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Ecological impacts of traditional crop plants - a basis for the assessment of transgenic plants

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ABSTRACT

For risk assessment of transgenic higher plants, pursuant to European Union Directive 94/15/EEC, traits of the organism are important. To verify the assumption that behaviour of a plant can be predicted from its traits, the ecological impacts resulting from the cultivation of eleven non-transgenic crop species were studied. It was hardly possible to infer effects directly from traits. Ecological impacts of agricultural practices are more easily identifiable. Adverse effects linked to certain traits frequently correlate with maladjustment to local environmental conditions (e.g. climate). Less attention is paid to...
these effects within the scope of conventional risk assessment. It is concluded that:

effects cannot be fully anticipated from phenotypic traits, although this is a prerequisite for the currently practised form of risk assessment;

the significance of the parameters 'gene transfer' and 'invasiveness' is much lower in practice than indicated by their importance in risk assessment; and

ecological impacts of major practical importance are not taken into account, because they concern agricultural practice.

Limitation of risk assessment to impacts on ecosystems NOT used agriculturally leads to an unacceptable limitation of the scope of protection. Since only phenotypic traits are deemed significant for possible risk, restriction of risk assessment to transgenic plants seems inappropriate.

The introduction of more "ecologically beneficial" breeding goals in terms of a prophylactic and extensive environmental protection is proposed in the long term, to allow more consistent regulations that do not place transgenic plants at a disadvantage.

To partially relieve the current shortcomings, Annex II B of EU Directive 94/15/EEC could include (e.g.) a question about whether the genetic modification allows, promotes or requires changes in agricultural practice and possible environmental impacts resulting from practice that has been modified due to the new traits.

**Keywords:** transgenic plants, risk assessment criteria, European Union Directive 94/15/EEC, ecological impacts, concept of familiarity

**INTRODUCTION**

A project has been carried out to consider the risk assessment criteria in EU Directive 94/15/EEC of the European Union (adapting to technical progress for the first time Council Directive 90/220/EEC on the deliberate release into the environment of genetically modified organisms), in the light of documented ecological impacts of the cultivation of traditional non-transgenic crop plants.

**RISK ASSESSMENT OF TRANSGENIC PLANTS IN GENERAL**

Although risk assessment of genetically modified organisms (GMOs) is currently carried out in almost all industrialised countries and much experience has accumulated, there are still a number of uncertainties. These include:
1 What is the basis of comparison?

Guidance is provided by the Concept of Familiarity (OECD 1993), which states that experiences with existing crops are a suitable basis for the risk assessment of transgenic plants. In the past, crop plants have been modified by traditional breeding including sophisticated techniques, and some of the traits introduced may have had an impact that is comparable to that of traits introduced by genetic engineering. Originally, the Familiarity Concept was designed to indicate where there is knowledge, where there are areas of uncertainty, which questions can be addressed and where it is necessary to gain additional knowledge. In the meantime, some interpretations arose that go beyond this, stating that risk is virtually absent with well-known traditional crop plants, as long as the trait introduced is not too unfamiliar.

2 Which kind of risk to assess?

This is addressed, among others, by the Exotic Species Model (Sukopp and Sukopp, 1994, which describes what may happen after the introduction of non-indigenous species into new habitats. Such a species with new traits may show unintended and unforeseen behaviour even after long lapses of time where it remains 'dormant'. The risks mainly derive from invasiveness of the species, and, if there are fertile relatives, from gene transfer that may lead to invasive hybrids. In both cases, unwanted ecological impacts may result.

What is to be protected?

The question of what to protect, i.e. why the whole procedure of risk assessment is carried out, is more controversial. Grossly, there are two sets of opinions:

a) Restriction to 'Natural Ecosystems', implying that only ecosystems that are not previously influenced by human activities are to be protected; this is a rather narrow scope.

b) Assessing the general impact on the environment; all activities that may have an ecological impact are to be considered, including agricultural practice.

Which safety standards to use?

The question of which standard of safety should be normative is highly controversial at
present, and is currently under discussion in the European Union. An input by national Competent Authorities is required and the project aimed to provide such a contribution.

In spite of these areas of uncertainty, there are common grounds for risk assessment as it is currently practised. A set of ideas form the basis for virtually all current risk assessments, as for example:

Experiences with traditional crop plants are the basis for any assessment. It is hardly conceivable that anything else could serve as that, especially if widespread cultivation is concerned.

In transgenic as well as in traditional plants, a trait in a species leads to a certain behaviour.

New traits are the fundamental entities that are to be assessed, together with all other traits defined by the species. Behaviour can thus be inferred from the plant's (new) traits, and a newly introduced trait alters the behaviour of the plant, dependant on the conditions the plant meets, in a more or less predictable way.

However, there remain some questions, for example:

How far-reaching is experience about ecological effects resulting from the cultivation of crop plants?

Which effects have really been observed?

Which of the observed effects are relevant in practice?

In particular, how relevant are gene transfer and invasiveness, since they are most frequently addressed in risk assessment?

Can individual effects be attributed to certain traits, i.e. is there a firm link between cause and effect? If so, what are these effects and traits and do they have something in common?

Can effects be assessed in terms of whether they have been caused by the traits of the plants or by the cultivation conditions, since the latter are frequently deemed irrelevant for risk assessment? Or do plant traits determine cultivation conditions and thus exert an influence on agricultural practice?

Is it useful to take 'secondary' or indirect effects into account in order to avoid a negative
environmental impact?

Such effects are difficult to assess and hence they play a minor role in risk assessment today. However, they may be ecologically highly relevant.

In order to address some of these questions, and to challenge current risk assessment, the project turned around the Concept of Familiarity. Traditionally bred and transgenic plants are basically comparable, and traits introduced in the past into crop plants may have led to different impacts including gene transfer and invasiveness. So knowledge about such events should be compiled in order to assess the criteria for risk assessment of transgenic plants, as far as possible. A compilation of knowledge about ecological impacts resulting from the cultivation of traditional crop plants (with no restriction as to the type and cause), a correlation of traits and established effects, and finally a risk assessment according to Annex II B of the EU Directive 94/15/EEC, where appropriate were undertaken.

The project outline was to carry out pilot research, in order to come to a definition of the plants to be investigated, then carry out literature research and interviews with experts and exchange the results in order to comment them. Summaries and interpretations of the results were commented upon by Austrian and foreign experts, and all the material was discussed at a workshop. Then three cases were assessed on the basis of Annex II B and some proposals for modifications were reached, after intense debate.

Plant traits considered relevant for the investigation were the tendency to cross-breed, invasiveness, persistency, repression of varieties and cultivars, constituents, resistances, susceptibility to diseases, stress tolerance, requirements for water and nutrients, root formation, and finally, where possible, the influence on micro-ecology. The experts interviewed came from 'conventional' and 'biological' plant breeding. They included academic agronomists, botanists, ecologists, regulators, industrial researchers, and many others, mostly from Austria but also from Germany and Switzerland. After long debates, it was agreed that the following plants should be considered: apple, carrot, cocksfoot, maize, potato, oilseed rape, Robinia, spruce, sunflower, Jerusalem artichoke (Topinambour), and wheat. This group of plants is characteristic for our latitude, although it is definitely not and was not intended to be representative.

RESULTS

After interviews with experts and literature screening, it appeared that, contrary to initial expectations, knowledge with regard to ecologically important parameters is rather scanty. Most people referred to agronomic performance parameters, which were documented in great detail. However, there were very few unambiguous indications of ecological impacts due to defined plant traits. At most, there were some reports with circumstantial evidence covering facts that may have an ecologically relevant impact due to a certain trait, but were
far from 'sound science'. Hence, direct correlations between trait and effect could only be established in very few cases. (A prerequisite was that the time frame and the surface area were defined and that the plant was well characterised, genetically as well as physiologically.)

Ecological impacts due to agricultural practices were more easily identifiable. Adverse effects that could potentially be linked to certain traits frequently correlated with maladjustment to local environmental conditions such as climate.

Invasiveness leading to a shift in the range of species, potentially occurred with Robinia and Topinambour. However, beside the factors specific to the species, i.e. pioneer traits, many others specific to environment have to be taken into account. (Here, in particular the time frame and the anthropogenic influence are important. Although not a consistent rule, there is a tendency that less domesticated species tend to be more invasive.) Nevertheless, invasiveness was not deemed a great problem in the species investigated, as far as practical relevance is concerned. Only with Robinia has potential invasiveness led to a special policy, preventing widespread cultivation of the tree in plantations in Austria. For invasiveness, there are several sets of structured criteria for assessment available that work quite well.

Outcrossing potential may be attributed to apple, carrot, wheat, and cocksfoot but, again, outcrossing never was deemed a problem. even if it obviously occurred, as in carrot and the cocksfoot. The only case where there were reports that hybrids gain selective advantage was the apple, which may hybridise with the crab apple and repress the latter at extreme sites, such as behind sand dunes.

Structured criteria for assessment are available that make use of different factors relevant for outcrossing, such as generative reproduction, related plants in the natural flora, cross-fertilisation, fertilisation by insects/wind, sexual compatibility, flowering period, fertility, the hybrids' competitiveness etc.) An important point is that the hybridisation potential depends heavily on the time period investigated, although quantitative predictions appear very difficult.

The other traits investigated could be associated, more or less, with all the plant species. Resistances against biotic stress may consist of monogenic or polygenic traits; they are determined by the balance between parasites and recipient plants. and are brought about either by morphological (e.g. hairiness) and/or physiological (e.g. cellular immunity) traits. Ecologically important is the potential to select for immunity to parasites, which may be greater with monogenic traits. However, they are easier to introduce.

Tolerances of abiotic stress factors in general determine the suitability for local cultivation and are therefore relevant for the area where a plant is grown. Negative impacts may arise
when the culture reaches the borders of the natural geographic distribution or is maladapted, e.g. to the climate. A prominent example of such a problematic crop plant is maize. Cold tolerant varieties may have advantages from an ecological point of view, since they grow faster in their juvenile phase and there is less need for herbicide application. Also, erosion may be reduced. However, if grown on unfavourable sites where maize cultivation was impossible before, the same problems arise as with less cold tolerant strains in warmer climates. From the breeder's point of view, abiotic stress factors are more constant and easier to work with than parasite stress; on the other hand, tolerances are complex traits and selection is more difficult.

Plant constituents are ecologically relevant if toxic or allergenic, and may also be responsible for tolerances or resistances. Further, they are of great importance since they determine quality features and thus influence the economic value of the plant and so the cultivation area, which is the most important single factor for ecological impacts.

Seen from a systemic point of view, there are several agricultural developments that may have ecological impacts in a broad sense, although they are not immediately attributable to specific traits. Nevertheless, breeding goals may contribute. Among those developments are the tendency to increase yield through high-input varieties that turn high cultivation intensity into high yield. Although high-yielding varieties are not more susceptible to diseases, the expansion of the cultivation area and the higher intensity lead to increased infestation stress. Further, quality goals according to the demands of the processing industry lead to the preference of traits that can be clearly, namely chemically, defined, and others remain less important. Contrary to high expectations, the breeding objectives have remained rather unchanged over time as: higher yield, resistance, herbicide tolerance, stability, improved harvesting, homogeneity, etc. Ecological goals are scanty. This may also be due to the lack of ecological evaluation standards of breeding goals. The lack of adaptation of varieties to the respective site may be balanced by cultivation measures, which in turn may have an ecological impact. This seems to be the most important cause for unwanted developments and is especially important when the cultivation area is expanded.

Since other goals predominate, and less than optimal nutrient uptake is easily compensated for, less attention is paid to the interactions between plant and soil at the roots. Monogenic resistances, as mentioned, are more easy to obtain, but the improvement in terms of reduced infestation may be counteracted by more aggressive pathogens derived from selection. Hence, they may not provide permanent protection. Finally, the decline of genetic diversity in agricultural ecosystem may have contributed to such negative impacts, as an unbalanced exploitation of the soil, parasite stress, more aero-chemicals, erosion, etc. However, besides the time frame as an important factor for the degree of change, diversity has to be clearly defined; does it refer to the number of varieties within a species, the varieties in use, or the gene pool of whole species including seed banks and wild relatives.
USE OF ANNEX II OF DIRECTIVE 94/75/EEC

Wheat with the trait of short stalks is an example for assessment according to Annex II B. The problem is that, briefly, stalks of long stalked varieties break easily, due *inter alia* to fungus infestation, wind, rain, etc. The achievement of high yield due to high input or to variety-specific traits results in heavier ears. Accordingly, the stalks break more easy. Short stalk varieties show less risk of breaking, hence the need for fungicide application is reduced. This potentially beneficial outcome, however, may be counterbalanced by the tendency to increase input even more in order to increase yield. The ears grow heavier and the stalks start to break again. It was considered whether this situation can be covered by the questionnaire of Annex II.

In general, it was observed that many criteria are applicable. For the 'genetic modification' the new trait 'short stalk' was used. The assessment went well until reaching question D9 'Potentially significant interactions with non-target organisms', where the problem of stalk breaking should be addressed. However, the term 'target organism' refers to the parasite from which the plant should be protected, by means of the product of the introduced gene, in a direct way. Eventually the parasite could become resistant to this product. In the present case, however, only the environmental conditions for a parasite (the fungus) are modified, so the wording appeared inappropriate.

Therefore it is proposed to request wider data on modified conditions for the interaction with other organisms. However, not only interactions with organisms, but also possible interactions with the abiotic environment are important and may be relevant. Therefore, it is suggested that information about the abiotic environment should be included. Finally the question arose as to what extent high-input cultivation is linked to the short stalk trait, and whether short-stalk wheat is also suitable for low-input cultivation. Therefore we propose to include effects on cultivation measures also.

Our proposal, derived from this example, is to assign to Section D of Annex II all modifications concerning interactions with other organisms, the abiotic environment, and agricultural practice. Section H should deal with individual ecological effects of these modifications. Hence, a consistent framework could evolve where a comprehensive view is generated that takes into account those impacts that seem relevant in practice.

We also assessed cold tolerant maize (see above), and Robinia, where we concentrated on the 'exoticity' aspect. Details are provided in another publication (Torgerson, 1996).

**IMPLICATIONS**

What impact on risk assessment in general may be derived from our findings? As a general result, we found that ecologically relevant effects can rarely be anticipated from
phenotypic traits - although this seems to be a prerequisite for the current form of risk assessment. In practice, the significance of the parameters 'gene transfer' and 'invasiveness' appears to be much lower compared to their importance in current risk assessment protocols. However, structured criteria for investigation of these parameters are available, so that assessment is a more or less straight-forward task. Is it that one does what one can do, irrespective of the relevance? In contrast, those ecological impacts that are of major practical importance are not taken into account in current risk assessments. The reason may be that there are no formal criteria available, and they frequently concern agricultural practice, which is hard to assess properly. Differences in the time frame are not addressed by current risk assessment, and long-term impacts and rare effects can hardly be assessed. This may be due to the fact that most of what is known of a crop plant is derived from agronomical investigations. Usually, they do not cover long time intervals, especially if perennial plants are not involved, as with most crop plants. For example, criteria for the assessment of forest trees are altogether lacking - they are simply not comparable with wheat and maize. Therefore, uncertainty is greater for plants that are long-lived or whose cultivation area is very large. Finally, I want to stress an old argument: if phenotypic traits and not the breeding techniques are relevant, it is inconsistent to investigate only transgenic plants. It puts transgenic plants at a disadvantage, and leaves out varieties that may have traits with similar impacts.

In the light of these considerations, how do the concepts referred to appear? The Concept of Familiarity still is attractive. However, in our opinion, it has lost some of its glamour. Remarkably little is known about those ecological effects of conventional crop plants that can really be attributed to distinct traits, and thus are accessible for proper risk assessment. In general, "Familiarity" appears to refer primarily to agronomic performance. Hence, it is not surprising that short-term effects predominate, since this is also the case in the assessment of agronomic performance. The Exotic Species Model (Sukopp and Sukopp, 1994) is not very well suited for the assessment of single cases, since it makes statements on a statistical basis about effects of introduced species. Since risk assessment is canonically Case to Case, there is a certain tension, although the model is very thought provoking. Furthermore, introduced species are not generally comparable to transgenic organisms for different reasons, at least at present. This situation may change when there are transgenic plants available that are entirely different from their ancestors.

**SCOPE**

The question of Scope is one of the most pressing issues. Should risk assessment be reduced to investigating impacts on 'natural ecosystems', or is it about ecologically relevant impacts, regardless of the cause of effects?

If restriction to natural ecosystems is chosen a full assessment should only be performed if genetic pollution is likely to lead to the repression of indigenous species. Irrespective of the slight inconsistency (the result is taken as prerequisite), this way inevitably leads to
some important consequences In order to exploit the benefits in terms of simplification, the current procedure is all too exaggerated and costly for the result that may be obtained. Our findings suggest (but do not prove) that repression of an indigenous species is a very rare effect. 'Natural ecosystems' are scanty in central Europe and are mostly confined to reserves and National Parks, etc. The chance of detecting such a rare event may be close to zero, even retrospectively. Since the relevance appears so low, the assessment outcome 'not relevant' for the risk of an impact on an indigenous species in a 'natural ecosystem' is very probable. and an elaborate risk assessment seems unjustified. The logical consequence is to replace risk assessment with a simple notification and an informal mini-assessment in order to check whether there is any conceivable risk. This solution of the problem leads to advantages like great simplifications and considerable savings, since nobody has to bother with unlikely effects that cannot be anticipated anyway. It would be technology-friendly, enhance competitiveness, etc. However, there are drawbacks. Firstly one would have to give up the precautionary principle as a general rule in biotechnology politics. Secondly, a limitation to "natural ecosystems" excludes virtually all central Europe. It depends on how the term is understood but, taken literally, the area covered would be ridiculous. Thirdly, the most relevant risks as recognised from our interviews would be deliberately overlooked. That may be intentionally so, but it would certainly lead to a severe loss of trust in public, since most people have a different understanding of 'risk' and 'risk assessment' than this confined view would allow for.

Considering ecological relevance regardless of the cause of effects is another alternative. This broad view appears to be more appropriate in terms of the aims of risk assessment, but would also lead to important consequences. In the first place, one would have to investigate all effects that cause environmental harm with conventional plants, such as for example tolerances, etc., that may lead to the expansion of the cultivation area. The advantage would be that this view appears more compatible with the original intention of the old EU Directive 90/220, as stated in the preamble. Even if the possible results of such an assessment are of low significance, it would create awareness of potential problems with experts.

Finally, this seems what the public expects from risk assessment. However, although easily conceivable, it would be very difficult, if not impossible, to put into practice. To extend the meaning of 'risk' to such a degree inevitably triggers the discussion of what a risk is while the assessment is performed - and probably never ended. Marketing would be virtually impossible. Furthermore, the assessment would also have to cover non-transgenics for consistency reasons, with enormous consequences. It is thus no wonder that this is obviously against the European Commission's intentions. Such a gross change of framework conditions and agricultural policy is unlikely.

**PROPOSALS**

In search for a third way, the group came up with two proposals.
In the long term, it would be desirable if 'ecological sustainability' could be introduced as a 'leitbild' for breeding goals and the framework thus shaped to induce a shift towards an ecologically more compatible way of agriculture. This would lead to more consistent regulations that do not discriminate against transgenic plants, but implies a general rethinking of current risk assessment strategies. However, there are some problems associated. Firstly, the interpretations of the term 'ecological sustainability' differ widely, and long-lasting debates will probably arise over its meaning. Secondly, this strategy implies a far-reaching reorientation of agricultural policy, hence, it is, at best, a long-term goal. In the short term, there is no alternative to relieving the obvious shortcomings.

It was agreed to propose a possible way to proceed. Since effects from agricultural practice have been found to be of paramount importance in terms of ecological impact, we propose to (at least) try to assess grossly the possible influence of a particular new trait on the agricultural practice. To this end, one has to amend Annex II B to EU Directive 94/15/EEC accordingly.

Firstly, adequate criteria must be established, since they are obviously lacking. One argument frequently brought forward concerns the possible delay for applications due to such a broader assessments. However, considering the difficulties with the current schemes, a longer delay is hardly conceivable. Higher costs would arise, since post-marketing monitoring would be necessary. And finally, new ways of modelling realistic agronomic conditions must be found. However, they are needed also in other contexts.

Our proposal for an amendment to Sections of Annex II to EU Directive 94/15 is as follows:

SECTION B:

*Change Section 3(b)*

FROM: 'specific factors affecting survivability, if any.'

TO: 'specific abiotic factors affecting survivability (temperature, water, soil and nutrient needs, stress tolerances).

*Add a new item 3.c as:*

'Genetic homogeneity, genetic adjustment potential'.

*Add a new item 5.b) as:*

Form of utilisation and cultivation.

*Change Section 6*
FROM: 'In the case of plant species not normally grown in the Member State(s), description of the natural habitat of the plant, including information on natural predators, parasites, competitors and symbionts.'

TO: 'In the case of plant species not grown in agriculture and forestry in the Member State(s), description of the natural habitat of the plant and the ecosystem in which it is to be grown, including information on natural predators, parasites, competitors and symbionts.'

Change Section 7
FROM: 'Potentially significant interactions of the plant with organisms other than plants in the ecosystem where it is usually grown, including information on toxic effects on humans, animals and other organisms.'

TO: 'In the case of plant species grown in agriculture and forestry in the Member States, potentially significant interaction with the biotic and abiotic environment in the ecosystem in which it is usually grown, and possible changes to these interactions in the ecosystem in which it is to be grown, including information about toxic effects on humans, animals and other organisms.'

SECTION D:

Change Section 9
FROM: 'Potentially significant interactions with non-target organisms.'

TO: 'Do any modified conditions result for interaction with other organisms and the abiotic environment?'

Add new item:
'Does the genetic modification allow, promote or require changes in agricultural practice, including possible expansion of the growing area into other ecosystems?'

SECTION H:

Change Section 4
FROM: Possible environmental impact resulting from potential interactions with non-target organisms.'

TO: Possible environmental impact resulting from potential interactions with other organisms and the abiotic environment.

Add new item:
5. Possible environmental impacts resulting from agricultural practice that has been modified due to the new traits, including possible expansion of the ecosystem where it is grown.

CONCLUSION

Returning to the initial questions, are there new insights into possible answers?

What is the basis of comparison?

On the basis of traits in a species, traditional and transgenic, plants are basically comparable. Accordingly, regulations have to be consistent for all kinds of crop plants.

Which kind of risk to assess?

From experiences with traditional crop plants, risks that arise from agricultural practice are at least as important for ecological impacts as gene transfer and invasiveness.

What is to be protected?

We conclude that the limitation of risk assessment to impacts on 'natural ecosystems' excluding ecosystems used agriculturally leads to an unacceptable limitation of the scope of protection. However, extending the concept of 'risk' too widely would lead to a gridlock. Nevertheless, impacts from agricultural practice should be taken into account on a provisional basis.

Which safety standards to use?

This is too political a question to be answered by scientists. Whether the yardstick of comparison should be industrialised agriculture as currently found in many industrialised countries and being propagated in many others, or the aim of a future, more sustainable agriculture of whatever shape, or something entirely new, is open for debate.

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