Effects of Herbicide-Tolerant Crop Cultivation

Michel Beckert • Yves Dessaux

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Investigating the Durability of a Weed Management Tool

CNRS-INRA Collective scientific expertise

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Foreword

The post-war introduction of chemical herbicides significantly facilitated crop management by reducing weed competition, thus making possible both increased yields and increased opportunities for mechanised harvesting. Because herbicide use presents phytotoxicity issues for crop plants, the agrochemical industry has traditionally sought to develop selective herbicide molecules, intended to have a maximal effect on weeds while exerting a minimal effect on the crop. Beginning several years ago, however, an alternative strategy has emerged: rather than searching for new herbicide molecules and families, companies now seek to create crop varieties genetically adapted to existing active ingredients. Thus, over the past 15 years, plant breeders have developed varieties tolerant to a particular herbicide (or family of herbicides) – usually broad-spectrum – which can then be marketed as a crop variety-herbicide combination.

Developers of herbicide-tolerant varieties (HTVs) argue that the genetic trait of herbicide tolerance is attractive for farmers because of the effectiveness and ease of use of the associated herbicides. Companies likewise promote the advantages of being able to treat crops during the growing season, so that herbicide treatments may be tailored to the weed flora actually present, thus a priori making possible reductions in herbicide use relative to systematic preventive treatments. Finally, in terms of environmental impacts, they emphasise that certain herbicides associated with these varieties have more favourable ecotoxicological profiles than other regularly used herbicides.

Regulatory approval of HTV crops poses questions as to how to these varieties should be evaluated. Their legal status will vary according to the breeding technique by which they have been developed. Evaluation criteria can be defined with regard to the various impacts – agronomic, environmental, economic and judicial – that the development and use of HTVs and their associated herbicides may have.

Context of the Evaluation Request: Questions Submitted to the INRA and CNRS

At the global level, varieties marketed with the HT trait are either transgenic varieties or varieties developed without transgenic techniques from individual plants possessing either spontaneous or induced mutations. In France, all HTVs currently proposed for admission to the official catalogue of varieties of agricultural plant species are the result of selections based on spontaneous or induced mutations. While mutagenesis is considered a method of genetic modification by the European Directive 2001/18/EC,[1] varieties so obtained are excluded from its sphere of application and are thus subject to the same evaluation procedures as varieties issuing from conventional plant breeding programmes. Nevertheless, HTVs developed from natural or induced mutants have begun to attract popular opposition, as testified by the destruction of fields of mutant HT sunflowers in 2009, 2010 and the summer of 2011.

It is in this context that the public authorities and evaluative bodies in France are seeking informed perspectives on the development of HTVs based on spontaneous or induced mutations. The Ministries of Agriculture and of Ecology desiring to have additional analytical elements at their disposal as to the real and long-term effects of the cultivation of these varieties – and in particular their compatibility with existing environmental policies, such as the plan for the reduction of pesticide use (Ecophyto 2018) – the INRA and CNRS have produced, at the ministries' request, 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).

A Few Preliminary Definitions

The term **herbicide-tolerant variety** refers to cultivated varieties into which the HT trait has been intentionally introduced; it does not include a species' inherent capacity to tolerate application of an herbicide. The principal plant species considered in this ESCo, and for which HTVs have been developed, are major temperate field crop species: maize, soybeans, wheat, oilseed rape, sunflower, sugar beet, rice and chicory/endive.

This ESCo is focused on the **agronomic trait of herbicide tolerance**, regardless of how it has been introduced into a cultivated variety (traditional breeding methods, mutagenesis or transgenesis). By **traditional breeding methods**, we mean those methods of variety improvement based exclusively on naturally occurring

[1] Directive 2001/18/EC spells out the authorisation procedure for voluntary release and placing on the market of genetically modified organisms (GMOs). See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:106:0001:0038:FR:PDF

processes: sexual crossing and selection. The terms **genetic modification** and **GMO** (genetically modified organism) are used in the sense adopted by Directive 2001/18/EC: including DNA modifications resulting from mutagenesis, transgenesis or cellular fusion and the organisms so obtained.

The central question is that of the **agronomic efficacy of the HT strategy**: the coupled use of an HTV and its associated herbicide over the short, medium and long terms. The effects of HT crop cultivation will depend on the type of herbicide to which the variety has been rendered tolerant and on the crop species and cropping systems involved, but also on the scale of HTV adoption, which will in turn be a function of socio-economic and legal conditions.

This ESCo seeks to clarify the possible impacts of HTV cultivation within the European context, currently characterised by the use of non-transgenic varieties within specific cropping systems and a particular socio-economic context. As an exercise based on the analysis of scientific publications, however, this review is necessarily reliant on existing academic work on the subject. The most widely studied and best-documented HTVs are transgenic varieties cultivated in North America, where researchers have had the opportunity to study 15 years of HTV cultivation over an extensive area. The research effort devoted to transgenic varieties has developed in response to public debates prompted by GMO development. Whereas the transposition of results obtained in the Americas to the European context is straightforward in some respects (e.g. with regard to biological mechanisms), it is less so in others, given the differences in agronomic, ecological and legal contexts.

This ESCo having as its objective an analysis of the effects of HTV use, the production systems of reference will be those with the potential to adopt HT varieties: that is to say, conventional systems in which weed management relies at least in part on herbicide use, whether or not strategies are in place to reduce input use. When production systems include coupled use of an HTV and its associated herbicide, such systems will be designated as **HT systems**.

Box 1 ESCo Principles and Methods

This ESCo has been conducted jointly by the CNRS and INRA according to principles and methods developed by the INRA.

Scientific Expertise in Support of Political Decision-Making

The public research expertise function in support of political decision-making was reaffirmed by the 2006 Research Orientation Bill. Deploying scientific arguments in support of political positions is now a necessity within the sphere of international negotiations. Scientific information is so extensive, however, and is produced in such widely divergent and highly specialised fields that it is not easily accessible to decision-makers. The ESCo, developed by the INRA since 2002, is defined as an activity of knowledge gathering and analysis covering research in widely diverse fields and intended to inform public action.

(continued)

Box 1 (continued)

Guidelines Governing the Scientific Expertise Process at the INRA

This activity is guided by a charter specifying its organising principles, the respect of which guarantees the rigour of the results. The document describes four such principles: competence, plurality, impartiality and transparency.

- *Competence applies first of all at the institutional level: the INRA will only undertake expertise exercises within its sphere of competence. The principle of competence applies to the qualification of research experts based on their scientific publications; it also applies to the management of the expertise in accordance with established quality procedures.*
- *Plurality implies a pluri-disciplinary approach to the questions being asked, including the human and social sciences as well as the life sciences, in order to situate the subject within a broader perspective. Plurality likewise manifests itself in the diversity of the experts' institutional homes. A plurality of research domains and disciplinary points of view helps stimulate debate and critical analysis.*
- *The principle of impartiality is guaranteed by having each participating expert declare any personal or professional interests that might be considered prejudicial in relation to the subject of the ESCo. The group as a whole is likewise held to a standard of impartiality.*
- *Finally, the respect for transparency is shown in the production of analytical and summary documents resulting from the expertise; these documents are made publically available.*

An ESCo is an institutional expertise activity governed by the national expertise guidelines to which the CNRS and INRA formally subscribed in 2011.

The ESCo: Definition and Role

An ESCo conducts a review of the academic and scientific knowledge on a specific subject, extracting and assembling key elements in order to respond to questions posed by the ESCo's requestors. The questions addressed to the CNRS and INRA for this ESCo are detailed in the mission statement specific to this review (cf. Annex 1), itself the result of an iterative discussion between the requestors and the group of experts in order to establish the content and limits of the expertise. A steering committee, organised at the initiative of the requestors, serves as an interface between the experts and the requestors and ensures the good operation of the process.

Each expert writes a report citing all the bibliographic references he or she has consulted. The sum of these contributions forms the official full report for the scientific expertise, available online via the CNRS and INRA Web sites. The experts are solely responsible for the report's content.

(continued)

Box 1 (continued)

The INRA adheres to specific conditions governing the expertise process: the quality of the documentation, making sure bibliographic references are up to date, the transparency of the discussions taking place among the experts, and the dynamics of the working group responsible for the writing of the summary and other outreach documents in a format that combines scientific rigour with readability for a general audience.

Seven ESCo's have been conducted by the INRA to date: "Increasing carbon stocks in French agricultural soils"; "Pesticides, agriculture and the environment"; "Drought and agriculture"; "Fruit and vegetable consumption"; "Agriculture and biodiversity"; "Pain in farm animals"; and "Dietary behaviours".

Methods and Scope of This ESCo

An ESCo is based on international, peer-reviewed scientific references. This means that information will be lacking for certain phenomena, in particular newly emerging trends: either because of a lack of published studies or because those studies that are available have been conducted in contexts widely different from those obtaining in France. For example, since the majority of HTV crop areas worldwide are those planted to transgenic varieties in the American context, relatively few studies focus on the introduction of non-transgenic HTVs into cropping systems different from those prevailing in North America. The transposition onto a European context of results supported by evidence obtained on the other side of the Atlantic is not always possible.

Approximately 15 French research experts from a variety of different institutions (the INRA, the CNRS and the Universities of Bordeaux, Clermont, Evry, Paris XI and Nice Sophia Antipolis, among others) were called upon for the "Herbicide-tolerant plant varieties" ESCo. Their areas of expertise include ecology, agronomy, herbicide chemistry, genetics, economics, sociology and law. The full report is supported by a bibliographic corpus of more than 1400 references, assembled by three documentation specialists (belonging to the INRA and INIST-CNRS) and composed primarily of peer-reviewed scientific articles, complemented by statistical data, monographs and technical reports (Box 2). From these references, the experts have extracted, analysed and assembled the relevant elements in order to clarify the questions at hand.

This ESCo is not intended to supply specific advice, recommendations or practical solutions to the questions posed by the public authorities. Its goal is to provide, to the fullest extent possible and using an interdisciplinary approach combining the economic, social and life sciences, a "state of scientific knowledge" with regard to the impacts linked to the development and use of HTVs. It highlights specific problems associated with these varieties.

Organisation of the Summary Document

The first chapter of this document presents the principal herbicide modes of action, the biological mechanisms involved in the development of herbicide resistance in plants and the various techniques underlying the breeding of cultivated varieties possessing this trait.

The second chapter reviews the use of these varieties, relying primarily on the well-documented American example. It highlights the specific characteristics of the different HTVs available, the reasons that may motivate adoption of these varieties by farmers and the consequences of that adoption in terms of pesticide use.

The third chapter describes the biological mechanisms underlying diffusion of the HT trait and the appearance of herbicide-resistant weeds, as well as strategies intended to prevent and/or manage these phenomena.

The fourth chapter covers changes in agricultural practices associated with the introduction of an HTV into a given cropping system. It likewise considers the question of how these analytical elements may or may not apply to the specific agronomic context of French cropping systems.

The evaluation of the environmental impacts of HTV use is the subject of the fifth chapter. Here, we consider the possible effects of HTVs on biodiversity in agricultural areas as well as the effects of water and soil contamination by HTV-associated herbicides.

Finally, a concluding chapter outlines the principal reflections of the research experts based on their review and discussion of the scientific material across multiple disciplines.

Box 2 Bibliographic References Cited by the Experts

Methodology

An initial research equation, combining the keywords "resistance/tolerance" and "herbicide", was used to create a preliminary bibliography of close to 13,000 references based on searches of the major international bibliographic databases. An overview of themes to be covered was thus established, and the leading specialist researchers in the field were identified.

An iterative process of exchange between the documentation specialists and the research experts was necessary in order to sift out the relevant documents, identify any gaps in the initial corpus and find ways to address them. The elaboration of research equations specific to the relevant herbicide classes and molecules and the use of additional resources made it possible to strengthen the bibliographic corpus and to cover the missing areas.

More than **1400 documents** *were thus selected by the experts and are cited in the full ESCo report.*

(continued)

Principal Sources of Information Utilised

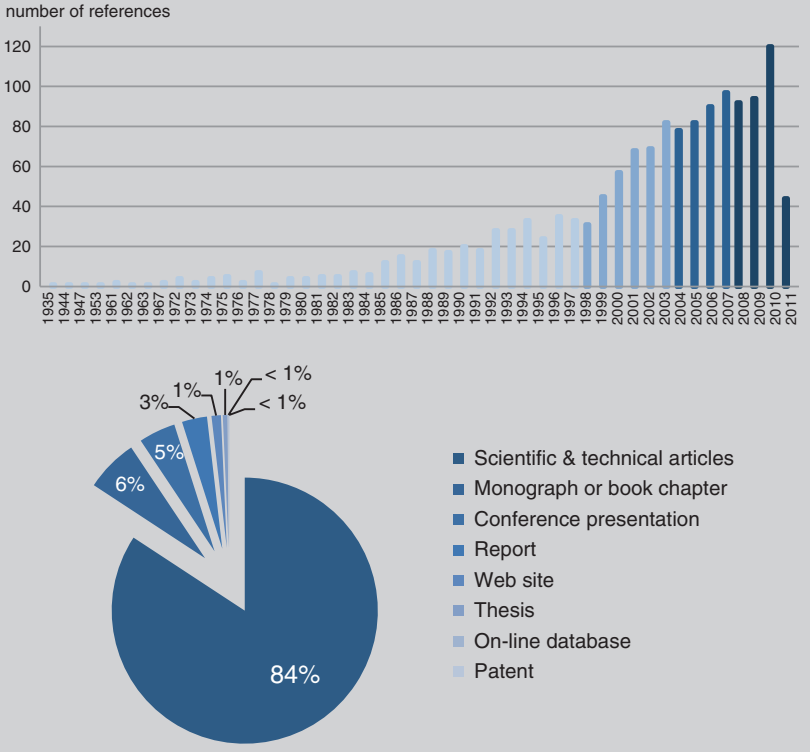
A range of international bibliographic databases were consulted – Web of Science, ScienceDirect, Pascal (a multidisciplinary database), CAB Abstract (an agricultural references database), MEDLINE/PubMed (a biomedical reference database) and Francis (a social science reference database) – as well as scientific research engines such as Scirus.

Other scientific and technical information sources were also consulted: documents from the AFSSA (the French Agency for Food Safety, now known as ANSES), reports from the European Commission, online herbicide databases, etc.

Characteristics of the Works Cited

The use of bibliometric analyses was limited by the volume and heterogeneity of the bibliographic sources from which the references were drawn. Only those fields common to all the reference types were analysable.

As for the timeliness of the references, over half of the references cited are less than 10 years old (published after 2003), and more than a quarter were published during the past 3 years, as illustrated in the following graph (each shade of blue represents a quarter of the total number of publications).

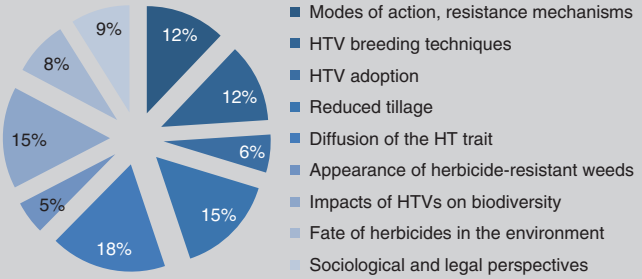


(continued)

Box 2 (continued)

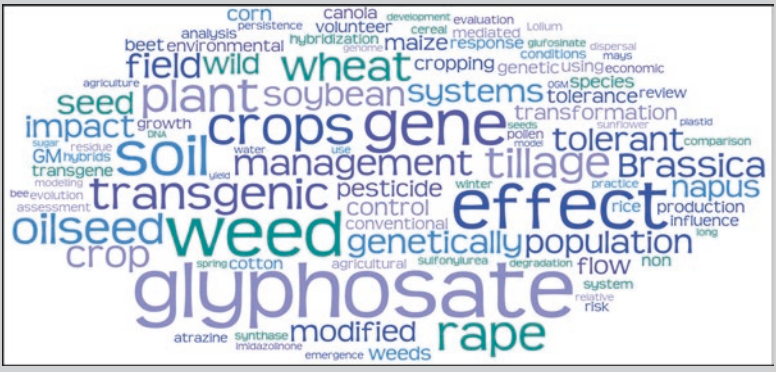
A quarter of all articles cited appeared in one of nine journals:

- *Weed Science*
- *Weed Technology*
- *Theoretical and Applied Genetics*
- *Pest Management Science*
- *AgBioForum*
- *Weed Research*
- *Agriculture, Ecosystems and Environment*
- *Journal of Applied Ecology*
- *Proceedings of the National Academy of Sciences of the United States of America*



An analysis of words appearing in the titles of the references cited makes it possible to illustrate the subjects covered and their relevance to the themes discussed in this ESCo.

In the following word cloud, the size of the words is proportional to the frequency of their appearance in the titles of the works cited (the more frequently a word appears, the larger its size). Note however that the size differences are relative, not absolute: the word "glyphosate" represents 4.6 % of titles, the word "management" 4 % of titles and the word "hybridization" 1.5 % of titles (the words "herbicide" and "resistant/resistance" were excluded from the cloud).



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