EFFECTIVENESS OF GLYPHOSATE RESISTANCE MANAGEMENT PRACTICES

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Introduction

Unlike many factors that affect the development of weed resistance to herbicides (Stoltenberg 2004), herbicide selection intensity and can be directly affected by the grower. Herbicide selection intensity is determined by herbicide efficacy, persistence, and frequency of application (Gressel and Segel 1990). The greater the number of susceptible weeds that are exposed to a herbicide and killed, the greater the selection intensity upon that weed population. Reduced herbicide selection intensity will reduce the probability of resistance development and prolong the usefulness of a herbicide mode of action. However, it is essential to balance the benefits of responsible herbicide stewardship with the need to maintain satisfactory levels of weed management. One rationale for adopting an integrated approach to weed management is to reduce herbicide selection intensity on our weed populations.

Although the integration of weed management practices is recommended to reduce the potential for weed resistance to glyphosate (Boerboom and Owen 2006), research to quantify the effectiveness of such integration under field conditions is limited. To address this information need, field data from a long-term experiment (Stoltenberg and Jeschke 2007) at the University of Wisconsin Arlington Agricultural Research Station was analyzed to determine the probability (or likelihood) of occurrence of giant foxtail (*Setaria faberi*), redroot pigweed (*Amaranthus retroflexus*), common lambsquarters (*Chenopodium album*), velvetleaf (*Abutilon theophrasti*), and giant ragweed (*Ambrosia trifida*) resistance to glyphosate as affected by crop sequence, tillage system, and intensity of glyphosate use. The goal was to provide a quantitative assessment of the effectiveness of integrated weed management practices to reduce the risk of selection for resistance to glyphosate among some of our most common weed species.

Methods

For this analysis, five weed management treatments were compared in continuous corn and corn-soybean rotation in moldboard plow, chisel plow, and no-tillage systems. Specific treatments in the corn-soybean rotation are shown in Table 1. Weed management treatments in continuous corn were the same as those listed for corn in Table 1, except they were imposed each year from 1998-2005.

Table 1. Weed management treatments in a corn-soybean rotation 1998-2005.

No.	Soybean: 1998, 2000, 2002, 2004	Corn: 1999, 2001, 2003, 2005
1	Glyphosate POST †	Glyphosate POST
2	Glyphosate POST	Glyphosate POST fb LPOST ‡
3	Glyphosate POST	Glyphosate POST fb cultivation
4	Glyphosate POST	Non-glyphosate herbicides
5	*S*-metolachlor PRE § fb glyphosate POST	*S*-metolachlor PRE fb glyphosate POST

† POST = postemergence; ‡ POST = late postemergence; § PRE = preemergence.

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The probability or likelihood of resistance associated with weed management treatments was estimated using the methods described by Jasieniuk et al. (1996). Estimated resistance probabilities were based on the number of plants of each weed species exposed to glyphosate at the time of treatment, outcrossing rates specific to each weed species, and the assumption that resistance to glyphosate was conferred by a single-gene, incompletely-dominant mutation. Resistance probabilities were calculated based on a field size of 75 acres; probabilities for each species are presented as relative to the lowest probability among weed management treatments.

As for many herbicides, the frequency of traits conferring weed resistance to glyphosate is not known, but has been assumed to be much lower than that for triazine herbicides and ALS inhibitors, due in part to the relative low number of weed species that have developed resistance to glyphosate. Frequency of herbicide resistance traits are thought to vary with many factors, including herbicide mode of action, and are based on expected rates of spontaneous (or natural) genetic mutation, e.g. 1×10^{-5} to 1×10^{-12} (Gressel, 2002; Jasieniuk et al., 1996; Maxwell and Mortimer, 1994; Maxwell et al., 1990). For this analysis, a frequency of 1×10^{-10} was used for traits conferring resistance to glyphosate.

Results

Glyphosate-resistant weeds were not observed in this experiment from 1998-2005. The results presented below pertain only to the probability or likelihood of weed resistance occurring based on the methods and assumptions stated above. Also as stated above, resistance probabilities were calculated based on a field size of 75 acres (and the estimated number of weeds treated with glyphosate), and are presented as relative to the lowest probability among weed management treatments for each species.

Crop sequence and tillage effects on resistance probabilities varied among species (data not shown), but among weed management treatments, the lowest probabilities of giant foxtail (Table 2), redroot pigweed (Table 3), and common lambsquarters (Table 4) resistance to glyphosate were associated with *S*-metolachlor PRE integrated with glyphosate POST or glyphosate POST rotated annually with non-glyphosate herbicides. For giant foxtail and redroot pigweed, the relative probability of resistance was more than 20-fold greater for glyphosate POST, glyphosate POST fb LPOST, and glyphosate POST fb cultivation than *S*-metolachlor PRE fb glyphosate POST.

Table 2. Relative probabilities of giant foxtail resistance among weed management treatments. Data were pooled across crop sequence and tillage treatments.

Weed management treatment	Number of plants treated 1998-2005	Relative probability of resistance †
	Millions / 75 acres	
Glyphosate POST	388	47 c ‡
Glyphosate POST fb LPOST §	303	37 c
Glyphosate POST fb cultivation §	220	27 c
Glyphosate POST rotated annually with non-glyphosate herbicides	83	10 b
S-metolachlor PRE fb glyphosate POST	8	1 a

† Probability of resistance relative to the lowest probability among treatments.
‡ Means followed by the same letter do not differ at the 5% level of significance.
§ LPOST and cultivation in corn only.

Table 3. Relative probabilities of redroot pigweed resistance among weed management treatments in a chisel plow system. Data were pooled across crop sequence treatments.

Weed management treatment	Number of plants treated 1998-2005	Relative probability of resistance †
	Millions / 75 acres	
Glyphosate POST	96	21 c ‡
Glyphosate POST fb LPOST §	256	55 d
Glyphosate POST fb cultivation §	102	22 c
Glyphosate POST rotated annually with non-glyphosate herbicides	22	5 b
S-metolachlor PRE fb glyphosate POST	4	1 a

† Probability of resistance relative to the lowest probability among treatments.
‡ Means followed by the same letter do not differ at the 5% level of significance.
§ LPOST and cultivation in corn only.

Table 4. Relative probabilities of lambsquarters resistance among weed management treatments in a chisel plow system. Data were pooled across crop sequence treatments.

Weed management treatment	Number of plants treated 1998-2005	Relative probability of resistance †
	Millions / 75 acres	
Glyphosate POST	280	5 b ‡
Glyphosate POST fb LPOST §	186	3 ab
Glyphosate POST fb cultivation §	189	3 ab
Glyphosate POST rotated annually with non-glyphosate herbicides	62	1 a
S-metolachlor PRE fb glyphosate POST	86	1 a

† Probability of resistance relative to the lowest probability among treatments.
‡ Means followed by the same letter do not differ at the 5% level of significance.
§ LPOST and cultivation in corn only.

Table 5. Relative probabilities of velvetleaf resistance among weed management treatments 1998-2005. Data were pooled across crop sequence and tillage treatments.

Weed management treatment	Number of plants treated 1998-2005	Relative probability of resistance †
	Millions / 75 acres	
Glyphosate POST	29	2 b ‡
Glyphosate POST fb LPOST §	34	2 b
Glyphosate POST fb cultivation §	39	3 b
Glyphosate POST rotated annually with non-glyphosate herbicides	15	1 a
S-metolachlor PRE fb glyphosate POST	24	2 b

† Probability of resistance relative to the lowest probability among treatments.
‡ Means followed by the same letter do not differ at the 5% level of significance.
§ LPOST and cultivation in corn only.

For common lambsquarters, the relative probability of resistance was five-fold greater for glyphosate POST than either *S*-metolachlor PRE integrated with glyphosate POST or glyphosate POST rotated annually with non-glyphosate herbicides (Table 4). However, the relative probability of common lambsquarters resistance did not differ among glyphosate POST fb LPOST, glyphosate POST fb cultivation, glyphosate POST rotated annually with non-glyphosate herbicides, and *S*-metolachlor PRE fb glyphosate POST treatments; this result was attributed to the limited efficacy of *S*-metolachlor on common lambsquarters and the relatively high number of common lambsquarters plants exposed to glyphosate in this treatment. Other PRE herbicides, e.g. acetanilides, with greater efficacy on common lambsquarters would be expected to greatly reduce the number of common lambsquarters plants exposed to glyphosate, and thus, further reduce the likelihood of resistance occurring.

The lowest probability of velvetleaf (Table 5) resistance to glyphosate was associated with glyphosate POST rotated annually with non-glyphosate herbicides. In contrast, the probability of giant ragweed resistance did not differ among weed management treatments (data not shown); this result was attributed in part to greater variability associated with giant ragweed densities than with other weed species.

Conclusions

These results suggest that integrated weed management practices, particularly the use of effective non-glyphosate herbicides, are important for reducing the likelihood of weed resistance to glyphosate. As such, these results provide quantitative support for recommendations that integrated weed management practices are critical for glyphosate resistance management.

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