Les variétés végétales tolérantes aux herbicides.

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Collective expertise

Herbicide-tolerant plant varieties

Agronomic, environmental and socio-economic effects

Weed control in crop fields constitutes a major factor in determining agricultural yields. This fact explains the importance of synthetic herbicides in agriculture since their introduction in the years following World War II. The principle of chemical weed control is to apply a product that selectively eliminates weeds without affecting the crop itself. Over the past fifteen years, in parallel with research into new selective herbicide molecules, a complementary approach has been developed: the selection of crop plant varieties tolerant to existing herbicidal substances. This herbicide tolerance permits the coupled utilization of a plant variety and its associated herbicide (or family of herbicides), which is thus applied 'post-emergence', that is to say, to already developed crop and weed plants in the field.

These varieties, known as herbicide-tolerant varieties (HTVs), offer farmers first of all a technical response to the challenges of weed control. Their use is likewise presented as permitting a reduction in the quantities of herbicides used. At the global level, the most widespread HTVs are the result of transgenic breeding, while others are obtained by selection techniques based on naturally occurring variability or by mutagenic techniques.

In France, for a number of different plant species, non-transgenic HTVs are beginning to be cultivated or are currently the object of petitions for inclusion in the Official Catalogue of Agricultural Species and Varieties. In this context, the public authorities and evaluative bodies in France are considering the various perspectives for future development of HTVs. The Ministries of Agriculture and Ecology wish to avail themselves of analytical elements with regard to the real effects, both medium- and long-term, of the cultivation of HTVs and their compatibility with existing environmental policies, notably the French plan for the reduction of the use of pesticides (Ecophyto 2018). These lines of questioning have led to the request, made to CNRS and to INRA, for a multidisciplinary Collective Scientific Expertise (ESCo) on the agronomic, environmental, socio-economic and legal impacts, both direct and indirect, of the utilisation of varieties possessing herbicide-tolerant traits (potential impacts on human health being excluded from the purview of this ESCo).

November 2011

CNRS INRA

. Issues in the evaluation of the effects of HTV cultivation

This ESCo considers the **agronomic trait of herbicide tolerance** (HT), meaning the ability of a plant to tolerate an herbicide to which its species is normally sensitive, regardless of the technique of genetic improvement by which that trait has been obtained. The central question is that of the agronomic efficacy of the coupled use of the HTV and its associated herbicide over the short, medium and long terms. The effects of HTV cultivation depend on the type of herbicide to which the variety has been rendered tolerant, on the crop species and cropping systems involved, and on the scale of HTV adoption. The latter is in turn a function of socio-economic and legal conditions.

This expertise seeks to clarify the possible effects of HTV cultivation in the European context, characterised at the moment by the use of non-transgenic varieties within specific cropping systems and a particular socio-economic context. As an exercise founded on a review of the scientific literature, however, this ESCo depends perforce on existing academic work on the subject. The most extensively studied and best-documented HTVs are transgenic varieties cultivated in North America, where the research community benefits from 15 years' perspective on these varieties' cultivation over extensive geographical areas. Certain research questions on transgenic HTVs have likewise been motivated by debates surrounding the development of genetically modified organisms (GMOs).

Thus if the transposition of results obtained with GM varieties on the other side of the Atlantic may be directly relevant for certain aspects of the subject (for example the study of biological mechanisms), it may be disputable for others, given the differences in agronomic, ecological and legal contexts.

. Methodology and scope of the ESCo

The ESCo is an institutional activity governed by the national charter of expertise to which CNRS and INRA subscribed in 2011. It is defined as a work of analysis and knowledge gathering covering a range of highly diverse fields relevant to the clarifying of public action. The resulting 'state of scientific knowledge' is as complete as possible, and its analysis provides neither opinions, nor recommendations nor specific practical solutions to the commissioning body.

The analysis is conducted by an interdisciplinary team of research experts from diverse institutional backgrounds. For the present ESCo, approximately 15 experts from a range of French research institutions (INRA, CNRS, universities) were called upon, their competencies relating to ecology, agronomy, herbicide chemistry, genetics, economy, law, and other fields. The experts' work was supported by a bibliographic corpus of approximately 1400 references, composed primarily of scientific articles but also including statistical data, analyses of patents, books and technical reports. The exercise concludes with the production of a scientific report presenting the experts' analysis and conclusions, a synthesis intended for use by decision-makers and other interested parties, and a short synopsis (the present document).

Principal HTVs currently commercialised

This ESCo is focussed on the trait of **herbicide tolerance** intentionally introduced into a plant line within the context of variety improvement and declared as such. This notion is thus distinguished from a plant species' inherent capacity to tolerate the application of certain herbicides, the property on which chemical weed control in cultivated species is classically founded.

. Plant breeding techniques, species, and herbicides concerned

The HTVs currently commercialised throughout the world have been obtained by diverse methods:

- so-called 'traditional' selection, making use of natural genetic variability (the identification of spontaneous mutations followed by their integration into the genome of the cultivated plant by sexual crossing);
- mutagenic techniques to increase variability (the inducing of mutations by physical or chemical treatments);
- transgenic techniques that permit the insertion into the genome of the cultivated plant of a desired gene taken from another organism.

HTVs are available for the following major field crop species: maize, soya, cotton, oilseed rape, sunflower, sugar beet, wheat, rice, chicory.

The herbicides associated with HTVs belong to diverse herbicide classes—that is to say, they possess different modes of action: the target enzyme they inhibit in the plant is characteristic of the class. Their spectrum of activity may also be broader or narrower: some herbicides are selective, that is to say, affecting only certain botanical groups (as in the case of herbicide classes A, B, and C, for example); others, known as non-selective, have an herbicidal effect on all plant species, whether cultivated or non-cultivated (classes G and H).

. HTV breeding technique and herbicide type

A global survey of the principal varieties carrying the HT trait, currently commercialised and in cultivation for the most important field crop species, reveals two major groups of HTVs according to the selectivity of the herbicides with which they are associated:

- **varieties tolerant to a non-selective herbicide**. This includes the majority of HTVs currently in cultivation, notably in North and South America (maize, soya, oilseed rape, sugar beet). Developed in the mid-1990s, currently commercialised varieties within this first group are exclusively **transgenic**. These include the varieties marketed under the brand-name RoundUp Ready® (RR®), tolerant to glyphosate (class G), and, more recently and less widely developed, Liberty Link® (LL®), tolerant to glufosinate (class H);

- **varieties tolerant to a selective herbicide, albeit broad-spectrum**. Most varieties in this group are currently obtained through **selection based on natural variability** or by mutagenesis. These include first of all a large range of cultivated plants tolerant to class B herbicides (notably the Clearfield® range) and maize varieties tolerant to class A herbicides. Although poorly represented at the global level, certain of these varieties are cultivated in France (maize and sunflower); others are the object of petitions for inclusion in France's Official Catalogue of Agricultural Species and Varieties (sunflower and oilseed rape).

The correlation currently observable between the breeding technique used to develop the HT trait and the selectivity of the associated herbicides results from the link between utilisable genetic resources and utilisable modes of selection. Although spontaneous mutations conferring resistance exist for all herbicide classes, these mutations appear at highly variable frequencies and carry widely different physiological 'costs' to the plant depending on the herbicide class. Only those traits for resistance that are identified within cultivated species or their interfertile relatives can be exploited in varietal improvement via traditional selection methods or mutagenesis (the case with resistance to class A, B, and C herbicides). This has not been the case with resistance to glyphosate or glufosinate, traits that developers have first identified in microorganisms and then introduced into the cultivated plant species with the help of transgenic techniques.

. Plant breeding techniques and regulatory status of the resultant HTVs

In Europe, new varieties must be listed on the official national catalogue of a European member state before being placed on the market within the European Union. To obtain official listing, a new variety must satisfy a number of criteria, notably in terms of its agronomic and technical qualities. In addition, European Commission directive 2001/18, relating to the deliberate release into the environment of GMOs, provides for supplementary procedures for varieties obtained by transgenic methods, subjecting them to a prior evaluation in terms of their environmental and health effects and requiring that the resulting products be labelled as such.

The development of new technologies capable of being utilised in the genetic improvement of plants – some still in the laboratory stage, others nearing commercial development – has given rise to a reflection at the European Community level with regard to the regulatory status of the varieties so developed. Two such new technologies have been applied to the development of HTVs in the laboratory: both are based on homologous recombination, permitting the insertion of a new gene or the targeted, single-nucleotide modification of the genome. The resulting plants, like plants obtained by mutagenesis or as the result of spontaneous mutations, carry no molecular trace of the modification other than the modified sequence itself and therefore cannot be distinguished on this basis from plants obtained by traditional selection.

Dynamics of HTV development

. Rapid adoption at the global level

The dynamics of HTV adoption are well documented only for the transgenic RoundUp Ready RR® varieties, the spread of which has been the subject of a number of studies, notably in the United States. Their diffusion in that country has been particularly striking: in less than 10 years, the planting of HTVs of this type has reached 80% of total production area for cotton and soya; for sugar beet, HTVs have been adopted on 98% of total production area in just two years.

Quantitative and qualitative data concerning the adoption of varieties tolerant to a selective herbicide are on the other hand rare, and come primarily from the companies responsible for the varieties' development. In the one documented case where these varieties were approved for commercial release at the same time as varieties tolerant to a non-selective herbicide (the case of spring oilseed rape in Canada), their diffusion seems to have been limited, transgenic varieties tolerant of a non-selective herbicide (RR® and LL®) having rapidly conquered most segments of the market.

. Factors in HTV adoption by farmers

A review of the literature permits the identification of expected advantages of HTVs on the one hand, and, on the other, motives cited by farmers in their HTV adoption decision.

Diverse technical advantages of HTVs are advanced by the firms responsible for their development, by seed companies, and by agricultural advisory services. Four principal anticipated benefits of HTVs can be identified, although it is not possible to gauge their respective weight within adoption decisions:

- an expansion in the range of weeds controlled relative to the classic use of selective herbicides within non-HTV systems, and notably an effectiveness on weeds botanically close to crop species, invasive weed species, and parasite species;
- a facilitation of the farmer's work through a reduction in the number of herbicide treatments, an increased flexibility in the use of post-emergence treatments, and/or a shift to no-till systems facilitated by the HT strategy;
- a reduction in the quantities of herbicides used enabled by the substitution of a single molecule for a multi-herbicide program and the adjustment of quantities applied in function of weeds actually present;
- the securitisation of weed control and a reduction in the risks of yield losses caused by weed competition.

In the field, studies among farmers who have adopted HTVs constitute a means of identifying their motives for adoption *ex post*. The sole studies available have been made among North American farmers using transgenic RR® HTVs. Initial studies showed that the anticipated yield gains, which could *a priori* explain the choice of an HTV, were only confirmed in cases where previous weed-management difficulties were affecting yields. Later studies on the reasons for HTV adoption permitted two principal conclusions:

- if the price of HT seed, perceptibly higher than that of non-HT seed, may be a brake to adoption, the cost savings gained in the management of weeds, both direct (herbicide costs) and indirect (flexibility and savings in work time), at least in the short term, constitutes a major motive for adoption;

- a strong linkage has been observed between adoption of an HTV and reduced tillage. The joint implementation of these two techniques has likewise been favoured in regions sensitive to erosion, where the shift to no-till benefits from financial incentives (in the United States). The commercial success of the transgenic HT RR® soya in Argentina is explained by the possibility HTVs offer of a successful transition to direct seeding.

. Commercial strategies within the HTV market

In terms of the commercial supply of HTVs, the strategies of seed developers have been the object of theoretical economic studies in the context of the North American market. Contrary to the European legislative framework, which ensures commercial protection of a plant variety *via* a New Variety Certificate (NVC), possibly accompanied by a patent on the specific genetic trait if the latter is considered as an invention, the American system permits the patenting of a variety itself. The strategy of obtaining patents has been widely adopted by seed developers since it gives them broader protections than those provided by an NVC – as much against other breeders as against farmers.

The coupled utilisation of an HTV and its associated herbicide creates a link within the market between demand for HT seeds and demand for the associated herbicides. The firms that have developed HTVs are in most cases businesses in the crop-protection sector that either already possessed or have acquired a seed-development arm. In any event, in order to favour growth in their herbicide sales they generally have an interest in also signing non-exclusive licenses with other seed companies for exploitation of the HT trait.

When the company loses its monopoly on the herbicide molecule (as in the case of glyphosate, the patent for which expired in 2000), it can still realise profits from sales of the HT seed. Business practices such as “tying sales” (purchase of seeds conditional on purchase of the herbicide) enable the company to retain some market power in the herbicide market but violate competition law. In order to limit competition from generic herbicides, companies thus tend to modify their commercial formulations and/or offer stronger guarantees to farmers who use the HT seed in combination with ‘their’ brand of the herbicide.

Effects on weed flora, durability of the HT innovation and changes in herbicide consumption

The adaptation of weed flora under the selection pressure exerted by an herbicide over time leads to the appearance and spread of weeds that are not killed, or are no longer killed, by the herbicide, thus rendering the HT strategy less effective or even inoperable. The evaluation of the phenomena at work, as demonstrated by field investigations, thus constitutes a major question for this ESCo. Their effects are manifest in the evolution of herbicide use associated with transgenic HTVs in the United States. The scope and speed of these phenomena vary markedly according to the species cultivated and the classes of herbicides considered.

. Phenomena of weed species evolution and their consequences on the durability of the HT strategy

Three phenomena contribute to the progressive appearance within cultivated fields of weeds little affected by, or resistant to, an herbicide associated with an HTV.

From the first year of cultivation, the space freed by the destruction of weeds sensitive to the herbicide is susceptible to being occupied by other species. If this phenomenon of "weed shift" is easily understandable in the case of selective herbicides, which by definition are not active against all botanical families, it likewise obtains in the case of non-selective herbicides, the use of which selects for species naturally less sensitive to the herbicide or which develop after the herbicide’s period of effectiveness.

Furthermore, the spontaneous appearance of herbicide-resistant weeds (*via* mutation) is a recognized phenomenon for all classes of herbicides and has been observed to date in 200 plant species worldwide. The appearance and spread of such forms of resistance are not a specific consequence of the cultivation of HTVs but may be amplified by the conditions in which herbicides are used in HT systems.

This effect is clear in North America in the case of glyphosate, where the massive and rapid adoption of transgenic RR® varieties from the 1990s onward (on which the herbicide is applied at lower rates than for other uses) marked the beginning of the development of glyphosate-resistant weeds as an effect of the selection pressure exerted. On the other hand, for certain classes of selective herbicides, prior use on a large scale had led to the development of numerous resistant mutants prior to the introduction of an HTV. The phenomenon is particularly marked for classes A, B, and C, which made possible the creation of HTVs making use of this spontaneous variability.

No-till, often associated with HTVs, has also contributed to the selection of spontaneous resistance by favouring the development of certain weeds. A theoretical study applied to the case of weed control in wheat cultivation in Australia showed that recourse to mechanical weed management or the lengthening of rotations could postpone the point at which the growing of wheat would need to be abandoned as no longer sufficiently profitable due to the spread of resistant weeds.

Finally, **the spread of an HT trait** can occur *via* the dissemination of seeds produced by HTVs and their descendents, and by the spread of their pollen, capable of fertilising non-HT cultivated plants or related, interfertile wild plants. The risks of diffusion of the HT trait are thus above all a function of the species cultivated and its geographic area of cultivation, which determine the survival of volunteers, the establishment of so-called feral populations (beyond field boundaries) and the existence of interfertile weeds. Maize, which has no related weed species in Europe and volunteers of which will not survive the winter, is thus much less of a concern than oilseed rape.

The question of gene flow from cultivars to related, non-cultivated plants appears crucial for the durability of the HT strategy. Gene flow of this sort – possible for all genes – has been demonstrated in the case of sugar beet, rice, sunflower, oilseed rape and wheat. Weed species botanically closely related and interfertile with cultivated species – the origin of the weed management difficulties that make the use of HTVs particularly attractive – are thus also those with the strongest likelihood of acquiring the HT trait.

Various options, both biological (e.g., the use of asynchronous flowering periods) and biotechnological (e.g., the insertion of the transgene into chloroplast DNA, which is not transmitted by pollen) have been proposed to reduce the probability of transfer of the gene for tolerance by sexual reproduction. None of these methods, however, makes it possible to completely eliminate the risk of transfer into related non-cultivated species.

. Evaluation of changes in herbicide consumption

In the short term, the substitution of a single, broad-spectrum herbicide for a weed-control program including several selective products can potentially lead to a reduction in application rates for the same effectiveness. In the case of tolerance to a non-selective herbicide (glyphosate), *a priori* evaluations as well as statistical data confirm this reduction in the quantities of herbicides used during the initial years of cultivation. However, recent studies conducted in the United States show that the difference in herbicide consumption between transgenic, RR® cultivation and non-HT cultivation, initially in favour of the HTVs, diminishes within a few years and even becomes unfavourable in the case of soya and cotton. This increase over time in the quantities of herbicides used with these HTVs is explained in part by **a recourse to supplemental herbicide treatments**: an increase in concentrations and/or in the number of applications of glyphosate in response to the phenomenon of weed shift, followed by the remedial use of complementary herbicides, notably against species that have become glyphosate-resistant.

Crop-protection practices associated with the adoption of varieties tolerant to a selective herbicide are poorly documented at the global level. With these varieties, the reduction of herbicide use is not necessarily the object in view: the HTV may be used rather as a complementary strategy to classical pre-emergence weed control in order to correct a specific weed management difficulty.

It is to be noted that the possibility of post-emergence treatment enables farmers, at least in theory, to adapt their weed control practices to weed populations actually present, and thus to avoid some applications or to limit them to infested areas – and in this way permits a reduction in quantities used per hectare. The concern to eliminate any resistant weeds as soon as they have appeared, however, can lead to technical recommendations for full-rate herbicide applications to an entire field and its borders.

On the other hand, an awareness of the risk of development of resistant weeds is now leading seed developers and agricultural advisors to recommend from the start the **preventive use**, either together or in succession, **of several herbicidal substances** – a strategy whose interest has been established by theoretical studies. To facilitate this combined use of several herbicides, companies have developed crop varieties combining multiple tolerances – to glyphosate and to one or even two other herbicidal modes of action. This treatment strategy of using a mixture of herbicides belonging to two classes is only appropriate, however, in cases in which no resistance to any of those herbicide classes pre-exists among the target weed species present.

As they have been used up to this point in the United States in particular, HTVs belong to a weed-management logic based on herbicide use in parallel with a reduction of other weed-control methods, both mechanical (tillage operations) and agronomic (rotation length). Their use may, moreover, reinforce the tendency to resort to the aggregated use of herbicides, both preventive and curative.

Effects on the environment

. Impacts on non-target organisms and on biodiversity

The possible effects of HTVs on the environment may *a priori* be caused by the varieties themselves and/or by their associated herbicides. Since HTVs are typically planted within conventional cropping systems, their advantages or disadvantages are evaluated with reference to a conventional system not using HTVs. Insofar as the adoption of HTVs is linked to other alterations in the cropping system – or in the larger system of production – it is at these levels that the evaluation of their impacts is relevant.

No effect of HT crop plants themselves has been demonstrated, but little research has been done in this direction. Thus the few studies that have been done on bees within the cultivation of HT oilseed rape have only taken into consideration a limited number of possible effects.

A single research program conducted in England sought to compare conventional cultivation and HT cultivation within real-world agricultural conditions. It found that the effects on biodiversity seem to be linked first of all to weed control, that is to say, to the reduction of non-cultivated flora, the direct consequences for associated fauna, and the repercussions on the entirety of the food web. While reduced tillage, which can be associated with HTVs, has a tendency to favour the development of weed flora early in the season, the effects of broad-spectrum herbicides in reducing weed flora overall appear to be dominant. The effects of HTV adoption on biodiversity thus depend on the efficacy of the associated weed-control regimen compared to prior methods of weed control – which in general are less effective, except for maize (before the banning of atrazine).

. Chemical contamination of water and soil resources

Here again, methodological difficulties not specific to HTVs are encountered in any attempt to predict the contamination of ground and surface waters: uncertainty about the molecule's fate in the soil and in water because of the variability of transfer and transformation phenomena as a function of environmental conditions (pH, organic matter levels, etc.) and climatic conditions; lack of and difficulty of access to analytical data produced by companies as part of their requests for herbicide registration.

The degradation and transfer reactions of herbicides in the environment depend on their physical and chemical properties and are thus specific to each molecule. As a result, data acquired for one molecule cannot be extrapolated to all the mole-cules belonging to the same herbicide class. The two best-documented cases, and for which there exist follow-up field studies in addition to laboratory findings, are those of atrazine and glyphosate. Although it is advertised as being relatively non-persistent in the environment, glyphosate and especially its principal degradation product, AMPA, are among the contaminants most often found in water resources in France.

The primary environmental argument in favour of HTVs is a reduction in the quantities of herbicides applied: the analysis of effective weed-control practices (in the United States; see above) has shown the reality of this claim but also its limits in the medium term. A secondary argument is the replacement of old substances by molecules with more favourable eco-toxicological profiles. While the results of eco-toxicity tests performed in the laboratory are difficult to extrapolate due to the diversity of real-world conditions, data on the persistence of glyphosate suggest this view must be reconsidered when degradation products are taken into account.

The main effect linked to HTV adoption appears to be the use of the same molecules across a larger area, leading automatically to higher levels of these molecules in ground and surface waters and raising the risk of reaching regulatory limits for their presence in drinking water.

Furthermore, evaluation of the environmental impacts of HTV utilisation is confronted by a number of well-established methodological questions and challenges (noted for example in the ESCos on 'Pesticides' and on 'Agriculture and Biodiversity') which cannot be treated at length in the present ESCo: the impact of herbicides on non-target organisms and on biodiversity more generally, the movement and fate of pesticides in the physical environment, the comparative evaluation of the impact of different systems, the relevance of the indicators utilised, etc. These questions are not specific to HTVs but are valid for all herbicide use.

Cultivation of HTVs in France

If analysis of the North American case has shown the risks associated with large-scale cultivation of certain HTVs, these results are not directly transposable to the French context. The implications of an eventual widespread diffusion of HTVs in France are to be considered with respect to the current characteristics of cropping systems, but also in function of existing patterns of change likely to favour HTV adoption or to influence its consequences. These effects will likewise depend on the types of HTVs involved.

The social context (public perception of GMOs in agriculture) and the regulatory context also set the American case apart from the European. In the United States, GMOs have not encountered significant opposition, and transgenic HTVs have been in use for approximately 15 years. In Europe, on the other hand, including in France, the social context is not favourable to genetically modified plants: conflicts surrounding their use have led to the strict regulation of procedures for their approval and eventual planting, and has limited the number of transgenic varieties listed in the French and EU catalogues to date. Two transgenic HT maize varieties are listed in the European catalogue; in France, their use is not prohibited by moratorium but the herbicide to which they are tolerant is not approved for use in this manner. The only HTVs currently in cultivation or in the process of official recognition are thus non-transgenic. Nevertheless, they too are the focus of contention, leading for example to the sabotage of fields planted with HTVs obtained by mutagenesis, with these protests widely publicised in the media.

The status of varieties obtained by mutagenic techniques is contested by certain individuals and groups who perceive the cultivation of HTVs of this type as a means of avoiding the regulations governing cultivation of GMOs in Europe.

. The agricultural context in France

With the exception of the quinquennial surveys of agricultural practices conducted by the Ministry of Agriculture's statistical service, the significant lack of data concerning farmers' actual practices means that only a very general and imperfect picture of the current situation and its evolution is possible. Nevertheless, based on these surveys, on more qualitative analyses and on an informed understanding of agronomic conditions, a number of overall trends may be identified (with a caveat with respect to their latest tendencies, given that results from the 2011 agricultural survey are not yet available).

Study of the North and South American cases have revealed a strong correlation between the adoption of HTVs and reduced tillage. These American agricultural systems are based either on very short rotations or on continuous culture of a single crop, systems which tend to amplify problems of weed control. This situation has contributed to the widespread, even universal adoption of HTVs. In France, practitioners of reduced tillage are still in the minority but they are increasing (in 2006, 34% of arable fields for the major crops were in reduced tillage, a figure rising above 50% for farms larger than 300 ha). Crop rotations, too, remain more highly diversified; but the trend is toward a simplification of rotations, with the inclusion of spring crops within winter-crop cultivation systems becoming less common.

. Issues of concern within the use of HTVs

The first fields of sunflowers tolerant of class B herbicides (Clearfield®, tolerant of an imidazolinone herbicide, and Express Sun®, tolerant of a sulfonylurea herbicide) were planted in France in 2010; in 2011 they covered an estimated surface area of 80,000 ha (or more than 10% of total sunflower hectarage in France).

The chief particularity of the French/European context resides in the fact that, at least for the time being, the only HTVs in cultivation are those obtained by selection of spontaneous variability or by mutagenesis. These varieties are tolerant to a selective herbicide (most often of class B), and can offer a solution to weed-control challenges encountered in the management of some of the most important crops cultivated in France. Thus weeds closely related to and interfertile with the cultivated crop, in some cases belonging to the same species (sugar beet, sunflower and oilseed rape); invasive species such as common ragweed; and parasitic plants such as broomrape (in sunflower cultivation) are difficult to eliminate. The risk of transfer of the HT trait to weeds belonging to interfertile species is elevated, however. There likewise exists a strong probability of the development of resistance in common ragweed, a species with a strong capacity to spread, already highly abundant in France and one which has become resistant to class B herbicides in other parts of the world.

In addition, class B herbicides are already widely used in cereal crops. The introduction of HT oilseed rape or HT sunflower within cereal-oilseed crop rotations will increase the frequency of utilisation of herbicides with this mode of action within the same fields and, in consequence, increase the selection pressure exerted on weeds.

To prevent this risk of the development of resistance and the diffusion of the HT trait, technical guidelines for the cultivation of HT sunflower recommend restricting use of these varieties to situations with difficult weed flora, and in that case to combine several herbicidal modes of action within the cultivation of the HT itself and/or at the scale of the rotation. In the case of sunflower, however, adhering to this style of weed-control program can in certain agronomic conditions lead to the application of greater quantities of herbicides than those recorded in non-HT cultivation.

In France, the phenomena of transfer of the HT trait and the development of resistance, as with repercussions on herbicide use, will depend on the conditions of HTV utilisation. A use of HTVs that is limited in time and space, respects 'best agronomic practices', integrates mechanical methods of weed management and maintains diversified rotations would limit the risks and preserve the efficacy of the HT technology over time. Surveys conducted in the United States, however, have shown that farmers appear little inclined to adopt preventive measures likely to reduce the risks of development of resistance when those measures run counter to the simplifications (in tillage practices and in herbicide applications) that motivated the choice of HTVs in the first place. The question thus presents itself as to what policies, guidelines and/or incentives can be put in place to encourage respect of such measures in company with HTV cultivation.

French hectarage in HT sunflower is sufficiently high to have made its appearance in the national survey of agricultural practices for 2011. It could be made the object of targeted surveys, recording motives for and conditions of adoption, crop-protection practices applied and concomitant changes in weed flora.

Varieties tolerant to selective herbicides, such as those in cultivation in France and Europe, may appear to be useful complementary tools when confronting certain difficult weed-management situations or in the context of a diversification of weed-control strategies. Their repeated use, however, and/or their use without regard to accompanying changes in weed flora, can rapidly render them ineffectual, prompting a reoccurrence of the same or even more complex challenges. This problematic is not specific to HTVs and applies generally to the use of crop protection products and varietal resistance to bio-aggressors. The durability of the innovation depends on the efficacy of the guidelines governing its use, both at the field level and on a regional scale. A finer understanding of the biology and ecology of the most difficult-to-eradicate weeds, and of the effects of crop rotations on their development, would contribute to the improved use of these management tools.

Finally, use of these innovations poses the question of the compatibility of the relevant weed-management objectives with current policies for the preservation of biodiversity within agricultural areas and the reduction of pesticide use.

Collective Scientific Expertise completed by CNRS and INRA
at the request of the Ministries of Agriculture and Ecology

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To learn more:

M. Beckert, Y. Dessaux, C. Charlier, H. Darmency, C. Richard, I. Savini, A. Tibi (editors), 2011. Herbicide-tolerant plant varieties: Agronomic, environmental and socio-economic impacts. Collective Scientific Expertise, CNRS-INRA (France).

This document, the full scientific report (430 pages) and its synthesis (84 pages) are available on the CNRS and INRA Web sites.

A video of the colloquium presenting the ESCo's results is likewise available online.

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