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Abstract

Like crop producers elsewhere, soybean producers in Nebraska are challenged with managing weeds that are evolving resistance to an increasing number of herbicides. We surveyed Nebraska soybean growers, crop advisors, and industry professionals to identify current agronomic practices, assess the distribution of herbicide resistance and strategies for weed management, and gauge perceptions of new herbicide-tolerant soybean technologies. We found that producers rely heavily on herbicides and are challenged with several herbicide-resistant weeds. Our findings also suggest that new herbicide-tolerant soybean technologies will be readily adopted. Extension educational programs promoting a holistic approach to weed management will be critical.

Keywords: weed management, herbicide resistance, herbicide-tolerant soybeans

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Introduction

Weed management has changed significantly in the 20 years since glyphosate-tolerant soybeans and corn were introduced to the market in 1996 and 1997, respectively (Owen, 2016). The rapid adoption of these technologies allowed producers to shift away from using multiple herbicide sites of action (SOA) to control the complete spectrum of weeds present in agronomic fields. Glyphosate proved to be a very effective nonselective herbicide with excellent crop safety and no soil residual activity, enabling growers to make multiple applications within a season. Because of the overreliance on glyphosate within and across growing seasons, weeds have evolved resistance to it. This circumstance has presented challenges to weed control, particularly in soybeans, where postemergence herbicide options are limited. In the United States, 16 weed species have evolved resistance to glyphosate (Heap, 2017). In Nebraska, six species have evolved resistance to glyphosate (Knezevic et al., 2017), several of which also have evolved resistance to other herbicide SOA (Table 1).

Table 1.

Weeds Confirmed to Have Evolved Resistance to Glyphosate and Other Herbicide Sites of Action (SOA) in Nebraska

	Resistance to additional herbicide SOA			
Glyphosate-resistant weed species	**Photosystem II inhibitors (group 5)[a]**	**ALS inhibitors (group 2)[a]**	**HPPD inhibitors (group 27)[a]**	**Growth regulators (group 4)[a]**
Palmer amaranth (*Amaranthus palmeri*)	✓	✓	✓	
Common waterhemp (*Amaranthus rudis*)	✓	✓	✓	✓
Common ragweed (*Ambrosia artemisiifolia*)				
Giant ragweed (*Ambrosia trifida*)				
Horseweed (or marestail) (*Conyza canadensis*)		✓		
Kochia (*Kochia scoparia*)	✓	✓		✓

Note. ALS = acetolactate synthase. HPPD = hydroxyphenylpyruvate dioxygenase. Adapted from *Guide for Weed, Disease, and Insect Management in Nebraska* (Nebraska Extension Publication EC130), by S. Z. Knezevic, C. F. Creech, A. J. Jhala, R. N. Klein, G. R. Kruger, C. A. Proctor, . . . R. Werle, 2017, Lincoln, NE: University of Nebraska–Lincoln Extension.
[a]Weed Science Society of America herbicide SOA classification.

It has been 30 years since the most recent herbicide SOA, hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors, were released (Heap, 2017). Existing estimates do not indicate that any new SOA herbicides will become commercially available within the next decade. The forthcoming technologies for weed management in soybeans consist of genetically engineered varieties that can tolerate postemergence application of the growth regulators dicamba (Roundup Ready Xtend soybeans—Monsanto) and 2,4-D (Enlist soybeans—DowAgroSciences) and pre-emergence application of HPPD inhibitors (Balance GT soybeans—Bayer) or reduced plant-back interval for some acetolactate synthase (ALS) inhibitors (BOLT soybeans—DuPont). Despite the potential of these technologies, off-site movement and selection for additional resistance are major concerns that accompany the increased use of these herbicides. There are already reported cases of resistance to these SOA in Nebraska, different from the time when glyphosate-tolerant soybeans and corn were introduced and no glyphosate-resistant (GR) weeds were known to be present. Additionally, these are commonly used herbicides in corn, which is typically the rotational crop where soybeans are planted. Using similar herbicide programs for corn and soybeans will increase the likelihood for resistance to multiple SOA, potentially limiting the number of effective herbicide options in the future. Growers must be mindful of the risks when adopting the new technologies; otherwise, the technologies' life spans are likely to be short, and the future of weed management will be uncertain. Additionally, Extension must understand producer practices and perceptions and respond with appropriate educational

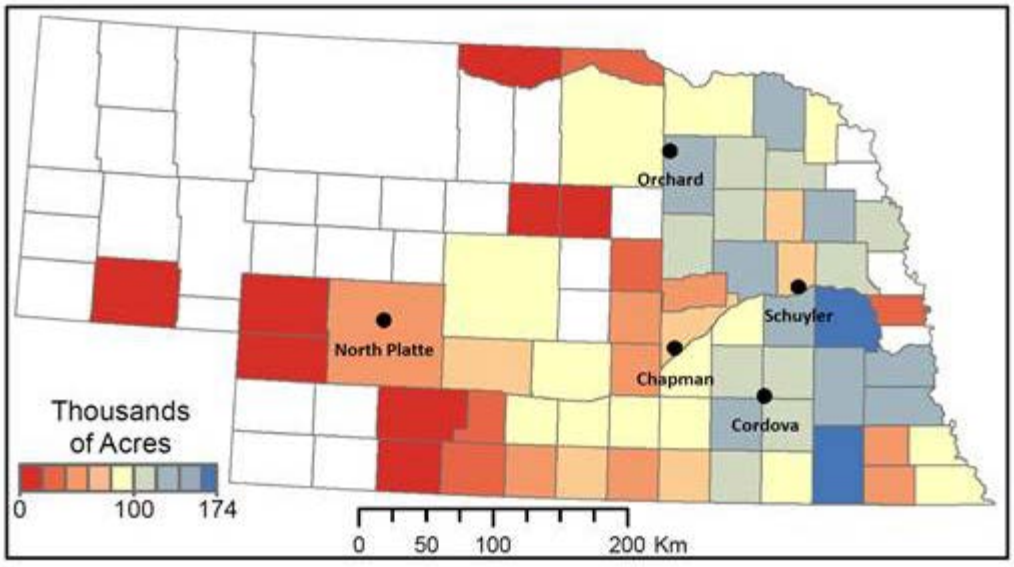
programming.

Methodology

We conducted a survey at two University of Nebraska–Lincoln (UNL) Extension field day events in the summer of 2016. One event was the Soybean Management Field Days, held at four locations (Chapman, Cordova, Orchard, and Schuyler) across the major soybean-growing areas of Nebraska, and the other was the UNL Water and Crops Field Day, held in one location (North Platte) (Figure 1).

Figure 1.

Soybean Production Area of Nebraska and Survey Locations



Source for Nebraska soybean production area: 2015 U.S. Department of Agriculture National Agricultural Statistics Service's Quick Stats (https://quickstats.nass.usda.gov/).

Our goal was to survey Nebraska growers, crop advisors, and industry professionals for the following purposes:

1. to obtain information on agronomic practices related to soybean production (irrigation, tillage system, row spacing, and crop rotation);

2. to determine the presence of herbicide-resistant weeds and strategies for weed management; and

3. to gauge perceptions growers, crop advisors, and industry professionals have about forthcoming herbicide-tolerant soybean technologies.

Across locations, a total of 291 participants returned the survey (for a response rate of 44%, which was higher than that for another similarly purposed direct mail survey [Conley, Krupke, Santini, & Shaner, 2007]). Herein, survey results are expressed as percentages, and participant responses to open-ended questions are conveyed.

Results and Discussion

Agronomic Practices Adopted by Survey Participants

A total of 239,000 ac of soybeans (4.5% of Nebraska soybean acres) were managed by respondents of the survey. The majority (59%) responded that they irrigated soybeans, 25% indicated that they did not irrigate, and 16% indicated that they managed irrigated and nonirrigated fields. The vast majority (72%) were in no-till systems, whereas 28% used some type of tillage (conventional or strip-tillage). Participants were asked to identify the typical 4-year rotation strategy in their soybean production fields, and more than 99% of participants reported rotating to a crop other than soybeans. An average of 2.1 crops were grown in a 4-year rotation period, with corn as the primary rotational crop. Those who reported rotation with crops other than corn used alfalfa, wheat, and/or sorghum. Crop rotation is an important strategy for herbicide-resistance management (Norsworthy et al., 2012). Because glyphosate is a primary herbicide option for weed control in soybeans and corn, inclusion of alternative crops such as sorghum and/or wheat in a soybean-corn cropping system and diversification of herbicide programs when these two crops are grown are of great importance for effective herbicide resistance management.

Presence of Herbicide-Resistant Weeds

Most participants (94%) believed they had GR weed species in their operations, primarily common waterhemp (69%), horseweed (69%), Palmer amaranth (21%), giant ragweed (7%), and kochia (7%). Additionally, 70% of participants reported having more than one GR species in their operations. The most common combinations were horseweed and either common waterhemp or Palmer amaranth. Having GR horseweed and common waterhemp or Palmer amaranth at the same location adds an extra level of complexity to weed management because of differences in these weeds' life cycles. Horseweed emerges primarily in the fall in Nebraska, whereas common waterhemp and Palmer amaranth emerge from May until late July (Avellar, Butts, Kruger, & Werle, 2016; Werle, Bernards, Arkebauer, & Lindquist, 2014; Werle, Sandell, Buhler, Hartzler, & Lindquist, 2014).

A significant proportion of participants (45%) reported the presence of weed species resistant to herbicide SOA other than glyphosate in their operations. They reported the following cases of resistance, each of which has been confirmed in Nebraska (Knezevic et al., 2017):

- ALS inhibitor resistance—common waterhemp, horseweed, kochia, and Palmer amaranth;
- atrazine resistance—kochia, common waterhemp, and Palmer amaranth;
- HPPD inhibitor resistance—common waterhemp;
- 2,4-D resistance—kochia and common waterhemp; and
- dicamba resistance—kochia.

Participants also reported reduced control for the following herbicides and weed species:

- HPPD inhibitor—horseweed,
- 2,4-D—horseweed, and
- protoporphyrinogen oxidase (PPO) inhibitor—common waterhemp and Palmer amaranth.

Possible explanations for the reduced control of these species by these herbicides are novel or unconfirmed cases of resistance in Nebraska or improper application timing (spraying when weeds are too big for effective control), which will be further investigated by UNL weed scientists.

Major Strategies for Control of Herbicide-Resistant Weeds

According to participants' comments, crop and herbicide rotation, use of soil residual herbicides, timing (control when weeds are small), use of full herbicide label rates, seed bank management, tillage, overlap of soil residual products, and fall herbicide application were participants' main strategies for control of resistant weeds. More than 80% of responses were directly related to herbicides. When asked how they select herbicides, 55% of participants reported that price plays an important role, 65% selected herbicides with multiple effective SOA, and 62% followed recommendations from their advisors. Therefore, making sure that advisors are aware of the importance of diversified strategies will play a key role in the success of weed management in years to come.

Most participants (89%) reported including soil residual herbicides in their weed management programs. The use of residual herbicides is a practice that is highly recommended for weed management. Surprisingly, most participants (76%) reported that they used herbicides from multiple effective SOA at each application, whereas 13% did not and 11% were not sure. The use of mixtures of multiple effective SOA has been reported as an effective way to prevent resistance evolution (Beckie & Reboud, 2009; Evans et al., 2016). With the occurrence of GR weeds in Nebraska, growers have increasingly used a combination of glyphosate plus a PPO-inhibiting herbicide for postemergence broadleaf weed control. However, if a GR species is present, this application would contain only one effective SOA. Further surveys need to be conducted to understand producers' perceptions regarding effective SOA.

According to the survey results, only 24% of all respondents and 27% of those who reported GR horseweed used/recommended the use of herbicides in the fall. In Nebraska, the majority of horseweed seedlings emerge in the fall (Werle, 2017), as is also the case for other winter annual weeds (e.g., henbit, tansymustard, downy brome) (Werle, Bernards et al., 2014); fall herbicide application or other fall strategies (e.g., cover crops) could be of great value in assisting producers with weed management. Hasty, Sprague, and Hager (2004) reported that fall application of burndown plus soil residual herbicides can effectively manage winter annual weeds and early-season summer annual weeds. According to our survey, most producers (72%) were in no-till systems; however, 41% of those who reported the presence of herbicide-resistant horseweed did some type of tillage. This finding illustrates the adverse effect of herbicide-resistant weeds leading producers to incorporate mechanical practices (i.e., tillage) for weed management.

Perceptions About Forthcoming Herbicide-Tolerant Soybean Technologies

When asked about the impact that new herbicide-tolerant soybean technologies (Roundup Ready Xtend, Enlist, Balance GT, and BOLT soybeans) will have on weed resistance, 37% of respondents indicated that the occurrence of resistant weeds will be reduced, whereas 40% indicated that the occurrence of resistant weeds will increase. The remaining 23% indicated that resistance would remain unchanged. Even though 63% reported that herbicide resistance will either increase or remain the same, 91% of participants reported that they would adopt these new technologies. Such a high level of adoption, if combined with a lack of diversified weed management strategies, could quickly lead to the selection of additional resistance. If producers are not good stewards of these

technologies, the future of weed management in soybeans and corn will become very uncertain.

Alternative Weed Management Strategies That Could Be Explored

The incorporation of nonchemical strategies as part of an effective herbicide resistance management program will become increasingly important for the success of weed management in row crop production (Owen, 2016). Below we discuss some strategies that could be better explored by Nebraska growers.

Use of Narrow Row Spacing

Most participants in our survey (69%) planted soybeans in 30-in. row spacing, whereas 31% planted soybeans in 20-in. rows or narrower. The standard for most soybean producers across Nebraska has been 30-in. row spacing. However, a summary of several research studies conducted across the United States indicated a yield advantage of 4 bu/ac when soybeans were planted at 15-in. row spacing as compared to 30-in. row spacing (Jeschke & Lutt, 2016). Because of faster canopy closure, narrow row spacing has been shown to reduce the likelihood of weed resurgence in soybeans later in the season (Bradley, 2006). Moreover, smaller yield losses have been detected in narrow-row soybean systems as compared to wide-row soybean systems when herbicide applications have been delayed (due to environmental conditions or operational issues [Bradley, 2006]). Therefore, narrower row spacing is a cultural strategy that could be implemented by Nebraska producers to increase yield potential and enhance weed management.

Use of Cover Crops

The use of cover crops is increasing in Nebraska and across the Midwest. Cover crops can suppress weeds in different ways: through direct competition, by physically hindering weed seedling emergence, through allelopathy (release of inhibiting substances), by tying up nitrogen, and so on (Schonbeck, 2015). Approximately one third of participants responded that they have adopted cover crops to some extent in their operations. All respondents were asked to provide reasons for either using or abstaining from using cover crops (Figure 2).

Figure 2.
Reasons for Use or Abstinence from Use of Cover Crops Among Nebraska Soybean Producers and Advisors

Reasons for Using Cover Crops	Reasons for Abstaining from Using Cover Crops
Erosion control	Time demand and cost
Cattle feed	Difficulty of establishing in the fall after harvest
Increased organic matter	Limited moisture
Soil health	Limited growing season
Nitrogen management	Yield reduction of subsequent crop
Improved water retention	Limitations based on current herbicide program
Weed suppression	Lack of education/information

	Difficulty of terminating
	Lack of equipment

Research is being conducted in Nebraska and beyond to address growers' concerns regarding the inclusion of cover crops as part of their cropping systems.

Additional Practices

In our survey, participants were not asked about whether they rogued weed escapes and controlled weeds in field edges and/or roadsides. However, these are also important strategies for weed and herbicide resistance management (Norsworthy et al., 2012) and are constantly discussed during Extension activities at UNL and beyond. Visual inspections of Nebraska soybean fields in August indicated that hand weeding weed escapes and controlling weeds on field borders could significantly reduce problem weed populations in the state.

Conclusion

Nebraska growers rely heavily on herbicides for weed management. With the increased numbers of resistant weeds and limited tools available, Extension professionals should encourage growers to diversify their systems and adopt a proactive herbicide resistance management plan. Research has shown that mixture of multiple effective herbicide SOA at each application reduces the likelihood of resistance. Moreover, a true crop and herbicide rotation, along with incorporation of narrow row spacing and cover crops, could help producers manage troublesome weed populations. A holistic approach combining effective rotation of crops, herbicides, and herbicide tolerance traits with nonchemical practices will be key for the success of weed management programs. Extension educational efforts are critical, and will become even more critical, for helping growers achieve sustainable weed management.

Author Notes

Rodrigo Werle is now an assistant professor of agronomy and an Extension cropping systems weed scientist in the Department of Agronomy at the University of Wisconsin–Madison in Madison, Wisconsin. Josh Miller is technical market manager for plant health at BASF.

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