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Introduction

There has been concern about the evolution of glyphosate resistance in some Iowa weeds for many years although the field-wide existence of any problems has not been previously reported. It is important to recognize that in reality, common waterhemp (***Amaranthus rudis****) with resistance to glyphosate was reported in fields near Everly and Badger, Iowa as early as 1998 (Zelaya and Owen 2002). However, the likelihood of weeds evolving resistance to herbicides pre-dates glyphosate-resistant weed biotypes by five decades (Harper 1956). The first identification of herbicide resistant weed biotypes pre-dates glyphosate-resistance by four decades (Ryan 1970) and currently there 19 herbicide mechanisms of action to which weeds have evolved resistance which compromise 334 weed biotypes from 190 weed species and infest an area that is impossible to estimate (Heap 2009). To date, 16 weed species have evolved resistance to glyphosate. All of these incidents of evolved herbicide resistance have one thing in common; the mismanagement of herbicide use. This paper will describe the current herbicide resistant weed situation for Iowa in general terms, address the implications of herbicide resistant weeds and suggest solutions to the problems.

Causes of evolved herbicide resistance in weeds

While it may seem intuitively obvious that the cause of herbicide resistance in weeds is the use of herbicides, the situation is not nearly that simple. Herbicides do not directly cause the evolution of resistant biotypes but rather select for the rare individual weeds within a weed population that have the genetically heritable mutation(s) that allows these weeds to exist in the presence of the herbicide. Given that generally the frequency of these mutations within a weed population is extremely low, and that the resistant weed biotype does not likely have an ecological advantage compared to the weeds that are naturally sensitive to the herbicide, unless the herbicide in question is used repeatedly as the primary, if not sole tactic for weed control, the resistance trait will never become a major economic problem. Thus, the actual cause of the evolved resistance to herbicides is the manner in which herbicides are used (Owen 2009). When a specific herbicide or herbicide mechanism of action is used repeatedly, the resistant biotype has a considerable advantage over the sensitive biotype and can quickly become the predominant phenotype in a field. The higher the initial frequency of resistance in the unselected weed population, the faster that the population shifts from a sensitive to a resistant response to the herbicide (Owen 2006).

The sources of the problem

There can be no question that the root of the problem is how growers view “weed management”, perhaps better termed “weed control”. The current socio-economic situation in commercial agriculture places a premium on speed, cost, convenience and simplicity. Interestingly, while the demographics of agriculture in Iowa have changed considerable during the last several decades, the root cause of herbicide resistance is the same; an emphasis on one herbicide with a diminishing use of alternative weed management tactics. The reliance on atrazine for the control of broadleaf weeds resulted in weed resistance during the 1980’s, the reliance on ALS inhibitor herbicides (i.e. Pursuit) resulted in resistance to these herbicides in the late 1980’s and 1990’s and now, reliance on glyphosate has resulted in glyphosate resistance throughout the Midwest, Southeast, Delta and Northeast/Delmarva in key weed species.

While it cannot be said that growers who included alternative tactics to the use of glyphosate would not experience glyphosate resistant weed biotypes, there is strong evidence to support this conclusion (Cardina et al. 2002, Heggenstaller and Liebman 2005, Westerman et al. 2005, Murphy et al. 2006, Swanton et al. 2006, Anderson and Beck 2007). Furthermore, models the predict the evolution of glyphosate resistance support the premise that more

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Amarnathus rudis* and ***A. tuberculatus* are the same weed however there has been taxonomic confusion about the correct species. Currently, most reports recognize the original authority and the species name used is ***A.***

tuberculatus.

diverse weed management tactics slow the shift of a weed population from a sensitive to resistant phenotype (Neve 2008). Thus, the conclusion that decisions made by growers to use (perhaps better stated misuse) an herbicide contributes strongly the evolution of herbicide resistance, and their hesitancy to proactively include alternative tactics further exacerbates the situation.

However, the sole blame cannot be fairly placed upon the backs of the growers. Certainly agchem advisers also must be recognized as contributors to the problems. Also very important were/are the misguided representations of herbicides by the basic manufacturers through their marketing programs and how problems of performance were addressed. Together, the message from these influential sources of information and recommendations made the grower decisions predictable and just as predictable was the inevitable response of the weeds to evolve resistance. How quickly we forgot the lesson "learned" in the 1980's and 1990's when resistance ALS-inhibitor herbicides became so prevalent.

Given the original message that resistance to glyphosate would never occur, it might be understandable why growers have not managed the current system better. However, most companies have dramatically changed the "official" recommendations for the use of glyphosate to include alternative tactics and the recommendations from Iowa State University have always stressed the importance of an integrated approach for weed management. Despite current recommendations that stress the inclusion of alternative weed management strategies, growers have been largely reluctant to adopt tactics for weed management that they deem inconvenient and complex.

Herbicide resistant weeds in Iowa

A number of recent publications describe the herbicide resistant weed situation in Iowa. These include previous ICM papers, refereed journal publications, ICM Newsletter articles and blogs (Zelaya and Owen 2004, Owen and Zelaya 2005, Owen 2006, 2007, 2008). Iowa has a long history of weeds resistant to triazine herbicides, particularly common lambsquarters (***Chenopodium album***) and redroot pigweed (***Amaranthus retroflexus***). More recently, resistance to ALS inhibitor herbicides has been identified in Iowa shattercane (***Sorghum bicolor***), common waterhemp, giant ragweed (***Ambroisa trifida***), common cocklebur (***Xanthium strumarium***), and common sunflower (***Helianthus annuus***) populations. It should be noted that while only a few ALS resistant species have been reported in Iowa, globally 103 weed species have been identified as having ALS resistant biotypes. Many of these weed species exist in Iowa and it is possible that ALS resistant biotypes exist but have yet to be identified. Giant foxtail (***Setaria faberi***) populations that have evolved resistance to ACCase inhibitor herbicides have also been identified in Iowa.

Recently, weeds that have evolved resistance to PPO inhibitor herbicides have been identified in Iowa. A recent series of experiments in grower fields across Iowa has identified common waterhemp populations that are resistant to PPO inhibitor herbicides. Globally, three weed species with PPO resistant biotypes have been identified and importantly all of these biotypes are reported to have multiple resistances to other herbicides (i.e. PPO resistance and ALS resistance) (Heap, I., 2004). The results from the Iowa experiments demonstrate multiple resistances in common waterhemp to PPO and ALS herbicides. Finally, populations of glyphosate resistant giant ragweed have been identified in Iowa in 2009. Experiments are currently underway to better characterize these populations as well as to evaluate suspected putative glyphosate resistant populations of common waterhemp and horseweed (marestail) (***Conyza canadensis***).

The solution and management of herbicide resistant weeds

The first point that must be understood is that weeds are able to adapted to whatever crop production systems that is used and to any and all weed management tactics implemented (Owen 2008). Changes in weed communities in response to agriculture and specifically to herbicides are inevitable and represent an excellent ecological example of "Darwinian Evolution" in fast forward. Weed shifts (which includes the evolution of herbicide resistant weed populations) have always been a feature of agriculture and the only thing that is different now compared to the beginning of "modern" production agriculture is the scale of the enterprises and the limited number of weed management tactics that are used.

The wide-spread use and effectiveness of herbicides has allowed for more efficient weed control and thus farm size has increased considerably while the number of farms has declined consistently for the last few decades. Perhaps the greatest and globally most important change in agriculture is the unprecedented adoption of genetically engineered crops, particularly those that have resistance to glyphosate. It has been proposed that glyphosate resistant crops and the use of glyphosate have limited the choices available to growers. While there may have been some herbicides that basic manufacturers chose not to re-register because of presumed declining markets due to glyphosate resistant crops and there is no question that the change in marketplace resulted in some companies to reduce the investment in basic herbicide discovery research, generally the availability of glyphosate resistant crops (and now glufosinate resistant crops) has not dramatically changed the available weed management tactics available for the production of corn and soybeans. In fact, it can be argued, given the declining prices of herbicides due to the current marketplace, growers actually have more choices available for weed management than prior to the adoption of genetically engineered crops. What has changed is the perception of weed management and how these tactics are used.

Just as was experienced during the "ALS inhibitor herbicide era", glyphosate quickly became the primary if not sole tactic for weed control and predictably, the tactic quickly began to fail. It is suggested that agriculture is at the precipice of glyphosate resistance in the Midwest weed populations. In the Midsouth, Southeast and Delta, agriculture has stepped off the precipice as is seen in the prevalence of glyphosate resistant horseweed (marestail) and Palmer pigweed (Amaranthus palmeri) populations. However, in the Midwest, most of the weed populations are still sensitive to glyphosate but this situation will likely be short-lived unless the plethora of available alternatives for weed management is quickly included by growers (Owen 2008). Is the inclusion of these alternative tactics by growers something that growers willingly accept?

The evidence suggests that growers will not proactively include alternative strategies as they tend not to believe that a problem exists until it is found in their fields (Johnson and Gibson 2006). Given the biology of weeds, once the problem is discovered, it is likely too late and remediation is the only strategy available (Owen 2008). Unfortunately, control of glyphosate resistant weeds maybe more challenging and management options more difficult than prior to the occurrence of the evolved resistance.

What is the solution of managing herbicide resistant weeds? Simply put, do not facilitate the evolution of herbicide resistance. While this is likely too late in the case of ALS inhibitor herbicide resistance in Iowa, deterring the evolution of resistance to glyphosate, glufosinate and PPO inhibitor herbicides is well within the reach of many Iowa growers. A well-thought and timely integrated weed management (IWM) program is the key component. Most growers will balk at this and the reasons provided for why they will not implement an IWM program will include (not in the order of importance) expense, time requirement, lack of convenience, lack of simplicity, and failure to recognize the inevitability of herbicide resistant weed populations. Thos growers who have glyphosate resistant weed populations are likely to adopt glufosinate resistant crops, but this herbicide will also ultimately have resistant weed populations evolve unless growers shift to IWM programs. IWM programs include:

- Use of alternative herbicides to control "weeds of concern" (i.e. common waterhemp)
- Use of alternative herbicide application timing (i.e. a herbicide with soil activity should be applied early preplant on all acres regardless of the genetically engineered trait in the crop)
- Scouting
- Recognize the selectivity differences of different herbicides – use products that will control the weeds that occur in the fields
- Use the correct herbicide rates – reduced herbicide rates can contribute to the evolution of herbicide resistant biotypes
- Protect crop yield – successfully killing weeds is not synonymous with weed management. Killing weeds after they have caused significant losses of crop yield potential and thus profit.
- Understand that all fields are different and thus should be managed differently
- Consider the inclusion of mechanical tactics in specific fields or areas within fields
- Convenience and simplicity are harbingers for the evolution of herbicide resistance
- Optimize crop management – a competitive crop is an excellent weed management tactic
- Weed seeds are important – management the weed seed rain by minimizing weed seed production and optimize conditions to maximize weed seed predation

- Recognize that the most important manner by which new weeds (new species or new herbicide resistance populations) enter a field is through normal crop production practices (i.e. harvesting) – optimize sanitation as an IWM tactic by isolating problem fields and cleaning equipment after working in these fields
- Keep detailed records for each field

Conclusions

Iowa has now joined most of the other Midwest states and has weed populations resistant to most of the commonly used herbicide families including glyphosate and PPO inhibitor herbicides. Importantly, some of the herbicide resistant common waterhemp populations demonstrate resistance to several herbicide families and typically are cross resistant to all ALS inhibitor herbicides. While glyphosate resistance is not as widely found in Iowa as in other Midwest states, anecdotal evidence suggests that without immediate proactive adoption of IWM tactics, Iowa agriculture faces the same dire consequences of widely dispersed glyphosate resistant weed populations as currently found in some neighboring states. Fortunately, the choices available for weed management have increased despite concerns that the adoption of genetically modified crops has diminished available tactics. These tactics can include the use genetically modified crops and should include alternative herbicides and other cultural and mechanical strategies. While many growers still believe in the myth that a new "silver bullet" will soon become commercially available, it is unlikely that anything new of the magnitude demonstrated with the introduction of genetically engineered crops is forthcoming in near future. Thus, growers need to develop diverse IWM programs to optimize weed management, protect crop yield potential and deter the impending evolution of new herbicide resistant weed populations with the many tactics and herbicides currently available.

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