour pressure indicates that its entry into the soil is negligible. Despite the strong bonds to the soil, glyphosate has been found in Swedish groundwater samples taken between 1985 and 2004, and a handful of these samples exceeded the limit value of 0.1µg/l (Adielsson et al, 2006). Samples taken in 2005 showed the presence of glyphosate but none of the samples were over the limit value (Adielsson et al). The substance has also been found in surface water and drinking water. In a Danish survey carried out between 1999 and 2006 by the Geological Survey of Denmark and Greenland (GEUS), it was found that glyphosate only leaks through a soil profile with light clay (Kjær m. fl. 2007). In soil with normal microbial activity, glyphosate is broken down relatively fast. Glyphosate can bind so strongly within plants that it remains bound and is not broken down until the plant itself degrades. Glyphosate has a low toxicity for *Daphnia* but moderately high toxicity for algae and *Lemna*. Products containing glyphosate can have negative effects on crops (Relyea 2005), but the study shows that it is the surface-active substance in the products that causes this, not glyphosate. When products containing glyphosate were re-registered in 2006, a risk assessment was carried out for amphibians, for the surface-active substance polyethoxylated tallowamine (POEA). The risk assessment concluded that a toxicity/exposure ratio (TER) above the trigger value was obtained at a 5 metre distance and that these risks could be handled using the ”Guide for wind-altered protection distance with use of agricultural boom sprayer” (Swedish Chemicals Agency 2006, not published). Since glyphosate is a non-selective herbicide, it may have effects on other plants in the environment when used carelessly.

3.2.3.12 Effects of relevant herbicides

An introduction of herbicide tolerant maize, sugar beet and/or rape would increase the usage of products containing glyphosate. At the same time, usage of the products that are already in use on these crops would probably decrease. Increased usage of glufosinate ammonium is unlikely, as increased areas of usage would be unlikely to be approved, due to the properties of the substance that constitute a danger to health.

With the help of a risk indicator (Bergkvist 2004) or risk index, it is possible (in a simple, approximate way) to compare different substances' risk trends in relation to the quantity used. There are two kinds of indicators – health-related and environment-related. The health index, in the report on risk indicators, does not include risks for consumers or animal health. It focuses only on operators. The main reason for this was that the National Food

Administration considered the residue of plant protection products in domestic products to be at a safe, low level, rarely exceeding the maximum residue level (MRL). As such, it deemed that the risk for the consumer is low and that checks of residue in animal feed did not suggest any problems either. The risk index is based on the intrinsic properties of the substance that are hazardous for humans and the environment, plus certain exposure factors. In addition, the number of doses of the substance permitted is also included. The number of doses is based on the quantity of the active substance sold and a standard dose per hectare. The index calculated here is based on the number of doses that maize, sugar beet and rape would be able to bear, based on the current scale of cultivation.

Based on the risk index calculated (see formula for calculation of risk index and table 2 below):

For **sugar beet** it would be

- better for the operator's health to use glyphosate
- better for the environment to use glyphosate
- very much worse for the operator's health to use glufosate ammonium
- better for the environment for two out of three substances to be replaced with glufosinate ammonium.

compared with the substances that are most commonly used today.

For **rape** it would be

- better for the operator's health for two out of three substances to be replaced with glyphosate
- better for the environment to use glyphosate
- very much worse for the operator's health to use glufosinate ammonium
- worse for the environment for two out of three substances to be replaced with glufosinate ammonium

compared with the substances that are most commonly used today.

For **maize** it would be

- worse for the operator's health to use glyphosate
- worse for the environment for two out of three substances to be replaced with glyphosate
- very much worse for the operator's health to use glufosinate ammonium
- worse for the environment to use glufosinate ammonium

compared with the substances that are most commonly used today.

The fact that the risk indices for the substances that are used in sugar beet or rape are much higher than for maize is due to the fact that these crops are major and that the substances that are mostly used are, practically speaking, only used for them. Sugar beet is a herbicide-intensive crop, in which it is not unusual to use three to four treatments. As a result of this, the number of hectare doses is higher than for rape, despite the fact that the total area of sugar

beet cultivation is smaller. The substances that are used for maize area also used for other grass crops, pastureland and grain, making the dosage per hectare low.

It is dangerous to look only at risk indices for an assessment of the effects of the herbicides concerned, since they are based on so few parameters. Parameters such as Acceptable Operator Exposure Level (AOEL), discovery of residue or propensity for resistance should also be weighed in. This risk index is, as has been mentioned, based on the intrinsic properties of the substance and on a certain amount of general exposure for the operator and the environment. This does not necessarily mean that products containing these active substances have similar risk indices in relation to each other. In a risk assessment at product level, attention is paid to the type of exposure to which the operator and the environment are exposed, which may increase or decrease the risks laid out in the risk index calculated below (table 2).

Formula for calculation of risk index

$$\textit{Environment Risk Indicator} = \sum(SQ * RDR^{-1} * (ET + P + B + M) * AME * TF * MR * LI)$$

$$\textit{Operator Health Risk Indicator} = \sum(SQ * RDR^{-1} * OT * FT * TF * AMO)$$

where

SQ	Annual Sold Quantity of an active substance in gram.
RDR	The Recommended Dose Rate in the most representative crop
ET	Environment Toxicity score
OT	The short and long-term Operator Toxicity score
P	The potential Persistence score
B	The potential Bioaccumulation score
M	The potential Mobility score
AME	Application Method (Environment exposure) score.
AMO	Application Method (Operator exposure) score.
LI	The potential Leaching Index score
FT	Formulation Type score.
MR	Monitoring Result score.
TF	Treatment Frequency score

Table 2. Calculated risk index (based on cultivated areas 2007)

Active substance	Health index	Environmental index	Number hectar doses	Total index Health (health index x number of hectar doses)	Total index Environment (environmental index x number of hectar doses)
Maize					
Bentazone	13,5	262,5	200	**2 700**	**52 500**
Thifensulfuron-methyl	4,5	115,9	500	**2 250**	**57 950**
Rimsulfuron	4,5	49,2	5 500	**24 750**	**270 600**
Glufosinate ammonium	78	62,9	11 000	**858 000**	**691 900**
Glyphosate, salt	6,0	11,4	11 000	**66 000**	**125 400**
Sugar beets					
Phenmedipham	24	19,2	108 000	**2 592 000**	**2 073 600**
Metamitron	13,5	97,4	108 000	**1 458 000**	**10 519 200**
Ethofumesate	18,0	112,0	70 000	**1 260 000**	**7 840 000**
Glufosinate ammonium	78	62,9	41 000	**3 198 000**	**2 578 900**
Glyphosate, salt	6,0	11,4	41 000	**246 000**	**467 400**
Rape					
Metazachlor	18,0	368,1	40 000	**720 000**	**14 724 000**
Quimerac	18,0	163,4	32 000	**576 000**	**5 228 800**
Chlopyralid	18,0	466,6	5 000	**90 000**	**2 333 000**
Glufosinate ammonium	78	62,9	84 000	**6 552 000**	**5 283 600**
Glyphosate, salt	6,0	11,4	84 000	**504 000**	**957 600**

3.2.4 Studies carried out

Few studies on herbicide tolerant crops have been carried out in Sweden. In the period between 2004 and 2006, the Swedish Agricultural Board issued permits for three field trials of herbicide tolerant crops, covering a total acreage of just under 8 hectares. Since 2002, a research project has been ongoing at SLU, studying the environmental consequences of cultivating herbicide tolerant crops[11], but the results of this project have not been published yet. As such, there is inadequate knowledge of the effects of large-scale cultivation of herbicide tolerant crops in Sweden.

A small number of studies have been carried out abroad, where the effects of herbicide tolerant crops on other organisms have been studies (Dewar et al 2003, Firbank 2003, May et al 2005). The results of these studies are not directly transferable to Swedish conditions, since both geographical and climate-related differences affect the length of the growth season, the occurrence of pests and weeds, and the choice of crop and agricultural methods. Even geological conditions and soil fertility often differ from country to country. Despite this, the results of foreign studies offer some guidance as to the expected effects of cultivation of

[11] (http://www.evp.slu.se/ogras/hemsida_sv/anstallda/Hakan_Fogelfors/konsekvensanalys_GM_1.htm)

herbicide tolerant crops in Sweden. These studies also show that there is a need for large-scale studies to be carried out in Sweden too.

Several of the studies of herbicide tolerant crops that have been carried out so far have been limited both in time and scale (Squire et al 2003). Small-scale studies have the advantage that they are relatively cheap to implement, which makes it possible to carry out field tests at all. Disadvantages include that they are limited in time and spread, and that that the number of replications may be low. This means that the studies only discover the large differences between experiment and control group and that long-term effects are difficult to detect and that it is often impossible to draw general conclusions based on the results (Snow et al 2005). One basic problem in terms of ecological processes is that changes often take place over a long time period, while the experiments that are carried out in order to be able to predict the consequences of an operation are often relatively short-lived. As such, long-term experiments spread over a large geographical area are needed in order to determine the large-scale effects of herbicide tolerant crops on biodiversity (Freckleton et al 2004). However, large-scale, long-term experiments of cultivation of herbicide tolerant crops are lacking, and the question is whether it is feasible to carry out such tests before a crop has been approved for commercial cultivation (Snow et al 2005, Andow & Zwahlen 2006). As a result, there will be a need for studies before the crops can be introduced, and follow-up studies to analyse the effects after commercial cultivation of a crop has begun.

An alternative way of evaluating long-term effects is to use mathematical models to analyse the effects of cultivation of herbicide tolerant crops on biodiversity. Watkinson et al (2000) modelled the effects of cultivation of herbicide tolerant sugar beet on the occurrence of goosefoot (*Chenopodium album*) a weed that is of great importance for certain birds) in arable land, and how this could affect the population development of the skylark (*Alauda arvensis*). According to the model, the quantity of the weed would be greatly reduced by the cultivation of herbicide tolerant sugar beet, and this would affect the birds that are dependent on the weed seed as a source of food.

The results of the model also depend on which farmers use the new technology – those who have large numbers of weeds on their land or those who have small amounts of weeds. Therefore, it is not only more effective weed control that will affect the results, but also which farmers take on the new crop (Watkinson et al 2000). Butler et al (2007) developed a risk assessment model that makes it possible to assess the possible effects of, for example, herbicide tolerant crops, on the bird fauna of the agricultural landscape. According to the model, only a limited negative effect on the bird population size is expected as a result of a transition from conventionally grown rape, sugar beet and maize to their herbicide tolerant variants.

Farm-scale evaluations

The most extensive study of the effects of herbicide tolerant crops on biodiversity so far were carried out in the United Kingdom between 2000 and 2003. These ’farm-scale evaluations’ (FSEs) of the effect of genetically modified herbicide tolerant crops on biodiversity studied herbicide tolerant maize, sugar beet, fodder beat, winter rape and spring rape on a total of 65 different fields per crop, over a large geographical area (Champion et al 2003). The study consisted of a comparison between the presence of weeds (number of plants, biomass, seed setting and frequency of seeds in seed banks) and insects in conventional crops and herbicide tolerant crops. The study also compared the presence of weeds and insects in the border zones surrounding the different fields (Roy et al 2003). In order to minimise the effects of surrounding factors, each field was divided into two halves. The conventional crop was cultivated on one half and the herbicide tolerant variant on the other. Farmers were

encouraged to continue growing the conventional crop in the same way they always had, and they were given instructions for growing the genetically modified herbicide tolerant crop from SCIMAC, a government-funded collaboration of different agricultural organisations in the UK (Champion et al 2003). Compared with the conventional method, the new method involved later treatment of the herbicide tolerant crop with a broad spectrum plant protection product containing both glyphosate and glufosinate ammonium (Champion et al 2003). The study used maize and rape that was tolerant of glufosinate ammonium and sugar beet that was tolerant of glyphosate (Champion et al 2003). Interest in studying rape, maize and sugar beet was mostly based on the fact that these crops act as break crops as part of a crop rotation that, in the UK, mostly consists of grain. Weed control in cultivation of grain is so effective that in general, the only chance weeds have of reproducing and renewing their seed bank is when break crops are grown. A possible reduction in the quantity of weeds in herbicide tolerant crops as a result of more effective weed control could, as such, deplete the weed seed bank and as such constitute a long-term threat to insects and birds that depend, directly and indirectly, on weed seeds. The substantial reduction noted primarily in farmland birds in the UK could as such be aggravated by the cultivation of herbicide tolerant crops (Watkinson et al 2000, Firbank et al 2006).

The main results of the study can be summarised as follows: the difference in biodiversity was greater between different crops than between herbicide tolerant crops and conventional crops of the same type (Hawes et al 2003). Oil crops contained more of certain weeds and insects than sugar beet or maize (Hawes et al 2003). The presence of weeds was higher early in the season in fields with herbicide tolerant crops compared with conventionally grown crops. This was a result of the fact that herbicide tolerant crops are sprayed later. Once the herbicide tolerant crops had been sprayed, the pattern was reversed for all crops except maize, where the quantity of weeds in the field of herbicide tolerant crops was higher throughout the season. Seed setting and the subsequent quantity of seeds in the seed bank was also reduced in fields of herbicide tolerant rape and beet. The situation was roughly the opposite for maize. The quantity of weed seeds was higher in herbicide tolerant maize than in conventional maize, but this was not reflected in the number of seeds in the seed bank in subsequent years (Heard et al 2003). However, later calculations where data for 2003 and 2004 was included show a higher quantity of weed seeds in the seed bank in areas sown with herbicide tolerant maize compared to conventional maize (Firbank et al 2006). The presence of insects followed roughly the same pattern as the presence of weeds. The more weeds, the more insects (Haughton et al 2003, Hawes et al 2003). In general terms, in fields of herbicide tolerant rape and sugar beet, the number of pollinator insects was reduced while the number of detritivores increased, but the results were not clear-cut. The number of butterflies in beet, winter rape and spring rape and the number of hemiptera and bees in beet fields were lower in the of herbicide tolerant crops, while springtails were more abundant in these crops (Haughton et al 2003, Bohan et al 2005). The presence of other insects, such as spiders and ground beetles, did not differ significantly between the herbicide tolerant and conventional crops. A reduced quantity of pollinator insects can be explained by the fact that the quantity of flowering grass decreased, while the increased quantity of detritivores is due to the abundance of dead vegetation after the relatively late spraying of the herbicide tolerant crops (Hawes et al 2003).

Effects outside the fields were also studied as part of the FSEs. Weed coverage, flowering and seed setting was lower on the edges of fields where the herbicide tolerant rape and sugar beet was grown, but higher in fields containing herbicide tolerant maize. The most significant effects were found in the loosened but unsown topsoil closest to the crop. However, similar but weaker effects were also found further from the crop. The presence of butterflies was lower on the edge of the fields containing herbicide tolerant rape and sugar beet, but there was

no difference between conventional and herbicide tolerant maize. However, some differences were detected in the presence of bees, snails, ground beetles and other beetles but the direction of these changes varied. Sometimes there were statistically significantly more insects close to herbicide tolerant crops, and in other cases there were significantly fewer insects (Roy et al 2003).

Conclusions from the FSEs

All in all, there were less weeds and insects in and around the fields where herbicide tolerant crops were grown, but the results were not clear-cut and the effects varied depending on the crop and the season. In general, the quantity of weeds and insects were reduced in herbicide tolerant spring rape and beets compared to the conventional crops. The results of this included less weed seeds in the fields containing herbicide tolerant crops than in the fields containing their conventional equivalents. Weed seeds are a resource that affects seed-eating insects and also higher trophic levels, such as birds (Burke, year unavailable).

The situation was the opposite for maize – there were more insects and weeds in the herbicide tolerant maize compared with the conventionally cultivated maize. The FSEs showed that the different agricultural and weed control methods that come as a result of cultivating the herbicide tolerant crop will affect biodiversity. Extensive cultivation of herbicide tolerant rape and sugar beet could lead to a long-term decrease in the weed population compared with conventional cultivation of the same crops. This could, in turn, affect the insect fauna, which could have effects at higher trophic levels, such as birds in the agricultural landscape. Depletion of weeds and weed seeds could also have a negative effect on seed-eating bird species in the agricultural landscape (Burke, year unavailable). It is possible that replacing conventional maize with herbicide tolerant maize could benefit biodiversity. However, it is worth pointing out that the modified maize variety that was used in the FSEs was tolerant of glyphosate ammonium and was compared with the herbicide atrazine, which is not approved for use in Sweden. The reduced presence of weeds in conventionally cultivated maize fields in the FSEs was primarily a result of the fact that the fields were sprayed with atrazine before the growth of the crops. As such, the ban on atrazine will probably lead to an increased quantity of weeds in conventionally cultivated maize fields in the future, compared with that found in the FSEs (Perry et al 2004). However, Perry et al (2004) show in new analyses of the FSE results that it is likely that even without atrazine, the quantity of weeds would be lower in conventionally cultivated maize fields than in fields containing maize that is tolerant of glufosinate ammonium. A similar analysis relating to insects drew the same general conclusions (Brooks et al 2005).

Comments on the FSEs

The farm-scale evaluations constituted the first extensive study of the possible ecological consequences of cultivation of herbicide tolerant crops in Europe. The study generated a great deal of attention when its results were presented in 2003, and have been commented on since then. The extent of the study, with a large number of test fields all over the UK, and the solid set-up of the experiments, aroused admiration and inspired confidence in the results of the study. However, the study has also been criticised for not taking into account alternative cultivation techniques in connection with the cultivation of herbicide tolerant crops, use of alternative herbicides in conventional crops, or different spraying techniques or times (Andow 2003, Chassy et al 2003, Freckleton, 2004, Amman 2005, Sanvido et al 2006). What FSE does show – which the researchers who carried out the study were quick to point out – is the effect on certain groups of organisms when using the methods and herbicides included in the study. As a result, it does not give a complete picture of the effects of cultivation of herbicide tolerant crops on biodiversity. Rather, it shows the effects that are expected when cultivating

crops in the prevailing conditions at the time the study was carried out. The study forms an important basis of information in so far as it is the most extensive and relatively long-term study available to us.

Subsequent studies

The studies carried out after the farm-scale evaluations have been few and nowhere near the scale of the FSE studies. Herbicide tolerant cotton and soya beans have been grown for a relatively long time and on a large scale in the USA and Canada, but only limited studies have been carried out on the environmental impact of these crop variants.

Studies that came after FSE focused on alternative cultivation techniques, development of band spraying and the possibility of varying the time of spraying that result from the increased flexibility of herbicide tolerant crops in terms of spraying. This makes it possible to maximise the weed quantity at the time at which it is most advantageous for many species that depend on weeds, directly or indirectly. Some of these methods are presented below.

Band spraying

Changes in spraying methods can benefit biodiversity in the cultivation of herbicide tolerant crops compared with established spraying techniques of conventional crops. In field studies of herbicide tolerant sugar beet, May et al (2005) showed that band spraying with glyphosate (which involves spraying close to the crops and not all over the field) gave an increased quantity of weeds in the fields compared to the weed level when spraying the entire field. Only standard spraying with glyphosate early in the season gave similar results to band spraying. Weed control methods used for conventional cultivation of sugar beet gave lower quantities of weeds than both early full spraying and band spraying. The lowest level of weeds and the lowest quantity of seeds were found in the areas where the whole field had been sprayed with glyphosate on two occasions. The sugar beet harvest was as large or larger with band spraying and early whole field spraying compared to conventional sugar beet cultivation. The yield was highest with two whole-field sprays of glyphosate, but this also gave the lowest quantity of weeds. The study shows that different weed control strategies can give a different result to that of the farm-scale evaluations.

Changed time of spraying

Dewar et al (2003) carried out experiments to test the hypothesis that later spraying of herbicide tolerant crops provides the conditions for greater diversity, as the weeds are allowed to grow for a longer period and as such constitute a resource for higher trophic levels (primarily insects and birds). Later spraying in fields of herbicide tolerant sugar beet, especially where combined with band spraying, gave an increased quantity of weeds and an increase in insect population. However, if the spraying is carried out too late the harvest is reduced significantly. Freckleton et al (2004) studied the long-term effects of later spraying. They found that few of the weeds that benefited from the later spraying managed to spread their seeds before the time of spraying.

If seed spread does not occur, a slow depletion of the seedbank will occur and as such the weed quantity will decrease in the long term. As such, the positive effects of later spraying as discovered by Dewar et al are only short-term benefits. However, Freckleton’s study suggests that an earlier end to the spraying process can give space for late-growing weeds to set seeds, thereby contributing to the preservation of the seedbank. All in all, this shows that there is an opportunity to affect the quantity of weeds by altering the timing of the spraying process. It is important that the spraying is carried out at a time that makes it possible for the weeds to spread their seeds, if the end objective is to benefit biodiversity.

Conservation tillage

Conservation tillage is judged to have many positive environmental effects, such as reduced soil erosion, reduced nutrient leakage and a reduction in the amount of fuel used in agriculture (Snow et al 2005, Brookes & Barfood 2006). In the USA and Canada, there has been an increase in conservation tillage in connection with the switch to cultivation of certain herbicide tolerant crops (Amman 2005, Sanvido et al 2006). In Canada there has been a significant increase in this cultivation method linked to the switch to cultivation of herbicide tolerant rape, and now half of the total arable area of 2.6 million hectares is cultivated using conservation tillage (Brookes & Barfoot 2006). The development in relation to herbicide tolerant maize is not as clear. In the USA, the acreage where conservation tillage is used has only increased marginally since herbicide tolerant maize was introduced. It is unclear why the switch from conventional tillage to reduced tillage has not materialised with the introduction of herbicide tolerant maize in the USA, but it may be because the method is less suitable for the cultivation of maize.

Neither conservation tillage nor band spraying are methods that are limited to herbicide tolerant crops, but the use of these methods is facilitated if there is access to broad spectrum plant protection products to which the crops are resistant.

3.2.5 Resistance, hybridisation and changes in weed variety

3.2.5.1 Resistance and hybridisation

One of the fears relating to cultivation of herbicide tolerant crops is that widespread use of one specific herbicide may lead to the weeds developing resistance to the herbicide.

Resistance occurs through the natural selection of naturally resistant weeds. According to Heap (2006), there are currently 315 cases of resistant weeds in 183 species all over the world. The number of cases of resistant weeds has grown exponentially since the end of the 1970s. In the USA and Australia, resistant weeds are significantly more common than in northern Europe.

Since its introduction in the mid 1970s, glyphosate has been used widely all over the world. In 1996, the first case of glyphosate resistance was discovered in Australia. According to Heap (2006), there are 13 weed species that are resistant to glyphosate. Three of these weed species have been found in glyphosate tolerant crops (Cerdeira & Duke 2006). The weed species Canadian horseweed (*Conyza canadensis*) is resistant to glyphosate and almost only occurs in glyphosate tolerant soya bean crops. However, the selection process for resistance in Canadian horseweed started before glyphosate tolerant crops were introduced, since Canadian horseweed had already been treated in soya bean crops with glyphosate, before the sprouting of the crop. Cases of glyphosate resistance have been recognised many times in vineyards, fruit cultivation and one-sided crop rotations, often in combination with conservation tillage.

For a long time, weed resistance to glyphosate was considered to be of minor risk (Bradshaw et al 1997). Now we know better, and by using other operational mechanisms, either mixing other substances with glyphosate or alternating glyphosate use with use of conventional herbicides, it is possible to prevent resistance from occurring. In Sweden, couch grass has been tested for resistance to glyphosate but no resistance was found (Åkerblom Espeby & Fogelfors 2006).

Glyphosate has a unique action which inhibits the enzyme EPSPS and prevents protein synthesis. The resistance mechanism varies between different species of weeds. In some cases it is a change in the receptors (target site resistance) and in others it is a change in the metabolism or transport processes. In some species of weeds, both resistance mechanisms are present (Muelleder et al 2007).

No species of weeds are currently known to be resistant to glufosinate ammonium.

In Canada, rape plants have been found to be resistant to several herbicides, known as multi-resistance. Rape plants carry two or more resistance genes (Hall et al 2000). This is likely to be a result of hybridisation between different trans genes at several stages. The reason for this may be insufficient safety distance, and that different types of genetically modified rape were mixed (Beckie et al 2003). Resistance to several herbicides can also occur if resistant volunteers from previous years remain in the field or in nearby fields and pollinate subsequent years' crops which have a different type of resistance (European Commission 2003). Multi-resistance in crops can result in volunteer plants that are extremely difficult to control.

Hybridisation between weeds and crops can also result in weeds that are difficult to control. This has been studied most in oil plants (see Palm & Ryman 2006, Sanvido et al 2006 and Cerdeira & Duke 2006). There are no Swedish field studies on this subject.

3.2.5.2 Changes in the weed flora

In the USA, glyphosate tolerant crops have been cultivated for approximately 10 years on a large scale. Problems have arisen when species that are difficult to control, such as black bindweed, persicaria and field bindweed, spread. Even winter annual weeds, such as shepherd's purse and dead nettle, are spreading. These changes have led to increased costs for farmers (Cerdeira & Duke 2006, Knezevic 2007).

3.2.5.3 Assessment of effects on cultivation in Sweden

Maize is grown continuously in Sweden. Current weed control strategies, mainly based on sulfonylureas, constitute an extremely high risk for the development of resistance in weeds. Sulfonylureas inhibit the production of the enzyme ALS, thus inhibiting protein synthesis. According to Heap (2006), there are 95 species of weeds in the world that are ALS resistant. The introduction of glyphosate tolerant maize would constitute a route to a different weed control mechanism and a more sustainable strategy for weed control could be developed. Sugar beet is grown as part of a crop rotation cycle with other crops here in Sweden. Cultivation in the context of crop rotation results in variation in the crops cultivated in a field over time, and this brings a variety of weed control strategies. As such, the weed population is not subject to the same plant protection product on a continuous basis, reducing the risk of resistance. Oil plants are also cultivated in crop rotation, thus diminishing the risk of weeds developing resistance. In order to avoid changes in the weed flora and thereby reduce the risk of resistance that leads to more chemical control methods, it is important not to grow glyphosate tolerant crops or only use glyphosate too often in a crop rotation (Knezevic 2007). Changes in the weed flora and problems with resistant weed strains also occur in conventional cultivation. Resistant weeds and changes in the weed flora can lead to increased costs and more chemical control methods. However, each case must be assessed individually. As such, it is important to follow up changes in the weed flora and the effectiveness of chemical treatment on farms that grow herbicide tolerant crops. It is also extremely important to develop a weed control strategy for every herbicide tolerant crop that is cultivated. In this way, it is possible to prevent problems from arising. It is suitable to develop weed control strategies according to the principle of integrated weed control, where chemical weed control

is integrated with other cultivation techniques.

According to Directive 2001/18/EC, a supervision plan is also required in order for the cultivation of genetically modified crops to be approved. This supervision should make it possible to trace and identify all direct, indirect, immediate, delayed or unexpected effects on the health of people, animals and the environment that may occur. Supervision plans often include an element where the person responsible for cultivation of the crop answers a number of questions after each cultivation season. For example, for crops with introduced herbicide tolerance, there are questions relating to any possible changes observed relating to the weed flora and the effectiveness of control thereof. In addition to the fact that this supervision ensures that negative effects are picked up on quickly, it also contributes to raising awareness of the problem of resistance among farmers.

4 Description of crops and cultivation, including the conventional alternatives

4.1 Maize

Silage maize is a suitable fodder for cattle. Cultivation of maize has more than doubled in the last five years, and in Sweden it currently accounts for around 11,000 hectares. Approximately 85 percent of the maize cultivated is concentrated in Skåne, Kalmar, Halland, Gotland and Västra Götaland (according to the agricultural register). Maize is a heat-loving crop and it is possible to cultivate it in favourable conditions as far north as the Mälardalen valley. In Germany, maize is used for the production of biogas. It is possible that this type of production may take place in Sweden in the long run. However, maize as part of a crop rotation system increases the risk of problems with fusarium toxins in grain, especially if conservation tillage is used. It is judged in this investigation that the acreage of maize could increase to 20-25,000 hectares, one percent of Sweden's total arable acreage. However, the cultivation of maize has fluctuated significantly in a historical sense, and it is possible that there may be problems with its cultivation that are not yet known, which could discourage an increase in maize cultivation.

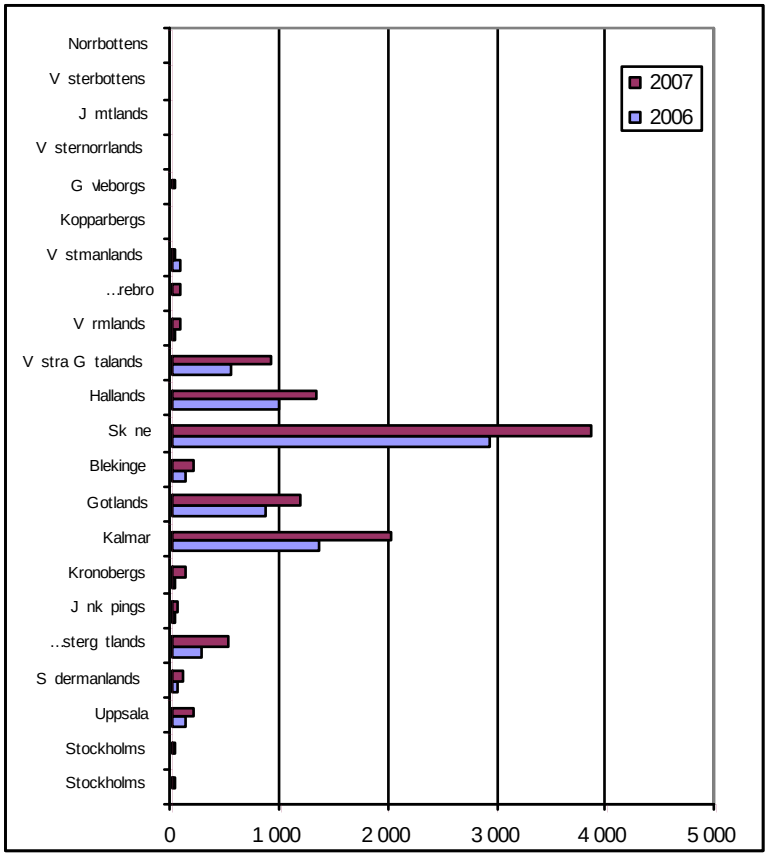

Figure 3. Total area under maize in different counties 2006 and 2007, hectare. (Source The Swedich Board of Agriculture)

Maize is sensitive to shadow weeds and the weeds must be controlled. Chemical weed control is the dominant method at the moment, and usually involves treatment with two sulfonylureas, thifensulfuron-methyl and rimsulfuron, two times. In most cases this functions satisfactorily, but not on black nightshade, *Solanum nigrum*. Black nightshade is controlled using bentazone, fairly late in the cultivation process. It is important to control black nightshade, since it can change the taste of the milk. The strategy with thifensulfuron-methyl and rimsulfuron brings with it an increased risk of weed resistance, since both substances belong to the group of ALS inhibitors. In Denmark and Germany the maize acreage is considerably larger, and here there is also access to more and better weed control preparations.

In studies comparing glyphosate tolerant maize and maize cultivation using conventional weed control, the yield is equal (Gianessi et al 2002, Marra et al 2005, PG Economics 2003). However, these results are mostly from maize for grain and from foreign studies. Fredriksson (2007) has carried out comparative calculations of the net financial result of conventional maize and glyphosate tolerant maize. The net financial result is 592 SEK more with glyphosate tolerant maize (costs for coexistence and possible compensation have not been calculated after rules of this nature adapted to suit Swedish conditions were not available at the time of the calculation). In the calculation, it is assumed that weed control using glyphosate would make one saving of treatment in the crop rotation. It is reasonable to assume that this is the case, since treatment of herbicide tolerant maize in the spring can take place at a time that gives a better effect than treatment of conventional crops at the time that is current practice. Any crop can be grown after glyphosate treated maize, in contrast to rimsulfuron treated maize. Glyphosate tolerant volunteer plants do not present a problem either in Swedish conditions.

If we compare the quantity of active substance in a conventional chemical weed control strategy in 2006, with the equivalent effect using glyphosate, the quantity of active substance increases significantly. The quantity would increase by 151 percent, without taking into consideration the fact that one standard treatment with glyphosate in the crop rotation is being replaced. If we estimate that one normal glyphosate treatment is replaced in the crop rotation, the quantity of active substance increases by 101 percent. The reason for this is that low-dosage products are currently used in the cultivation of conventional maize.

4.2 Sugar beet

Sugar beet is currently cultivated on approximately 41,000 hectares and 95 percent of this cultivation takes place in Skåne (Swedish agricultural register). Over the next 10-15 years this cultivation may be drastically reduced as a result of changes in the EU sugar policy. These changes involve a major restructuring of the EU sugar policy, including a 39 percent reduction in the price of sugar and compensation for farmers for 60 percent of this price decrease, in the form of support that is not linked to production[12]**.** Focusing on bioenergy from sugar beet crops with a higher energy yield than current sugar beet crops, which are refined in order to give a maximum yield of white sugar, may be a possible way of increasing the cultivation of sugar beet (SoU 2007:36). However, since this will require investments in new refining methods, this investigation judges that this change may not become a reality for 10 to 15 years.

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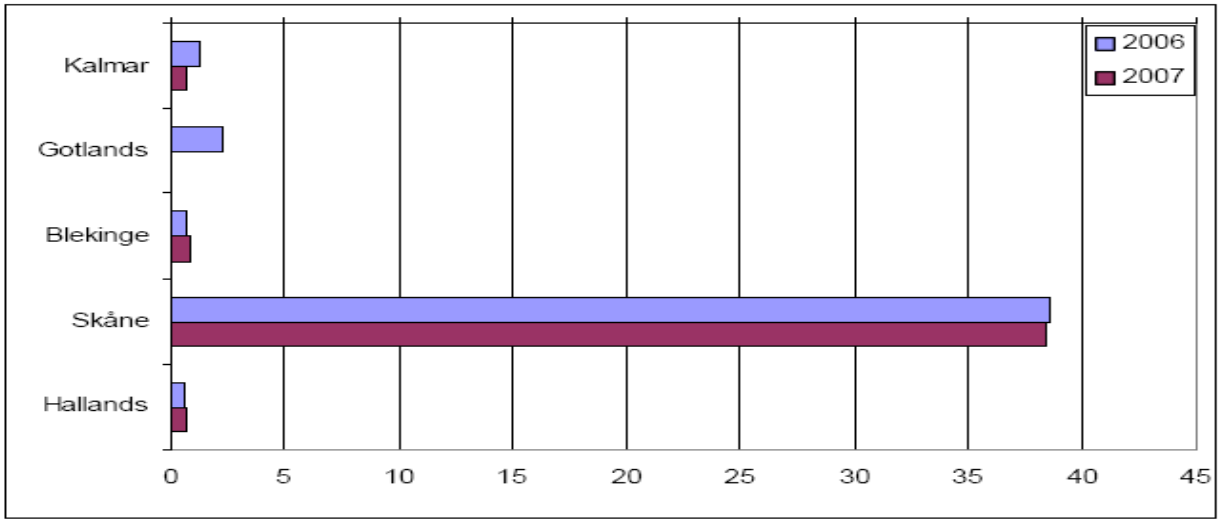

Figure 4 Total area under sugar beets in different counties 2006 and 2007, 1000 hectares. (Source The Swedish Board of Agriculture)

Sugar beet is sensitive to competition from weeds and the yield can be reduced dramatically if control measures are not taken. In conventional cultivation, weeds are controlled using chemicals, with several different preparations applied to small weeds at an early stage. The number of treatments is often 3-4. Weed tolerance is extremely low, especially for tall weeds, as they compete for light, nutrients and water. If there is more than 5 percent cover of tall weeds in July, it is worth implementing further measures. Weed control is relatively expensive – over EUR 100 per hectare – and in order to save money in sugar beet cultivation, it is standard practice to apply intensive weed control measures to the crops in the crop rotation where weed control is cheaper (eg grain).

According to Fredriksson (2007), a transition from conventional sugar beet to glyphosate tolerant sugar beet would have the following consequences on the profitability of the cultivation process:

- The farm's sugar quota could be produced on reduced acreage
- Higher costs for seed
- Lower costs for weed control products
- One saved weed spraying
- One saved glyphosate treatment in the rest of the crop rotation

The net effect of this would be a profitability increase of approximately EUR 150 per hectare. This calculation does not include costs for coexistence and possible compensation.

The quantity of active substance used would also be reduced dramatically per hectare if glyphosate tolerant sugar beet was cultivated. According to Statistics Sweden, in 2007 an average of 2.6 kg of active substance was used for weed control on 95 percent of the sugar beet acreage. If 4 litres of Roundup Bio is used instead, on glyphosate tolerant sugar beet, the quantity of active substance is reduced by 29 percent, without taking into consideration the fact that one conventional glyphosate treatment is being replaced. If the same estimation is used taking this into consideration, the quantity of active substance is reduced by 43 percent.

Seed beets with glyphosate tolerance should not cause any problems in the rest of the crop rotation, since seed beets are rare and competitively weak, and are easy to control using most other preparations. Any seed beets from conventional sugar beet cultivation are easily controlled in glyphosate tolerant sugar beet.

4.3 Rape

Oil crops are currently cultivated on approximately 90,000 hectares (Swedish agricultural register). According to Svensk Raps (Swedish Rape), it is possible to grow 150,000 hectares of oil crops in the long-term, without causing crop rotation problems. There is demand for cooking oil and oil for the production of biodiesel. The government report Bioenergy from agriculture – a growing resource (SoU 2007:36) reaches the conclusion that rape and RME is the best crop and product in financial terms, with a predicted increase in its cultivation, on the condition that there is an outlet for the by-products. Combined with the fact that herbicide tolerant rape is economically advantageous for farmers (Fredriksson 2007), this points towards an increasing acreage of herbicide tolerant rape. Rape flour is also suitable for use as fodder protein. Currently we import a large proportion of the supply.

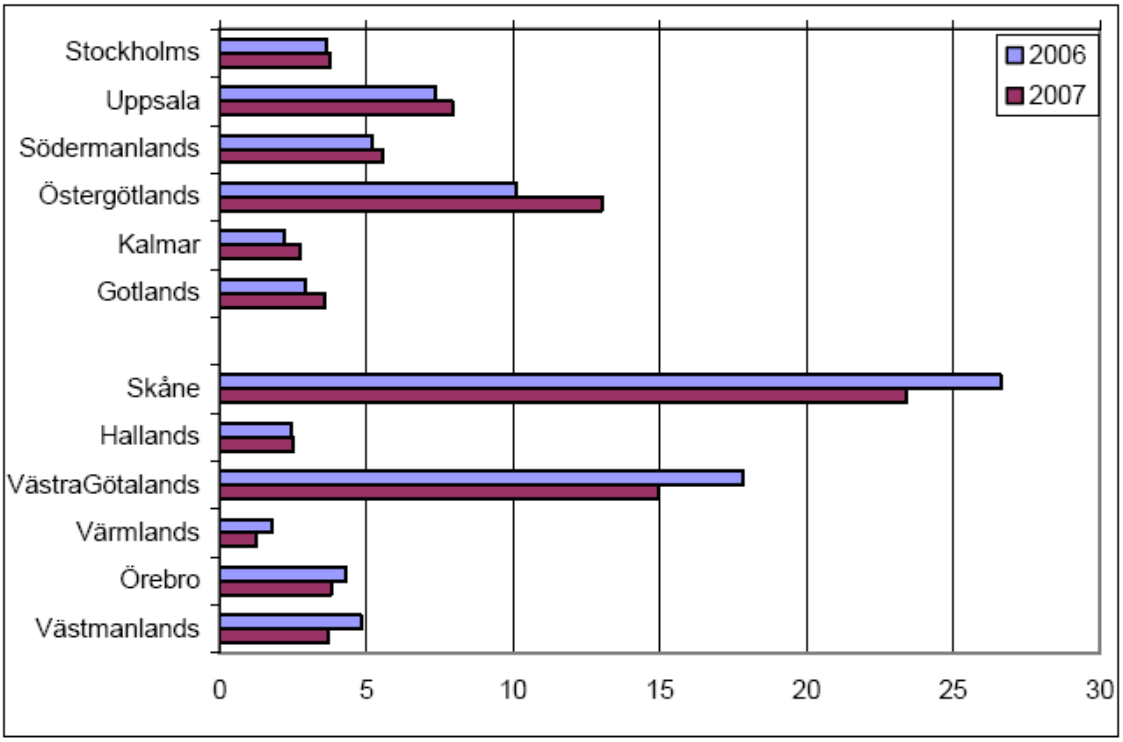

Figure 5. Total area under rape and turnip in differnet counties 2006 and 2007, 1000 hectares. (Source The Swedish Board of Agriculture)

Provided that oil crops grow quickly, they are not particularly sensitive to competition from weeds. Experience shows that it is primarily tall weed species that are significant here, in particular charlock in the context of spring oil crops. Not all of the acreage is treated every year. According to an investigation carried out by Statistics Sweden, 40 percent of spring oil crop acreage and 80 percent of winter oil crop acreage was treated with herbicides in 2006. Conventional treatment currently uses metazachlor and quinmerac and the effects thereof are usually satisfactory. The cost of these preparations is relatively high, around EUR 75 per hectare. Charlock cannot currently be controlled using chemicals. There is a need for better alternatives on organic soil with high weed pressure.

Fredriksson (2007), has listed the most significant consequences of a switch to glyphosate tolerant rape in the context of spring rape. The three most important aspects are increased yield, higher sowing costs and lower weed control costs. The net economic result is SEK 189-347 higher per hectare after a switch to glyphosate tolerant spring rape, excluding costs for coexistence etc. No similar calculations have been made for winter rape.

According to Statistics Sweden (2007), 80 percent of all winter rape acreage is treated with 860g of active herbicide substance per hectare. A switch to glyphosate tolerant winter rape would involve a 33 percent increase in the quantity of active substance, without taking into consideration the fact that one conventional glyphosate treatment is being replaced. If the same estimation is used taking this into consideration, the quantity of active substance increases by two percent.

In spring rape, 470g of active substance is used on 40 percent of the acreage, according to SCB (2007). The quantity of active substance increases by three percent if glyphosate tolerant rap is grown, without taking into consideration the fact that one conventional glyphosate treatment is being replaced. If the same estimation is used taking this into consideration, the quantity of active substance decreases by 17 percent.

Glyphosate tolerant volunteer rape can be controlled successfully in most crops, but glyphosate tolerant sugar beet can cause problems in fallow fields in crop rotations. Cultivation of glyphosate tolerant sugar beet is less advantageous if it becomes necessary to use conventional weed control. In the context of this kind of crop rotation it is probably better not to grow glyphosate tolerant rape.

4.4 The assessments of the investigation regarding expected developments in the EU and Sweden

Herbicide tolerant maize, oil crops or sugar beet could bring an increase in profitability for farmers (Fredriksson 2007) and access to new weed control methods.

Approval for cultivation of genetically modified crops has taken an extremely long time thus far. There is no indication that this situation is likely to change in the near future.

Processing times of up to 10 years are not uncommon. Apart from Bt maize, which has already been approved, and a potato variant with increased starch production, herbicide tolerant maize is one of the crops that has come the furthest in the application procedure. Depending on how long the trials take that form part of the approval process, herbicide tolerant maize could be approved for cultivation in around 4-5 years. In terms of trials, it is extremely important that the type of crop is suitable for the conditions of the countries where it is to be cultivated. A herbicide tolerant crop that is approved does not automatically become a candidate for cultivation in the EU. If the intention is to sell seed, the type will presumably be modified to suit the areas where large-scale cultivation is likely. Neither maize nor oil crops nor sugar beet are grown on a large scale in Sweden compared to the rest of Europe. Future variants of herbicide tolerant crops may turn out to be limited in terms of their potential for large-scale cultivation in Sweden.

If genetically modified crops that suit Swedish conditions are approved, it may be the case that objections from consumers and companies that may use the crop could hinder or prevent cultivation. This is probably not only the case for crops that are used as fodder or food products. It could also apply to other products manufactured from such crops for environmental purposes, such as biodiesel or ethanol. If the use of a herbicide tolerant raw material makes it difficult to sell a product, then it is likely that a non-GM variant would be

used instead. As such, approval of a herbicide tolerant crop does not mean that it would automatically be cultivated in Sweden.

Other factors that could have a negative effect on the will to cultivate herbicide tolerant crops relate to future rules for coexistence. It is possible that the will to cultivate herbicide tolerant crops could be inhibited by possible demands for protection zones and the risk of being held liable for compensation, if neighbouring growers of non-GM crops find there is admixture in their crop above the approved level. This will primarily affect oil crops and other crops where there is a high risk of spread outside the area of cultivation.

Based on the above information, this investigation judges that maize is the genetically modified crop with herbicide tolerance that is closest to being approved for cultivation in the EU and Sweden. However, it is judged that it will take at least 5-10 years before it is cultivated on a large scale. Approval of herbicide tolerant oil crops and sugar beet is expected to take even longer.

5 Likely effects on the environment and the environmental objectives

5.1 A non-toxic environment

Use of genetically modified crops with herbicide tolerance could have significant consequences for the environmental objective of *A non-toxic environment*. The genetic modification that causes tolerance of plant protection products is assessed according to directive 2001/18/EC on the deliberate release of genetically modified organisms (see part 2.3.1 for more detailed information). Assessment of the herbicide is carried out according to directive 91/414/EEC on plant protection products (see part 2.4 for more detailed information). No applications for permission to use weed control for a herbicide tolerant crop have been submitted to the Swedish Chemicals Agency.

From the perspective of the environmental objectives, it is a negative development when herbicide tolerant crops are developed which require the use of plant protection products that have undesirable effects. One example of this is maize that is tolerant of **glufosinate ammonium**. The European Food Safety Authority (EFSA 2005)[13]. The following judgements were issued concerning the maize: i) the estimated exposure for operators when spraying maize with glufosinate ammonium was too high, even with personal protection equipment; ii) a high risk was identified for mammals, and iii) a high risk was identified for arthropods and plants living in the vicinity of the maize field.

Glufosinate was accepted for use as an active substance in the EU in spring 2007 despite the above risks, but only for use in the cultivation of apples (Commission, 2007). In the formulated product, glufosinate ammonium is used (a variant of glufosinate) and in studies and evaluation data it is primarily glufosinate ammonium that has been used. This decision means that glufosinate is on a list of accepted active substances on Annex 1 of directive 91/414/EEC on plant protection products. For use in member states, all types of usage must be tested for approval of plant protection products and the conditions in Article 4.1b of directive 91/414/EEC must be observed. This includes use of the crop in food products. Glufosinate has been assessed by the EU technical committee for classification and labelling as toxic to reproduction in category 2 (EU technical committee)

An introduction of herbicide tolerant crops and utilisation of these properties means, in practice, an increase in dependence on chemicals in plant production. This represents an increase from levels that are already high. The Commission has recently submitted a proposal for a thematic strategy for sustainable use of herbicides. The proposed Community regulations in this area state that member states must draw up action plans in order to reduce the risks of, and dependence on, herbicides.

[13] Conclusion on the peer review of glufosinate. EFSA Scientific Report (2005) 27, 1-81.

In terms of the generational timescale of the environmental objectives, **glyphosate tolerant** maize could be introduced relatively soon for cultivation in Sweden. With an optimised weed control strategy for glyphosate tolerant maize, this could bring about an increase (see episode 3.2.3.12) in the risks of herbicide use with maize. From a longer-term perspective, glyphosate tolerant oil crops and sugar beet could also be approved for cultivation in Sweden. With these crops there is the opportunity to reduce these risks. However, if resistance to glyphosate occurs, the opposite could be true. Nonetheless, the risk of resistance is judged to be small as long as the crops are cultivated as part of a crop rotation with other crops, and the risk of resistance is taken into consideration in the weed control strategies used. A further condition in order to ensure reduced risks is that the formulation of the product does not give rise to any further toxicity.

One advantage of using **glyphosate tolerant** crops is that weed control treatments can be applied at the point in time that gives optimal effectiveness on perennial weeds. The time of treatment can also be selected to ensure a significantly lower risk of diffuse leakage.

However, volunteer plants from herbicide tolerant crops could begin to appear as weeds in subsequent crops. This development could bring both an increase in herbicide usage and a need for products with higher risks. Nonetheless, the risk of this is judged to be small, as long as herbicides with other functional mechanisms are used in these crops.

5.2 *A varied agricultural landscape* and *A rich diversity of plant and animal life*

The environmental quality objective *A varied agricultural landscape* aims to achieve long-term sustainable utilisation of the resources of the agricultural landscape. This means that the value of the agricultural landscape and farmland for food production and other types of production must be protected, while areas of natural and cultural heritage are preserved and strengthened. The effect of an introduction of herbicide tolerant crops must therefore be assessed on the basis of this environmental quality objective. According to proposition 2004/05:150, this objective includes ensuring that the agricultural landscape is used in such a way as to minimise negative environmental effects, benefit biodiversity, protect and preserve threatened species and types of environment, and prevent the introduction of foreign species and genetically modified organisms that may threaten biodiversity.

The purpose of the environmental quality objective *A rich diversity of plant and animal life* includes achieving more effective, focused and better coordinated work for preservation and sustainable utilisation of biodiversity. This environmental quality objective is designed to supplement the other environmental quality objectives and cover aspects that are so broad that they are not naturally covered by the other objectives. A landscape and ecosystem perspective is central here, and there are many points of contact between the objectives *A varied agricultural landscape* and *A rich diversity of plant and animal life*. As such, all aspects relating to biodiversity in the agricultural landscape are also relevant to the objective of *A rich diversity of plant and animal life*.

There are fears, both nationally and internationally, that a switch to herbicide tolerant crops will lead to such effective weed control that it will have negative effects on biodiversity (Commission, 2003). Another aspect is the spread of GM crops to nearby conventional fields. Others focus on the benefits of a switch to herbicide tolerant crops, since this is expected to reduce the amount of plant protection products used in agriculture and promote cultivation techniques that are environmentally beneficial (see references in Bohan et al 2005).

However, the results of the most extensive field study of herbicide tolerant crops so far, farm-scale evaluations (FSE), do not offer any clear-cut answers regarding the effects on biodiversity. Rather, the results show that the effects are specific to the crop. In both sugar beet and rape, the presence of weeds and certain insects was lower in the herbicide tolerant variants than in the same crops cultivated in a conventional way. In fields containing herbicide tolerant maize, the situation was the opposite. Subsequent studies have shown that if the spraying strategy is changed, different results are obtained. Spraying strategy and the agricultural methods used are therefore significant for the effects of herbicide tolerant crops on biodiversity and, by extension, on the environmental quality objectives. However, how this affects different organisms also depends on how dependent these organisms are on the areas where herbicide tolerant crops are to be cultivated. It is also important to study the land to be used to cultivate genetically modified crops. The size of the fields and the current presence of weeds have an effect on the scale of the impact from a wider perspective. Species that tend to be concentrated in areas containing herbicide tolerant crops are affected more seriously than species where the areas containing these crops form a small proportion of the species' habitat. As such, both positive and negative effects will have the largest impact on species that spend a significant amount of their time in the affected environments. This makes the situation complex and difficult to interpret. The extent to which studies carried out in other countries can be applied to Swedish conditions is also unclear, and it could be dangerous to draw general conclusions based on FSE and other studies.

Shortcomings in our knowledge of the effects of herbicide tolerant crops on biodiversity become very clear when we survey the literature available. Moreover some of the reports and summaries have not been published in scientific journals, which means that they have not been subjected to a scientific review process. As such these reports have not been put through a standard scientific quality assurance process, which makes their value as sources of facts uncertain.

On this basis, a discussion is presented below on what possible effects cultivation of herbicide tolerant crops may have on the environmental objectives. Maize is discussed individually and sugar beet and rape are discussed together. The reason for this is that, in the context of the farm-scale evaluations, the effects on biodiversity went in the same direction for rape and sugar beet, while the effects of the maize crops were quite different.

5.2.1 General discussion of impact on the environmental objectives *A varied agricultural landscape* and *A rich diversity of plant and animal life*

Herbicide tolerant crops have been cultivated for 10-15 years in the USA and Canada. By following their herbicide statistics it is possible to form a picture of how use of herbicides changes when there is a switch to herbicide tolerant crops. In the USA and Canada, total herbicide use (quantity of active substance) in rape (herbicide tolerant + conventional rape) in 2005 was 22 percent lower than it would have been if the entire acreage had been used for conventional rape. Cumulatively, since 1996, the quantity of active substance used has been 11 percent lower in herbicide tolerant rape than in cultivation of conventional rape (Brookes & Barfoot 2006). For herbicide tolerant maize, the average herbicide usage (quantity of active substance) in the USA in the last five years has been 0.6-0.7 kg/hectare lower than for conventional maize. In Canada, the equivalent statistic is 0.88-1.069kg/hectare (Brookes & Barfoot 2006). However, the long-term alterations are difficult to predict as an increase in resistant weeds could demand an increase in herbicide usage (Garcia and Altieri 2005). It is also unclear whether a reduced quantity of herbicide could lead to increased use of fungicides and insecticides (Garcia and Altieri 2005).

Later spraying of herbicide tolerant crops has a positive effect on biodiversity, as more weeds will be able to develop until spraying takes place. However, if crops are sprayed before the weeds have been able to set seed, the quantity of weeds will be reduced in the long term, as no new seeds will be supplied. This kind of spraying procedure would create an extremely targeted natural selection process, where late-flowering weeds would be disadvantaged. This could have significant effects on diversity. The consequences should be investigated more closely.

Is later spraying of herbicide tolerant crops sustainable in the long term? Since there was no experience of cultivation of herbicide tolerant crops in the UK when the farm-scale evaluations began, there was a lack of knowledge on how to spray these crops. In the FSEs, farmers followed the spraying instructions provided by SCIMAC, which stated that spraying should take place 4-8 weeks after sowing. However, with increased experience of cultivation of herbicide tolerant crops, it is likely that the time of spraying will change. In the USA, where farmers have altered the time of spraying in order to optimise crop yield, glyphosate spraying has been carried out earlier and glufosinate ammonium spraying has been carried out later than suggested in the original recommendations (Heard et al 2003). If the same development happens in Sweden in the context of cultivation of glyphosate tolerant crops, the possible positive effects of later spraying in herbicide tolerant crops will disappear when farmers find out the optimal time of spraying in order to maximise crop yield.

5.3 Maize

The risk index reviews described in part 3.2.3.12 show that if the herbicides that are currently used in maize crops are exchanged for glyphosate or glufosinate ammonium, this would not bring about any reduction in health risks. A change to glufosinate ammonium would not have any positive environmental effects, while a change to glyphosate would have certain environmental benefits, compared to one of the other substances compared.

By gaining access to herbicide tolerant maize, farmers have access to a new herbicide strategy that, when used correctly in a crop rotation, could contribute to keeping weeds under control, so that the need for herbicide is not increased by, for example, resistance.

Based on the analyses of the amount of active substance used, we can expect a major increase in the amount used in each crop. This applies even if we consider usage over the course of a crop rotation, where one standard glyphosate treatment is replaced by the treatment applied to the maize.

It is somewhat difficult to assess the effects on biodiversity and the environmental objective A varied agriculture landscape of a switch to cultivation of herbicide tolerant maize in Sweden. The primary reason for this is that no large-scale tests have been carried out in Sweden. It is difficult to draw conclusions when only one variant of herbicide tolerant maize has been used in large-scale field trials. In the farm-scale evaluations, the maize grown was tolerant of glufosinate ammonium, which had a slight positive effect on biodiversity, compared with conventionally cultivated maize (see part 3.2.4). It is not known what the effects would have been if the maize used had been tolerant of glyphosate instead, but it could bring a reduction in the quantity of weeds and insects in glyphosate tolerant crops compared to conventionally cultivated maize – in other words, the exact opposite of the results of the farm-scale evaluations.

Cultivation of maize is currently limited in Sweden (Figure 3), but it is estimated that in the future it could increase to around 20,000-25,000 hectares, which represents about 1 percent of total Swedish acreage (part 4.1). However, regionally speaking, maize makes up a larger proportion of acreage, since 85 percent of all maize is cultivated in a handful of counties. The maize acreage can be expected to increase if there is a switch to herbicide tolerant variants, since the profitability of these crops is greater than that of conventionally grown maize (Fredriksson 2007). A possible increase in demand for maize as an energy crop could also contribute to increasing maize acreage. For cultivation of rough fodder, maize will partly replace intensively cultivated pasture, a crop that is often associated with relatively low biodiversity. Maize cultivation will primarily increase on dairy farms where intensively cultivated pasture currently dominates. An increased acreage of maize in these areas would increase heterogeneity at a landscape level, which in many cases is positive for biodiversity (Benton et al 2003). However, an excessive concentration of maize to certain areas could have negative effects on biodiversity and species with limited spread and ability to spread could therefore be affected by an increased acreage of maize. The extent to which an introduction of herbicide tolerant maize would cause this development is unclear.

The risk of negative effects on biodiversity as a result of the herbicide tolerance characteristic spreading outside the fields where the crop is grown is small in the case of maize, partly because maize has no reproductively compatible relatives in Sweden, and partly because the competitive advantages for plants that gain this characteristic are negligible outside areas that are regularly sprayed (part 3.2.1).

As such, the effects on biodiversity and the environmental objectives are expected to depend primarily on changes in cultivation techniques (herbicide usage and tillage) as a result of a switch to herbicide tolerant maize. The main change, compared with conventionally grown maize, is the later spraying of herbicide tolerant maize and the possible reduction in the number of treatments. These changes are likely to be positive for biodiversity, but they may need to be regulated through legislation in order to maintain this positive effect over time. In the farm-scale evaluations, this led to better seed setting in weeds in fields of herbicide tolerant maize, compared with fields of conventionally grown maize. There did not seem to be any long-term negative effects of cultivation of herbicide tolerant maize, since there was no depletion of the weed seed bank in fields of herbicide tolerant maize. Weeds in turn constitute a significant source of feed for higher trophic levels, such as insects and birds.

Increased profitability for farmers in a transition from conventional to herbicide tolerant maize could bring positive environmental effects. Increased profitability for dairy farmers could contribute to fewer dairy farms being shut down, which in turn would mean that the quantity of grazing animals would not continue to decrease at current levels. Good access to grazing animals is critical for the chances of fulfilling the environmental objectives and maintaining an open and varied landscape. In order to have a positive effect on the environmental objectives, however, it is important that the young animals are allowed to graze on natural pastures.

5.3.1 Conclusion regarding cultivation of herbicide tolerant maize

In terms of *A nNon-toxic environment* objective, a switch to cultivation of herbicide tolerant maize offers very little potential of reducing the risks, evaluated as a risk index. On the contrary, it could lead to an increase in these risks. Farmers gain access to a new weed control strategy, which, when used correctly in a crop rotation, reduces the risks of resistant weeds. In this way, it is possible to avoid problems of weeds that are difficult to control and thus avoid an increase in the need for herbicides. If the current levels of herbicide used in maize are

replaced with glyphosate, however, there will be a major increase in the quantity of active substance used.

The limited acreage of maize that is grown in Sweden, the limited risks of gene spread and the slight positive effect on diversity (compared to conventionally cultivated maize) shown by the cultivation of herbicide tolerant maize in the farm-scale evaluations indicate that cultivation of maize tolerant of glufosinate ammonium in Sweden probably will not have a negative effect on biodiversity and on *A varied agricultural landscape*, in the short or long term.

This conclusion may change if maize acreage increases significantly, which may happen if climate change makes maize a more favourable crop than other alternative rough feed crops, or if maize becomes popular as a future energy crop.

If glyphosate tolerant maize is to be cultivated in Sweden, there is currently no solid basis of information to enable an assessment thereof, since the environmental effects of this cultivation do not only depend on the type of herbicide the crop is tolerant of, but also other factors including choice of agricultural method, choice of strategy for use of plant protection product, the land used for cultivation, and the acreage cultivated. More studies are needed here.

5.4 Sugar beet and rape

Based on the risk index calculated in part 3.2.3.12, from an environmental and health point of view, it would be an improvement to use glyphosate (as a salt, in products in Sweden, glyphosate only exists in various salt forms) in sugar beet cultivation, instead of the products that are most commonly used at present. An equivalent switch in rape would give an equivalent environmental improvement, while replacement of two of the three most commonly used substances would also bring an improvement in the health risks. Having the option of using glufosinate ammonium on these crops would not bring an improvement in terms of health. It is more likely to bring an increase in health risks. However, with some of the substances compared, a switch to glufosinate ammonium would bring a decrease in environmental risks. By gaining access to herbicide tolerant oil crops or sugar beet, farmers have access to a new weed control strategy that can contribute to keeping weeds under control, so that the need for herbicide is not increased by, for example, resistance.

Based on the analyses of the quantity of active substance used, we can assume there will be an increase in quantity used in oil crops. If we look instead at usage over an entire crop rotation, a standard treatment with glyphosate can be replaced and the increase is extremely small in a crop rotation with winter rape. The quantity decreases in a crop rotation with spring rape.

For sugar beet, based on the analysis of quantity of active substance used, we can assume there will be a decrease in the quantity used on sugar beet crops. Even if we take into consideration the entire crop rotation, one standard treatment with glyphosate can be replaced, which causes a decrease in the quantity of active substance used.

Both rape (including turnip rape) and sugar beet are grown on significantly larger areas than maize. The majority of sugar beet cultivation takes place in the county of Skåne (see Figure 4), while rape is grown on flat country all over southern Sweden (see Figure 5). A switch to herbicide tolerant variants of these crops would cover more land than maize crops, both geographically and in terms of acreage, and as such it is likely that its effects on biodiversity and the environmental objectives would be more significant. Rape and turnip rape also bring the problem of gene spread to related species.

It should be possible to cultivate conventional variants without admixture from genetically

modified crops. If admixture should occur, and the genetically modified content is greater than 0.9 percent of the yield, then the farmer growing conventional crops would be forced to mark his harvest as genetically modified, and as a result may suffer financially. In order to avoid this, there will be a demand for protection zones around herbicide tolerant rape and turnip rape crops.

An increase in demand for rape as an energy source could also lead to an increase in rape acreage, but pests limit the extent to which rape cultivation can grow. The current acreage is around 90,000 hectares and this is expected to be able to increase to around 150,000 hectares (part 4.2). New rape cultivation will mostly replace grain and will probably be concentrated in the areas where rape is already grown. An increase in the quantity of rape grown in areas dominated by grain is likely to have a positive effect on diversity, through the increase in spatial heterogeneity created (Benton et al 2003). An increase in the quantity of rape grown in areas already dominated by rape is likely to have only a marginal positive effect. The profitability of herbicide tolerant rape is higher than that of conventional rape cultivation. As with maize, however, it is unclear to what extent the introduction of herbicide tolerant rape will affect the land cultivated.

The risk that gene spread from herbicide tolerant rape will have a *directly* negative effect on biodiversity is judged to be small, since the competitive advantages for plants that have gained this characteristic are negligible outside areas that are regularly sprayed. For sugar beet, the risk of gene spread is also judged to be small, since sugar beet is not usually allowed to flower. As with maize, the biggest effect on biodiversity and the environmental objectives with these crops is *indirect*, in the sense that the cultivation of these crops brings about a change in the behaviour of operators.

The results of the farm-scale evaluations show a potential negative effect on biodiversity with a switch to herbicide tolerant rape and sugar beet. Fields containing these crops showed a reduction in flowering weeds and butterflies, compared to their conventional equivalents. Even outside the fields, in the unsown area closest to the herbicide tolerant crop, there were less weeds and butterflies. Species or populations with a high degree of specialisation or species with a limited ability to spread, which spend a significant amount of their time in affected environments, are likely to be hit harder than species that use these environments temporarily. The decrease in the quantity of insects that would be caused by a switch to herbicide tolerant rape and sugar beet could also have negative effects on certain ecosystem services, such as pollination of crops. In areas where large areas of herbicide tolerant crops are grown there could be a lack of pollinating insects.

The negative effects on weeds and pollinating insects found in the farm-scale evaluations could, to a certain extent, be counteracted by changing spraying strategies or agricultural methods. Therefore, the effect of herbicide tolerant rape and sugar beet cultivation on biodiversity depends on how and when the fields are sprayed, and whether cultivation methods are used that differ from conventional ploughing followed by sowing.

The significant reduction in herbicide usage (measured in the quantity of active substance) that would be brought by the introduction of herbicide tolerant sugar beet would probably be positive for biodiversity and the environmental objectives (see part 4.2). Weed control in sugar beet is relatively expensive and in order to lower costs, it is standard practice to apply intensive weed control measures to the crops in the crop rotation where weed control is cheaper (e.g. grain). A switch to herbicide tolerant beet, where a cheaper herbicide with broad action could be used, could therefore lead to a reduction in the intensiveness of weed control in the rest of the crop rotation, which could have a positive effect on biodiversity and the environmental objectives.

5.4.1 Conclusion regarding cultivation of herbicide tolerant sugar beet and rape

In terms of *A non-toxic environment* environmental objective, cultivation of glyphosate tolerant oil crops or sugar beet would bring the possibility of reducing both health and environment-related risks, in the form of risk indices. Cultivation of strains that are resistant to glufosinate ammonium would not reduce health risk indices. However, there would be some opportunity to reduce environmental risks. Farmers gain access to a new weed control strategy, which reduces risks including the risk of resistance in weeds. In this way, it is possible to avoid the problems of weeds that are difficult to control, thus avoiding the need for an increase in herbicide usage. If the herbicides currently used in oil crops and sugar beet are replaced with glyphosate or glufosinate ammonium, there is also the possibility of reducing usage, calculated in terms of quantity of active substance, primarily in sugar beet but also in spring rape.

Cultivation of herbicide tolerant variants of rape and sugar beet in Sweden could have negative effects on the environmental objectives *A varied agricultural landscape* and *A rich diversity of plant and animal life*. Depending on cultivation methods used, an introduction of these crops could go against the content of both objectives in the sense that:

- negative environmental effects should be minimised and biodiversity should be favoured,
- threatened species and types of environment should be protected and preserved,
- foreign species and genetically modified organisms that could threaten biodiversity should not be introduced.
- Depletion of biodiversity, in terms of genetic variation, should be avoided.
- Large-scale cultivation can also lead to depletion at a landscape level. However, this applies regardless of the type of crop, and is not specific to herbicide tolerant crops.

The possible reduction in weeds and certain insects could constitute a long-term threat to biodiversity and as such could affect targets 1 and 2 of the objective of *A rich diversity of plant and animal life*. However, such negative effects on weeds and insects could be counteracted, according to experience from other countries, by employing alternative cultivation techniques. It is not known whether it is realistic to use these methods in Sweden. Ecosystem functions such as pollination by insects could also be affected negatively. There is a need for more research surrounding these issues.

A reduction in quantities of herbicides used is probably positive for diversity. The risk of gene spread, primarily from rape, to wild relatives, is tangible, but the risk of effects beyond cultivated fields is judged to be small. The risk of gene spread from sugar beet is judged to be small, since the crop is not usually allowed to flower. However, little is known about the long-term effects of gene spread on biodiversity and the likelihood of reaching the environmental objectives. There is a need for further investigations here.

5.5 Conservation tillage and band spraying

Cultivation techniques that include various forms of conservation tillage could be advantageous for several environmental quality objectives, such as *Zero eutrophication, A varied agricultural landscape* and *A rich diversity of plant and animal life*. The effects on *A non-toxic environment* may be negative, since this cultivation technique requires weed control using plant protection products.

In the USA, use of conservation tillage has increased in connection with the introduction of herbicide tolerant crops, and this has often been presented as a positive environmental effect brought about by the cultivation of herbicide tolerant crops (Ammann 2005). The reported increase in use of conservation tillage in connection with the cultivation of herbicide tolerant crops is a correlation between two variables, and as such it is difficult to determine what is cause and what is effect. Although an increase in conservation tillage is interpreted as a positive environmental effect in many cases, there may be alternative explanations for this connection and this is rarely discussed (Snow et al 2005). There are also disadvantages to conservation tillage, such as an increase in resistant weeds. In Sweden, conservation tillage is most suitable for sugar beet and oil crops. Maize is often planted in soil with a lower clay content, where conservation tillage is not suitable.

Use of band spraying in the cultivation of herbicide tolerant crops can bring some positive effects on diversity, without compromising on yield. The flexibility of herbicide tolerant crops in terms of spraying make it possible to combine high sugar beet yield with increase in the occurrence of weeds. Done right, band spraying could thus become a method that is accepted by farmers, which reduces the negative effects that the use of a broad spectrum herbicide could have on biodiversity.

5.6 Resistance in weeds

Long-term persistent usage of one or a handful of herbicides can lead relatively quickly to weeds developing resistance to these herbicides (Snow et al 2005). This is not unique to herbicide tolerant crops. It is also the case for with plant protection products used in conventional crops. Herbicide resistance could also occur through cross-pollination between herbicide tolerant crops and sexually compatible wild species. The appearance of resistant weeds, especially multi-resistant individuals that are resistant to several herbicides, could have an indirect effect on the likelihood of reaching the environmental objectives. Weed control methods that involve more intensive herbicide usage, such as extensive use of conventional and broad spectrum herbicides to get rid of resistant weeds, could also have an indirect effect on non-target organisms. Farmers' keenness to preserve small biotopes like unsprayed field margins and fallow land could also decrease if these areas harbour weeds that are difficult to control, which could spread into the fields. In this case, there would be a negative effect on the objective of *A varied agricultural landscape*.

5.7 Concluding summary

Herbicide tolerant crops that are approved for cultivation in the EU could, depending on factors such as the hardiness of the crop, also be cultivated in Sweden. It is therefore important to investigate and identify the effects that this kind of cultivation could have on our environment and on the health of people and animals. We must also investigate the options available for minimising the negative effects that are identified.

The changes in herbicide usage – namely, a change to the active ingredient glyphosate – which could come about as a result of the cultivation of herbicide tolerant maize, sugar beet and rape are expected, from the perspective of the environmental objective of *A non-toxic environment*, to reduce the risks in the case of sugar beet and rape, while risks would increase with maize cultivation. A similar change to use of the active ingredient glufosinate ammonium is expected to increase risk levels in all three crops. However, glufosinate ammonium is not expected to be approved for this usage in Sweden. At the same time, this kind of cultivation is expected to lead to an increase in herbicide dependence, which is already extensive in which could, in the long term, impede the work to reduce environmental

levels of substances that do not occur in nature. It could also make it difficult to reach this environmental objective.

There is a clear lack of knowledge surrounding the ecological effects of cultivation of herbicide tolerant crops in Swedish conditions. The predicted effects on biodiversity and on the environmental quality objectives are therefore based on fundamental ecological theories and research carried out abroad. If herbicide tolerant crops are grown in the same way that they were grown in the farm-scale evaluations, this could lead to negative effects on biodiversity and on the possibility of reaching the environmental quality objectives *A rich cultivation landscape* and *A rich diversity of plant and animal life*.

Therefore, cultivation of herbicide tolerant crops could, in the long term, make it difficult to fulfil the environmental quality objectives. We can construct theories on the possible effects of cultivation of these kinds of crops in Sweden, based on experience from cultivation of herbicide tolerant crops in other countries and studies of the effects of this cultivation. However, there is no sure way of predicting the reality of commercial cultivation of herbicide tolerant crops in Sweden. The effects of this kind of cultivation depend on a number of factors. These include the choice of crop, type of tolerance, choice of agricultural method, choice of strategy for use of plant protection products, and the type of land and size of area where the crops are grown.

As a result the negative effects that could arise as a result of cultivation of herbicide tolerant crops could, to a certain extent, be counteracted by altering cultivation methods and usage of plant protection products, in order to minimise the negative effects on biodiversity. However, it is unlikely that this would happen on a voluntary basis, since in some cases it is impossible to reconcile optimal crop yield with an abundance of weeds (see for example Dewar et al 2003 in terms of sugar beet).

6 Options for limiting environmental impact

6.1 What action is necessary?

6.1.1 Relevant studies for Swedish conditions

There are few studies on how an introduction of herbicide tolerant crops affects the environment, both within and beyond the fields. Studies are often carried out in conditions that in major or minor ways differ from Swedish conditions. As such, conclusions drawn regarding effects and expected developments in Sweden are shrouded in uncertainty. That is why it is extremely important to begin working to improve the basis of information specific to Swedish conditions. One prerequisite for studies to be carried out is funding. Funding should be made available to relevant authorities and research bodies for research in this area.

Below are some examples of studies and supervision with the aim of being able to evaluate the introduction of commercial cultivation of genetically modified crops with herbicide tolerance on the basis of a well-founded set of information, in the near future. It is important that studies are carried out *before* the possible introduction of such crops, but there is also a need for continued supervision after this introduction.

- **Impact on non-target organisms**: Comparative studies, similar to the farm-scale evaluations but specific to Swedish conditions (and focusing on the types of modified herbicide tolerant crops likely to be introduced in Sweden). This kind of study should aim to observe changes relating to the presence and species composition of weeds, insects and birds in and in the vicinity of fields containing GM crops.
- **Study of alternative cultivation methods**: Comparative study looking at alternative types of agricultural methods (conservation tillage etc.) compared to the most common methods used with the crop in question. A variant of the above study, in order to ascertain the best possible techniques in order to minimise negative impact on the environmental quality objectives.
- **Gene spread studies**: These kinds of studies are primarily important for rape, where resistant weeds can occur, through hybridisation both with wild species and with conventional variants in relatively nearby fields. This kind of study should ascertain the extent to which gene spread occurs and how safe methods of prevention can be developed.
- A more far-reaching study should also investigate the **level of genetic variation** in wild hybrids as well as their fitness. This study should aim to provide useful knowledge of the three stages of gene spread 1) Deliberate release/escape 2) spread/multiplication 3) damage (Muir 2004).
- **Long-term supervision**: of seed and plant composition in weeds in and around fields containing herbicide tolerant and genetically modified crops.
- **Long-term supervision of gene spread:** Aiming to gain a more solid basis of information in terms of long-term effects.
- **Registration and follow-up of genetically modified crops with herbicide tolerance:** Depending on the potentially different conditions of the fields where cultivation of herbicide tolerant crops will take place, it would be suitable to register the fields' biodiversity status in order to gain a better picture of the main types of field used. This could provide a picture of the effects on biodiversity of commercial cultivation of herbicide tolerant crops.
- **Other studies and supervision**: Further suggestions in terms of studies and supervision programmes are given in the European Commission's final report from the working group on herbicide tolerant crops (European Commission 2003).

6.1.2 Information and regulations

Any genetically modified crop that is herbicide tolerant and that is to be cultivated in the EU is assessed according to several different regulations: i) for cultivation, according to directive 2001/18/EC on release into the environment; ii) for use as fodder and in food products, according to regulation 1829/2003/EEC; and iii) for use of herbicide on crops, according to directive 91/414/EEC.

As a result, the crop itself will be assessed according to one regulation and the herbicide and usage thereof will be assessed according to another. In order for the overall assessment of use of the herbicide tolerant crop to be clear, all information and all assessments relating to environmental and health risks, both for the crop and the herbicide, should be reported at the same time. Sweden should work to promote parallel assessments under both regulatory frameworks, in order for there to be a more comprehensive and complete assessment available for future decisions on approval or rejection.

6.1.3 Impact on non-target organisms

Herbicide tolerance means that the mechanism in a herbicide that normally kills plants doesn't work. The tolerant plant survives and the active ingredient remains or is broken down in the plant. The substance or its metabolites could therefore be present in fodder and food products and non-target organisms and wild animals could also take in these metabolites if they eat the plant. In the EFSA's conclusion regarding glufosinate ammonium,[14] the residue levels were judged to be low if the suggested usage in the EU is implemented correctly.

When assessing a herbicide tolerant crop, new gene production should be assessed, both in itself and in terms of the results of its activity. As is often the case with new technology, there are always some questions that fall between the stools of different regulatory frameworks. It is important that these issues are also dealt with.

6.1.4 Measures for counteracting negative or promoting positive environmental impact

An introduction of herbicide tolerant crops would, as has been mentioned, bring risks of undesired developments in several respects. Below are some of the measures that could be appropriate, based on the discussions in this report.

6.1.4.1 Maize

- Develop guidelines for cultivation of herbicide tolerant maize and implement these in practice. These guidelines should also include weed control strategies to prevent:
  - resistance, for example by alternating between herbicide tolerant and conventional variants in order to minimise possible effects,
  - herbicide tolerant crops from appearing as weeds in subsequent crops.
- Regulate the size of the seed bank, for example by:
  - changing treatment times,
  - using band spraying,
  - using conservation tillage.
- Compensatory measures to create better conditions for meeting the environmental quality objectives, for example:
  - intermittent fallow (agricultural stubble is left on the land after the harvest and cultivation is modified to achieve high levels of biodiversity)
  - unsprayed field margins,
  - uncultivated field margins,
  - non-chemical agricultural methods used in crop rotation,
  - etc.

[14] Conclusion on the peer review of glufosinate. EFSA Scientific Report (200%) 27, 1-81.

6.1.4.2 Oil crops

- Develop guidelines for cultivation of herbicide tolerant oil crops and implement these in practice. These guidelines should also include weed control strategies to prevent:
  - resistance, for example by alternating between herbicide tolerant and conventional variants in order to minimise possible effects,
  - herbicide tolerant crops from appearing as weeds in subsequent crops.
- Regulate the size of the seed bank, for example by:
  - changing treatment times,
  - using conservation tillage.
- Compensatory measures to create better conditions for meeting the environmental quality objectives, for example:
  - intermittent fallow (agricultural stubble is left on the land after the harvest and cultivation is modified to achieve high levels of biodiversity)
  - unsprayed field margins,
  - uncultivated filed margins,
  - non-chemical agricultural methods used in crop rotation,
  - etc.

6.1.4.3 Sugar beet

- Develop guidelines for cultivation of herbicide tolerant sugar beet and implement these in practice. These guidelines should also include weed control strategies to prevent:
  - resistance, for example by alternating between herbicide tolerant and conventional variants in order to minimise possible effects,
  - herbicide tolerant crops from appearing as weeds in subsequent crops.
- Regulate the size of the seed bank, for example by:
  - changing treatment times,
  - using band spraying,
  - using conservation tillage.
- Compensatory measures to create better conditions for meeting the environmental quality objectives, for example:
  - intermittent fallow (agricultural stubble is left on the land after the harvest and cultivation is modified to achieve high levels of biodiversity)
  - unsprayed field margins,
  - uncultivated field margins,
  - non-chemical agricultural methods used in crop rotation,
  - etc.

6.1.5 Control mechanisms

In order to implement the abovementioned measures to counteract undesired environmental impact and promote positive environmental effects, various forms of control mechanisms are required. The control mechanisms that are available include legislation (in the form of regulations and supervision), financial mechanisms (in the form of charges and support for environmentally-friendly farming), and informative mechanisms (using information and advice to bring behavioural change). National action programmes, certification of crops and sectoral agreements can also influence farmers to implement certain measures. Control mechanisms should be selected depending on each measure and the desired effect.

The need for measures and control mechanisms in order to counteract negative and promote positive environmental impact in connection with an introduction of herbicide tolerant crops in Sweden should be addressed in contexts where the agricultural sector draws up guidelines for future work to achieve environmental objectives. In the immediate future, an appropriate forum for addressing this need would be during the establishment of an action plan for sustainable plant protection for 2010-2013.

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Acronyms

ALS	Acetolactate synthase
AOEL	Acceptable operator exposure level
Bt	Bacillus thuringiensis
DT_{50}	Half life time
EEG/EEC	Europeiska ekonomiska gemenskapen / European Economic Community
EFSA	European Food Safety Authority
EG/EC	Europeiska gemenskapen / European Community
EU	European Union
FSE	Farm-Scale Evaluations
GMO	Genetically modified organism
Koc	Adsorption coefficient for organic carbon
LC_{50}	Lethal concentration, median
LD_{50}	Lethal dose, median
MRL	Maximuml residue level
NOEC	No observed effect concentration
OECD	Organisation for Economic Co-operation and Development
SCIMAC	Supply Chain Initiative on Modified Agricultural Crops
SF	Safety level

Appendix 1 The task - only in the Swedish version

Appendix 2 Comparative parameters for active substances in selected herbicides

Comparative parameters for the most common used active substances in maize, sugar beet and rape and the active substances that could be used in the genetically modified crop (data from review reports of the substances, Draft Assessment Report or EFSA conclusion depending on the substance status in the EU assessment program)												
		Bentazone	Thifensulfuron-methyl	Rimsulfuron	Phenmedipham	Metamitron	Ethofumesate	Metazachlor	Quinmerac	Clopyralid	Glufosinate ammonium	Glyphosate
Classification		Xn; R 22 Xi; R 36 R 43 N; R 52-53	N; R 50/53	N; R 50/53	N; R 50/53	Xn; R 22 N; R 50/53	N; R 51/53	Xi; R 43 R 52	N; R 50/53	Xi;R 41 N; R51/53	T; R 20/22, R 48/22, R 48/23, Cat 2, R 61; Cat 3, R 62	Xi; R 41 N; R 51/53 (acid) N; R 51/53 (salt)
LD_{50} (mg/kg bw)	oral	1400-1800	> 5000	>5000	>8000	1183	>5000	>2000	>5000	>5000	1510	>2000
	dermal	>5000	> 2000	>2000	>2000	>4000	>2000	>2000	>2000	>2000	>4000	>2000
AOEL (mg/kg bw/d)		0.13 (SF 100)	0.07 (SF 100)	0,07 (SF 143)	0,13 (SF 100)	0,036 (SF 100)	2.5 (SF 100)	0.2 (SF 100)	0,079 (SF 100)	1.0 (SF 100)	0,0021 (SF 3000)	0,2 (SF 100)
CMR	Carcinogenicity	no	no	no	no	no	no	ja	no	no	no	no
	Genotoxicity	no	no	no	no	no	no	no	Unresolved questions on the genotoxic potential – further data required	no	no	no
	Reproduction	yes	yes	no	no	no	no	no	yes	yes	yes	no
MRL (mg/kg)		0.1	0.05	0,05	0,05	0,05	0,05	0,05	0,2	2	0,1	1
Residue analysis (result)		findings in drinking water***				findings in drinking water ***	findings in drinking water ***	findings in drinking water ***	findings in drinking water***	findings in drinking water ***		8 findings in grain* findings in drinking

											water***
Birds (LC50) (ppm)	>5000	5620	>5620	>2100	>5000	>5200	>5000	>2000	>5000	1100	>4640
Aquatic organisms Daphnia (mg/l)	64	470	>360	5,7	5,7	14	33,7	>100	>99	668	930
Algae (mg/l)	10.1	0,0159	1,2	0,086	0,4	3,9	0,032	>100	30	5	72,9
Lemna (mg/l)	5.4	0,0013	0,0046	0,23	0,4	>50	0,0071	96	89	1,5	53,6
Ground water	358 findings which 189 > 0.1 µg/l**	0 findings***	0 findings***	0 findings***	1 findings which 0 >0.1µg/l***	2 findings which 1 >0.1µg/l***	10 findings which 7 >0.1µg/l**	1 findings which 0 >0.1µg/l***	30 findings which 25 >0.1µg/l**	0 findings	13 findings which 5 > 0.1µg/l**
Guiding value for surface water (µg/l)	40	0,01	0,01	2 (MHPC 10)	1	30	0,2	100	50	10 (MPP 200)	10 (AMPA 500)
Persistens (days) DT_{50}whole syst	523	16	11	0,14	11	105-285	28		N/A	no	124
DT_{50}lab 20°C	45	6	40	37	12	97	25	18,9	148	8	49
Adsorption (Koc)	47	28	47	888 (PMP), 220 (MHPC)	Kfoc 122	147	114	Kfoc 50,8	5.15	Moderate to high, correlates to clay content and not to organic carbon	50660
Bioconcentration	log Pow <3	< 0.8	Log Pow <3	165	LogPow <3	144	Log Pow <3	Log Pow <3	<1.0	Log Pow <3	N/A.
Toxicity (NOEC mg/l)	>48 (fish); 120 (inv)	250 (fish); 100 (inv)	125 (fish), 1 (inv)	0,32 (fish) 0,061 (inv)	7,0 (fish), 10,0 (inv)	0,8 (fish) 0,32 (inv)	2,15 (fish) 0,1 (inv)	3,16 (fish) 100 (inv)	11 (fish) 17 (inv)	100 (fish), 18 (inv)	917 (fish), 455 (inv)
Risk of resistance	low	high	high	high	high	low	low	moderate	moderate	low	moderate

*Livsmedelsverket 2004

** Adielsson m fl 2006. Sammanställning av generella pesticiddatabasen

*** Generella Pesticiddatabasen, values from years <1990 - 2004, http://pesticid.slu.se/default.cfm

Appendix 3 Summary of comments on proposal - only in the Swedish version

Rapporten kan beställas från
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