Control of *Conyza* spp. with Glyphosate – A Review of the Situation in Europe

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Abstract

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In Europe, glyphosate resistant populations have developed in some weed species in perennial crops, including three species of the genus *Conyza* documented by the International Survey of Herbicide Resistant Weeds. *Conyza* spp. biology is reviewed in this paper and related to population dynamics and the development of resistant populations. Suboptimal growth stage at application, improper agricultural practices such as overreliance on glyphosate and long-term use of sublethal doses are identified as the most important factors of resistance development. Current control methods in perennial crops including mixtures of glyphosate with other active ingredients are discussed and effective weed management strategies are described to manage the development and spread of glyphosate resistant *Conyza* spp. in Europe.

Keywords: *Conyza canadensis* (L.) Cronquist; *Conyza bonariensis* (L.) Cronquist; *Conyza sumatrensis* (Retz.) E. H. Walker; resistance; weed management

Glyphosate has been used extensively on both agricultural and non-agricultural land for over 35 years and has become the world's most widely used herbicide because it is efficacious, economical and environmentally benign (Powles 2008). Global sales of all glyphosate herbicides in 2010 were over $4 billion (McDougall 2010).

The development of glyphosate tolerant crops has increased the consumption of this broad-spectrum herbicide for selective use in arable crops. Further reliance on glyphosate is likely as the number of approved herbicides in the EU is reduced, focusing attention on the potential for development of glyphosate resistance in Europe. In 2009 after completion of the review process under Article 8 of Directive 91/414/EEC out of the 981 active ingredients approved for use in 1993 just 26% were approved, 67% were withdrawn and 7% were rejected (Anonymous 2012). The transition to Regulation (EC) No. 1107/2009 with the change to hazard-based criteria makes the development of alternative strategies even more imperative (Dewar 2009; Clarke *et al.* 2011).

As of May 2012, 24 weed species have been reported to have developed resistance to glyphosate worldwide (Heap 2012). Although increased attention has been paid to the development of glyphosate resistant weeds over the past years, the number of species that have developed resistance to glyphosate is relatively low taking into account the diversity of different commercial applications and the amount of glyphosate used worldwide and comparing it with the number of biotypes resistant to other herbicide groups, such as PS II and ALS inhibitors (Heap 2012).

The majority of glyphosate resistant weed populations have evolved in two separate agricultural settings: perennial crops (orchards or vineyards) and glyphosate tolerant crops. In both situations a primary factor contributing to the evolution of resistance has been the sole reliance on glyphosate, usually multiple applications in one season both in the absence of other control methods and over an extended period of time. In addition, the repeated use of low rates and/or applications beyond the label recommended growth stages and lack of tillage have also been identified as important contributing factors (Dubois & Deschpmets 2009; Shaner *et al*. 2012). The association of the occurrence of weed resistance with reduced tillage is believed to be more the indirect effect of the overreliance on glyphosate rather than a direct cause (Soteres 2010).

Several *Conyza* species have developed resistance to glyphosate; this paper aims to provide background on three glyphosate resistant species of the *Conyza* genus found in Europe. Current control methods are described and weed management strategies are proposed to manage the development and spread of glyphosate resistance.

Biology and ecology of the genus *Conyza* (Family Asteraceae, Genus *Conyza*)

50–80 species of the genus *Conyza* grow in temperate and sub-tropical regions of America. Several species have been introduced into other continents and have become widely established throughout the world. In English, they are commonly referred to as Horseweed, Marestail or Fleabane, in Spanish as Erigeron, Pinet or Pinio, and in French as Erigéron and Vergerette. Three members of the *Conyza* family are commonly found as weeds in arable and non-cropped areas in Europe: *C. canadensis, C. bonariensis,* and *C. sumatrensis. C. canadensis* is diploid whilst the others are polyploids (Thébaud & Abbott 1995). There is also evidence of interspecific hybridisation at low levels (VanGessel 2001), for example about 3% between *C. canadensis* and *C. ramosissima* as described in Iowa (Zelaya *et al*. 2007).

All three species are summer flowering annuals, sometimes described as winter annuals which germinate over a wide period from late autumn through to spring. Plants overwinter at the rosette stage before the central stem extends to a height of 0.5–2 m with a branched pyramidal panicle of small indistinct white or pale yellow flowers. Plants are day-neutral allowing flowering at specific times depending on the locality but over a wide time period, up to 5 months.

The plants are hermaphrodite and usually self-fertile with only a small degree of cross pollination by a variety of insects including bees, butterflies, wasps and flies.

All species produce a large number of wind dispersed seeds (up to 200 000 per plant), which can be effectively spread over long distances reported to be over 100 km (Monsanto Company 2005). Wind dispersal is efficient due to the low settling velocity of the seed.

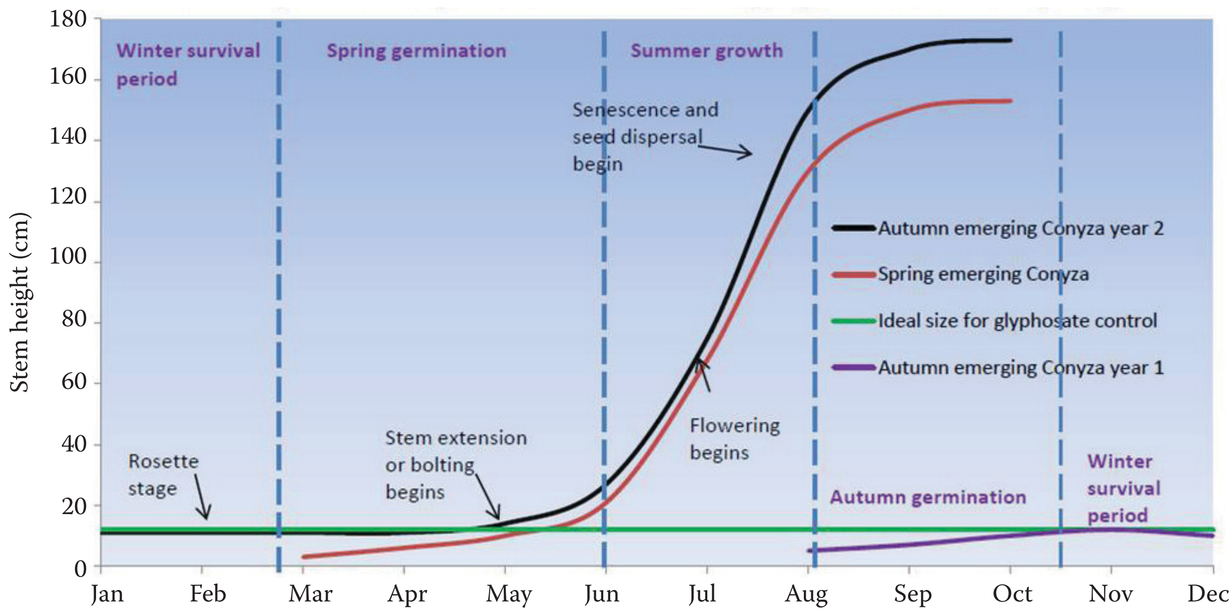

Figure 1. The lifecycle of *Conyza canadensis* – adapted from Loux *et al.* (2004)

The number of seeds and dispersion distance are correlated to plant height, with taller plants producing more seeds and dissipating them farther (Loux *et al*. 2004). Seeds can also be spread in watercourses and by human activity during harvest and transport.

Seeds ripen within 3 weeks after flowering and ripe seeds have a low physiological dormancy with 80% of seeds capable of germination immediately they are shed from the soil surface (Monsanto Company 2005; Karlsson *et al*. 2007). Seed remains viable for 2–3 years (Wu *et al*. 2007)

Conyza plants are able to tolerate a wide range of soil types as well as semi-shade, salinity and drought (Ohtsuka 1998)

Overwintering rosettes compete strongly with spring germinating plants for light, nutrients, and water and can quickly dominate within the weed spectrum if uncontrolled. There is also evidence of allelopathy such that *Conyza canadensis* roots release phenolic compounds which inhibit the germination of many other plant species (Xu *et al*. 2007).

Conyza plants are considered to have a high fitness and are extremely efficient weeds which have been particularly successful in spreading herbicide resistance within its population due to a combination of these ecological properties: prolific seed formation, wide range of pollinating insects or self-fertilisation, ability to outcross, short period from flowering to production of viable seed, non-specific habitat requirements, ease and distance of seed dispersal, long germination period, low dormancy and viability in soil for several years (Hao *et al*. 2009).

Distribution and habitat

Different species of the genus *Conyza* are found in Europe as neophytes introduced from both North and South America. These invasive species, now considered to be among the most common plant species in the recipient territory, behave primarily as ruderal plants, inhabiting road margins, recently abandoned fields, riverbanks, urban wasteland, etc. *Conyza* plants occur as weeds in more than 40 crops in 70 countries worldwide (Holm *et al*. 1997).

C. canadensis originates from North America and now extends across temperate zones of North, Central and South America, the Middle and Far East and Australia. It is widespread across Europe, particularly across the coastal region of North Western Europe, France, Spain, and the United Kingdom (Holm *et al*. 1997; Facility 2010).

C. canadensis prefers light soil and is usually found in well drained soils. It can grow in stony ground with little humus. Seeds of the weed germinate best in the light and usually from depths of no more than 1 cm (Wu *et al*. 2007).

C. sumatrensis originates from South America but is now scattered throughout the world, particularly in central Africa, Australasia, Central America, and Japan. Within Europe it is reported in Spain,

Table 1. Distinguishing features of three *Conyza* species (Sansom 2011)

	Conyza canadensis	*Conyza bonariensis*	*Conyza sumatrensis*
LEAVES	yellowish green, seedling leaves hairy adult leaves glabrous, (hairless) except leaf edges	greyish green very hairy	greyish green very hairy
	petiole narrow	petiole narrow	petiole broader in middle
	single visible rib	single visible rib	secondary veins visible
STEMS	glabrous	very hairy	very hairy
Average height (m)	1.5	1	2
Branching habit	branching from middle of main stem	secondary branches often taller than main stem & from the base	branching towards top of main stem
FLOWERS	ray florets white, ligulate slightly protruding	tubular, ray florets greenish yellow	tubular, ray florets cream
	inner disc florets yellow	inner disc florets inconspicous, white	inner disc florets inconspicuous
Bracts of the involucre	glabrous brownish inner surface pappus cream	densely hairy, some long hairs at apex are red/purple tipped	hairy but no long hairs near apex pale at the top

Table 2. Glyphosate rates for *Conyza* control different development stages

	Glyphosate rate at seedling-rosette stage (g a.i./ha)	Glyphosate rate at flowering (g a.i./ha)
France	900	1680
UK	1080	1800
Spain	1080–2160	2160 + partners see Table 3

France, and the UK (Holm *et al*. 1997; Facility 2010). *C. sumatrensis* has adapted itself to most soil types and is particularly found on disturbed or neglected ground.

C. bonariensis is found in North, Central and South America, Central Africa, Australasia and the Far East. In Europe it is recorded in France, Germany, Greece, Portugal, and most widely in Spain, where it is mostly found in coastal areas (Holm *et al*. 1997; Facility 2010). Germination is best in light soils (Wu *et al*. 2007).

Good control of *Conyza* is usually achieved with cultivation and herbicide treatments combined according to Good Agricultural Practice. Glyphosate is widely used in non-cropped industrial situations, perennial crops and, in corresponding programs, for the control of weeds pre-sowing and pre-harvest in annual crops and in glyphosate tolerant crops.

The recommended application rates of glyphosate will vary according to formulation and registration adopted for various usage across different European countries. Individual labels should always be followed. Examples of recommended rates in some countries are given in Table 2 and for mixtures in Spain in Table 3.

Studies done by the University of Córdoba showed that there is a variation in susceptibility among the species of *Conyza* and though there may be variation within biotypes in different populations it indicates that the rates of glyphosate required to give control can vary among the species. The populations studied by the University of Córdoba show the following order of susceptibility to glyphosate in the different species (De Prado 2007):

C. sumatrensis/albida >> *C. bonariensis* >> *C. canadensis*

Although correct identification may play a role in establishing management strategies, in most situations the exact species identification will not be necessary to decide on control methods.

Conyza control in arable crops, perennial crops and non-crop situations

In European arable crops *Conyza* is easily controlled by tillage (Brown & Whitwell 1998) and even where primary tillage is not carried out, the control with glyphosate between one crop and the next is effective when applied at the rosette stage. Efficient control of *Conyza* in arable crops is also achieved through the disruption of the life cycle by crop rotation together with the use of herbicides with alternative modes of actions (Stachler 2008; Beckie 2009).

In non-crop areas, *Conyza* is well adapted and can quickly spread across many habitats. *Conyza* is found along field edges and roadsides and in natural settings like prairies and glades. In these areas the *Conyza* control can be achieved by chemical methods and physical methods such as mowing.

Conyza is relatively easy to control in non-crop sites using glyphosate if users:
- treat at the rosette stage of growth. After bolting, *Conyza* is more difficult to control (Gonzalez-Torralva *et al*. 2010);
- avoid difficult environmental conditions. *Conyza* can be more difficult to control under difficult environmental (i.e. drought stressed) or management (i.e. mowing) conditions (Adkins *et al*. 1998);
- use a proper sprayer set-up and calibration to obtain good spray coverage;
- mitigate hard water conditions which can reduce the effective glyphosate dose (Nalewaja & Matysiak 1993; Doğan *et al*. 2012).

In perennial crops, *Conyza* control can be achieved as described above, but in addition there are further constraints due to the absence or reduction of tillage depending on the system and soil conditions. Prior to conservation-tillage practices in orchards (mainly citrus and olive trees), *Conyza* plants were easily controlled by tillage. Even in the absence of

Table 3. Herbicide rates found to give the best efficacy on *Conyza* in Spain (Saborido 2011)

Rate (g a.i./ha)	Glyphosate alone	Glyphosate + MCPA	Glyphosate + fluoxypyr	Glyphosate + amitrole
Glyphosate	2160	1460	2160	2160
Partner	–	720	300	2580

primary tillage, glyphosate application in early spring is an effective tool for *Conyza* control.

In no-till systems, *Conyza* control will be primarily chemical, including the use of glyphosate both alone and with other herbicides. Integrated methods of control are recommended, with scientific studies supporting the use of glyphosate in mixtures of herbicides with different modes of action in preference to sequences or rotations in managing the development of resistance (Powles *et al.* 1997; Diggle 2003; Beckie 2009).

Frequent mistakes are made in the management of *Conyza* with glyphosate products, as with many other weeds, such as:

– ***Treatments using sub-lethal doses***: Glyphosate rates high enough to control more susceptible weeds, but lower than required for *Conyza* will successfully remove the weed competition whilst causing only physiological stress in well-developed, lignified *Conyza* plants. The affected *Conyza* plant, no longer actively growing, is not so susceptible to subsequent herbicide applications. Furthermore, plants can react to this stress situation by flowering profusely (Wada & Takemo 2010), so guaranteeing further proliferation on the farm and leading to the phenomenon of weed shifting in the direction of *Conyza*.

– ***Use of inappropriate mixtures or sequences of glyphosate with other herbicides***: The use of mixtures of glyphosate with other herbicides can cause antagonism, reducing the translocation of glyphosate through the weed (Selleck 1981; Flint & Barrett 1989). Antagonism can also occur when sequences are too close together, e.g. when the interval between glyphosate and 2,4-D was more than 3 days, the control level of *Conyza bonariensis* decreased (Werth *et al.* 2010).

– ***Treatments under drought stress conditions***: Under these conditions the stomata are closed and the systemic activity in weeds is reduced, resulting in poor weed control (De Ruiter 1998).

– ***Application at growth stages with higher tolerance to glyphosate***: Studies done in the glasshouse and the field by the University of Córdoba (De Prado 2007) have shown that the tolerance of the genus Conyza to glyphosate depends on the timing of its application. The susceptibility to glyphosate in both resistant and sensitive populations of Conyza is dependent on the growth stage, whereby the glyphosate rate required for control increases with the growth stage of the weed.

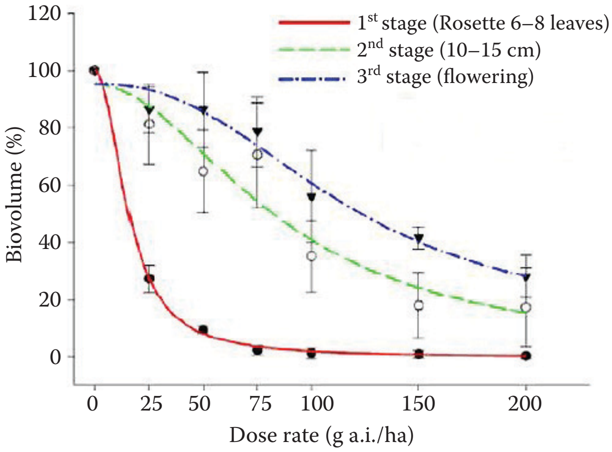

Figure 2. Dose response curves for *C. bonariensis* treated with glyphosate at different growth stages (De Prado 2007)

Development of glyphosate resistance in relation to *Conyza*

In recent years several factors have occurred together in some areas which resulted in *Conyza* spp. being preferentially selected from within the general weed flora and the species becoming dominant. Factors leading to the current situation are:

– Use of inadequate control techniques.
– Use of herbicides which are not effective on the genus *Conyza*.
– Use of sublethal doses.
– Overreliance on a single herbicide – glyphosate.
– Pesticide applications not carried out at the optimal stage of development.
– Particular physiological characteristics of *Conyza* spp. listed in the preceding section, Biology of *Conyza*, which ensure rapid seed spread and establishment.

The *Conyza* spp. management factors described and the risk factors for resistance development are closely aligned. As a result, in Europe, increasing *Conyza* spp. populations have been found in orchards and vineyards and cases of glyphosate resistance have been reported.

European resistance cases

The first European case reported dates back to 2003 (Urbano *et al.* 2007), listed in 2004 (Heap 2011): after studying six populations of *Conyza bonariensis*, resistance was found in olive tree fields in southern Spain. The glyphosate rates required to control resistant populations were 7–10 times higher than those needed to control susceptible populations. Subsequently, the first case of *Conyza sumatrensis* was identified in 2009 in the south of Spain and in 2010, the first case in Portugal in *Conyza bonariensis* was under review (Calha & Osma 2010; Dubois & Plancke 2010). All cases have arisen in orchards or vineyards after multiple applications of glyphosate as the only herbicide and from at least one of the following features: use at suboptimal doses, wrong timing for the weed and poor application technique.

Aside of these cases reported in Spain and Portugal, there is also a case of glyphosate resistance in *C. bonariensis* documented in Greece (Travlos & Chachalis 2010).

A case reported for *Conyza canadensis* in the Czech Republic in 2007 was found on railway ballast at the Prague-Bubny railway station, but though it was included in the International Survey of Herbicide Resistant Weeds (Heap 2011), it was never validated since subsequent testing of collected seed was susceptible to higher but normal recommended rates of glyphosate (Chodova *et al.* 2009).

New cases of suspected resistance are regularly reported and are investigated case by case to evaluate the actual resistance status.

Management of glyphosate resistant *Conyza*

Detection of resistance

The *Conyza* genus is highly diverse; it contains a large number of annual species with varied phenology. Over time weed populations will shift towards more tolerance from within the natural variability of the population (Hilgenfield *et al.* 2004; Owen 2008). However, if several uncontrolled species are found at the same time, the problem may be due to incorrect application of the herbicide and/or in unsuitable environmental conditions. Where there is just one species (exceptionally 2 or 3), it may be due to early resistance development by these species to the herbicide in question (Saavedra 2002).

Herbicide programmes, timing and integrated control methods

Numerous studies carried out on the control of *Conyza* spp. conclude:

– The most important factor in control is growth stage: the optimum time to control plants of the genus *Conyza* is from seedling to rosette stage (Shrestha *et al.* 2008).

Other factors influencing the level of control are:

– Water volumes: there is evidence that lower water volumes (no more than 200 l/ha) maximise efficacy due to higher herbicide concentration (Bradford *et al.* 2003; Doğan *et al.* 2012).
– Observation of Best Practice for all aspects of the spray application to achieve maximum coverage and uptake (BCPC 1998).
– The use of different active ingredients in conjunction with glyphosate where the development stage of any target *Conyza* plant has reached stem extension/bolting or tolerance/resistance to glyphosate is confirmed (Powles *et al.* 1997; Diggle 2003; Beckie 2009).
– Studies conducted in perennial crop situations in Spain have shown improvements in overall control from glyphosate with the addition of amitrol, clopyralid, flazasulfuron, fluoxypyr, glufosinate, and MCPA (Urbano 2008).

Figure 3. *Conyza* control options with glyphosate (Saborido 2011)

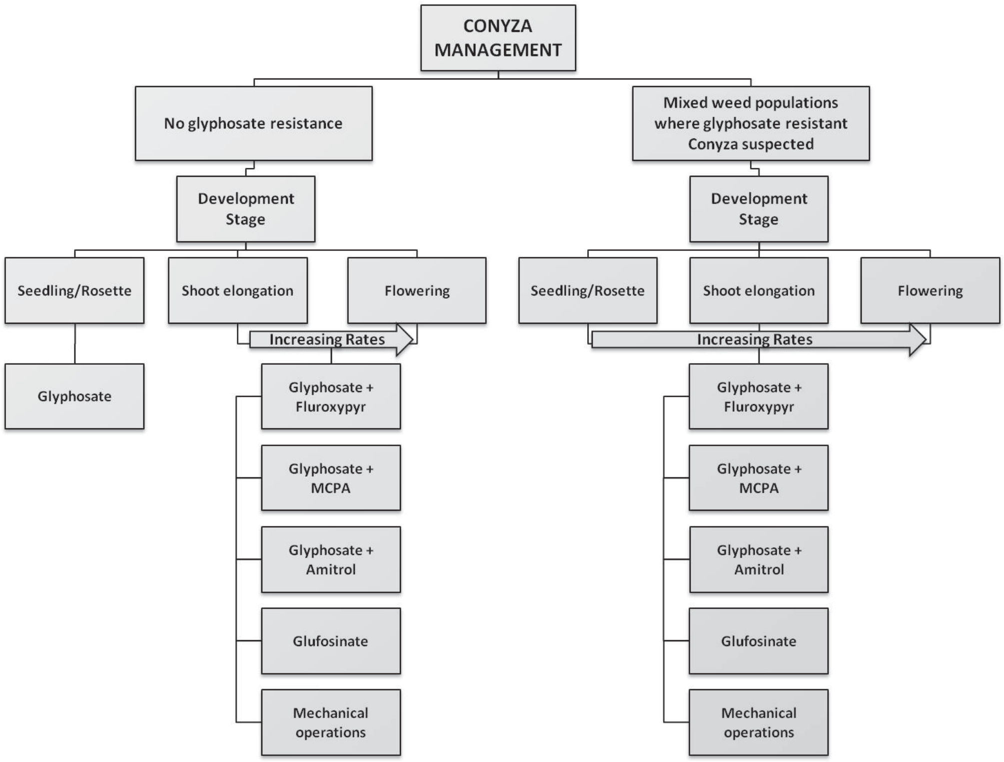

Figure 4. Decision tree for the control of *Conyza* (Saborido 2011; Monsanto trials Spain 2008–2011)

Some *Conyza* biotypes resistant to glyphosate have been reported in perennial crops on different farms in Spain. At these locations, *Conyza* control could not be achieved with glyphosate alone, so an integrated weed management approach is necessary, combining different methods of control.

The best methods for management of glyphosate resistant populations in perennial crops include the use of herbicides with a different mode of action, preferably in mixtures with glyphosate, but alternatively in a sequence of active substances (Powles *et al.* 1997; Diggle 2003; Beckie 2009; Werth *et al.* 2010) and the use of physical methods like mowing or tillage, where practical. Applications to *Conyza* spp. at an early development stage with active ingredients such as 2,4-D, MCPA, fluroxypyr, amitrol, glufosinate or flazasulfuron, preferably mixed with glyphosate will allow the control of both resistant and susceptible biotypes of *Conyza*.

The recommended application rates of glyphosate will vary according to formulation and registration in different European countries. Individual labels should always be followed, but Table 3 gives examples of the rates recommended in Spain.

The more advanced the development of *Conyza*, the more difficult is the control by chemical methods. By the time the plant reaches flowering physical control methods such as tillage or mowing of weeds are recommended to prevent the production of seed from glyphosate resistant biotypes.

General weed management and proactive resistance management

In order to manage the development of herbicide resistance in weeds, farmers should always follow general guidelines to reduce the risk of weed resistance occurrence, including the inspection of fields before and after application; controlling weeds early when they are small; addition of other herbicides (e.g. a selective and/or residual herbicide) and cultural practices (e.g. tillage or crop rotation) as part of the weed management system where appropriate. They should use the right herbicide product at the right rate and the right time and clean equipment before moving from field to field to minimise the spread of weed seeds as well as controlling weed escapes and preventing the weeds from setting seeds.

CONCLUSION

Adoption of integrated management of *Conyza* is essential to ensure that plants of this fast adapting genus will remain controllable in arable and perennial crops. Farmers are unlikely to be aware of glyphosate resistance development for up to 4 years after the first resistant plant arises due to the time it takes for overall weed control to become unsatisfactory (Calha *et al*. 2011). Since glyphosate is likely to be included in herbicide programmes due to the efficient control of other sensitive weeds, proactive management should be taken to pre-empt the development of resistant populations. Label warnings should be included on all glyphosate products and training in Good Agricultural Practice should be provided for both distributors and technical stakeholders. If awareness and Good Agricultural Practice are promoted, followed and monitored by all stakeholders, it should be possible to continue the integrated use of glyphosate herbicides in Europe without escalating populations of *Conyza* resistance.

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