AFPP – 22e CONFÉRENCE DU COLUMA
JOURNÉES INTERNATIONALES SUR LA LUTTE CONTRE LES MAUVAISES HERBES
DIJON – 10, 11 ET 12 DÉCEMBRE 2013

GLYPHOSATE BENEFITS BEYOND EUROPEAN RESISTANCE CASES

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RÉSUMÉ
BENEFICES DU GLYPHOSATE AU DELA DES CAS DE RESISTANCE EUROPEENS
Le glyphosate est un herbicide qui présente un risque limité de développer résistances. Son adoption croissante en Europe a conduit au développement de quelques *Lolium* spp. et *Conyza* spp. résistants au glyphosate en cultures pérennes, et représente un problème économique ainsi qu'un défi technique pour les agriculteurs touchés. Sur les parcelles où la résistance a été confirmée, l'utilisation de cet herbicide est justifiée pour contrôler d'autres adventices avec une gestion intégrée des mauvaises herbes (IWM) pour diminuer le nombre et la gravité des cas de résistance. La reconnaissance précoce du développement de la résistance au glyphosate et le suivi des mesures de contrôle des mauvaises herbes à problèmes (*Lolium* spp et *Conyza* spp.) avant la dissémination du pollen ou le développement des semences est la clé de l'utilisation durable du glyphosate en cultures pérennes en Europe.

Mots-clés : glyphosate, application, résistance, gestion intégrée, durabilité.

ABSTRACT
GLYPHOSATE BENEFITS BEYOND EUROPEAN RESISTANCE CASES
Glyphosate is a herbicide with limited risk to develop resistance. The increased adoption in Europe has led to resistance development in some *Lolium* spp. and *Conyza* spp. biotypes growing in perennial crops, and represents an economic issue as well as a technical challenge for the affected farmers. In the fields where resistance to glyphosate has been confirmed, the use of this herbicide is still justified to control other important weeds under Integrated Weed Management (IWM) practices to mitigate the number and seriousness of resistance cases. The early recognition of resistance development and the monitoring of control measures versus the problem weeds (*Lolium* spp and *Conyza* spp*.)* before pollen dispersion or seeds development is key for sustainable use of glyphosate in European perennial crops.

Keywords: glyphosate, application, resistance, integrated, sustainable.

INTRODUCTION

Glyphosate is a herbicide with many potential applications as it combines a wide weed control spectrum togheter with a quick inactivation upon contact with the soil. This active ingredient was first registered in France and other European countries in 1974-75, and since that time its use has grown widely and steadily, first thanks to an increasing number of application options in annual and perennial crops, followed by very affordable prices over the last 20 years. Furthermore, the application of modern biotechnology to plant breeding has facilitated the development of glyphosate tolerant varieties in crops like soybean, cotton, canola, maize, sugarbeets which –quickly adopted in the countries where this technology is allowed for cultivation- allows postemergence treatment with glyphosate without damage to the crop. Beyond the direct effects of reducing weed competition, the benefits of glyphosate application include improved flexibility, time savings for farmers, and easier adoption of conservation agriculture (reduced tillage with stubbles on the soil), which is more compatible than tillage to conserve soil fauna and bird habitats, reduces soil erosion, facilitates soil water management and minimizes CO_2 emissions.

The repeated and almost exclusive use of glyphosate under suboptimal conditions in European perennial crops, however, often associated with no tillage, has led in the last 10 years to the development of resistant biotypes in some species of *Lolium* and *Conyza*. Development of resistance with such practices has happened before with other herbicides (Heap, 2013).

Although some initiatives have been proposed to reduce arbitrarily the use of pesticides, the continued applications of glyphosate in conservation agriculture are supported by higher tier goals such as soil conservation, biodiversity compatibility, soil water management and mitigation of climatic change.

The economic challenge of weed resistance to glyphosate is likely to persist in the coming years because of attractive pricing for the end user. A thorough analysis of resistance management and mitigation measures is needed to :

- contribute to the sustainable use Directive 128/2009/EC
- compensate for continued erosion of widely used alternative herbicides (simazine, paraquat, terbuthylazine, fluometuron…)
- complexity arrising from the commercial introduction of some *Lolium perenne* glyphosate resistant varieties –developed through mutation and conventional breeding- for use in golf courses. These varieties are being deployed without known scientific risk evaluations, without the case by case risk management and without continued monitoring which would have been required if the breeding method included genetic modification.

The purpose of this communication is to analyze the weed resistance to glyphosate according to EPPO standard PP1/213 (EPPO, 2012) and Directive 128/2009/EC guidelines, looking for the most sustainable integrated weed management practices.

MATÉRIALS AND METHODS

GLOBAL EVOLUTION

The global evolution of glyphosate uses and resistance cases is being followed through business reports, updated Monsanto Technology User Guides, trade association publications, independent official monitoring (USDA, 2013), relevant articles in peer reviewed journals (such as those reported in Nandula, 2010 or Ríos, 2013), and the global list of resistant weeds (Heap, 2013) compiled and regularly updated.

STATUS IN EUROPE

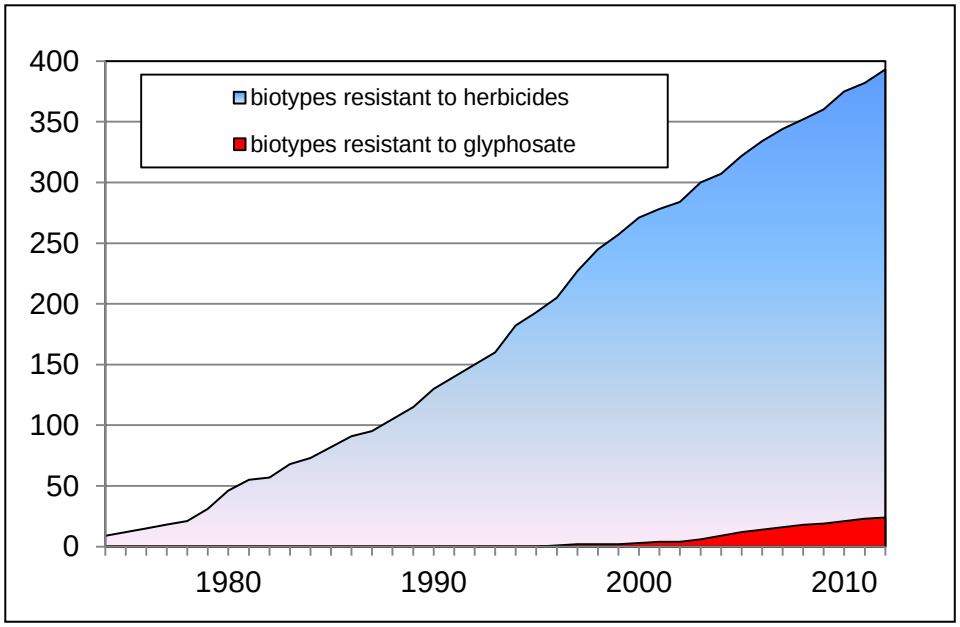
Although the range of approved uses for glyphosate is lower in Europe than in America –since no genetically modified (GM) varieties are allowed for planting-, this active ingredient is receiving high attention, often due to studies not representative of the conditions for the approved uses. Resistance development to glyphosate is in practice being monitored through the farmer complaint handling reports by herbicide distributors (confirmed under controlled screening conditions), and via publications by weed scientists in technical or peer reviewed journals. Once resistance is confirmed, further studies on the mechanism of action for each species may be undertaken by different experts, and trials to find alternative solutions economical acceptable to farmers have been arranged by Monsanto in cooperation with scientific experts or recognized trial organizations. Non-chemical alternatives such as tillage, mowing, biological control or seed predation have also been considered, in agreement with Directive 128/2009/EC guidelines on sustainable use of pesticides.

RESULTS

GLOBAL EVOLUTION

As shown in Figure 1, the first global case of *Lolium* resistant to glyphosate was found in Australia in 1996, 21 years after its commercial introduction but since then the number of species with confirmed resistant biotypes has grown up to 24 in 2012 (Heap, 2013). As glyphosate is globally the most used herbicide, it can be concluded that the risk of herbicide resistance is not as high as for herbicides with other mechanisms of action which are used less intensively. Consistent implementation of Good Agricultural Practices would have further reduced this number of glyphosate resistant cases.

Figure 1 : Evolution de la résistance au glyphosate dans le monde au cours du temps
(Global evolution of herbicide-resistance over the history of glyphosate use)



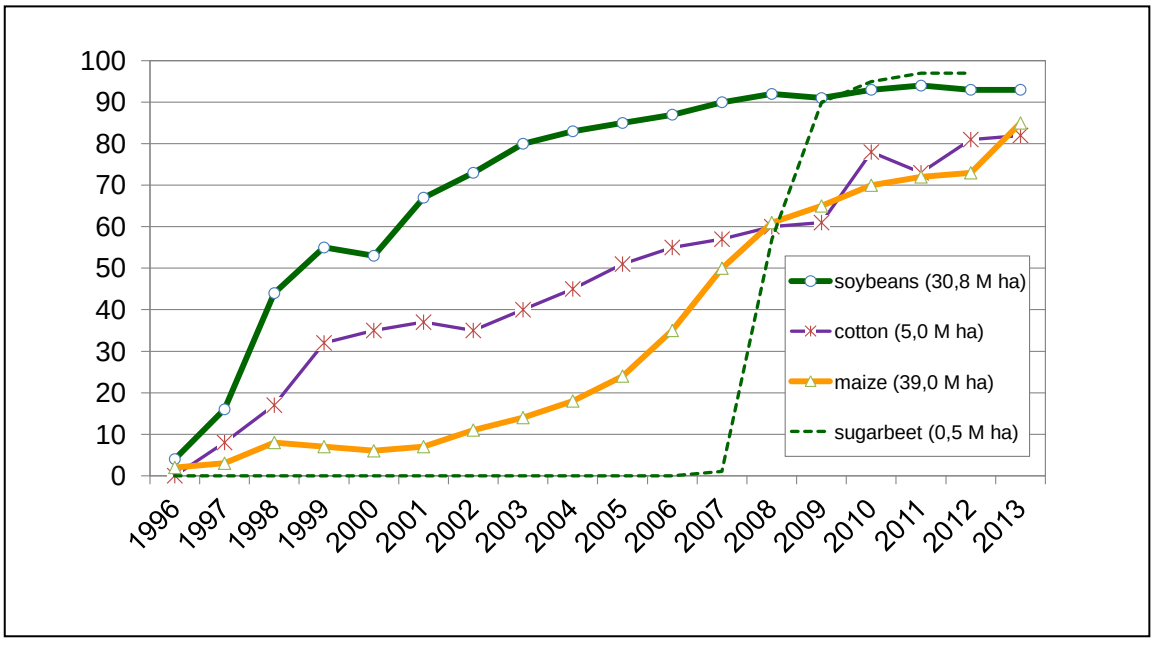
In addition to a very affordable price, part of the use intensification which has resulted in additional resistant biotypes has been the deployment of crop varieties tolerant to glyphosate in the USA, Canada, Brasil, Argentina, and others. The use of glyphosate over the top of a particular crop can be managed with a small risk of resistance in rotation with other herbicides. Potential problems arise when the crop

rotation involves different crops (soybean, cotton, maize) also tolerant to glyphosate. To delay or mitigate this agronomical challenge, Monsanto is producing every year a Technology User Guide for farmers planting genetically modified crops, including recommendations on refuges for insect resistant varieties or specific recommendations to avoid problems with weed resistance. These recommendations include sequences or tank mixtures with complementary herbicides (with different mode of action than glyphosate), which are being actively promoted with economic rebates for farmers with or without presence of glyphosate resistant weeds.

The monitoring of farmer satisfaction in the USA is being followed with periodic surveys (Prince et al., 2012), and the US Department of Agriculture is also reporting regularly the adoption of herbicide tolerant varieties of soybeans, maize and cotton, as displayed in Figure 2. The figure shows that despite the number of cases of glyphosate resistance noticed over the last years, the value of glyphosate and this technology remains high to the farmer for control of other (not resistant) species, as proven by the percentage of total planted surfaces which in 2013 reached 93% in soybeans, 82% in cotton, 85% in maize (and over 95% in sugarbeet in 2012).

Figure 2 : Adoption de varieties GM tolérantes en terme de % de surfaces plantées aux USA (entre parenthèses, surface total en M. ha pour 2012), selon l'USDA (2013) pour le soja, le coton et le maïs, et selon James (2012) pour la betterave sucrière)

(Adoption of GM herbicide tolerant varieties as % of the surface planted in the USA (in brackets, 2012 total surface in million ha), according USDA (2013) for soybean cotton and maize, and according to James (2012) for sugarbeet))



The spread of glyphosate resistant weeds –particularly when a glyphosate tolerant variety is followed in the rotation by another glyphosate tolerant variety of the same or alternative crop- has prompted Monsanto to update every year the Technology Use Guide (Monsanto, 2013) with recommendations on how to use herbicide resistant traits in a sustainable way. The weed management guidelines summarized in the last 2013 version can be summarized as :

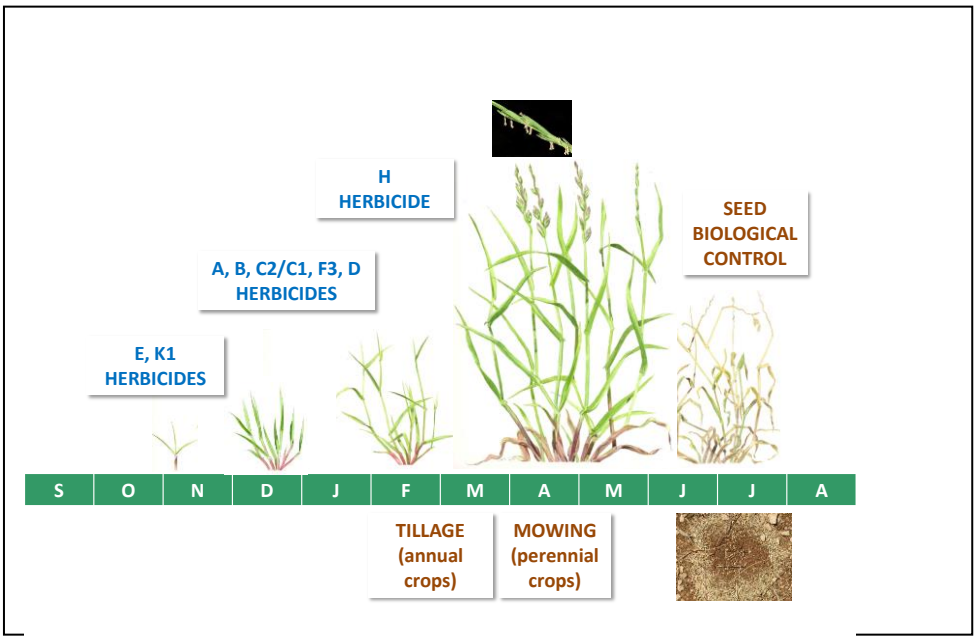
- Start with a clean field, free of weeds
- Use a diverse set of weed control tools, including residual herbicides that use a different mechanism of action

- Add other products, at the right rate and timing for the weed, to Roundup®[1]
- Control weed escapes and remove weeds before they set seeds.

STATUS IN EUROPE

In Europe the first cases of glyphosate resistant *Lolium* in Castellón, Spain, were confirmed around 2002, and later also in Italy (Collavo and Sattin, 2010). Ten years later we can say that the problem remains in the original area and new biotypes have been found in North Portugal and France. The first case of *Conyza* glyphosate resistance was confirmed in 2011 in south of France (Gard) (Dubois *et al*., 2011). The management of glyphosate resistant populations has been addressed in a holistic way according to the Directive 128/2009EC guidelines, looking for effective sequences or tank mixtures of glyphosate with alternative mechanism of action herbicides and keeping in mind that mechanical weed control with tillage in annual crops or mowing in perennial crops may still be useful., Biological control agents (such as foliage eating rabbits or seed harvester ants) are considered to be complementary compatible tools. These opportunities are sumarized in Figure 3.

Figure 3 : Solutions de gestion intégrée du *Lolium* spp. résistant au glyphosate
(Integrated weed management solutions for glyphosate-resistant *Lolium* spp.)



A similar approach has been followed with biotypes of *Conyza* resistant to glyphosate, which have been confirmed in Spain, Grece, Italy and France, with emphasis on herbicide application at the early rosette stages as described in a previous communication (Dubois *et al*., 2011).

From the trials completed to date (González-Torralva *et al.*, 2013; Travlos *et al.*, 2013; and non-published Monsanto trials), a number of active ingredients have proven useful to manage biotypes of the two described genus, but their application to particular crops may be limited by the regulatory status in each country, or lost when the availability for a particular use is cancelled. The latter was the case for terbuthylazine and fluometuron, the last representatives of herbicides with C_1 and C_2 herbicides for perennial crops, whose use in perennial crops was cancelled in 2012. The use of alternative herbicides

[1] Roundup is a registered trademark of Monsanto.

does not replace the applications of glyphosate. Other weeds are usually always present and the use of glyphosate strongly contributes to the triple sustainability of the integrated weed management program (environmental, economic and social). Some examples are illustrated in the following table.

Tableau I : Possibilité d'herbicides utilisables en séquence ou en mélange avec du glyphosate
(Potential candidates for use in sequence or tank mixed with glyphosate)

Glyphosate resistant	Active ingredient	Reason for continued glyphosate use
Lolium	cletodim	control of broadleaved weeds
	cycloxidim	control of broadleaved weeds
	flazasulfuron	control of *Veronica, Cirsium, Solanum*
	quizalofop	control of broadleaved weeds
Conyza	amitrol	control of *Lolium* and some broadleaves
	difufenican	control of *Lolium* and other grasses
	flazasulfuron	control of *Veronica, Cirsium, Solanum*
	fluroxypir	control of grasses
	MCPA	control of grasses unless mixed with glyphosate

The risk of developing resistance with other complementary herbicides is often higher when compared to glyphosate. It is recommended –where possible- that the alternative (different from glyphosate) herbicidal mode of actions are being rotated to avoid the development of double resistant biotypes.

Concerning non chemical tools, in annual crops soil tillage can be a valid alternative in the period February-March when most of the target tweeds have germinated and before planting of sunflower, maize or other spring crops.

Vegetation mowing is usually the preferred non-chemical option in perennial crops to avoid damages to crop roots. One treatment just before flowering of the target weeds is normally not sufficient. A glyphosate application immediately after mowing can delay the regrowth of *Conyza spp.*, but *Lolium spp.* maintain better the capacity to survive. Concerning biological control, however, *Lolium* is more sensitive than *Conyza* to foliar consumption by rabbits –as reflected by cinegetic emergencies in South Spain (Consejería de Agricultura, Pesca y Medio Ambiente, 2013)- and to seed predation by harvester ants (*Messor barbarus*).

The use of genetically modified (GM) varieties of maize, soybeans, cotton or sugarbeet tolerant to glyphosate as alternative tool to manage herbicide resistance in annual row crops has not been possible in the European Union in spite of the positive experiences in other continents for over 18 years. Other breeding techniques such as mutations (natural or artificial induced) which confer to sunflower or other crops the genetic tolerance to imidazolinone or sulfonylurea herbicides, however, are routinely and successful introduced in several european contries because of workable regulatory systems (in contradiction to overregulation of GM varieties). Quite recently, a non-GM variety of *Lolium perenne* tolerant to glyphosate has been commercialized in Spain for greens of golf courses. In this case, careful management will be required to reduce the risk of gene flow to weedy *Lolium* species.

DISCUSSION

Resistance to glyphosate herbicide has appeared in Europe with some biotypes of several *Lolium* and *Conyza* species. This agronomic challenge has first appeared in perennial crops because they combine several risk factors such as :

- No crop rotation
- No soil tillage

- Repeated use of the same active ingredient, often at low doses and suboptimal application timing
- Poor control over the last years.

The visibility of weed control issues and the ease of access in most european perennial crops provide an opportunity for appropriate monitoring which is most welcome. Farmers need to be aware that the problem can be serious when the tolerant weeds are allowed to flower and set seed. For this, weed scientists, distributors and farmers need to be aware and concious that the earlier they take mitigation actions, the more economical is going to be the selected integrated weed management strategy. In Monsanto, we believe that glyphosate herbicide labels should carry alert sentences such as «Some biotypes of *Lolium* spp. and *Conyza* spp. resistant to the recommended rates of glyphosate have been identified. The areas with these biotypes must be properly managed –before the weeds produce seeds- by using effective alternative registered herbicides, or with tillage or mechanical operations. Please consult your distributor or Monsanto representative for more information».

CONCLUSION

The resistance to glyphosate herbicide is an agronomic and economic challenge since alternative control options are usually more expensive. Communication to farmers on alternative options for control the glyphosate resistant biotypes at early stages is recommended. Glyphosate still has a fundamental role to play as a sustainable –following the good Agricultural Practices such as those described in TOPPS PROWADIS 2013 publications- and economic tool to control the wide range of non resistant weed flora present in agronomic fields.

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