

# ***Global Strategies for the Management of Herbicide Resistance Weeds***

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Stewarding available herbicides and herbicide technologies is a priority of Monsanto. Monsanto's weed resistance management programs (WRM) are focused on glyphosate and other herbicides important to agriculture and non-agricultural production systems. The goals of these WRM programs are to (1) delay evolution of herbicide resistance in new weed species and (2) retard or stop the spread of existing resistant populations. The tactics used to accomplish these goals include; (1) identify the most cost effective diversified weed management program, (2) design and implement effective farmer and farm advisor education and training programs, (3) design and implement marketing programs, as appropriate, to encourage adoption of best management practices, (4) monitor for resistance in order to identify it early, and (5) foster research to better understand mechanisms of resistance and to identify the most effective management strategy for each farming situation.

Resistance to glyphosate has increased over the last 15 years. The first recorded resistance to glyphosate was in areas where glyphosate was used in the traditional use markets: Australia 1996, *Lolium rigidum* in fallow ground; Australia 1997, *Lolium rigidum* in apples, Malaysia 1997, *Elusine indica* in rubber plantation. The first case of glyphosate resistance was recorded approximately 15 years after first use in Australia. To date glyphosate resistance has been found in populations of 23 species, across 18 genus and in 15 countries. Of these weeds, *Lolium* spp., *Conyza* spp., *Amaranthus* spp. *Digitaria* sp. and *Ambrosia* spp infest the largest areage with glyphosate resistant *Lolium* spp. and *Conyza* spp populations being the most widely distributed around the world. Currently a little more than half of the total number of glyphosate resistant species evolved as a result of intensive glyphosate use in Roundup Ready crops. Populations of *Conyza* spp. resistant to glyphosate were first reported in the U.S. approximately 4 years after the introduction of Roundup Ready soybeans. However, there had been previous selection pressure in this species due to the preplant use of glyphosate in conservation tillage systems. In the case of other weed species (i.e. *Amaranthus* spp., *Ambrosia* spp., *Sorghum halenpense*, *Conyza* spp. (Brazil), and *Digitaria insularis*) glyphosate resistance evolved after approximately 8-10 years of continuous use and intense selection pressure. Overall, considering the intensive use of glyphosate and the broad spectrum of weeds controlled by glyphosate (~300 worldwide) there are relatively few species (23) with evolved resistance compared to other popular herbicides and herbicide groups.

What we have learned from the evolution of weeds resistant to glyphosate is that intensive and exclusive use of any herbicide over an extended period of time is not a sustainable practice. The factors most often associated with the evolution of glyphosate resistance are; (1) exclusive reliance on glyphosate in the absence of other herbicides or mechanical weed control operations for weed control over multiple seasons, and (2) use of 'low dose'. The scientific evidence that low dose can speed the evolution of resistance to glyphosate and other herbicides has increased. In addition to the intensity of selection pressure and low dose, it has become more apparent, as we have learned more about glyphosate resistant mechanisms, that differences in frequency of resistance alleles among species and/or the time it takes for accumulation of resistance alleles within a biotype are critical factors to understanding the difference among species in terms of the probability for resistance to evolve.

Monsanto's strategy for managing glyphosate resistance includes defining best weed management practices for both proactive, those implemented before resistance has evolved, and reactive management,

those implemented to respond to the presence of resistance. In general, managing resistance to glyphosate and other herbicides means incorporating more diversity into the weed management program. An integrated approach composed of multiple herbicides applied in mixtures, sequences or rotations with consideration to appropriate mechanical and cultural practices provide the best opportunity to incorporate needed diversity. There is a increasing body of evidence from field trials and use of models that herbicide sequences (i.e. a soil active pre-emergence herbicide followed by a postemergence active herbicide) and postemergence mixtures are as effective or more effective than rotating from one herbicide to another in alternate years (Wrubel and Gressel 1994, Powles et. al. 1997, Neve et. al. 2011, Neve et. al. 2011).

Farmer education and training is a critical component of resistance management programs because ultimately the farmer decides on his weed management program. These programs must focus on proactive management practices and reactive practices. In many situations, proactive programs will require fewer inputs than reactive programs. However, since proactive programs generally include the use of herbicides with overlapping/redundant activity, the costs of these programs are generally higher than the farmer would otherwise consider which makes it a challenging decision for the farmer. This situation also is a challenge for weed scientists and farm advisors in terms of generating the appropriate information needed by farmers to make this decision. Surveys designed to better understand farmer's perceptions of resistance are useful in designing the best possible farmer education and training programs. For example, farmer perception studies have indicated that the reluctance of farmers to adopt proactive management strategies is greatest when they believe that (1) industry would provide new options for weed management, (2) individual action has little effect on resistance, and (3) there is low awareness of how practices affect resistance. This type of information suggests that we need to design farmer education programs that highlight the importance of individual action and to emphasize the shrinking number of effective herbicide options for managing some species.

Monsanto has developed a number of farmer focused programs to promote the proactive adoption of best management practices in Roundup Ready crops. In several countries, these programs are presented under a Roundup Ready Plus™ brand. These programs are designed to promote the implementation of diversified weed management programs in Roundup Ready crops and to promote the need for proactive management. The programs include developing the best technical recommendations in cooperation with academics and farm level agronomists, implementing farmer education programs to increase awareness of the need to implement best management practices, and promoting the benefits of proactive management. A basic message in these programs is about the importance of using other herbicides and/or weed control methods in addition to glyphosate. Recommended practices are developed in cooperation with academics and the herbicides included in the program are not restricted to those only sold by Monsanto. In addition, individual programs have been implemented to address special weed management situations. For example, farmer-focused programs has been implement in Canada and Brazil to restrict spread of glyphosate resistant *Kochia* sp. and glyphosate resistant *Digitaria insularis*, respectively.

Herbicide resistance is a serious issue that requires both the public and private sectors to aggressively develop and implement appropriate stewardship programs. Monsanto is committed to stewarding glyphosate and other herbicides and to working collectively with private and public organizations focused on this. Our ultimate success in influencing farmer practices lies in our individual and collective efforts to facilitate farmer understanding and adoption of diversified weed management programs.

## References

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