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Agronomic and Environmental Aspects of the Cultivation of Transgenic Herbicide Resistant Plants

by

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Summary

Introduction

The data and information for this document were collected through literature review, internet search, and expert surveys. Genetically modified bromoxynil resistant crops were not covered because of the low relative relevance compared to glyphosate and glufosinate resistant crops.

Section I Scope of Application

While herbicide resistance can also result from selection, the focus is on resistance due to genetic engineering. This is because the latter crops are planted at huge cropping areas at the moment (especially soybeans). It can be expected that this trend will continue, because other important crops with the HR-trait, like sweet corn, sugar beet, rice and wheat are already approved or under development. The most important traits in this sense are crops resistant to one of the two herbicides glufosinate and glyphosate.

Commercial cultivation of glyphosate and glufosinate resistant transgenic crops:

crop	global cropping area (mio ha)	% HR of global area	herbicide resistance against	country
corn	140	1.6 (3.1**)	glyphosate	Argentina, Bulgaria[1], Canada, USA
			glufosinate	Canada, USA
cotton	34	6.5 (13**)	glyphosate	USA, *
canola (oilseed rape)	25	12	glyphosate	Canada, USA
			glufosinate	Canada
soybean	79	46	glyphosate	Argentina, Canada, Mexico, Romania, South Africa, Uruguay, USA

http://www.transgen.de, James 2002, [1]Gianessi et al. 2002

** in brackets: HR/insect resistance (stacked)

* regulatory approval is currently pending for HR (glyphosate) cotton in Australia, Argentina, Mexico and South Africa, the product is under development in Brazil and Turkey

Section II Changes in weed susceptibility and weed population shifts

Generally, the selection pressure of a particular herbicide is enhanced, if it is more often applied than others and if the herbicide is highly suppressive. Glyphosate and glyfosinate are non selective herbicides. They are effective to a very large range of weed species. And they are applied in a still increasing number of different HR-crop species accompanied by changes in agricultural practice.

While weed control in HR crops is currently more simple and effective in many cases, this can be undermined in the long run by:

- genetic and structural shifts in weed communities and populations as a result of selection pressure exerted by the application of the respective herbicides and the variability in susceptibility of weed species or biotypes.
- escape and proliferation of the transgenic plants as weedy volunteers,
- hybridisation with - and HR-gene introgression into - related weedy species.

II.1 Selection pressure

Estimations based on plant physiology generally led to the conclusion that glyphosate and glyfosinate are low risk herbicides with respect to the evolution of herbicide-resistance in weed populations. On the other hand, the application patterns (large scale, dominating herbicides, large time window) may contribute to the selection processes.

Some weeds are difficult to control with glyphosate and glufosinate and some already developed resistance against glyphosate such as (officially recorded): rigid ryegrass (*Lolium rigidum*), italian ryegrass (*Lolium multiflorum*) and goosegrass (*Eleusine indica*). Some experts additionally identified marestail (*Hippuris vulgaris*) and fleabanes (*Erigeon*) as resistant. The mechanisms of resistance against glyphosate are partly elucidated. No glufosinate-resistant weed biotype has been recorded so far.

It is reasonable to assume that more resistant species and biotypes will develop if glyphosate is regularly used in a considerable proportion of crop fields. Judging from the experience with the above species, resistance may evolve after 10 to 20 years, if it is used 1-3 times a year. Many weed scientists recommend to use additional herbicides in glyphosate resistant cotton and multiple applications of glyphosate or residual herbicides and glyphosate in soybean, particularly in regions where glyphosate has been used for a long time period now. The implementation of a long-term plan to reduce the selection pressure on weeds by glyphosate is also recommended by some experts. It should be avoided, for example, to plant glyphosate resistant crops continuously.

II.2 Herbicide resistant volunteers resulting from intraspecific and interspecific gene flow

Gene transfer frequencies are highly variable. Influencing factors aside from species specific ones include wind direction and wind speed, climate, variability of the pollination system between varieties of the same species, abundance, diversity, and behaviour of pollinators (sometimes influenced by land marks) and the size of the pollen donor population. Also, different genotypes or varieties sometimes show different frequencies of cross-pollination. Most experiments were done with small pollen sources. Large pollen sources, such as crop fields make gene flow more likely.

Intraspecific gene flow

Intraspecific gene flow generating herbicide resistant offspring has two aspects, the generation of weedy volunteers and seed impurities.

As crop plants can be volunteers in subsequent crops they also may have to be controlled by herbicides or other means.

Oilseed rape (canola), cereals, and potato are examples of crops that often have to be controlled in other crops. Volunteer control is of high importance in oilseed rape. Bolting sugar beet are considered as a source for cross pollination and HR-introgression into “volunteer -“ or weed beet. Volunteers of soybean (in cotton) and corn (in soybean [and sugar beet]) are known from parts of the USA, where glyphosate resistant varieties of three of these crops are grown. If the volunteer crop is resistant against the herbicide used in the subsequent crop, major problems may arise.

Seed impurities can lead to financial losses when plants are sprayed with a herbicide against which they are not resistant. It is also of importance that many consumers want to choose between genetically modified food and organic or conventional food. The latter aspect is important for all transgenic traits, not only HR. The prevention of seed contamination has to be addressed in HR plants with a moderate or high chance of cross pollination such as (regarding the currently grown HR crop species and cropping regions) oilseed rape, sugar beet and - to some extent – corn. Seed production, grain handling, storage and transport are the main sources of contamination.

Details for relevant HR-crop species:
Corn: Gene flow though cross pollination and seed exchange by farmers may be important aspects in Mexico and other centres of diversity of corn. Corn volunteers are known in warm regions and additional control methods for them are applied in the US-Corn Belt. Problems are recorded from soybean and sugar beet. In many colder regions (where corn does not survive low temperatures) the likelihood of growing unwanted HR corn due to impure seed may become relevant.
The probability of growing low levels of unwanted HR (or generally of unwanted GM) corn depends on many aspects in farming, such as field sizes, crop rotations, weather conditions, on the abundance of pollinators and – most important in US and European corn production: seed production management.

Cotton: Commercial cotton varieties do not seem to create severe problems as volunteer plant. Most seeds of modern cultivars do not survive more than one season – in contrast to wild cotton. Nevertheless, the occurrence of volunteer cotton in soybean crops has been reported from the USA.

Oilseed rape: Volunteer oilseed rape is creating control problems in many areas and crops in Europe and in Canada. Oilseed rape volunteers and feral plants may play a significant role in gene transfer from transgenic crops to wild relatives and possibly serve as stepping stones. Feral plants include populations at field margins, soil dumps and roadsides mostly derived from seed spills.
In Canada no management plan has been implemented for canola volunteers so far. Farmers and regulators seem to rely on the options to use alternative herbicides for volunteer control but this practice is not considered as sufficient by some experts. The level of HR genes is usually below 0,25% in conventional seeds in Canada. Organic canola industry has stopped because consumers are not willing to buy contaminated products.
In European agriculture it might be technically possible but economically difficult (see management recommendations below) to maintain a 0,3% seed impurity level and a 1% impurity level in agricultural production when 10% of the rape growing area is transgenic (e.g. herbicide resistant). It was suggested to delay post-harvest cultivation and to repeat shallow stubble tillage in production in order to reduce seed persistence in soil. It may be necessary to minimize overlapping flowering periods between different (HR and conventional) varieties. A regional border management and the use of additional herbicides are other options to keep impurities below the mentioned level. A complete prevention of volunteer occurrence seems impossible even by a combination of the above post-harvest cultivation and wide rotations. The use of additional herbicides against volunteer oilseed rape is proposed by some experts.

Sugar beet: Cross pollinating bolters and annual weed beet as well as the contamination of organic seed and *B. maritima* at the sea coast are of concern in the scientific discussion on gene flow in sugar beet. Annual weed beets cause serious problems in parts of Europe, including Belgium, Germany, England and northern France. The control of bolting beet is recommended in order to prevent outcrossing of HR into weedy forms. Bolting HR sugar beets can pollinate weed beets resulting in HR resistant weed beets. The hybridisation between annual weed beets and cultivated HR beet is likely to happen when HR varieties are grown. Bolters have to be monitored and controlled in seed production areas. If the bolting plants and weed beets are not removed immediately, stable weed beet complexes form quickly and are difficult to eradicate. Moreover, certified seed with low impurity levels should be produced and used. A thorough control of ruderal beets will be necessary and the implementation of upper isolation distances (1000 m and more) in seed production areas may be necessary.

Soybean: In Europe, soybean is not weedy. In US cotton and corn areas, keeping out volunteer soybeans can be a challenge. Glyphosate resistant varieties of all three crops are planted in the USA.

Interspecific gene flow

The relevance of *interspecific* gene flow of a herbicide resistant plant to weeds highly depends on the cropping region and the abundance of interfertile relatives of a crop. In the current biosafety discussion of HR crops the control of oilseed rape relatives in Europe and the implications of hybridisations between corn and teosinte in Mexico are addressed. Weed control methods in other crops within crop rotations in Europe have been recommended to control possibly occurring weedy hybrids of oilseed rape and wild species.

The following weedy plants may raise control problems due to introgression of HR genes from oilseed rape:

- *B. rapa* (which is grown as a crop but also known as a weed) (in Europe and Canada)
- backcrosses of *B. napus/R. raphanistrum* hybrids with the weed parent (in Europe)
- backcrosses *B. napus/Erucastrum gallicum* hybrids with the weed parent (in Canada).

Herbicide resistant weeds are under control, as long as different herbicides are sprayed in cereals (or other rotational crops). Thus, herbicide use in cereals may become an obligation although it could be omitted in particular integrated farming systems.

Some Canadian experts stated that the current management strategies were not sufficient to avoid introgression of HR-genes into weedy relatives and volunteers in Canada.

Mexican researchers are currently investigating and discussing the case of teosinte.

Wheat and rice, two very important crops of which HR varieties are expected to be approved soon, both have weedy relatives in certain anticipated release and growing regions. Precautious control methods are proposed for the wheat fields in the western USA.

Interfertile weedy relatives of rice are abundant in parts of Asia and red rices (subspecies) are known in many parts of Asia, Oceania, Africa and Latin America. A combination of different modes of containment and genetically introduced containment traits is proposed in order to reduce the likelihood of gene transfer to red rice.

Section III Impacts on agricultural practice and agronomy

HR cropping induces changes in agricultural practices and agronomy, e.g. altered weed control, yields, net income, soil tillage, planting and crop rotation.

III.1 Weed control patterns

In non-HR farming, farmers apply a sequence of different herbicides or tank mixtures to control competition of weeds with the crop. Some of these herbicides can only be applied before crop emergence and are therefore often routinely applied as a precautionary measure.

HR crops allow the post emergence application of a single herbicide with a wide spectrum of activity.

Spraying at postemergence can imply a restriction to a very short time period in respect to weed development. This can be problematical, if the weather conditions are unfavourable for herbicide applications.

Glufosinate or glyphosate can be used alone, in combination with preemergence herbicides for programs that provide soil residual control, or with mechanical weeding. As the maximum weed size for effective control is higher with glyphosate than with other herbicides, the potential time period for spraying is extended. This allows more flexibility.

No overall picture about changes in weed control patterns can be drawn:

Crop injury within the sprayed field is expected to be lower in HR crops but injury caused by drift is expected to be higher. More postemergence applications as well as daytime applications of the highly supressive herbicides contribute to drift problems. The effect of glyphosate and glufosinate is higher at daytime and wind speeds are higher too.

Postemergence applications increased in HR resistant soybean and canola, postemergence applications are expected to increase in herbicide resistant sugar beet (UK) but not in corn. Information on possible changes in oilseed rape in Europe is missing.
According to the experts statements, the adoption rate of *economic threshold models* is low in any crop covered by the study. It will further decrease in canola and probably in soybean.

Changes in overall *amounts of herbicides* used are more difficult to assess because different herbicides are applied at different particular, and varying rates. In soybean, a slight overall reduction, but also increased amounts in reduced or no till systems (at least in Argentina) have been reported. Recently, increasing herbicide use is observed in some areas where HR soybean has been planted for many years because of evolving resistant or tolerant weeds (see above) and is recommended for some HR cotton areas (additional herbicide types recommended here which results in higher amounts too). One reason of several others for an overall decrease in herbicide use in cotton was the adoption of glyphosate resistant varieties. Amounts used in European corn or sugar beet field tests have been less in HR plots. Oilseed rape should not be sprayed with herbicides as it is mostly not economically sound in Germany and the UK.
A reduction of amounts does not necessarily mean a reduction of effectiveness (see below) or of application numbers.

Reduced herbicide *application frequencies* can lower soil compaction and erosion. The survey indicates that canola farmers may spare one application in HR varieties in Canada, but this is not supported by publications. Application frequencies in soybean also decreased. A decrease in application frequency is expected for European sugar beet and oilseed rape in France. An increase in German oilseed rape is expected with glufosinate resistant cultivars. An additional application is predicted for HR corn in Germany too. No changes in application frequencies, or differing results have been reported for soybean and cotton.

The *number of herbicides (types)* used in HR varieties (compared to conventional ones) decreased in Canadian canola, in US and Argentinean soybean and probably in cotton areas. Nevertheless numbers of herbicide types are probably increasing according to experts recommendations in some cotton areas. In HR soybeans, not only glyphosate but also triazolopirimidines and imidazolinones are used. Herbicide numbers are expected to decrease in European sugar beet and oilseed rape and probably in corn.

Mechanical weed control decreased with introduction of HR varieties in cotton, in US soybean (from < 10% to 0 in Iowa), in Argentinean soybean (at those locations where it was still done), and may have decreased in Canadian canola. It is expected to decrease in European sugar beet (30% to 0% of the acreage).

Weed suppression is improved in nearly all HR crops and regions. It is expected to be improved with HR sugar beet and HR oilseed rape, but not with HR corn, in Europe.

III.2 Yields

Reliable data of independent research institutions on yield differences between conventional varieties and HR varieties are scarce. Varying results make general statements impossible.
One major problem is the correlation with co-variables, e.g. farm size, education and skills of the farmers.

Corn: Mixed results on yield differences (no differences and increased yields in HR varieties) in the USA are recorded. No significant differences have been found in German test fields.

Cotton: Varying results make general statements impossible.

Oilseed rape: Yields in Canadian canola are higher on average with HR in about half of the growing conditions according to the expert survey. Maximum yields were gained by a non-HR variety. No differences were found in European field tests.

Soybean: Mixed results were published for US soybean. In summary and on average yields of HR varieties were about the same or less. Argentinean HR soybean varieties yielded less than their conventional counterparts.

Sugar beet: Yields of HR varieties increased but results were not statistically significant in Germany. Yields increased in other european field tests too. Yield gains are expected by UK experts.

III.3 Net income

Corn: Gains were only rarely found in the German HR varieties (compared to non-HR).

Cotton: Net returns increased due to reduced herbicide costs in the USA.

Oilseed rape: About half of the HR growing farmers in Canada had higher returns according to the experts. The outcome was accounted to a lower dockage, earlier planting and reduced herbicide costs. Some published results indicate lower yields and lower economic returns for HR canola, probably depending on the farm and soil type. No gains and sometimes losses were found in European field tests with HR oilseed rape. Weed control is often not economically justified (Germany, UK).

Soybean: Savings through cheaper herbicides often equalized or outweighed higher seed costs and sometimes lower yields in the USA. No clear-cut increase in net returns can be stated for Iowa (HR) soybean but for Nebraska and Argentinean (HR) soybean.

Sugar beet: Higher net returns are expected for HR sugar beet compared to conventional varieties by UK experts due to higher yields and lower herbicide costs.

When the net income increased in a HR crop, the better profits were mostly attributed to lower herbicide costs and less tillage (which implies less labour and fuel costs) often summarised as production costs. The correlation between less tillage and HR may not commonly be given, which implies that cost reductions due to HR are mainly due to reduced herbicide costs. Highly suppressive herbicides seem to be of importance in the first one or two years of tillage reduction.

III.4 Tillage

The adoption of conservation tillage has widely been enforced and propagated since many years. It does not depend on herbicide resistant crops. Surveys indicate that 1,8% of cotton and 3% of canola farmers but 46% of soybean farmers planted HR varieties in order to reduce tillage. Findings on the significance of HR for the adoption of reduced tillage practice in cotton and Canadian canola were mixed.

Soybean farmers who used no-till had a higher probability of adopting HR, but the use of HR did not affect no-till adoption in the late nineties. Nowadays, reduced tillage practice and the planting of HR cotton are both increasing and seem to encourage each other. Experts predict an increase in reduced tillage when HR varieties are planted in Europe.

Most of the Argentinean (HR) soybean farmers shifted to reduced or no-tillage.

However, price reductions for agricultural products account for a strong trend to save tillage runs by applications of non-selective herbicides – pre-seeding or in HR crops, worldwide.

III.5 Crop rotations

In Canada and Argentina some loss of fallow land, which was planted to HR crops, has been recorded.

III.6 Reasons to adopt HR crops

Several reasons may theoretically account for the adoption of HR-crops by farmers, e.g. improved weed control, cost reduction and yield increase. For most cases, a combination of reasons can be assumed, and different priorities for different crops and growing situations are given. Simplicity, high effectiveness, and low herbicide costs in HR crops are the most mentioned and most highly ranked reasons in published results as well as in the expert survey. The option to reduce tillage, the convenience in timing of weed control and the reduced herbicide application frequency are further important reasons. In general, farmers are adopting HR because they want to reduce production risks.

Section IV Impacts on biodiversity

Agricultural biodiversity is of very high concern. Where agricultural land covers a large proportion of the land, many conservation strategies have to include agricultural practices.
Reduced amounts of herbicides, considered to have less toxic effects to vertebrates than several other herbicides, have to be balanced against negative effects of a stronger weed and wild plant suppression (and its effects on the food web including vertebrates), loss of fallow land, drift effects on margins and uncropped land, increased narrow row production, and additional volunteer control effects in oilseed rape/canola – depending on the production systems.
In general, herbicides are known to have more indirect effects on biodiversity through plant suppression (with consequences for the food chain) than direct toxic effects.
European large scale tests with sugar beet and oilseed rape showed, that less amounts or less applications of highly effective herbicides in HR crops do not cause less damage to biodiversity but the opposite. Diversity and abundance of the field flora and most arthropdods (including important pollinators and benefial pest predators) declined.
The results indicate, that compounded data on direct toxic effects to a restricted number of tested animals are an insufficient indicator for environmental effects of herbicides. The indirect effects (highly efficient and non-selective weed control) accounted for the outcome.
The effectiveness of weed control in commercial HR crops in Canada, the USA and Argentina is also higher than in conventional systems.
The decrease in biodiversity compounded over time and large areas would be much greater than detected in the UK-trials.
Findings in HR corn were different. Biodiversity was higher in glufosinate resistant corn than in conventional corn where atrazine was used in the large-scale trials mentioned above. A comparison without atrazine (which is forbidden in some countries) is missing. As an overall result, the strong relation between field flora and arthropods was obvious.

Some HR systems can be modified to favour wild plant abundance, but it is questioned whether it will be done without further encouragement. Field tests with a 50% dosage in fodder beet, and band spraying in combination with economic threshold evaluation and postemergence application in sugar beet have shown to result in a higher wild plant abundance followed by a higher abundance of beneficial predator arthropods on sites with a rich seedbank reservoir.

Unsprayed patches and patchy (precision) fertilisation would also positively contribute to these effects. The development and propagation of patchy weed control and its devices may encourage this new practice of weed control. Nevertheless, patchy weed control of difficult weeds with selective herbicides and ecological farming are likely to be more favourable, particularly to field plant (species) diversity. As seedbank losses are already quite dramatic, it would be important to conserve areas with a still diverse seedbank through adapted agricultural practices. However, use of HR in high biodiversity fields is predicted by experts. The propagation and implementation of the above biodiversity favouring concepts as well as adoptions in the timing of agricultural operations and the reestablishment of seedbanks would make some of these options realistic.

Price reductions for agricultural products account for a strong trend to save tillage runs by applications of non-selective herbicides. Some experts consider soil conservation as more important than biodiversity. However, both resources are highly important. The challenge is to conserve both by an integrated concept.

In addition, many monitoring concepts for environmental effects of transgenic plants do not even include the monitoring of field flora and seed rain/seedbank dynamics, although these are the key indicators for biodiversity under different herbicide regimes.

The need for a regulatory system which encourages agricultural methods favourable to biodiversity is evident.