INTEGRATED WEED MANAGEMENT IN SUNFLOWER: CHALLENGES AND OPPORTUNITIES

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ABSTRACT

The purpose of effective weed management is the inclusion of the best measures and strategies to make sustainable sunflower production, and unfavourable for weeds. Weed management strategy based on single approach, and use of only herbicide-tolerant sunflower hybrids, and application only post-emergent acetolactate synthase inhibiting (ALS)-herbicides, are not sustainable strategies. Application of pre-emergent herbicides in herbicide-tolerant sunflowers would protect the crop for the first four to five weeks of growth and should also provide flexibility for timing of post-emergent herbicides application. Moreover, over reliance on a single herbicide and herbicides with the same mode of action in herbicide-resistant sunflower, can lead to weed population shifts, spread of herbicide-resistant weeds, and herbicide-resistant volunteer plants in subsequent crops. The risk of transfer of the trait for herbicide tolerance into weeds belonging to related species is elevated. Herbicide-resistant weeds pose significant threats, and until we find a better solution to manage herbicide-resistant weeds, farmers will need to implement more diversity into weed management. Additional challenges are that no new herbicidal modes of action developed in the past 30 years, and some herbicides has been banned in many countries. Integrated weed management (IWM), is a sustainable approach to managing weeds by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks. Therefore, increasing concern over herbicide side effects on human health and the environment, herbicide resistant weeds, weed shifts, invasive weeds, and slow development of new herbicides are some reasons for urgent need of implementation of integrated weed management in sunflower production.

Key words: integrated weed management, herbicides, herbicide tolerance, sunflower, weed resistance

INTRODUCTION

Weeds continue to pose a huge challenge for the sustainable production of sunflower despite decades of implementation of contemporary methods in order of their control. The development of weeds resistant to herbicides and weed shifts indicate the inefficient of modern agro-technical measures. Integrated Weed Management (IWM) is a sustainable approach to the management of weeds by combining all available weed control techniques, including preventative measures, monitoring, crop rotations, tillage, crop competition, mechanical and physical control, herbicide rotation, herbicide mixtures, biological control, nutrition, irrigation, flaming, etc. in a way that minimizes economic, health, and environmental risks (Swanton et al., 2008). The objectives of IWM-based systems are to reduce the reliance on herbicides by adopting agronomic measures: (1) reduction of weed seed banks in the soil (2) decrease of the density of weeds emerging in crops, (3) reduction of their relative competitive ability, and (4) control of emerged weeds using non-chemical techniques (Pardo et al., 2010).

As with all technologies, herbicides also face some challenges including safety and environmental issues, and the evolution of herbicide resistant weeds. To avoid or delay the development of herbicide resistant weeds, a diverse, integrated program of weed management practices is required to minimize reliance on herbicides with the same MOA. Weed management diversity must include chemical and nonchemical weed control strategies (Vencill et al., 2012). In the past two decades weed management has become a key issue for European agricultural practices due to following reasons: (1) frequent herbicide treatments in most crops throughout Europe, except, of course, in organic farming, (2) herbicides are the pesticide residues most frequently found when analyzing the quality of surface and ground-waters, (3) the development of weed populations resistant to the most frequently used herbicides has become a real threat to the sustainability of current chemical weed control strategies, (4) the increase in cost of chemical crop protection, due to the withdrawal of several old and cheaper herbicides (Ramesh, 2015). Therefore, these are key points for implementing innovative strategies which focus on lower pesticide inputs and combine all available weed control techniques within the IWM concept.

HERBICIDES DISCOVERY FOR SUNFLOWER: QUO VADIS?

Producers have fewer herbicide options for broadleaf weed control in sunflower compared to most other row crops. They traditionally relied on pre-emergence (PRE) herbicide, which require timely rainfall for activation (Kerr et al., 2004). On the other hand, the agricultural chemical industry has not brought any new herbicides with novel sites of action to market in last 30 years (Figure 1). In addition, tougher registration and environmental regulations on herbicides have resulted in a loss of some herbicides, particularly in Europe (Heap, 2014; Kraehmer et al., 2014). The demand for new resistance management solutions is rewarding the renewed focus on herbicide discovery. However, the regulatory requirements to develop and register new herbicides are ever increasing, especially in Europe. Consequently, the total cost for the discovery and development of one new herbicidal active ingredient is approaching 200 million euros (Phillips McDougall, 2012 cit. Kraehmer et al., 2014). In some sunflower regions pyroxasulfone is a new soil-applied herbicide which has the potential for use in sunflower (Olson et al., 2011).

The wide use of glyphosate in glyphosate-tolerant crops (Roundup Ready®) crops has slowed down herbicide discovery, and also resulted in a generation of farmers with little knowledge of weeds and weed-control techniques. The widespread appearance of glyphosate-resistant weeds, forewarned growers that the use of glyphosate alone for weed control was not sustainable. Growers began adding more diversity in their herbicide program, primarily through the addition of pre-emergence herbicides. Farmers will need reeducation in weed-control practices which may include diversification of cropping systems, the adoption of herbicide-resistance management strategies (Heap, 2014). This is a good example of the consequences of reliance on a single herbicide in weed management.

In order to restrict competition from generic herbicides, companies thus tend to modify their commercial formulations and/or offer stronger guarantees to farmers who use the herbicide-tolerant varieties in combination with their brand of the herbicide (Beckert et al., 2011). Examples of this can be seen in the market of herbicides in sunflower. Obviously, herbicides in sunflower are a non-renewable resource which should be protected.

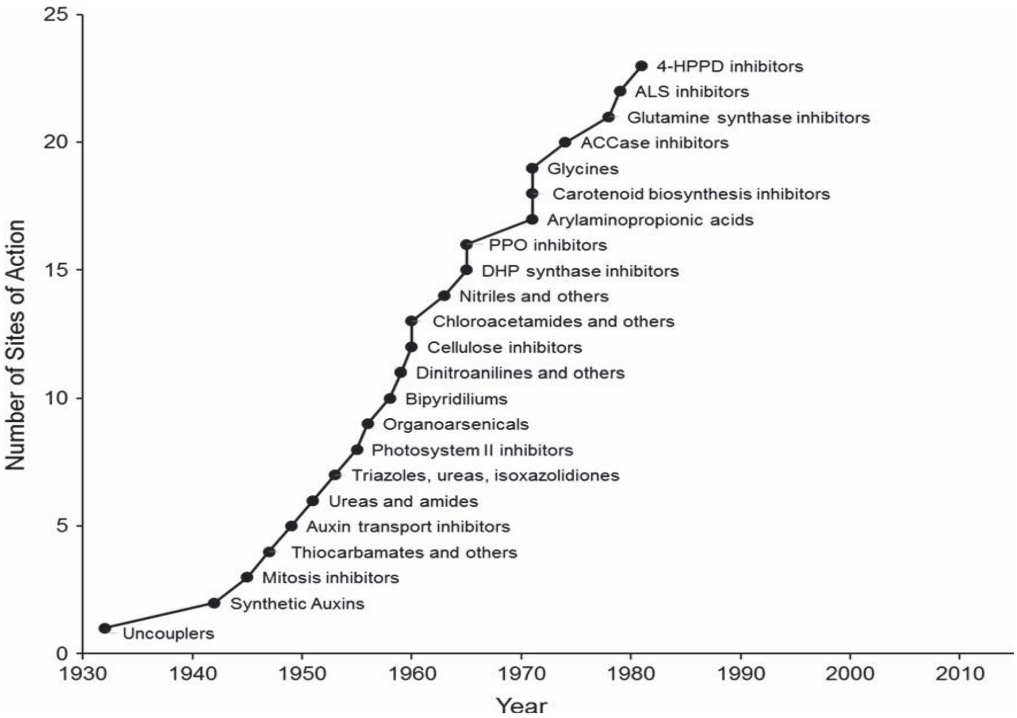

Figure 1. Chronological increase in the number of commercially available herbicide sites of action (Heap, 2014)

SUCCESSES AND CONCERNS WITH WEED MANAGEMENT SYSTEMS BASED ON THE USE OF HERBICIDE-TOLERANT SUNFLOWER HYBRIDS

Introduction of imidazolinone- and tribenuron-tolerant sunflower hybrids in practice is a revolutionary advancement in sunflower production. After launch in 2003, Clearfield® production system has been well adopted in sunflower growing countries (Table 1) due to a wide spectrum of weed and broomrape (*Orobanche cumana*) control, a high level of consistency, flexibility in the timing of herbicide applications, season-long weed control, and a low rate of herbicide application (Malidza et al., 2000, 2003 & 2012; Zollinger 2004; Nagy et al., 2006; Phening et al., 2008; Kukorelli et al., 2011; Kaya et al., 2012 & 2013). It is expected that the combination of improved imidazolinone formulation in new Clearfield Plus production system will provide a more efficient, flexible and reliable weed control system in sunflower, including more freedom in crop rotation. (Sala et al., 2012, Pfenning et al., 2012; Weston et al., 2012). Tribenuron-methyl contributes to weed control in sunflower by controlling annual broadleaf weeds and the perennial weed *Cirsium arvense* post-emergence, has excellent sunflower safety to tribenuron-tolerant hybrids, increasing the range of available herbicides in sunflower increasing no-till/conservation tillage practices, is non-transgenic, and has no restrictions in crop rotation (Zollinger 2004; Jocic et al., 2008 and 2011; Bozic et al., 2012). Sunflower hybrids tolerant to mentioned ALS-inhibiting herbicides, may be useful additional tools in cases of some difficult weed management situations or for diversification of weed-control strategies. However, their widespread and repeated use with associated herbicides, without regard to accompanying changes in weed flora, can rapidly make them ineffective strategy. Weed management strategy based on single approach, and use of only herbicide-tolerant sunflower hybrids, and application only post-emergent ALS inhibiting herbicides are not sustainable. Sustainable use of these sunflowers production systems can be caused by the compatibility of the weed-management objectives with current policies for the preservation of biodiversity within agricultural areas and the reduction of pesticide use. With herbicide-tolerant sunflower hybrids, the reduction of herbicide use is not necessarily and this hybrids and associated herbicides may be properly used as a complementary strategy to classical pre-emergence chemical weed control to correct a specific weed management difficulties (Beckert et al., 2011; Nagy et al., 2006). Before commercialization of imidazolinone- and tribenuron-tolerant sunflower hybrids, soil-applied herbicides were especially important because there was no post-emergent herbicides for control of broadleaf weeds that could be applied. Despite available efficient post-emergence herbicides (imazamox, tribenuron), soil-applied herbicides are important as assurance that weeds will not emerge with the crop and be too large to control with the post-emergence herbicide application. Application of pre-emergent herbicides in imidazolinone-tolerant sunflowers would protect the crop for the first four to five weeks of growth and should also provide flexibility for timing of post-emergent herbicides application. Otherwise, weed control without pre-emergent herbicide must be initiated in the second to third week of crop growth. The information gained from this study could help producers of both IMI- and tribenuron-tolerant and conventional sunflower improve the cost effectiveness and efficacy of their weed management practices (Elezovic et al., 2012; Knezevic et al., 2011 & 2013). Experiences with Clearfield® production system for sunflower in Hungary indicate that the application of pre-emergent herbicides (dimethenamid-P + pendimethalin, fluorochloridon, etc.) with subsequent application of imazamox based products is an efficient and reliable practice (Nagy et al., 2006).

The French Technical Centre for Oilseed Crops and Industrial Hemp claims that the area planted to imidazolinone- and tribenuron-tolerant hybrids reached more than a million hectares in Europe (Spain, Turkey, Greece and eastern European countries) in 2009 and close to 2 million hectares in 2010. In France, BASF and DuPont estimate that imidazolinone- and tribenuron-tolerant sunflower hybrids accounted for 20,000 and 15,000 ha, respectively, in 2010, and 50,000 and 30,000 ha in 2011, or approximately 11% of the total area planted to sunflower in France for that year (Beckert et al., 2011).

Table 1. Year of introduction of Clearfield® production system for sunflower into various countries and total cultivated area with such system in Europe from 2007-2011

Countries	Year	Estimated total area in cultivation since 2007 in Europe (000 ha)
Turkey	2003	
Serbia, Spain	2004	
Bulgaria, Hungary, Romania, Slovakia	2005	
Moldova, Ukraine	2006	
Croatia, Italy	2007	240
Russia	2008	560
South Africa	2009	800
France, Kazakhstan	2010	1.450
Czech Republic	2011	2.850

Source:http://www.agro.basf.fr/agroportal/fr/fr/cultures/les_oleagineux/le_tournesol/les_herbi /dossier_clearfield.html

The new weed management strategy based on the use of sunflower hybrids tolerant to ALS-inhibiting herbicides is a efficient tool to control some invasive weeds, and to reduce concentrations of the plant's allergenic pollen in the air. A major key for the success of *Ambrosia artemisiifolia* control when using this technologies will be the management of resistance due to very frequent use of ALS-inhibiting herbicides and the control of volunteer sunflowers in following crops (Kukorelli et al., 2011; Reisinger et al., 2013). However, there is strong probability of the development of resistance in some invasive weeds such *A. artemisiifolia*, which is already very abundant in sunflower production area, and which has become resistant to ALS-inhibiting herbicides in some parts of the world (Heap, 2016).

HERBICIDE-RESISTANT WEEDS AND RESISTANCE MANAGEMENT

Repeated exposure of a weed population to any herbicide in isolation may have two effects: (1) weed species that are not controlled by the herbicide will dominate the population (species shift), and (2) the pressure will be exerted on the population to select any resistant individuals that may be present (herbicide resistance). The development of both the species shift and herbicide resistance can be effectively managed by the practice of IWM (Beckie, 2014). Herbicide resistance threatens future agricultural productivity and needs to be better understood. Currently, more than 60% of the global herbicide market (value) is represented by products from only four mode of action, all of which actually have serious resistance issues (Kraehmer et al., 2014). Herbicide-resistant weed populations are evolving very fast as a natural response to the selection pressure imposed by the repeated use of herbicides with the same mode of action. The development of weed populations resistant to the most frequently used herbicides is a real threat to current weed control strategies in sunflower. There has never been a widely adopted technology that is not without disadvantages. Despite previous successes, strategy with over-reliance on herbicide-tolerant sunflower hybrids and accompanying herbicides are a double-edged sword and not sustainable. They can be a solution for the herbicide management, but on the other hand represent a risk for the development of resistance. The appearance and spread of herbicide-resistant weeds are not a specific result of the cultivation of herbicide-tolerant sunflower, but may be intensified by the conditions in which associated herbicides are used in such production systems. Herbicide resistance in weeds is a global problem and huge challenge no farmer can afford to ignore. Farmers are usually unwilling to use proactive management of weeds to prevent or delay the selection for herbicide resistance. The cost and effort of preventing/delaying resistance to many herbicides are widely perceived or estimated to be the same as that of managing herbicide resistant weeds, and therefore farmers often do not change their weed management program until resistance has occurred. The lack of proactive management of the evolution of herbicide- resistant weed populations may be due to farmers' primary interest in optimizing short-term economic returns, or inability to assess the economic risks associated with herbicide resistant weeds. There are currently 468 unique cases (species x site of action) of herbicide resistant weeds globally, with 249 species (144 dicots and 105 monocots). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 160 different herbicides. Herbicide resistant weeds have been reported in 86 crops in 66 countries (Heap, 2016). Now, there are more weed species that are resistant to ALS-inhibiting herbicides than to any other herbicide group. In addition, ALS-inhibiting herbicides are already widely used in cereal and other crops. The introduction of IMI-tolerant oilseed rape, IMI- and tribenuron-tolerant sunflower and within cereal-oilseed crop rotations will increase the selection pressure on weeds. In most cases, resistance to ALS-inhibiting herbicides is cross-resistance caused by an altered ALS enzyme. The frequent occurrence of weed populations resistant to ALS inhibitors can be attributed to the widespread usage of these herbicides (Tranel & Wright, 2002). A plant does not evolve resistance because herbicides cause a genetic change in the plant that makes it resistant. Rather, a few plants with natural resistance to the herbicide survive an application of the herbicide, and as those plants reproduce and each generation is exposed to the herbicide, the number of resistant plants in the population increases until they dominate the population of susceptible plants (Vencill et al., 2012). How to outsmart herbicide-resistant weeds? Herbicide-resistant weed management practices most often recommended by weed scientists include: (1) using different herbicide MOAs in annual rotation, tank mixtures, and sequential applications; (2) adopting crop rotations that allow use of alternative MOAs or that change the balance of weeds in a field or both; (3) expanding the use of cultural control measures, such as increased seeding rates and altered planting dates; (4) using only labelled herbicide rates at labelled application timings; (5) preventing seed movement and using clean crop seed; (6) scouting fields; and (7) controlling weed escapes (Vencill et al.,2012).

Careful management of herbicides, including integrated use of crop rotation, cultural practices and rotated use of herbicides with different modes of action are critical to minimize the development of herbicide resistance. Diversifying weed management practices and using multiple herbicide mode of action need to be more widely implemented.

RISK OF GENE FLOW FROM HERBICIDE-TOLERANT SUNFLOWER CROP TO WEEDY SUNFLOWER

In addition to evolved weed resistance via herbicide selection pressure, resistance may also occur through gene flow. Weedy forms of cultivated sunflower (*Helianthus annuus*) are invasive species widely distributed in several regions of the world and are commonly controlled by applying ALS-inhibiting herbicides, such as imidazolinones or sulfonylureas. The widespread adoption of herbicide-resistant crops has exposed the weedy population to the high risk of crop-to-weedy gene flow. Due to high competitive ability, invasiveness and increasing area with herbicide-tolerant sunflower hybrids, problem with the weedy sunflower form had increased during the last decade. Weedy sunflower is also considered of major concern in the sunflower growing areas (Vischi et al., 2006; Ureta et al., 2008; Muller et al., 2009; Poverene & Cantamutto, 2010; Saulic et al., 2013). In addition, weedy sunflower causes decline in yield over 50% under more than 4 plants m^{-2} in sunflower crop (Muller et al., 2009). Risk of gene flow from sunflower hybrids to wild relatives was confirmed by some researchers (Marshall et al., 2001, Massinga et al., 2003, Bozic et al., 2015), who found that gene flow depends on distance. Development of strategies to avoid gene flow should focus on: isolation distances, pollen traps, male sterility and temporal reproductive barriers (Roumet et al., 2013). Herbicide resistant common sunflower populations have been reported (Bozic, 2010; White et al., 2002; Vrbnicanin et al., 2012). Differences in the level of herbicide-resistance could result in different fitness of weedy sunflower populations which could promote the invasiveness of these populations. To ensure sustainability and efficiency of weed management systems based on the herbicide-tolerant sunflower and associated ALS-inhibiting herbicides, crop rotation and herbicide usage with different modes of action should be considered. Except of herbicides use in sunflower crop with tolerance to imidazolinones and tribenuron-methyl, it is recommended to control weedy sunflower with mechanical measures as soon as the first weeds are detected on a field, and before they produce seeds and build up a big population (Muller et al., 2009; Presotto et al., 2012).

MANAGEMENT OF HERBICIDE-RESISTANT SUNFLOWER VOLUNTEERS

Control of common sunflower in many subsequent crops traditionally has been difficult. Because cross-resistance to selected imidazolinone, sulfonylurea, and triazolopyrimidine herbicides (Baumgartner et al., 1999), several herbicides are available to control imidazolinone - resistant common sunflower in maize, but in soybean options are very limited (All-Khatib et al., 2000). Our dose response experiments confirmed that the new tribenuron-tolerant hybrids has a higher tolerance to tribenuron-methyl and slightly cross-resistance to imazamox. Similarly, tribenuron-tolerant hybrids were slightly resistant to imazamox (Malidza et al., 2012). By the contrary, the Clearfield Plus® trait confers high levels of tolerance to imidazolinones but complete susceptibility to sulfonylureas (Sala et al., 2008). Herbicides in Clearfield® production system are efficient in control of volunteer sunflower susceptible to imidazolinones, which also has a positive plant-health effect. With the wide-spread application of such technology, this advantage can turn to a disadvantage, as the possibilities of control imidazolinone-resistant volunteer sunflower decrease (Nagy et al., 2006).

CONCLUSION AND PATH FORWARD

IWM requires that weeds are managed with more than just herbicides. Higher level of complexity partly explains why IWM has not received the same attention as integrated management of other pests. Because of the diversity and flexibility of weed communities, weed management needs to be a continuous process. Adding to the complexity is the fact that most non-chemical tools are not as effective as herbicides, i.e. they cannot be considered as stand-alone methods, but has to be combined with other methods in a systematic way to provide sustainable and reliable weed control. It is difficult for weed researchers to provide credible IWM advice if they are conducting little or no real IWM research in sunflower. Finally, the challenge for weed scientists is to develop innovative, economical IWM systems that can be integrated into current and future cropping systems to bring a more diverse and integrated approach to weed management.

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