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A Statewide Survey of Stakeholders to Assess the Problem Weeds and Weed Management Practices in Nebraska

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Nomenclature:
2,4-D; acetochlor; atrazine; glufosinate; glyphosate; mesotrione; *S*-metolachlor; common waterhemp, *Amaranthus rudis* J.D. Sauer; horseweed, *Conyza canadensis* (L.) Cronq.; kochia, *Kochia scoparia* (L.) Schrad.; Palmer amaranth, *Amaranthus palmeri* S. Wats.; corn, *Zea mays* L.; grain sorghum, *Sorghum bicolor* (L.) Moench ssp. *bicolor*; soybean, *Glycine max* (L.) Merr.; wheat, *Triticum aestivum* L.

Key words:
Glufosinate-resistant crop; glyphosate resistance; multiple herbicide–resistant crops; herbicide drift, resistance management

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Abstract

Stakeholders were surveyed across Nebraska to identify the problem weeds and assess common weed management practices. A total of 425 responses were returned across four Nebraska extension districts (Northeast, Panhandle, Southeast, and West Central). Collectively, 61.2% of total farmed or scouted areas in Nebraska were under no-till production, and corn and soybean were the major crops (82.3% of total farmed or scouted area). Common waterhemp, horseweed, and kochia were the most problematic weeds statewide. Widespread occurrence of glyphosate-resistant (GR) weeds such as common waterhemp, horseweed, kochia, and Palmer amaranth were a serious problem in GR crop production. Additionally, 60% of growers in Nebraska reported the presence of at least one GR weed species on their farms. The most commonly used preplant burndown herbicides were 2,4-D and glyphosate, followed by saflufenacil and dicamba. In Nebraska, 74% and 59% of corn and soybean growers, respectively, were using PRE herbicides; however, more than 80% of growers were using POST herbicides for in-crop weed management. Atrazine alone or in premix or tank mix with mesotrione, *S*-metolachlor, or acetochlor were the most widely applied PRE herbicides in corn and grain sorghum, whereas the most commonly used PRE herbicides in soybean were the inhibitors of acetolactate synthase (ALS) and protoporphyrinogen oxidase (PPO). Glyphosate was the most frequent choice of the survey respondents as a POST herbicide in GR corn and soybean; 2,4-D was the most commonly used POST herbicide in grain sorghum and wheat. In Nebraska, only 5.2% of total crop area was planted with glufosinate-resistant crops. Most of the respondents (89%) were aware of the new multiple herbicide–resistant crops, and 80% of them listed physical drift and volatility of the auxinic herbicides as their primary concern. Forty-eight percent of survey respondents identified herbicide-resistant weed management as their primary research and extension priority.

Introduction

The discovery of 2,4-D during World War II initiated a new era of chemical weed control in agriculture by reducing the need for mechanical and manual weed management (Fite 1980; Peterson 1967). Additionally, the discovery of residual herbicides including atrazine in the early 1960s promoted conservation agriculture in the United States (Triplett et al. 1964), and consequently the use of herbicides increased markedly. For instance, Fernandez-Cornejo et al. (2014) noted that the use of pesticides (including fungicides, herbicides, and insecticides) increased about three-fold (from 89 million kg ai in 1960, to 287 million kg ai in 1981) in the first 20 yr of conservation agriculture, though herbicide use increased more than 10-fold (from 16 million kg ai in 1960 to 217 million kg ai in 1981). The rapid adoption of glyphosate-resistant (GR) crops since their introduction in 1996 changed the herbicide use pattern in modern agriculture (Benbrook 2016).

During the first 10 yr of GR crop commercialization in the United States, weed management programs relying only on POST application of glyphosate were sufficient to provide broad-spectrum weed control in GR crops; however, the evolution of GR weeds reduced the value of this technology. As of 2018, 41 weed species have been reported resistant to glyphosate worldwide, including 17 species in the United States (Heap 2018), and 6 in Nebraska (Jhala 2018). Despite the increasing number of GR weeds and their widespread occurrence in the United States, growers continue to widely adopt GR crop technology. A recent survey reported that 89%, 91%, and 94% of corn, cotton (*Gossypium hirsutum* L.), and soybean acreage in the United States was under herbicide-resistant technology, primarily with GR crops (USDA-ERS 2017).

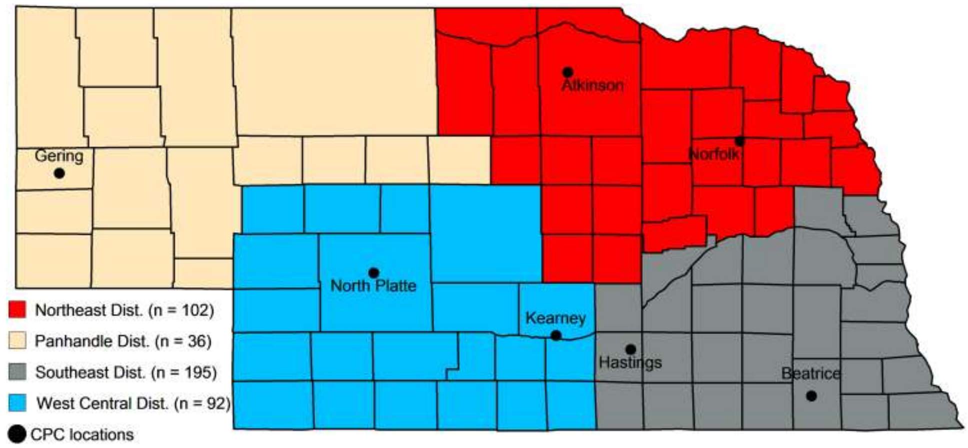

Figure 1. County map of Nebraska divided into four districts along with seven locations of the extension meetings, Crop Production Clinics (CPCs), where the survey was conducted in 2015.

The choice of herbicides and agronomic practices in a cropping system can greatly influence a weed management plan. Widespread adoption of GR crops rapidly reduced the use of tillage for weed management in the Midwest (Sarangi and Jhala 2018). The results of a growers survey from six states including Nebraska reported that 56% of growers have shifted from conventional tillage to no-till or reduced tillage after the adoption of GR crops, and the adoption rate of conservation tillage was higher among continuous GR cotton and soybean growers (Givens et al. 2009b). Additionally, the adoption of conservation tillage and changes in weed management practices altered the dynamics of the weed population (Buhler 1995; Nichols et al. 2015), resulting in a shift in the weed flora toward small-seeded weeds such as *Amaranthus* spp. (Kruger et al. 2009). A survey of weed scientists from 11 states in the midwestern, northeastern, southeastern, and southern United States noted that dayflower (*Commelina* spp.), common waterhemp, morningglory (*Ipomoea* spp.), nutsedges (*Cyperus* spp.), and winter annuals were the most problematic weeds in GR crops (Culpepper 2006). Additionally, the same survey anticipated that annual grasses, common lambsquarters (*Chenopodium album* L.), copperleaf (*Acalypha* spp.), giant ragweed (*Ambrosia trifida* L.), and other *Amaranthus* spp. (along with common waterhemp) will become more problematic within the next few years as a result of the weed shifts.

Several surveys have been conducted in recent years to assess the attitude and perception of growers and crop consultants about their agronomic and weed management practices, as well as to identify problem weeds in the post-commercialization era of GR crops (Gibson et al. 2005; Norsworthy 2003; Riar et al. 2013a, b; Webster and Macdonald 2001). Givens et al. (2009a) noted that surveys conducted among growers and stakeholders provide invaluable information for weed scientists and agricultural analysists for understanding the current benchmarks for weed management in GR crops. Though several multistate surveys have included respondents from Nebraska (Prince et al. 2012b; Givens et al. 2009b; Shaw et al. 2009), no extensive survey was conducted to understand the growers' perceptions of the most problematic weeds and their management practices in different regions of Nebraska.

The University of Nebraska Extension, comprising 83 county offices and four extension centers serving 93 counties throughout the state, has an enormous impact on the state's youth, families, farms and ranches, communities, and economy. A survey was developed for participants (growers, certified crop advisors, crop consultants, certified pesticide applicators, cooperative managers, and industry sales representatives) attending the University of Nebraska Extension's winter annual meetings. The objectives of this survey were to identify stakeholders' perceptions of most problematic weeds and assess their attitudes and perceptions about weed management practices in Nebraska.

Materials and Methods

The survey was conducted at seven (Atkinson, Beatrice, Gering, Hastings, Kearney, Norfolk, and North Platte) locations in 2015 during winter extension meetings organized by the University of Nebraska Extension. Seven locations represent four major extension districts defined by the University of Nebraska Extension based on their agroclimatic characteristics, soil texture, and cropping systems (Figure 1). Responses recorded at Atkinson in Holt County and Norfolk in Madison County represent the Northeast district; Gering in Scottsbluff County represents the Panhandle district; Beatrice in Gage County and Hastings in Adams County represent the Southeast district; and Kearney in Buffalo County and North Platte in Lincoln County represent the West Central district. Paper copies of the questionnaire were distributed to all participants; the questions were mostly open-ended but some closed questions were also included. The questionnaire was pretested on 10 people, including weed scientists, agronomy undergraduate and graduate students, and field research technicians, to assess its acceptability and readability. Later, their responses and comments were reviewed by the survey team, and minor amendments were made to the text. The final questionnaire (Table 1) was divided into four sections:

1. Crop Production and Problem Weeds
2. Herbicide Use
3. GR Weed Management
4. Weed Management Research and Extension Priorities

Respondents were asked about their primary occupation and their county and state of residence. Respondents were disqualified from the survey if they were not involved in farming, or making a decision regarding a farm or agribusiness, or if they did not reside in Nebraska. In Section 1, respondents were asked about their total number of farmed or scouted acres (Question 1.1 in

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Table 1. A condensed version of the survey questionnaire.

General information:

Please best describe your primary occupation. Which county and state are you from?

Section 1: Crop production and problem weeds

1.1 How many acres did you farm/scout last year (2014)? How many of these acres were under tillage and no-till production?

1.2 How many acres (farmed/scouted) were under different crops (corn, dry edible bean, grain sorghum, soybean, sugarbeet, wheat, and others)?

1.3 What are the five most difficult-to-control weeds in your opinion? Please write them in order, where #1 is the weed most difficult to control.

1. ____________; 2. ____________; 3. ____________; 4. ____________; 5. ____________

1.4 Which herbicide-resistant weeds do you have on your farm/scouted areas, or are you concerned about in the future? Do you have any glyphosate-resistant weeds on your farm/scouted areas? Please list them.

Herbicide-resistant weeds: ____________; Resistant to (herbicide name): ____________

Already present: 1. ____________; 2. ____________; 3. ____________; 4. ____________

Concerned about: 1. ____________; 2. ____________; 3. ____________; 4. ____________

Section 2: Herbicide use

2.1 Do you use preplant burndown herbicides? Please list the most common (top three) preplant burndown herbicides in order, where #1 is the most commonly used herbicide.

1. ____________; 2. ____________; 3. ____________

2.2 Do you use preemergence (soil residual) herbicides? Please list the most common (top three) preemergence herbicides in order, where #1 is the most commonly used herbicide.

Corn: 1. ____________; 2. ____________; 3. ____________

Soybean: 1. ____________; 2. ____________; 3. ____________

Grain sorghum:1. ____________; 2. ____________; 3. ____________

Wheat: 1. ____________; 2. ____________; 3. ____________

Others (____): 1. ____________; 2. ____________; 3. ____________

2.3 Do you use postemergence herbicides? Please list the most common (top three) postemergence herbicides in different crops in order, where #1 is the most commonly used herbicide.

Corn: 1. ____________; 2. ____________; 3. ____________

Soybean: 1. ____________; 2. ____________; 3. ____________

Grain sorghum: 1. ____________; 2. ____________; 3. ____________

Wheat: 1. ____________; 2. ____________; 3. ____________

Others (____): 1. ____________; 2. ____________; 3. ____________

2.4 What was the average cost (per acre) of weed control in Roundup Ready (glyphosate-resistant) crops?

Section 3: Glyphosate-resistant weed management

3.1 How serious is the weed resistance to glyphosate? Answer using a scale of 1 to 10 where 1 is “not at all serious” and 10 is “very serious.”

3.2 Do you rotate between Roundup Ready and non–Roundup Ready crops?

Yes ____________; No ____________

Table 1. (*Continued*)

3.3 How many farmed/scouted acres were under the LibertyLink (glufosinate-resistant) system in 2014?

LibertyLink corn: ____________

LibertyLink soybean: ____________

3.4 Do you scout/advise to scout fields before and after herbicide applications?

Yes ____________; No ____________

3.5 Do you control weed escapes or prevent seed set later in the season?

Yes ____________; No ____________

If Yes, with which herbicides or methods (inter-row cultivation, or manual weeding etc.)?

3.6 Are you familiar with herbicide sites of action?

Yes ____________; No ____________

3.7 Are you using herbicides with multiple sites of action?

Yes ____________; No ____________

3.8 As a way of managing potential glyphosate-resistant weeds, how effective are the following practices in your opinion? When answering please use a scale of 1 to 10, where 1 is “not at all effective” and 10 is “very effective”:

a. Rotating herbicide-resistant crops from year to year (for example, alternating Roundup Ready crops with conventional or LibertyLink varieties).

b. Tillage.

c. Rotating crops (for example, planting corn in 2014 and soybean in 2015).

d. Using the correct labeled rates of herbicide at the proper timing for the size and type of weeds present.

e. Using a residual preemergence herbicide followed by glyphosate postemergence in Roundup Ready crops.

f. Using a residual preemergence herbicide followed by glyphosate tank-mixed with other postemergence herbicides in Roundup Ready crops.

3.9 Are you aware of new multiple herbicide–resistant crops coming to the market? For example, Balance GT (isoxaflutole and glyphosate-resistant), Enlist corn and soybean (2,4-D- and glyphosate-resistant), and Roundup Ready 2 Xtend soybean (dicamba and glyphosate-resistant), etc.

Yes ____________; No ____________

3.10 Do you have any concerns such as volatility or drift hazards, etc., with the adoption of these new multiple herbicide–resistant crops? Please list them.

1. ____________; 2. ____________; 3. ____________

Section 4: Weed Management Research and Extension Priorities

4.1 What are your future research and extension needs/expectations from the University of Nebraska–Lincoln’s Weed Scientists and experts?

1. ____________; 2. ____________; 3. ____________

Table 1); however, the responses were later converted into hectares. In the same section, respondents were asked to rank the five most problematic weeds according to their importance in crop production (Question 1.3). In Section 2, respondents were asked to list their top three commonly used preplant, PRE, and POST herbicides in order of their frequency of use (Questions 2.1 to

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Table 2. The number of survey respondents categorized based on their occupational classification.

Occupational class	Districts				Nebraska
	Northeast	Panhandle	Southeast	West Central	
	No. of respondents				
Growers	40	11	71	29	151
Crop consultants[a]	19	12	52	30	113
Others[b]	43	13	72	33	161
Total respondents	102	36	195	92	425

[a]Survey respondents with the primary occupation of certified crop advisor, crop consultant, agronomist, and farm manager were considered as "crop consultants."
[b]Survey respondents not categorized as growers or crop consultants were considered as "others," which included certified pesticide applicators, farm workers, cooperative managers, and industry sales representatives.

2.3). Section 3 included questions regarding different methods of managing GR weeds and delaying the evolution of GR weeds. This section was composed of several dichotomous questions with a possible answer: Yes/ No, as well as a slider-scale question (Question 3.8) about different approaches for managing and delaying the evolution of GR weeds at the farm level. In this section, respondents were also asked to list their concerns regarding the future adoption of crops resistant to multiple herbicides. In Section 4, respondents listed one to three research or extension priorities to improve future weed management practices in Nebraska (Table 1).

A total of 425 valid responses were returned across the seven locations in the statewide survey conducted in Nebraska in 2015. Respondents were categorized into three groups: growers, crop consultants, and others, based on their primary occupation reported. Considered as growers were those who owned farms and directly participated in farming or decision making on their farms. The survey respondents with the primary occupation of agronomist, certified crop advisor, crop consultant, or farm manager were categorized as crop consultants. Respondents not categorized as growers or crop consultants were placed in the third category, "others", which included certified pesticide applicators, cooperative managers, farm workers, and industry sales representatives. Out of 425 respondents, 36%, 27%, and 37% were listed as growers, crop consultants, and others, respectively (Table 2). The maximum number of responses were listed from the Southeast district ($n = 195$), followed by the Northeast ($n = 102$), West Central ($n = 92$), and Panhandle ($n = 36$) districts.

Data were imported to R (R Core Team 2016) and the results interpreted based on the frequency distribution for most of the questions, with a mean (average) and median calculated wherever possible. Pearson's correlation coefficient (r) was estimated to quantify the association between average farm size and the adoption of no-till production system or the cost of weed management; two-sample t-tests were used for the test of significance ($P < 0.05$). An ANOVA F-test was used to determine the test of significance ($P < 0.05$) for the effectiveness of the weed management strategies (Question 3.8 in Table 1).

To rank the problem weeds and most commonly used herbicides in Nebraska, relative problematic/importance points was used. For example, five, four, three, two, and one problematic point was assigned to rank #1, #2, #3, #4, and #5 problem weeds, respectively (Question 1.3 in Table 1), and the relative problematic point (RP) was calculated for each weed species by using Equation 1:

$$RP = \sum_{r=1}^{5} \frac{FX}{n} \quad [1]$$

where F is the number of respondents choosing a particular rank (r) for a certain weed species, X is the problematic points associated with that particular rank, and n is the total number of responses for that rank, including all the weed species. The top problematic weeds were reported at the state and district levels in Nebraska, and similarly, the most common preplant burndown, PRE, and POST herbicides (Questions 2.1 to 2.3 in Table 1) were ranked based on their level of importance, where three, two, and one importance points were assigned to rank #1, #2, and #3 of the most commonly used herbicide, respectively. The relative importance point for an herbicide was then calculated using Equation 1; however, r ranged from 1 to 3 in this case.

Results and Discussion

Crop Production and Problem Weeds

The growers and crop consultants represented 1.6% (120,951 ha) and 6.8% (526,806 ha), respectively, of the total area planted with the major crops (7,786,961 ha reported by USDA-NASS 2014b) in Nebraska in 2014. Average farmed areas reported by the growers for the 2014–2015 farming years were 710, 829, 814, and 961 ha in the Northeast, Panhandle, Southeast, and West Central districts, respectively, and the state average was 801 ha (Table 3). However, Figure 2 shows that the median farmland size was relatively lower than average farm holdings mentioned earlier and ranged from 392 to 648 ha in four districts, with a median value of 526 ha in Nebraska. It is evident that some of the larger values for per capita farm areas led to a relatively higher average value. A Census of Agriculture conducted by the United States Department of Agriculture (USDA) in 2012 reported that the average farm size in Nebraska was 367 ha; however, the USDA census data included farm areas under row crops and other commodity production systems such as dairy, fruit orchards, livestock and poultry farms, vegetables, and other woody crops (USDA-NASS 2014a), whereas in our survey the respondents were mostly row crop producers and pasture managers. The Census of Agriculture data collected between 1982 and 2007 showed that the midpoint acreage (a median estimate of the distribution of the farm size proposed by Lund and Price in 1998) in 16 states, including

Table 3. Information on average farm size, areas in no-till production, and primary crops.

Crop production questions	Districts				Nebraska
	Northeast	Panhandle	Southeast	West Central	
Farming areas (ha) reported by growers[a]	710 (111)	829 (333)	814 (103)	961 (181)	801 (69)
Scouted areas (ha) reported by crop consultants[a]	4,072 (1,206)	3,605 (1,284)	5,869 (1,273)	3,151 (1,036)	4,662 (697)
Area in no-till production (% of total area farmed or scouted)[b]	58.9	50.1	68.3	53.0	61.2
Area under primary crops (% of total area farmed or scouted)[b]					
Corn and soybean	90.0	34.5[d]	88.5	79.2	82.3
Dry edible bean[e]	NA[c]	7.2	NA	NA	——
Grain sorghum	0.1	NA	2.2	0.7	1.2
Sugarbeet[e]	NA	11.4	NA	NA	——
Wheat	4.3	NA	6.1	11.3	6.9
Others	5.6	46.9	3.2	8.8	7.8

[a]Values in parentheses represent the standard error of the mean (SEM).
[b]Responses of growers and the crop consultants were considered for this question.
[c]Abbreviation: NA, not available; respondents did not report the required information.
[d]No information on soybean was listed from the Panhandle district.
[e]Crop was reported only from Panhandle district of Nebraska; therefore, average state results were not calculated.

Nebraska, increased more than two-fold in 2007 compared to 1982, showing the consolidation of croplands as time progressed (MacDonald et al. 2013). The same report also noted that the shift to a larger farm size was higher in five major field crops, such as corn, cotton, rice (*Oryza sativa* L.), soybean, and wheat in the United States.

Crop consultants participating in this survey scouted average areas ranging between 3,151 and 5,869 ha in different districts, with a state average of 4,662 ha (Table 3). The maximum area in no-till production was reported from the Southeast district (68.3%), followed by the Northeast (58.9%), West Central (53.0%), and Panhandle (50.1%) districts, and the state average for no-till production area was 61.2%. A survey of no-till areas conducted in 2008 also showed that most of the no-till production fields were located in the Northeast and Southeast districts of Nebraska (NRCS-USDA 2008). The 2012 Census of Agriculture reported that an average 57% area of each farm was under no-till production in Nebraska (USDA-NASS 2014a), which was close to the results obtained in our survey. Estimation of the Pearson's correlation coefficient (r) showed that the percentage of area under no-till management was not dependent ($r = -0.12$; $P = 0.17$) on the farm size reported by the growers in Nebraska. Similarly, several other studies reported that the adoption of conservation tillage including no-till did not depend on the average farm size (Bultena and Hoiberg 1983; D'Emden et al. 2008; Knowler and Bradshaw 2007; Nowak 1987).

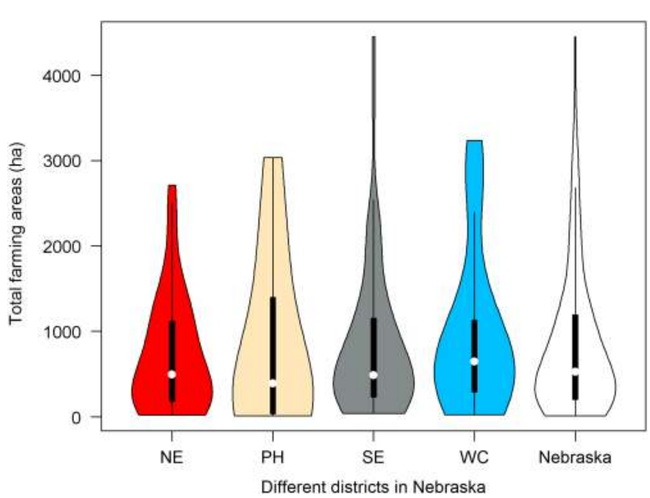

Figure 2. Violin plots combining a boxplot and a kernel density plot to present the distribution of total farmed areas (ha) reported by the growers. The white dot at the center of the boxplot shows the median of the total farming area. NE, Northeast; PH, Panhandle; SE, Southeast; WC, West Central districts.

Area under Different Crops

The survey results showed that corn and soybean were the major crops in Nebraska, sharing 82.3% of total farmed or scouted area reported (Table 3). The crop production summary for 2014 also recorded that 75% of major cropland in Nebraska was under corn and soybean production (USDA-NASS 2015). Survey results indicated that the maximum corn- and soybean-producing areas were in the Northeast district (90.0% of total farmed or scouted areas), followed by the Southeast (88.5%) and West Central (79.2%) districts. No soybean production area was reported from the Panhandle district; however, 34.5% of the area was listed under corn production. The Census of Agriculture conducted in 2012 also reported no or minimum harvest areas for soybean in the counties from the Panhandle district (USDA-NASS 2014a); but areas under dry edible bean (*Phaseolus vulgaris* L.) (7.2%) and sugarbeet (*Beta vulgaris* L.) (11.4%) production were reported from the Panhandle district (Table 3). Results also indicated that the areas in Nebraska under grain sorghum and wheat production were 1.2% and 6.9%, respectively. Other crops including alfalfa (*Medicago sativa* L.), hay, proso millet (*Panicum miliaceum* L.), and potato (*Solanum tuberosum* L.) accounted for 7.8% of the area in Nebraska. Diversity in crop selection was mostly reported from the Panhandle district, where 46.9% of the area was under production of crops other than corn, dry edible bean, and sugarbeet.

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Table 4. Respondents' ranking of the weeds most difficult to control.[a]

Rank	Districts				Nebraska
	Northeast	Panhandle	Southeast	West Central	
	Name of the problem weeds				
1	Common waterhemp (3.7)	Kochia (4.0)	Common waterhemp (3.2)	Kochia (3.3)	Common waterhemp (3.0)
2	Horseweed (2.3)	Common lambsquarters (2.1)	Horseweed (3.1)	Common waterhemp (2.5)	Horseweed (2.4)
3	Velvetleaf (1.4)	Field bindweed (1.1)	Kochia (2.1)	Horseweed (1.6)	Kochia (2.2)
4	Kochia (1.0)	Palmer amaranth (1.0)	Velvetleaf (0.9)	Palmer amaranth (1.3)	Velvetleaf (0.9)
5	Giant ragweed (1.0)	Canada thistle (0.9)	Common lambsquarters (0.8)	Foxtails (0.6)	Common lambsquarters (0.9)

[a]Values in parentheses represent the relative problematic points for a weed, calculated using the equation:

$$RP = \sum_{r=1}^{5} \frac{FX}{n}$$

where F is the number of respondents choosing a particular rank (r) for a weed species, X is the problem points (5 for r#1, 4 for r#2, 3 for r#3, 2 for r#4, and 1 for r#5) for that particular rank, and n is the total number of responses recorded in favor of that particular rank. The maximum possible relative problematic points for a weed species is 5.0.

Problem Weeds

The five weed species considered most difficult to control were common waterhemp, horseweed, kochia, velvetleaf (*Abutilon theophrasti* Medik.), and common lambsquarters (Table 4). Palmer amaranth, giant ragweed, and foxtails (*Setaria* spp.) were also listed as the sixth, seventh, and eighth most problematic weeds (data not shown). Higher relative problematic points (ranging between 2.2 and 3.0 out of a maximum possible 5.0 points) for common waterhemp, horseweed, and kochia showed that the majority of respondents listed them as the most problematic weeds in Nebraska. A recent survey conducted by the Weed Science Society of America (WSSA) showed that common waterhemp and horseweed were the most troublesome weeds in corn and soybean production systems in the United States (Van Wychen 2016a, b). Additionally, common waterhemp, giant ragweed, horseweed, kochia, and Palmer amaranth resistant to glyphosate have been confirmed in Nebraska (Chahal et al. 2017; Rana and Jhala 2016; Sandell et al. 2011; Sarangi et al. 2015; Sarangi and Jhala 2017), a condition that might have led to the difficulty in controlling these weeds in GR corn/soybean production systems. In a multistate growers' survey conducted in 2005–2006, Kruger et al. (2009) reported that common waterhemp, velvetleaf, and foxtails were the three most problematic weeds in GR corn and soybean rotation in Nebraska; however, due to the evolution of resistance to glyphosate and multiple herbicides in recent years, horseweed, kochia, and common waterhemp top the list of most problematic weeds. In a crop consultants' survey, Godar and Stahlman (2015) further reported that infestation of kochia had increased from 2007 (present in 47% of fields) to 2012 (present in 70% of fields) in western Kansas as a result of the evolution and widespread occurrence of GR kochia biotypes.

Common waterhemp, horseweed, velvetleaf, kochia, and giant ragweed were the five weeds considered most difficult to control in the Northeast district, whereas respondents from the Panhandle district listed kochia and common lambsquarters as the most problematic weeds, followed by field bindweed (*Convolvulus arvensis* L.), Palmer amaranth, and Canada thistle [*Cirsium arvense* (L.) Scop.]. Diversity in the crops and weed management practices in the Panhandle district was believed to have an impact on weed species composition. Kochia and common lambsquarters were the most problematic weeds in continuous corn or sugarbeet production systems in the Panhandle district; however, Canada thistle was a problem weed in alfalfa, pastures, and rangeland. Common waterhemp, horseweed, kochia, velvetleaf, and common lambsquarters were listed as the most problematic weeds in the Southeast district. Additionally, respondents from the West Central district reported that kochia and common waterhemp were the most problematic weeds, followed by horseweed, Palmer amaranth, and foxtails (Table 4).

Herbicide-Resistant Weeds

The majority of stakeholders reported the presence of GR weeds in Nebraska, but only a small number of responses were recorded from the Panhandle district, so results were not presented in

Table 5. Weeds listed by the respondents[a] for having confirmed glyphosate resistance.[b,c]

Responses	Districts		
	Northeast	Southeast	West Central
Confirmed glyphosate-resistant weeds	Common waterhemp (55)	Horseweed (58)	Kochia (46)
	Horseweed (52)	Common waterhemp (48)	Common waterhemp (37)
	Giant ragweed (14)	Kochia (33)	Horseweed (32)
	Kochia (10)	Giant ragweed (8)	Palmer amaranth (7)

[a]Responses of the growers and crop consultants were considered for this question.
[b]Values in parentheses represent the percentage of the respondents who reported a certain weed species.
[c]Sufficient responses were not recorded from the Panhandle district; therefore, data from the Panhandle district were not included in this table.

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Table 6. Respondents' ranking of the most commonly used preplant burndown herbicides.[a]

Rank	Districts				Nebraska
	Northeast	Panhandle	Southeast	West Central	
	Herbicides				
1	2,4-D (1.4)	Glyphosate (1.6)	2,4-D (1.3)	Glyphosate (1.5)	2,4-D (1.2)
2	Glyphosate (1.1)	Saflufenacil (1.2)	Glyphosate (0.9)	2,4-D (1.1)	Glyphosate (1.1)
3	Saflufenacil (0.6)	2,4-D (0.9)	Atrazine + mesotrione + *S*-metolachlor (0.5)	Dicamba (0.5)	Saflufenacil (0.4)

[a]Values in parentheses represent the relative importance points for an herbicide, calculated using the equation:

$$RP=\sum_{r=1}^{3}\frac{FX}{n}$$

where *F* is the number of respondents choosing a particular rank (*r*) for an herbicide, *X* is the importance points (3 for *r*#1, 2 for *r*#2, and 1 for *r*#3) for that particular rank, and *n* is the total number of responses for that particular rank. The maximum possible relative importance points for an herbicide is 3.0.

Table 5. An interesting aspect of this survey was that 22% of respondents in Nebraska did not record any information about the presence of herbicide-resistant weeds, and had no concern about a weed's ability to evolve herbicide resistance in the future (data not shown). It can be assumed that herbicide programs used by those respondents were highly effective for controlling weeds or that these respondents were mostly unaware of the evolution of herbicide-resistant weeds on their farms or scouted areas.

In the Northeast district, 55% and 52% of respondents noted the presence of GR common waterhemp and horseweed, respectively, and the presence of GR giant ragweed and kochia was also reported by 14% and 10% of respondents, respectively (Table 5). This information also corresponds with the most problematic weeds in this region (Table 4). The presence of common waterhemp resistant to both 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors and ALS inhibitors was also reported by some of the respondents from the Northeast district (data not shown). A field-collected common waterhemp biotype from the Northeast district (Platte County) has been confirmed resistant to HPPD-inhibiting herbicides (Oliveira et al. 2017b). Respondents from the Northeast district were mostly concerned about the spreading of GR common waterhemp, horseweed, and kochia throughout the region, along with the evolution of GR Palmer amaranth (data not shown). In the Panhandle district, the presence of kochia resistant to glyphosate, ALS inhibitors, and growth regulators was reported by some of the respondents, who were also concerned about the future presence of GR Palmer amaranth and Russian thistle (*Salsola tragus* L.) in the region (data not shown).

Most of the survey participants in the Southeast and West Central districts listed glyphosate- and ALS inhibitor–resistant weeds as the predominant weeds. In the Southeast district, 58%, 48%, 33%, and 8% of respondents reported the presence of GR horseweed, common waterhemp, kochia, and giant ragweed, respectively (Table 5). Additionally, 19% of stakeholders were concerned about the spread of GR Palmer amaranth in the Southeast district (data not shown). A Palmer amaranth biotype from Southeast Nebraska (Thayer County) was recently confirmed 40-fold resistant to glyphosate (Chahal et al. 2017). A recent survey by the WSSA ranked Palmer amaranth as the most troublesome weed in the United States (Van Wychen 2016a); however, our statewide survey revealed that Palmer amaranth is still not the biggest threat to Nebraska agriculture (Table 4), though respondents were concerned about the spread of this aggressive species in the near future. Similarly, Vieira et al. (2017) also reported that occurrence of GR common waterhemp is widespread in the eastern part of Nebraska, though GR Palmer amaranth is relatively uncommon in Nebraska. Common waterhemp and Palmer amaranth are dioecious species and can transfer (i.e., inter- and intraspecific hybridization) herbicide-resistant traits via pollen movement (Oliveira 2017; Sarangi et al. 2017b; Sosnoskie et al. 2012), which can also hasten the evolution of multiple herbicide–resistant biotypes in these species and promote their rapid spread.

In the West Central district, 46%, 37%, 32%, and 7% of respondents listed GR kochia, common waterhemp, horseweed, and Palmer amaranth, respectively, as the primary herbicide-resistant weeds (Table 5). Survey respondents were concerned about the spreading of these four weed species in the West Central district and were also concerned about the evolution of PS II inhibitor– and auxinic growth regulator–resistant kochia in the future (data not shown). Averaging across districts, the survey showed that 40%, 26%, 23%, and 11% of growers reported having no, one, two, and three or more GR weed species, respectively, in their fields (data not shown).

Herbicide Use

Preplant Burndown Herbicide Use

The Census of Agriculture conducted in 2012 showed that 82% of cropland in Nebraska was treated with at least one herbicide for weed management (USDA-NASS 2014a). Controlling existing vegetation before crop planting has been recommended for effective weed management in no-till production systems (Stougaard et al. 1984; Vangessel et al. 2001). Between 55% and 77% of growers in the four districts, and collectively, 72% of the growers in Nebraska indicated that at least one preplant burndown herbicide was used in the spring (data not shown). Participant responses across all occupational classes (growers, crop consultants, and others) were included to rank the most commonly used preplant burndown herbicides in Nebraska, with the results showing that 2,4-D and glyphosate were the top two commonly used preplant burndown herbicides in Nebraska, along with saflufenacil, a PPO-inhibiting herbicide, ranking third (Table 6), followed by dicamba, and atrazine plus mesotrione plus *S*-metolachlor (data not shown). Several multistate surveys that included Nebraska also reported that glyphosate and 2,4-D were the most popular choices among growers for preplant burndown applications (Givens et al. 2009a; Prince et al. 2012a). Additionally, Prince et al. (2012a) reported that synthetic auxins (e.g., 2,4-D) and PPO inhibitors were mostly used to control GR weeds during the spring.

PRE Herbicide Use

Sufficient responses for the use of PRE and POST herbicides were not recorded from the Panhandle district; therefore, survey results indicating PRE and POST herbicide use in the Panhandle were not included. In Nebraska, 74% and 59% of corn and soybean growers, respectively, reported using PRE herbicides (data not shown). Literature evaluating the change in herbicide use pattern following the adoption of GR crops reported that weed management in soybean has shifted from diverse herbicide programs including preplant, PRE, and POST herbicide applications to mostly POST-only herbicide programs (Shaner 2000; Young 2006); therefore, this survey result seems reasonable for the PRE herbicide usage pattern in soybean. However, several studies suggested that application of PRE herbicides in soybean is highly recommended to avoid marked yield reduction due to early-season crop–weed competition (Knezevic et al. 2003; Oliveira et al. 2017a; Sarangi et al. 2017a).

In Nebraska, the three most commonly used PRE herbicides in corn were atrazine plus mesotrione plus *S*-metolachlor, isoxaflutole plus thiencarbazone-methyl, and acetochlor plus atrazine (Table 7). Other major corn herbicides were atrazine plus *S*-metolachlor, acetochlor plus clopyralid plus flumetsulam, and atrazine (data not shown). Therefore, it is clear that commonly used PRE herbicides in corn predominantly included atrazine in herbicide premixes. The results of an Agricultural Chemical Use Survey conducted in 19 corn-producing states including Nebraska reported that atrazine was the most commonly used corn herbicide, applied to 60% of the surveyed farmlands in 2016 (USDA-NASS 2017). In this statewide survey, a few PRE herbicides were reported in grain sorghum; however, the most commonly used PRE herbicides were atrazine plus *S*-metolachlor, atrazine plus mesotrione plus *S*-metolachlor, and atrazine (Table 7). The Agricultural Chemical Use Survey, which included respondents from five grain sorghum-producing states in the United States including Nebraska, reported that 64% of planted grain sorghum areas were treated with atrazine alone or in tank mix or premix with other herbicides (USDA-NASS 2012).

In soybean, most commonly used PRE herbicides were cloransulam-methyl plus sulfentrazone, flumioxazin alone or in tank mixture with chlorimuron-ethyl and thifensulfuron-methyl (Table 7). The results also suggested that soybean growers were mostly relying on PRE herbicides belonging to the two primary sites of action (SOAs), ALS inhibitors and PPO inhibitors, whereas PRE corn herbicide programs were more diverse.

POST Herbicide Use

Most of the growers (more than 80%) applied POST herbicide(s) for weed control in row crops (data not shown), whereas glyphosate was the most commonly used POST herbicide for weed control in GR corn and soybean in Nebraska (Table 7). A multistate survey also noted that more than 95% of the GR crop growers in 22 corn-, soybean-, and cotton-growing states including Nebraska applied glyphosate as their primary POST herbicide (Prince et al. 2012a).

The statewide survey indicated that 10% and 15% of corn and soybean growers, respectively, did not use any preplant burndown or PRE herbicides and were relying only on glyphosate for POST weed control (data not shown). The most commonly used POST corn herbicides after glyphosate were mesotrione plus *S*-metolachlor plus glyphosate, and dicamba plus diflufenzopyr (Table 7). Soybean production systems were less likely to receive non-glyphosate herbicide applications compared to corn production systems; the relative importance points for glyphosate applied POST to soybean were 2.4 (out of 3.0) in Nebraska. Reports of the Agricultural Chemical Use Survey by the USDA noted that 85% of the soybean-producing areas in 19 states in the United States received glyphosate in 2015 (USDA-NASS 2016a). The most commonly used POST soybean herbicides after glyphosate were fluthiacet-methyl, clethodim, lactofen, imazethapyr plus glyphosate, and fomesafen (relative importance points ranging between 0.2 and 0.8; data not shown). A growers' survey by Prince et al. (2012a) reported that GR soybean growers are using non-glyphosate herbicides primarily to control volunteer corn. GR volunteer corn has been reported as a serious problem in GR corn–soybean rotation in Nebraska (Chahal and Jhala 2016), and clethodim was listed as one of the most commonly used herbicides for effective management of volunteer corn in GR or glufosinate-resistant soybean (Chahal and Jhala 2015).

No grain sorghum or wheat POST herbicides were listed by respondents from the Northeast district; therefore, results were presented only from the Southeast and West Central districts. 2,4-D, dicamba, and bromoxynil plus pyrasulfotole were three most commonly used POST herbicides in grain sorghum; however, halosulfuron-methyl was also listed by respondents from the West Central district (Table 7). Respondents of this survey listed 2,4-D, metsulfuron-methyl, and triasulfuron as the top three commonly used POST herbicides in wheat in Nebraska (Table 7). The Agricultural Chemical Use Survey conducted in 2015 also listed metsulfuron-methyl as the most commonly used herbicide in winter wheat in the United States (USDA-NASS 2016b).

Cost of Weed Management in GR Crops

An increasing number of GR weeds in Nebraska compels growers to use PRE herbicides more frequently and tank-mix other herbicides with glyphosate for weed management, a trend that certainly increased the cost of weed management in GR crops. Under the most extreme situations, growers are using other weed control options, including tillage and roguing for the management of GR weeds in Nebraska. Averaged across districts, the cost of weed management in GR corn and soybean were \$90 and \$81 ha^{-1}, respectively; however, responses for the average cost of weed management varied greatly within and across the districts (Table 8). Weed management cost (\$105 ha^{-1}) in GR sugarbeet was reported only from the Panhandle district, the major sugarbeet-producing area in Nebraska. The cost of weed management in GR crops negatively correlated ($r = -0.23$; $P = 0.03$) with the land holdings. Similarly, Tan et al. (2008) and Yilmaz et al. (2005) also reported that farm size had a negative impact on average herbicide cost and energy use in rice and cotton production systems.

Glyphosate-Resistant Weed Management

The Problem of GR Weeds

Survey results indicated that 60% of growers in Nebraska reported the presence of at least one GR weed species on their farms; therefore, the survey results reflecting the stakeholders' perceptions of GR weed management are discussed in this section. Respondents were asked to rate the problem of GR weeds on a scale of 0 to 10, with 0 meaning not at all a problem and 10 meaning highly problematic (Question 3.1 in Table 1). Averaged across districts, respondents reported that they were highly concerned (average score of 7.4 with a median 8.0) about the problem

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Table 7. Respondents' ranking of the most commonly used PRE and POST herbicides in major agronomic crops.[a]

Rank	Districts[b]			
Rank	Northeast	Southeast	West Central	Nebraska[c]
	PRE herbicides			
Corn				
1	Acetochlor + atrazine (1.8)	Atrazine + mesotrione + *S*-metolachlor (1.6)	Atrazine + mesotrione + *S*-metolachlor (1.4)	Atrazine + mesotrione + *S*-metolachlor (1.2)
2	Acetochlor + clopyralid + flumetsulam (1.2)	Isoxaflutole + thiencarbazone-methyl (1.1)	Acetochlor + atrazine (0.8)	Isoxaflutole + thiencarbazone-methyl (0.8)
3	Atrazine + *S*-metolachlor (0.9)	Atrazine + *S*-metolachlor (0.9)	Atrazine (0.8)	Acetochlor + atrazine (0.7)
Grain sorghum				
1	Atrazine + *S*-metolachlor (2.3)	Atrazine + *S*-metolachlor (2.4)	Atrazine + mesotrione + *S*-metolachlor (2.3)	Atrazine + *S*-metolachlor (2.2)
2	Atrazine + mesotrione + *S*-metolachlor (1.9)	Atrazine + mesotrione + *S*-metolachlor (1.6)	Atrazine + *S*-metolachlor (1.1)	Atrazine + mesotrione + *S*-metolachlor (1.7)
3	NA[d]	Atrazine (0.7)	NA	Atrazine (0.5)
Soybean				
1	Flumioxazin / Flumioxazin + chlorimuron-ethyl (1.3)	Cloransulam-methyl + sulfentrazone (1.3)	Cloransulam-methyl + sulfentrazone (1.4)	Cloransulam-methyl + sulfentrazone (1.2)
2	Cloransulam-methyl + sulfentrazone (0.8)	Chlorimuron-ethyl + flumioxazin + thifensulfuron-methyl (0.9)	Chlorimuron-ethyl + flumioxazin + thifensulfuron-methyl (0.6)	Flumioxazin / Flumioxazin + chlorimuron-ethyl (0.8)
3	Pendimethalin (0.7)	Flumioxazin/ Flumioxazin + chlorimuron-ethyl (0.7)	Flumioxazin / Flumioxazin + chlorimuron-ethyl (0.6)	Chlorimuron-ethyl + flumioxazin + thifensulfuron-methyl (0.7)
	POST herbicides			
Corn				
1	Glyphosate (2.0)	Glyphosate (2.3)	Glyphosate (1.7)	Glyphosate (2.0)
2	Mesotrione + *S*-metolachlor + glyphosate (0.9)	Dicamba + diflufenzopyr (0.9)	Dicamba + diflufenzopyr (1.2)	Mesotrione + *S*-metolachlor + glyphosate (0.8)
3	Mesotrione / mesotrione + glyphosate (0.8)	Mesotrione + *S*-metolachlor + glyphosate (0.7)	Mesotrione + *S*-metolachlor + glyphosate (0.8)	Dicamba + diflufenzopyr (0.8)
Grain sorghum				
1	NA	2,4-D (1.6)	2,4-D (1.3)	2,4-D (1.5)
2	NA	Dicamba (0.9)	Bromoxynil + pyrasulfotole (1.3)	Dicamba (0.9)
3	NA	Bromoxynil + pyrasulfotole (0.7)	Halosulfuron-methyl (1.2)	Bromoxynil + pyrasulfotole (0.9)
Soybean				
1	Glyphosate (2.3)	Glyphosate (2.5)	Glyphosate (2.5)	Glyphosate (2.4)
2	Fluthiacet-methyl (0.9)	Fluthiacet-methyl (0.7)	Clethodim (0.9)	Fluthiacet-methyl (0.8)
3	Clethodim (0.5)	Clethodim (0.4)	Fluthiacet-methyl (0.8)	Clethodim (0.5)
Wheat				
1	NA	2,4-D (2.3)	Metsulfuron-methyl (1.7)	2,4-D (1.9)
2	NA	Triasulfuron (1.0)	2,4-D (1.3)	Metsulfuron-methyl (1.0)
3	NA	Dicamba (0.7)	Triasulfuron (0.9)	Triasulfuron (0.9)

[a]Values in parentheses represent the relative importance points for an herbicide, calculated using the equation:

$$RP = \sum_{r=1}^{3} \frac{FX}{n}$$

where *F* is the number of respondents choosing a particular rank (*r*) for an herbicide, *X* is the importance points (3 for *r*#1, 2 for *r*#2, and 1 for *r*#3) for that particular rank, and *n* is the total number of responses for that particular rank. The maximum possible relative importance points for an herbicide is 3.0.
[b]Sufficient responses were not recorded from the Panhandle district; therefore, data from the Panhandle district were not included in this table.
[c]Collective responses from three districts (Northeast, Southeast, and West Central) were listed under Nebraska.
[d]Abbreviation: NA, not available; respondents did not report the required information.

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Table 8. Average cost of weed management in glyphosate-resistant crops as reported by the stakeholders.[a,b]

Crops	Districts				Nebraska
	Northeast	Panhandle	Southeast	West Central	
	$ ha^{-1}				
Corn	83 (22–173)	97 (49–161)	90 (20–210)	98 (20–247)	90 (20–247)
Soybean	72 (15–173)	NA[c]	84 (25–203)	91 (20–198)	81 (15–203)
Sugarbeet[d]	NA	105 (30–173)	NA	NA	—

[a]Responses of growers and crop consultants were considered for this question.
[b]Values in parentheses indicate the min to max range of the cost.
[c]Abbreviation: NA, not available; respondents did not report the required information.
[d]Crop was reported only from the Panhandle district of Nebraska; therefore, average state results were not calculated.

of GR weeds in Nebraska (Table 9). Respondents from the West Central district rated GR weeds as their biggest problem (average score of 8.1 with a median 9.0) compared to the other districts, explainable by the survey results showing that GR kochia was the biggest problem in the West Central district (Table 5). Because the literature suggests that kochia emerges earlier (in March) compared to other summer annual weeds in Nebraska (Dille et al. 2017; Werle et al. 2014), the application of preplant burndown herbicides in the spring is essential in controlling kochia. Because glyphosate was the stakeholders' first choice of preplant burndown treatment in the West Central district (Table 6), this made GR kochia management more difficult.

Non-GR Crop Production Systems

Collectively, 34% of growers in Nebraska responded positively toward rotating non-GR crops with GR crops (Table 9). The majority of the growers (73%) from the Panhandle district rotated GR and non-GR crops, whereas in other districts this number ranged between 19% and 38%, primarily due to the predominant production of GR corn and soybean in eastern and West Central Nebraska. Survey results indicated that the highest crop diversity (54.1% of total farmed or scouted areas under crops other than corn and sugarbeet) was reported in the Panhandle district (Table 3), which was believed to have led to the highest percentage of non-GR crops being planted in the Panhandle district. Results of this survey also revealed that in Nebraska, an average 5.2% area was under glufosinate-resistant crops (corn and soybean). A survey of crop consultants from four southern states in the United States similarly reported that 7% of cropland was under glufosinate-resistant cotton and soybean systems for the effective management of GR Palmer amaranth (Riar et al. 2013b).

Field Scouting and Late-Season Weed Control

Field scouting for weeds before and after herbicide application is the foundation for an integrated weed management program, reducing the risks of herbicide resistance evolution in weed species (Norsworthy et al. 2012; Young 2017). Averaged across districts, 93% of respondents reported they either have scouted or advised scouting farms before and after herbicide application (Table 9). Lambert et al. (2017) surveyed cotton growers from 13 southern and midsouthern states in the United States and noted that field scouting is a remedial management tool for herbicide-

Table 9. Respondents' knowledge and perception about the management strategies to control glyphosate-resistant weeds in Nebraska.

Glyphosate-resistant weed management questions	Districts				Nebraska
	Northeast	Panhandle	Southeast	West Central	
Average problem ratings for the weeds resistant to glyphosate (on a scale of 1 to 10)[a]	6.5 (0.3)	7.2 (0.5)	7.5 (0.2)	8.1 (0.3)	7.4 (0.1)
Glyphosate-resistant crops rotated with crops not resistant to glyphosate (% of total growers)	19	73	38	30	34
Percentage of total farmed/scouted areas under glufosinate-resistant crops[b,c]	2.9	4.3	6.9	4.5	5.2
Percentage of respondents scouted/advised to scout farms before and after herbicide applications[b]	94	87	93	93	93
Percentage of growers controlled weed escapes or prevented seed set later in the season	60	44	79	86	75
Percentage of respondents familiar with the herbicide SOA[d]	91	86	95	95	93
Percentage of growers using multiple SOAs in their herbicide programs	80	82	92	93	90
Percentage of respondents aware of new crops resistant to multiple herbicides	86	78	91	91	89

[a]Values in parentheses represent the standard error of the mean (SEM).
[b]Respondents for this question include only growers and crop consultants.
[c]Glufosinate-resistant crop area includes the total areas under corn and soybean except for the Panhandle district, where only corn area were reported.
[d]Abbreviation: SOA, site of action.

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resistant weeds; however, they also admitted that field scouting was expensive and labor-intensive. The percentage of growers controlling escaped weeds later in the season varied widely among different districts; the percentage of growers performing late-season weed control was lowest (44%) in the Panhandle district, whereas overall 75% of growers in Nebraska reported practicing late-season weed management (Table 9).

Late-season weed escapes are often ignored by growers, as they rarely affect crop yields; however, long-term biological, ecological, and economic benefits of late-season weed management cannot be disregarded. Several weed species, such as common waterhemp and Palmer amaranth, exhibit prolonged emergence patterns (Hartzler et al. 2004; Jha and Norsworthy 2009); thus, delayed emergence can cause weed escapes, as most POST herbicide applications in row crops are made early in the season. Bagavathiannan and Norsworthy (2012) noted that growers practicing low-input cropping systems, where priorities are given to farmland biodiversity, might not readily adopt late-season weed management strategies. This statewide survey also showed that glyphosate was the primary choice for most of the growers (25%) in Nebraska for late-season weed management; however, several other herbicides, such as dicamba plus diflufenzopyr (13%), 2,4-D (10%), fluthiacet-methyl (6%), and lactofen (4%), were also listed (data not shown). Manual and/or mechanical weed management was practiced by only 10% of the growers for late-season weed control (data not shown).

Use of Multiple Herbicide Sites of Action

This statewide survey showed that 93% of respondents had knowledge about herbicide SOAs, with 90% using at least two SOAs in their herbicide programs (Table 9). Prevalence of ALS inhibitor–resistant and GR weeds in Nebraska was believed to compel growers to use herbicides with multiple SOAs to reduce their reliance on glyphosate. Additionally, the inclusion of PRE treatments in the herbicide programs helped diversify the herbicide SOAs, as several commonly used PRE herbicides listed in this survey were premixes of two or more herbicides belonging to at least two SOAs (Table 7).

Weed Management Practices to Delay the Evolution of Resistance

Six management practices that might slow the rate of GR weed evolution were listed in Question 3.8 in Table 1, and the survey participants were asked to indicate their perception of the effectiveness of those management practices on a scale of 1 to 10. Results showed that stakeholders surveyed from all the districts appeared to rate the listed weed management practices in a similar way (P values: Districts = 0.2, Districts × Management practices = 0.7); however, a substantial difference ($P < 0.0001$) between practices was observed in this statewide survey. Residual herbicides applied PRE followed by POST application of glyphosate tank-mixed with other herbicides was rated as the most effective means (average rating of 8.6 with the median 9.0) to ensure adequate weed control and reduce the evolution of resistance (Figure 3). Respondents' perception of the effectiveness of herbicide applications following the label instructions (correct label rates, and weed types and growth stages) was also rated at a similar level (average rating of 8.4 with the median 9.0) as the aforementioned management practice. Tank-mixing herbicides for POST weed control was also considered one of the best management practices for delaying weed resistance evolution (Norsworthy et al. 2012). Several other studies also noted that PRE followed by a POST herbicide program using tank mixtures of two or more herbicides was considered the most effective measure to control GR weeds in GR crops (Ganie et al. 2016; Legleiter et al. 2009; Sarangi et al. 2017a). Among all of the weed management practices listed, tillage was considered the least effective (average rating of 6.1 with the median 6.0) option for GR weed management (Figure 3).

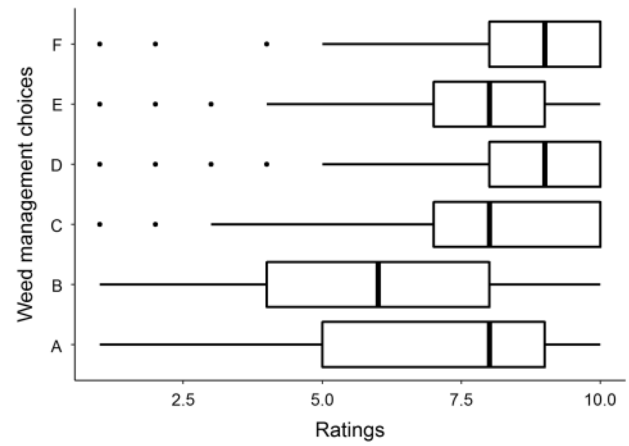

Figure 3. Boxplot presenting the respondents' perception of the effectiveness of weed management choices for controlling glyphosate-resistant weeds in Nebraska. The line at the center of each boxplot shows the median value of the ratings. Respondents rated the effectiveness of a weed management choice on a scale of 1 to 10, where 1 means not at all effective and 10 means very effective. Details about the weed management choices are listed in Table 1.

Adoption of New Multiple Herbicide–Resistant Crops

Lack of new broad-spectrum herbicides with a novel SOA is leading toward the development of multiple herbicide–resistant crops as an effective management strategy for GR weeds (Green 2014). Table 9 includes information regarding stakeholders' awareness of new multiple herbicide–resistant crops that were under the commercialization process in 2015. Results showed that 89% of the respondents in Nebraska were aware of these upcoming multiple herbicide–resistant crop technologies.

This survey also investigated the obstacles perceived by the survey participants for adopting the new multiple herbicide–resistant crops in the future. Responses by the stakeholders who were aware of the multiple herbicide–resistant crop technologies were included in this section. Among them, 45% of respondents showed no concerns regarding the adoption of new multiple herbicide–resistant crops in Nebraska (data not shown). This may be a reflection of their confidence in the potency of the new multiple herbicide–resistant crops for controlling herbicide-resistant weeds, particularly GR weeds, or indication of the lack of detailed information regarding the new technologies. The majority of the respondents (80%) among those who had expressed concerns regarding the adoption of the new technologies listed volatility or/and physical drift of the herbicides (mostly auxinic herbicides such as dicamba and 2,4-D) to nearby sensitive crops as their primary concern (Figure 4). Similarly, a survey of crop consultants in the midsouthern United States in 2011 reported that 77% of crop consultants were concerned about the off-target movement of the synthetic auxins to sensitive crops following the adoption of crops resistant to multiple herbicides (Riar et al. 2013b). In 2017, the use of dicamba on recently

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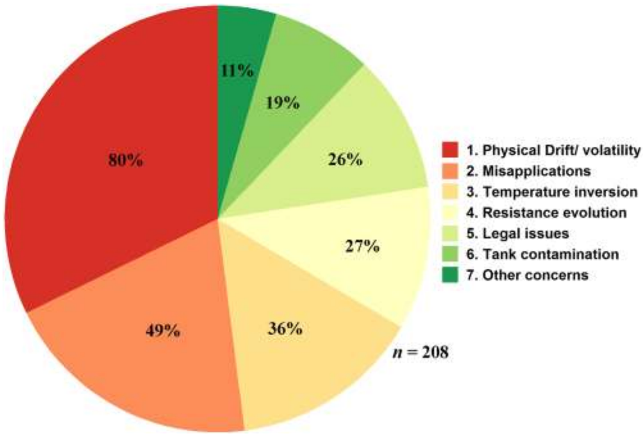

Figure 4. The relative importance of concerns reported by the survey respondents about the adoption of new crops resistant to multiple herbicides.

commercialized glyphosate/dicamba-resistant soybeans in the United States created a controversy because of its off-target movement (Bradley 2017a, b).

Several respondents (49%) also expressed their concerns regarding the misapplication of synthetic auxins and HPPD inhibitors to widely planted GR soybean areas (Figure 4). In this survey, 36% of respondents were also worried about the temperature inversion; however, they mentioned that a proper education and training program for growers and pesticide applicators could reduce long-distance herbicide drift due to temperature inversion.

Survey participants also feared the evolution of multiple-herbicide resistance in weed species; 27% of respondents noted that rapid adoption of new technologies would lead to the use of one or two specific herbicides as POST treatments, which would ultimately promote the evolution of multiple herbicide–resistant weeds (Figure 4). By 2017, nine weed species in Nebraska were confirmed resistant to at least one herbicide, with several showing multiple-herbicide resistance (Jhala 2018); therefore, a further increase in the number of weeds resistant to multiple herbicides is not desirable.

In this survey, 26% of respondents indicated that they did not want to deal with the legal issues following an off-target movement of auxinic or HPPD-inhibiting herbicides (Figure 4). According to these respondents, any sort of misapplication or off-target movement might create a conflict between neighbors, or between growers and pesticide applicators, that could end up in litigation. A substantial percentage (19%) of survey respondents also reported concerns about tank contamination due to improper sprayer cleanout (Figure 4). A survey by Riar et al. (2013b) also reported that 12% of crop consultants were concerned about tank contamination of auxinic herbicides following POST application in auxinic herbicide–resistant cropping systems. In our statewide survey, 11% of respondents also expressed their concerns regarding several other issues, including selection of proper nozzles for a particular herbicide application, seed cost, and market issues for selling produce, among others.

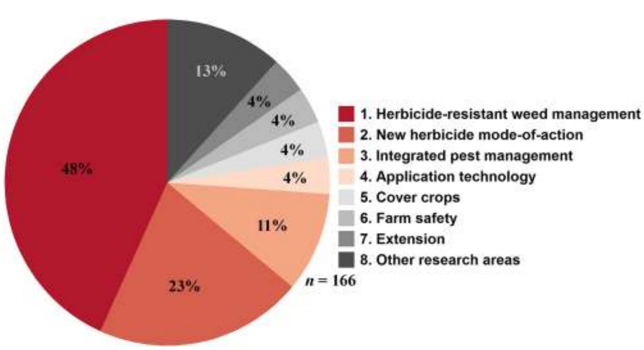

Figure 5. Future weed science research and extension priorities reported by the survey respondents.

Weed Management Research and Extension Priorities

Survey participants were asked to list three research and extension priorities to improve weed management in Nebraska (Question 4.1 in Table 1). Surprisingly, 61% of total respondents did not indicate any research or extension priority. Out of a total 166 respondents who listed at least one research or extension priority for future weed management, 48% indicated that there is a need to continue research on management of herbicide-resistant weeds in Nebraska (Figure 5). Several respondents also mentioned research on herbicide-resistant Palmer amaranth and kochia management by emphasizing topics such as the efficacy of different POST herbicides, determining the most effective timing for POST applications, and late-season weed control.

Several survey participants (23%) noted that additional herbicide SOAs are needed to control increasing numbers of weeds resistant to multiple herbicides in row crops. No corn/soybean herbicide belonging to a new SOA has come to the marketplace in the last three decades (Duke 2012), and there is little possibility of commercialization of a new SOA herbicide in the near future. Additionally, a substantial number of survey participants (11%) identified the need for integrated pest management research in the future (Figure 5). Respondents were also interested in multidisciplinary research data where economists, entomologists, plant pathologists, and weed scientists would come together to recommend a sustainable pest management program in row crops. Nonchemical weed management was also listed by some stakeholders as an integrated weed management research area.

Several respondents also listed research areas of application technology, cover crops, and farm safety as their top priorities (Figure 5). Reduction in the off-target movement of auxinic herbicides was the major research priority listed under the application technology. In this survey, 4% of respondents were in favor of having a more effective extension system to create awareness among stakeholders about best management practices for controlling herbicide-resistant weeds and developing sustainable production systems. Additionally, some respondents (13%) included research areas other than the aforementioned priorities (Figure 5), which included weed management research in new crops resistant to multiple herbicides, research on the biology and management of invasive and noxious weeds, and weed management research in pastures, popcorn [*Zea mays* subsp. *everta* (Sturtev.) Zhuk.], oat (*Avena sativa* L.), grain sorghum, and wheat.

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References

Bagavathiannan MV, Norsworthy JK (2012) Late-season seed production in arable weed communities: management implications. Weed Sci 60:325–334

Benbrook CM (2016) Trends in glyphosate herbicide use in the United States and globally. Environ Sci Eur 28:3. https://doi.org/10.1186/s12302-016-0070-0

Bradley K (2017a) Ag Industry, Do We Have a Problem Yet. Integrated Pest & Crop Management. https://ipm.missouri.edu/IPCM/2017/7/Ag_Industry_Do_we_have_a_problem_yet/. Accessed: October 5, 2017

Bradley K (2017b) Update on dicamba-related injury investigations and estimates of injured soybean acreage. Integrated Pest & Crop Management. https://ipm.missouri.edu/IPCM/2017/8/Update-on-Dicamba-related-Injury-Investigations-and-Estimates-of-Injured-Soybean-Acreage/. Accessed: October 5, 2017

Buhler DD (1995) Influence of tillage systems on weed population dynamics and management in corn and soybean in the central USA. Crop Sci 35:1247–1258

Bultena GL, Hoiberg EO (1983) Factors affecting farmers' adoption of conservation tillage. J Soil Water Conserv 38:281–284

Chahal PS, Jhala AJ (2015) Herbicide programs for control of glyphosate-resistant volunteer corn in glufosinate-resistant soybean. Weed Technol 29:431–443

Chahal PS, Jhala AJ (2016) Impact of glyphosate-resistant volunteer corn (*Zea mays* L.) density, control timing, and late-season emergence on yield of glyphosate-resistant soybean (*Glycine max* L.). Crop Prot 81:38–42

Chahal PS, Varanasi VK, Jugulam M, Jhala AJ (2017) Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Nebraska : confirmation, *EPSPS* gene amplification, and response to POST corn and soybean herbicides. Weed Technol 31:80–93

Culpepper AS (2006) Glyphosate-induced weed shifts. Weed Technol 20:277–281

D'Emden FH, Llewellyn RS, Burton MP (2008) Factors influencing adoption of conservation tillage in Australian cropping regions. Aust J Agric Resour Econ 52:169–182

Dille JA, Stahlman PW, Du J, Geier PW, Riffel JD, Currie RS, Wilson RG, Sbatella GM, Westra P, Kniss AR, Moechnig MJ, Cole RM (2017) Kochia (*Kochia scoparia*) emergence profiles and seed persistence across the central Great Plains. Weed Sci 65:614–625

Duke SO (2012) Why have no new herbicide modes of action appeared in recent years? Pest Manag Sci 68:505–512

Fernandez-Cornejo J, Nehring R, Osteen C, Wechsler S, Martin A, Vialou A (2014) Pesticide use in U.S. agriculture: 21 selected crops, 1960–2008. Washington, DC: US Department of Agriculture–Economic Research Service EIB 124. 11 p

Fite GC (1980) Mechanization of cotton production since World War II. Agric Hist 54:190–207

Ganie ZA, Sandell LD, Jugulam M, Kruger GR, Marx DB, Jhala AJ (2016) Integrated management of glyphosate-resistant giant ragweed (*Ambrosia trifida*) with tillage and herbicides in soybean. Weed Technol 30:45–56

Gibson KD, Johnson WG, Hillger DE (2005) Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol 19:1065–1070

Givens WA, Shaw DR, Johnson WG, Weller SC, Young BG, Wilson RG, Owen MDK, Jordan D (2009a) A grower survey of herbicide use patterns in glyphosate-resistant cropping systems. Weed Technol 23:156–161

Givens WA, Shaw DR, Kruger GR, Johnson WG, Weller SC, Young BG, Wilson RG, Owen MDK, Jordan D (2009b) Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol 23:150–155

Godar AS, Stahlman PW (2015) Consultant's perspective on the evolution and management of glyphosate-resistant kochia (*Kochia scoparia*) in western Kansas. Weed Technol 29:318–328

Green JM (2014) Current state of herbicides in herbicide-resistant crops. Pest Manag Sci 70:1351–1357

Hartzler RG, Battles BA, Nordby D (2004) Effect of common waterhemp (*Amaranthus rudis*) emergence date on growth and fecundity in soybean. Weed Sci 52:242–245

Heap I (2018) The International Survey of Herbicide Resistant Weeds. Weeds Resistant to EPSP Synthase Inhibitors http://www.weedscience.org/Summary/MOA.aspx?MOAID=12 Accessed: March 25, 2018

Jha P, Norsworthy JK (2009) Soybean canopy and tillage effects on emergence of Palmer amaranth (*Amaranthus palmeri*) from a natural seed bank. Weed Sci 57:644–651

Jhala AJ (2018) Herbicide-resistant weeds in Nebraska. Pages 18–19 in Knezevic SZ, Creech CF, Jhala AJ, Klein RN, Kruger GR, Proctor CA, Shea PJ, Ogg CL, Thompson C, Lawrence N & Werle R eds., 2018 Guide for Weed, Disease, and Insect Management in Nebraska. Lincoln, NE: University of Nebraska–Lincoln Extension EC130

Knezevic SZ, Evans SP, Mainz M (2003) Row spacing influences the critical timing for weed removal in soybean (*Glycine max*). Weed Technol 17:666–673

Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32:25–48

Kruger GR, Johnson WG, Weller SC, Owen MDK, Shaw DR, Wilcut JW, Jordan DL, Wilson RG, Bernards ML, Young BG (2009) US grower views on problematic weeds and changes in weed pressure in glyphosate-resistant corn, cotton, and soybean cropping systems. Weed Technol 23:162–166

Lambert DM, Larson JA, Roberts RK, English BC, Zhou XV, Falconer LL, Hogan RJ Jr., Johnson JL, Reeves JM (2017) "Resistance is futile": estimating the costs of managing herbicide resistance as a first-order Markov process and the case of US upland cotton producers. Agric Econ 48:387–396

Legleiter TR, Bradley KW, Massey RE (2009) Glyphosate-resistant waterhemp (*Amaranthus rudis*) control and economic returns with herbicide programs in soybean. Weed Technol 23:54–61

Lund P, Price R (1998) The measure of average farm size. J Agric Econ 49:100–110

MacDonald JM, Korb P, Hoppe RA (2013) Farm size and the organization of US crop farming. Washington, DC: US Department of Agriculture–Economic Research Service ERR 152. Pp 8–9

Nichols V, Verhulst N, Cox R, Govaerts B (2015) Weed dynamics and conservation agriculture principles: a review. Field Crop Res 183:56–68

Norsworthy JK (2003) Use of soybean production surveys to determine weed management needs of South Carolina farmers. Weed Technol 17:195–201

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60:31–62

Nowak PJ (1987) The adoption of agricultural conservation technologies: economic and diffusion explanations. Rural Sociol 52:208–220

[NRCS-USDA] Natural Resource Conservation Service–US Department of Agriculture (2008) Nebraska No-Till. Washington, DC: US Department of Agriculture. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ne/technical/?cid=nrcs142p2_029625. Accessed: October 5, 2017

Oliveira MC (2017) Evolution of HPPD-Inhibitor Herbicide Resistance in a Waterhemp (*Amaranthus tuberculatus* var. *rudis*) Population from Nebraska, USA. Ph.D. dissertation. Lincoln, NE: University of Nebraska-Lincoln. 129 p

Oliveira MC, Feist D, Eskelsen S, Scott JE, Knezevic SZ (2017a) Weed control in soybean with preemergence- and postemergence-applied herbicides. Crop Forage Turfgrass Manag 3. DOI: 10.2134/cftm2016.05.0040

Oliveira MC, Jhala AJ, Gaines T, Irmak S, Amundsen K, Scott JE, Knezevic SZ (2017b) Confirmation and control of HPPD-inhibiting herbicide–resistant waterhemp (*Amaranthus tuberculatus*) in Nebraska. Weed Technol 31:67–79

Peterson G (1967) The discovery and development of 2,4-D. Agric Hist 41:243–254

Prince JM, Shaw DR, Givens WA, Newman ME, Owen MDK, Weller SC, Young BG, Wilson RG, Jordan DL (2012a) Benchmark study: III. Survey on changing herbicide use patterns in glyphosate-resistant cropping systems. Weed Technol 26:536–542

Prince JM, Shaw DR, Givens WA, Owen MDK, Weller SC, Young BG, Wilson RG, Jordan DL (2012b) Benchmark study: I. Introduction, weed population, and management trends from the benchmark survey 2010. Weed Technol 26:525–530

R Core Team (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org. Accessed: February 3, 2017

Rana N, Jhala AJ (2016) Confirmation of glyphosate- and acetolactate synthase (ALS)-inhibitor–resistant kochia (*Kochia scoparia*) in Nebraska. J Agr Sci 8:54–62

Riar DS, Norsworthy JK, Steckel LE, Stephenson DO IV, Bond JA (2013a) Consultant perspectives on weed management needs in midsouthern United States cotton: a follow-up survey. Weed Technol 27:778–787

Riar DS, Norsworthy JK, Steckel LE, Stephenson DO IV, Eubank TW, Scott RC (2013b) Assessment of weed management practices and problem weeds in the midsouth United States—soybean: a consultant's perspective. Weed Technol 27:612–622

Sandell L, Datta A, Knezevic S, Kruger G (2011) Glyphosate-resistant giant ragweed confirmed in Nebraska. CropWatch. https://cropwatch.unl.edu/glyphosate-resistant-giant-ragweed-confirmed-nebraska. Accessed: October 5, 2017

Sarangi D, Jhala AJ (2017) Response of glyphosate-resistant horseweed [*Conyza canadensis* (L.) Cronq.] to a premix of atrazine, bicyclopyrone, mesotrione, and *S*-metolachlor. Can J Plant Sci 97:702–714

Sarangi D, Jhala AJ (2018) Comparison of a premix of atrazine, bicyclopyrone, mesotrione, and *S*-metolachlor with other preemergence herbicides for weed control and corn yield in no-tillage and reduced tillage production systems in Nebraska, USA. Soil Till Res 178:82–91

Sarangi D, Sandell LD, Knezevic SZ, Aulakh JS, Lindquist JL, Irmak S, Jhala AJ (2015) Confirmation and control of glyphosate-resistant common waterhemp (*Amaranthus rudis*) in Nebraska. Weed Technol 29:82–92

Sarangi D, Sandell LD, Kruger GR, Knezevic SZ, Irmak S, Jhala AJ (2017a) Comparison of herbicide programs for season-long control of glyphosate-resistant common waterhemp (*Amaranthus rudis*) in soybean. Weed Technol 31:53–66

Sarangi D, Tyre AJ, Patterson EL, Gaines TA, Irmak S, Knezevic SZ, Lindquist JL, Jhala AJ (2017b) Pollen-mediated gene flow from glyphosate-resistant common waterhemp (*Amaranthus rudis* Sauer): consequences for the dispersal of resistance genes. Sci Rep 7:44913 DOI: 10.1038/srep44913

Shaner DL (2000) The impact of glyphosate-tolerant crops on the use of other herbicides and on resistance management. Pest Manag Sci 56:320–326

Shaw DR, Givens WA, Farno LA, Gerard PD, Jordan D, Johnson WG, Weller SC, Young BG, Wilson RG, Owen MDK (2009) Using a grower survey to assess the benefits and challenges of glyphosate-resistant cropping systems for weed management in US corn, cotton, and soybean. Weed Technol 23:134–149

Sosnoskie LM, Webster TM, Kichler JM, MacRae AW, Grey TL, Culpepper AS (2012) Pollen-mediated dispersal of glyphosate-resistance in Palmer amaranth under field conditions. Weed Sci 60:366–373

Stougaard RN, Kapusta G, Roskamp G (1984) Early preplant herbicide applications for no-till soybean (*Glycine max*) weed control. Weed Sci 32:293–298

Tan S, Heerink N, Kruseman G, Qu F (2008) Do fragmented landholdings have higher production costs? Evidence from rice farmers in Northeastern Jiangxi province, P.R. China. China Econ Rev 19:347–358

Triplett GB Jr., Van Doren DM Jr., Johnson WH (1964) Non-plowed, strip-tilled corn culture. Trans ASAE 7:105–107

[USDA-ERS] US Department of Agriculture–Economic Research Service (2017) Recent Trends in GE Adoption. Washington, DC: US Department of Agriculture. https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption.aspx. Accessed: September 3, 2017

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2012) Agricultural Chemical Use: Field Crops 2011 (Barley and Sorghum). Washington, DC: US Department of Agriculture https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/BarleySorghumChemicalUseFactSheet.pdf

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2014a) 2012 Census of Agriculture: Nebraska State and County Data. Washington, DC: US Department of Agriculture AC-12-A-27. Pp 7–250

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2014b) Acreage. Washington, DC: US Department of Agriculture. http://usda.mannlib.cornell.edu/usda/nass/Acre//2010s/2014/Acre-06-30-2014.pdf. Accessed: September 3, 2017

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2015) Crop Production: 2014 Summary. Washington, DC: US Department of Agriculture ISSN: 1057-7823. Pp 8–45

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2016a) 2015 Agricultural Chemical Use Survey: Soybeans. Washington, DC: US Department of Agriculture. NASS Highlights No. 2016-4

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2016b) 2015 Agricultural Chemical Use Survey: Wheat. Washington, DC: US Department of Agriculture. NASS Highlights No. 2016-5

[USDA-NASS] US Department of Agriculture – National Agricultural Statistics Service (2017) 2016 Agricultural Chemical Use Survey: Corn. Washington, DC: US Department of Agriculture. NASS Highlights No. 2017-2

Vangessel MJ, Ayeni AO, Majek BA (2001) Glyphosate in full-season no-till glyphosate-resistant soybean: role of preplant applications and residual herbicides. Weed Technol 15:714–724

Van Wychen L (2016a) 2015 Baseline Survey of the Most Common and Troublesome Weeds in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. http://wssa.net/wp-content/uploads/2015_Weed_Survey_Final.xlsx. Accessed: October 5, 2017

Van Wychen L (2016b) 2016 Survey of the Most Common and Troublesome Weeds in Broadleaf Crops, Fruits & Vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. http://wssa.net/wp-content/uploads/2016_Weed_Survey_Final.xlsx. Accessed: October 5, 2017

Vieira BC, Samuelson SL, Alves GS, Gaines TA, Werle R, Kruger GR (2017) Distribution of glyphosate-resistant *Amaranthus* spp. in Nebraska. Pest Manag Sci https://onlinelibrary.wiley.com/doi/abs/10.1002/ps.4781

Webster TM, Macdonald GE (2001) A survey of weeds in various crops in Georgia. Weed Technol 15:771–790

Werle R, Sandell LD, Buhler DD, Hartzler RG, Lindquist JL (2014) Predicting emergence of 23 summer annual weed species. Weed Sci 62:267–279

Yilmaz I, Akcaoz H, Ozkan B (2005) An analysis of energy use and input costs for cotton production in Turkey. Renew. Energy 30:145–155

Young BG (2006) Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol 20:301–307

Young SL (2017) A systematic review of the literature reveals trends and gaps in integrated pest management studies conducted in the United States. Pest Manag Sci 73:1553–1558