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Consultant's Perspective on the Evolution and Management of Glyphosate-Resistant Kochia (*Kochia scoparia*) in Western Kansas

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Glyphosate is the leading herbicide used in glyphosate-resistant (GR) crops and no-till production systems. Evolved resistance to glyphosate in kochia was first reported in Kansas in 2007. Shortly thereafter, GR kochia became prevalent in western Kansas. An online survey of crop consultants was conducted in fall 2012 to gain their perspectives on evolving glyphosate resistance in kochia in western Kansas, to gather information on how grower weed management practices have changed from before to after occurrence of GR kochia, and to assess the effectiveness of management practices used during 2011 to 2012. Results of the survey indicated increasing infestation of kochia from prior to 2007 (present in 47% of fields) through 2012 (present in 70% of fields). It was estimated that greater than one-third of the cropland in western Kansas was thought to be infested with GR kochia by 2012. Growers increased glyphosate use rates from an average of 0.8 to 1.22 kg ae ha^{-1} and application frequencies from 2.0 to 2.9 from the period before 2007 to 2012. The spread of GR kochia has resulted in changing weed management practices. During the survey period, growers reduced the exclusive use of glyphosate from 49 to 15% for GR crop fields and diversified weed management practices. Though other herbicides in addition to or in place of glyphosate were often applied prior to kochia emergence and were effective in more than half the fields, at least one-fourth of respondents reported inconsistent results with alternative kochia control practices other than tillage. These results are educational and helpful in developing both proactive and reactive tactics to manage GR kochia.

Nomenclature: Glyphosate; kochia, *Kochia scoparia* (L.) Schrad.

Key words: Crop consultants, fallow, glyphosate rate, glyphosate resistance, herbicide resistance, herbicide-resistant crops, survey.

Glyphosate es el herbicida líder para uso en cultivos resistentes a glyphosate (GR) y en sistemas de producción con labranza cero. *Kochia scoparia* que evolucionó y adquirió resistencia a glyphosate se reportó por primera vez en Kansas en 2007. Poco después, *K. scoparia* GR se hizo prevalente en el oeste de Kansas. En el otoño de 2012, se realizó una encuesta en línea a asesores agrícolas para: recoger sus perspectivas sobre la evolución de resistencia a glyphosate en *K. scoparia* en el oeste de Kansas, recopilar información sobre cómo los prácticas de manejo de malezas de los productores han cambiado desde antes hasta después de la aparición de *K. scoparia* GR, y para evaluar la efectividad de las prácticas de manejo usadas durante 2011 y 2012. Los resultados de la encuesta indicaron que se dio un incremento en las infestaciones de *K. scoparia* desde antes de 2007 (presente en 47% de los campos) hasta 2012 (presente en 70% de los campos). Se estimó que más de la tercera parte del área agrícola en el oeste de Kansas estaba presumiblemente infestada con *K. scoparia* GR en 2012. Los productores aumentaron las dosis de glyphosate de un promedio de 0.8 a 1.22 kg ae ha^{-1} y las frecuencias de aplicación de 2.0 a 2.9 en el período desde antes de 2007 hasta 2012. La dispersión de *K. scoparia* GR ha resultado en cambios en las prácticas de manejo de malezas. Durante el período de la encuesta, los productores redujeron el uso exclusivo de glyphosate de 49 a 15% de los campos con cultivos GR y diversificaron las prácticas de manejo de malezas. Aunque otros herbicidas agregados a o en remplazo de glyphosate eran frecuentemente aplicados antes de la emergencia de *K. scoparia* y eran efectivos en más de la mitad de los campos, al menos un cuarto de los encuestados reportaron resultados inconsistentes con las prácticas alternativas de control de *K. scoparia* que no fueran labranza. Estos resultados son educativos y útiles en el desarrollo de tácticas proactivas y reactivas para el manejo de *K. scoparia* GR.

Kochia is a troublesome and economically important weed in row crops, small grains, and fallow fields in semiarid regions of the North American Great Plains (Dexter et al. 1981; Friesen et al. 2009). An annual C_4 plant, kochia thrives in hot, dry conditions and is especially problematic in

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no-till production systems (Anderson and Nielsen 1996) because of limited emergence from soil depths greater than 10 mm (Schwinghamer and Van Acker 2008). Populations of kochia have developed resistance to several herbicides, complicating management. Kochia has several characteristics that favor evolution and subsequent spread of herbicide resistance. Some of these characteristics include high genetic diversity (Guttieri et al. 1998; Mengistu and Messersmith 2002) that is facilitated by protogynous flowering and facultative open pollination, prolific seed production and long-distance seed dispersal from tumbling mature plants moved by wind (Eberlein and Fore 1984), and short seed life (Zorner et al. 1984).

Glyphosate is extensively used in global agriculture and is a potent nonselective herbicide that inhibits 5-enolpyruvyl-shikimate 3-phosphate, a key enzyme in the shikimate pathway (Herrmann and Weaver 1999; Steinrucken and Amrhein 1980). Though the herbicide was first commercialized in 1974, its use in crop production systems was limited to fallow and noncrop areas until the late 1990s when its use increased dramatically following the introduction of GR crops (Roundup Ready® crops, Monsanto Co.). The extensive use of glyphosate on GR crops has resulted in evolved resistance in several weeds at a rapid rate globally (Duke and Powles 2008; Heap 2014).

Differential kochia population response to glyphosate was first reported in Kansas in 2007 (Waite et al. 2013) and the same year a separate population was confirmed resistant to glyphosate (Godar 2014). By 2010, more than 10 geographically dispersed kochia populations in Kansas were confirmed resistant to glyphosate; resistance levels ranged from 3- to 11-fold compared to a susceptible population (Godar 2014). Yet, in a survey of Kansas growers in 2010, only 34% were concerned about GR kochia (Peterson et al. 2010). Presence of GR kochia has been reported in nine other Great Plains states and three Canadian provinces: South Dakota in 2009, Alberta and Nebraska in 2011, Colorado, Montana, North Dakota, and Saskatchewan in 2012, Manitoba (HJ Beckie, personal communication) and Oklahoma in 2013 and Idaho, Oregon, and Wyoming in 2014 (Beckie et al. 2013; Heap 2014; Kumar et al. 2014). For several reasons, including presence of kochia populations resistant to triazine and acetolactate synthase–inhibiting herbicides and increasing use of no-till and chemical fallow in the region, glyphosate has been the primary herbicide used for controlling weeds in many areas (Foes et al. 1999; Gianessi 2005; Heap 2014; Peterson et al. 2013). Continued heavy reliance on glyphosate resulted in evolved resistance in kochia.

In herbicide-dependent weed management systems, crop rotation influences herbicide use pattern. In western Kansas, winter wheat dominated the cropping systems until the late 1990s (Eberle and Shroyer 1997). Winter wheat continues to be the major component of cropping systems in the region but in recent years growers have integrated GR crops, mostly corn, into the rotation. A chemical fallow year is usually included in a 3-yr crop rotation. Thus, growers routinely apply glyphosate multiple times each year to control kochia and other weeds in GR crops (both preplant and in-crop), in postharvest wheat fields, and during summer fallow. As the effectiveness of glyphosate applications declined with evolving resistance in kochia, many growers returned to tank-mixing other herbicides with glyphosate for improved weed control, especially in preplant, postharvest, and fallow applications. Dicamba is the herbicide most often tank-mixed with glyphosate for improved kochia control in those situations (PW Stahlman, unpublished data).

Several local and regional surveys have been conducted in recent years to understand grower awareness, perceptions, and management response to GR weeds (Givens et al. 2011; Hurley et al. 2009; Johnson et al. 2007; Peterson et al. 2010; Prince et al. 2012a,b; Scott and VanGessel 2007; Shaw et al. 2009), with emphasis on GR horseweed [*Conyza canadensis* (L.) Cronq.] and Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] in the eastern half of the United States. Because of the increasing occurrence of GR kochia populations, we conducted a survey of crop consultants in Kansas to estimate the infestation of kochia, gather information on grower weed management practices during periods before and after the occurrence of GR kochia evolution, and evaluate the efficacy of kochia management practices during 2011 to 2012 in western Kansas.

Materials and Methods

Survey Method. An online survey was developed using Adobe® FormsCentral (Adobe Systems, San

Table 1. Condensed version of survey questionnaire.

PART A. Kochia infestation and presence of GR kochia

A1a. In 2011 and 2012, what percentage of summer fallow fields were infested with kochia?
Options -> 0-10%; 11-20%; 21-40%; 41-60%; 61-80%; >80%; I do not know

A1b. In 2011 and 2012, what percentage of row crop fields were infested with kochia?
Options -> same as A1a.

A2. In 2012, what percentage of all fields (crop and fallow) infested with kochia do you think were glyphosate-resistant populations?
Options -> 0%; 1-5%; 6-10%; 11-20%; 21-30%; 31-40%; 41-50%; >50%; I do not know

PART B. Glyphosate use rate and application frequency

B1. What was the most common rate of glyphosate (kg ae ha^{-1}) applied in glyphosate-resistant crops, **a.** before 2007? **b.** during 2007 to 2010? **c.** during 2011 to 2012? (Refer to the conversion table provided)
Options -> 0.44-0.62; 0.63-0.78; 0.79-0.95; 0.96-1.12; 1.13-1.35; 1.36-1.58; >1.58 kg ae ha^{-1}; I do not know.

B2. How many times was glyphosate applied in summer fallow in a season, **a.** before 2007? **b.** during 2007 to 2010? **c.** during 2011 to 2012?
Options -> 1; 2; 3; 4 applications; I do not know

PART C. Dependency on glyphosate, and efficacy with and without dicamba

C1. What percentage of glyphosate-resistant crop fields received glyphosate as the ONLY herbicide for in-crop weed management? Note: Do not consider POST herbicides applied for volunteer crop control.
Options -> 0-10%; 11-20%; 21-30%; 31-40% 41-50%; 51-60%; 61-70%; 71-80%; >80%; I do not know

C2a. How effective were glyphosate-only products in controlling kochia in summer fallow, **a.** before 2007? **b.** during 2007 to 2010? **c.** during 2011 to 2012?
Options -> very effective throughout the county; very effective in most fields; not satisfactory in several fields; not effective in several fields; I do not know.

C2b. How effective were POST applications of glyphosate PLUS dicamba products in controlling kochia in summer fallow, **a.** before 2007? **b.** during 2007 to 2010? **c.** during 2011 to 2012?
Options -> same as C2a.

PART D. Management practices and their effectiveness

D1. What percentage of your growers implemented the following practices to control kochia in 2011 and/or 2102, **a.** normal rate of glyphosate **b.** higher than normal rate of glyphosate **c.** multiple applications of glyphosate **d.** glyphosate plus dicamba **e.** other POST herbicides **f.** PRE herbicides **g.** tillage
Options -> 0-5%; 6-10%; 11-20%; 21-40%; 41-60%; >60%; I do not know

D2. How do you rate those practices based on their effectiveness in controlling kochia in 2011 and/or 2102? **a.** normal rate of glyphosate **b.** higher than normal rate of glyphosate **c.** multiple applications of glyphosate **d.** glyphosate plus dicamba **e.** other POST herbicides **f.** PRE herbicides **g.** tillage
Options -> effective in all fields; effective in most fields; effective in about half of fields; effective in only few; did not work at all; I do not know

Jose, CA) and sent electronically to 102 crop consultants in western Kansas. Herbicide product rate conversion tables and clarifying statements for certain questions were provided. All questions required an answer in order to complete the survey. A condensed version of the questionnaire is presented in Table 1 (see Stahlman 2012 for entire survey). Most questions were subdivided into three time periods: before 2007 (i.e., before first confirmation of GR kochia), 2007 to 2010 (i.e., more than 10 widely distributed kochia populations confirmed GR), and 2011 to 2012 (i.e., widespread presence of GR kochia throughout western Kansas). Most questions were close-ended with either numerical categorical or verbal rating options.

E-mail addresses of field agronomists/crop consultants were obtained from crop consulting companies or professional association (i.e., Crop Quest, Inc., Servi-Tech, Inc,. and Kansas Association of Independent Crop Consultants). An advance invitation was sent to potential participants along with a brief statement describing the purpose and objectives of the survey. Another email was sent 5 d later with a link to instructions and survey questions. Approximately 10 d later, a courtesy reminder was sent to complete the survey. The survey was administered in September 2012.

Statistical Analysis. Results are interpreted primarily based on frequency distributions for most questions. To derive an estimate of mean responses, numerical categories were transformed into midvalues for analysis wherever appropriate. In such cases, mean values were compared using one-way ANOVA or paired *t* test at $\alpha = 0.05$. In cases of nonnormal responses, a nonparametric Wilcoxon-Mann-Whitney test was performed ($\alpha = 0.05$).

Results and Discussion

Fifty-two crop consultants from 46 western Kansas counties completed the survey. The sample size represents slightly more than 50% of the known consultant population in western Kansas at that time. Collectively, the respondents scout and advise growers on approximately 0.5 million ha of cropland, which is more than 10% of the area surveyed. Effective response rate varied slightly among the questions and an "I do not know" response was higher for the period before 2007 compared to later time periods. This probably reflects the relatively young age of some respondents and failure of others to remember accurately that far back.

Kochia Infestation and Presence of GR Kochia. Seventy-six percent of respondents reported kochia infestation in > 10% of fallow fields during the period before 2007 (Figure 1A). Of those respondents, more than one-fourth reported kochia infestation in > 80% of fallow fields. During the 2007 to 2010 period, only 7% of respondents reported kochia infestation in ≤ 10% of fallow fields, whereas an additional 12% of respondents reported > 80% kochia-infested fallow fields compared to the period before 2007. More than half of the respondents reported an increased percentage of kochia-infested fallow fields during the 2007 to 2010 period compared to before 2007, and most reported a further increase in infestation during the 2011 to 2012 period (Figure 1B). Even respondents who reported low kochia infestation prior to 2007 reported an increased percentage of kochia-infested fields during the later survey periods. Class-interval means for percentage of kochia-infested fallow fields (90% was used as a midvalue for > 80%) were 47, 57, and 70% for the periods before 2007, 2007 to 2010, and 2011 to 2012, respectively ($P < 0.001$ for all combinations). Half of the respondents reported different levels of infestation in fallow and GR crops during 2011 to 2012; however, the class-interval mean for infestation was similar in fallow and GR crop fields (Figure 1C). These survey results indicate the prevalence of kochia throughout western Kansas.

Almost all respondents reported presence of GR kochia ranging from 1 to > 50% of fields during the 2011 to 2012 period (data not shown). While 90% of respondents reported GR kochia in at least 10% of fields, half of them reported GR kochia in > 50% of fields in their regions. The class-interval mean for GR kochia-infested fields was 46% of all kochia-infested fields, which equates to approximately one-third of total cropland represented in the survey and indicates the widespread occurrence of GR kochia in western Kansas.

Glyphosate Use Rate and Application Frequency. The most common recommended use rate of glyphosate since the mid-1990s is 0.87 kg ae ha^{-1}. For convenience of reporting survey results, glyphosate rates of 0.79 to 0.95 kg ha^{-1} were considered normal use rates. Responses for glyphosate use rate in fallow fields differed among the three time periods ($P < 0.001$ for all combinations) (Figure 2). Eighty-six percent of respondents reported that glyphosate use rate (per application) in fallow fields before 2007 was ≤ 0.95 kg ha^{-1} (Figure 2). The

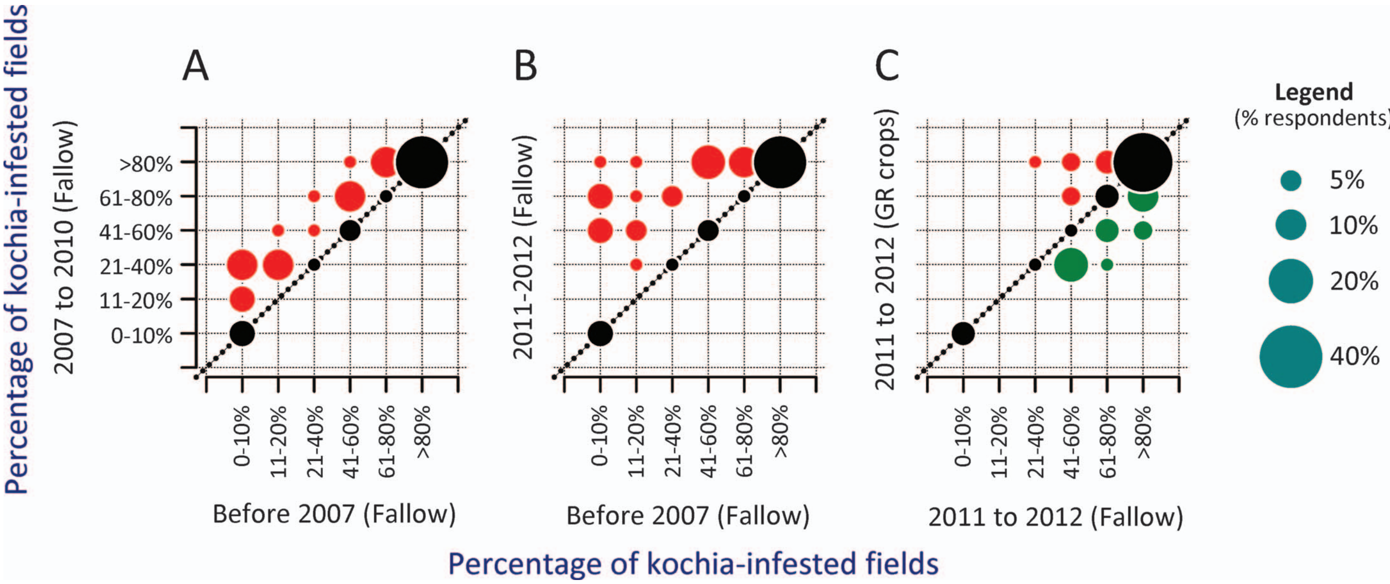

Figure 1. Bubble graph showing kochia infestation in glyphosat-resistant (GR) crops and fallow fields in western Kansas reported by crop consultants. Both axes are percentage of kochia-infested fields and circles represent percentage of respodents in proportion to circle size in the legend. (A) Kochia infestation in fallow fields in the period before 2007 plotted against that during 2007 to 2010 ($n = 41$), (B) kochia infestation in fallow fields before 2007 plotted against that during 2011 to 2012 ($n = 41$), and (C) kochia infestation during 2011 to 2012 in fallow fields plotted against that in GR crops ($n = 51$). (A and B) Red circles above the diagonal line indicate increase in kochia-infested fields during the survey period in Y-axis compared to that during the survey period in X-axis. Black circles along the diagonal line indicate similar levels of kochia infestation during both survey periods. (C) Red circles above the diagonal line indicate more infestation of kochia in GR fields than in the fallow fields and vice versa for the green circles below the diagonal line. Black circles along the diagonal line indicate similar levels of kochia infestation in GR crops and fallow fields. (Color for this figure is available in the online version of this paper.)

percentage of respondents reporting similar use rates decreased to 61 and 21% during 2007 to 2010 and 2011 to 2012, respectively (Figure 2). Glyphosate use rate increased in the two later periods compared with the use rate before 2007, with 78 and 90% of respondents reporting increased glyphosate use rate during 2007 to 2010 and 2011 to 2012 periods, respectively (Figure 2). Although only 2% of respondents reported ≥ 1.36 kg ha^{-1} use rates of glyphosate prior to 2007, 34% reported those higher use rates during 2011 to 2012. The low rates of glyphosate commonly used during the late 1990s and early 2000s may have facilitated evolution of glyphosate resistance in kochia (Gressel 2009). Continued reactive use of higher rates of glyphosate likely would further select for higher levels of resistance in kochia (Jugulam et al. 2014). Thus, the greater control of GR kochia with increased rates of glyphosate would be possible for only a few years.

Responses for glyphosate use rate in GR crops also differed among the three time periods ($P < 0.001$ for all combinations) (Figure 3). However, the responses did not differ between fallow and GR crop fields for any of the time periods ($P > 0.1$). The combined class arithmetic mean values for glyphosate use rates in fallow and GR crop fields were 0.8, 0.98, and 1.22 kg ha^{-1} for before 2007, 2007 to 2010, and 2011 to 2012, respectively (1.68 kg ha^{-1} was used as a midvalue for the $>$ 1.58 kg ha^{-1} rate).

Glyphosate application frequency per season in fallow fields averaged 2.0, 2.6, and 2.9 for before 2007, 2007 to 2010, and 2011 to 2012, respectively ($P < 0.001$ for all combinations) (Figure 4). Respondents reporting three or more applications of glyphosate per season increased from 28% before 2007 to 51 and 72% during 2007 to 2010 and 2011 to 2012, respectively. Although more than half of respondents reported increased glyphosate application frequency during the 2007 to 2010 period, more than two-thirds reported increased application frequency during 2011 to 2012 compared to before 2007. Most fields that received as many as three applications of glyphosate before 2007 also received a similar number of applications during later periods. Average number of glyphosate

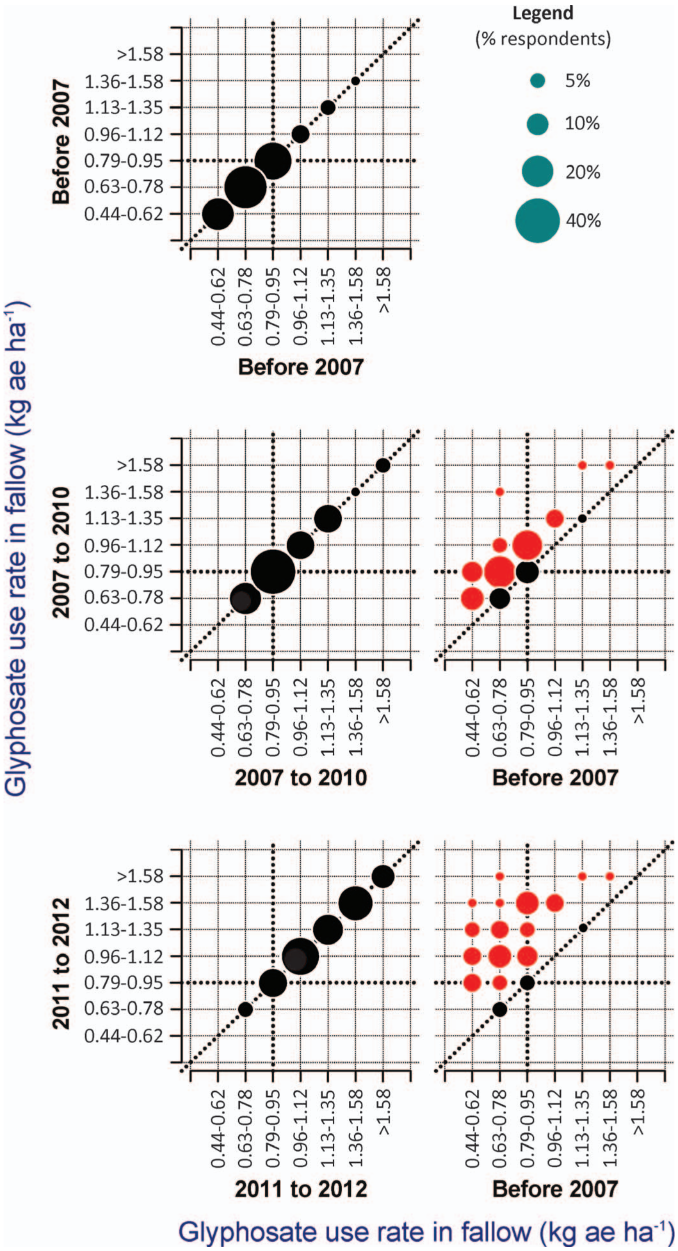

Figure 2. Glyphosate use rate in fallow fields in western Kansas reported by crop consultants ($n = 44$). Both axes are glyphosate use rate (kg ae ha^{-1}) and circles represent percentage of respondents in proportion to circle size in the legend. The highlighted grids represent normal use rates of glyphosate (0.79 to 0.95 kg ae ha^{-1}). Red circles above the diagonal line indicate increased glyphosate use rate during the survey period in Y-axis compared to that during the survey period in X-axis. Black circles along the diagonal line indicate no changes in the glyphosate rates during both survey periods. (Color for this figure is available in the online version of this paper.)

applications were similar in fallow and GR fields during corresponding time periods ($P > 0.5$ for all combinations, data not shown). Possible reasons for the increased glyphosate use rates and application frequencies reported in this survey include the declining cost of glyphosate during the survey years, evolving resistance and weed species shifts (Owen 2008, Westra et al. 2008, Wilson et al. 2007), and selection for prolonged kochia germination period (Dille et al. 2012).

Dependency on Glyphosate and Efficacy With and Without Dicamba. Frequency distribution for sole use of glyphosate in GR crops differed among the three periods ($P < 0.001$ for all combinations, data not shown). For the period before 2007, the percentage of GR fields reported to receive glyphosate-only applications varied widely among respondents, ranging from 11 to 80% of fields. However, more than half of the respondents reported sole use of glyphosate on > 50% of GR crop fields before 2007. Similarly, a majority of growers participating in a six-state study in 2006 and 2007 were reported to use only glyphosate for weed management in GR crops (Wilson et al. 2011). Hurley et al. (2009), Johnson et al. (2007), Scott and VanGessel (2007), and Young (2006) also reported glyphosate being used exclusively for weed management in GR crops. However, three-fourths of respondents in our survey reported sole use of glyphosate in GR crops declined to ≤ 50% of fields during the 2007 to 2010 period compared to the earlier period. Sole use of glyphosate continued to decline as only 25% of respondents reported it being used alone on ≤ 20% of fields during 2011 to 2012. The class-interval arithmetic mean for exclusive dependency on glyphosate in GR crops decreased from 49 to 15% of the fields during the survey years (90% was used as a midvalue for > 80%).

For the period before 2007, 85% percent of respondents reported effective control of kochia in most fields using only glyphosate (Figure 5A) and 91% reported effective kochia control using glyphosate plus dicamba (Figure 5B). However, the percentage of respondents reporting similarly effective kochia control using only glyphosate decreased to 44% during 2007 to 2010 and 8% during 2011 to 2012. Effective kochia control with glyphosate plus dicamba also declined during the 2007 to 2010 period compared to before 2007 (81 vs. 91% effectiveness) and declined further to 21% effectiveness during the 2011 to 2012 period. Drought stress in much of the survey region in 2010 and 2011 may partially explain the poor

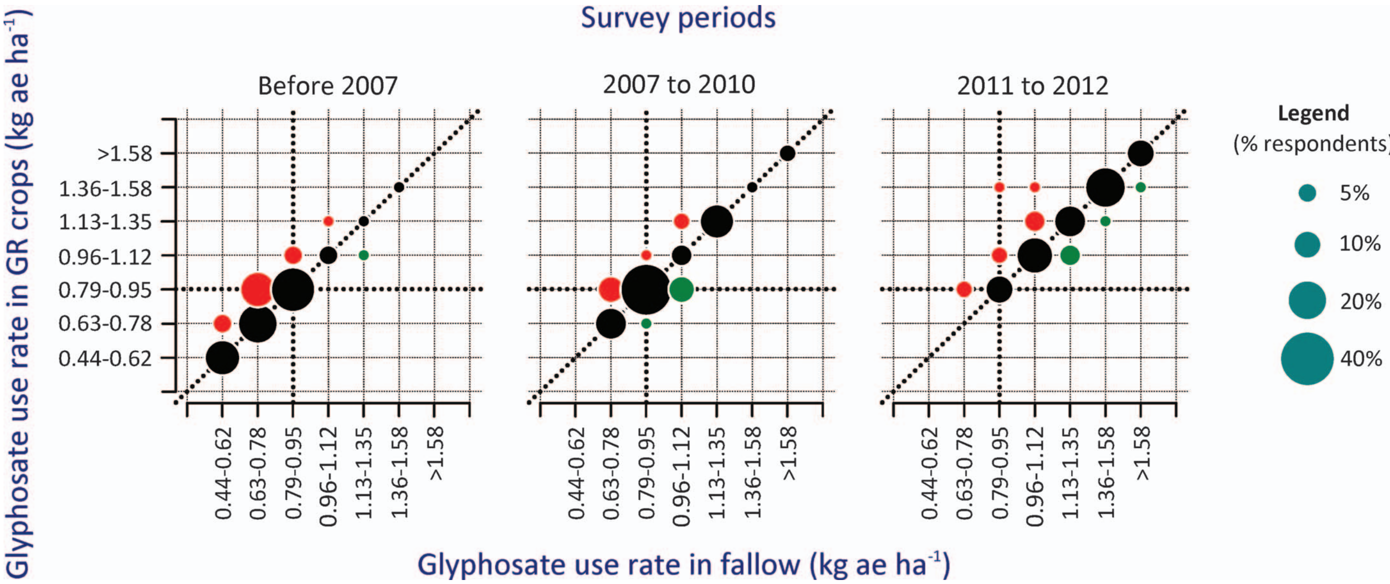

Figure 3. Glyphosate use rate in fallow fields in western Kansas plotted against that in glyphosate-resistant (GR) crop fields during 2011 to 2012 reported by crop consultants ($n = 44$, period before 2007; $n = 47$, 2007 to 2010; $n = 48$, 2011 to 2012 period). Both axes are glyphosate use rate (kg ae ha^{-1}) and circles represent percentage of respondents in proportion to circle size in the legend. The highlighted grids represent normal use rate of glyphosate (0.79 to 0.95 kg ae ha^{-1}). Red circles above the diagonal line indicate higher glyphosate use rate in GR crops compared to that in fallow fields and vice versa for the green circles below the diagonal line. Black circles along the diagonal line indicate similar rates of glyphosate applied in GR crops and fallow fields. (Color for this figure is available in the online version of this paper.)

control achieved with both glyphosate and glyphosate plus dicamba during 2011 to 2012. In addition, the results raise the possibility of multiple resistances to glyphosate and dicamba in western Kansas kochia populations. Dicamba resistance was reported in multiple Montana kochia populations in the mid-1990s (Cranston et al. 2001) and recently in Nebraska (Crespo et al. 2014). In greenhouse testing, 6 of 32 western Kansas kochia populations recovered from 420 g ae ha^{-1} dicamba POST (1.5 times common in-crop use rate) (Stahlman and Godar 2014). Most of these populations were also resistant to glyphosate.

Management Practices and Their Effectiveness During 2011 to 2012. More than half of respondents reported that the normal rate of glyphosate was used on fewer than 10% of fields, whereas the vast majority of fields received higher-than-normal rates of glyphosate or other chemical management practices (data not shown). Furthermore, three-fourths of respondents reported multiple glyphosate applications on > 60% of fields. Though higher-than-normal glyphosate use rates were effective in a higher percentage of fields compared to normal use rate or multiple applications of glyphosate, nearly three-fourths of respondents reported glyphosate alone was effective no more than half the time (Figure 6).

The number of growers using a POST herbicide other than glyphosate and PRE herbicides for kochia management were similar to those using multiple applications and higher rates of glyphosate (data not shown). Tillage was used much less frequently. Class-interval arithmetic means for kochia management practices (75% was used as a midvalue for > 60%) were 27% for normal rate of glyphosate, 52% for higher-than-normal rate of glyphosate, 56% for multiple applications of glyphosate, 50% for glyphosate plus dicamba, 57% for other POST herbicides, 52% for PRE herbicides, and 23% for tillage (data not shown). More than half and nearly three-fourths of respondents reported effective kochia control in most fields with POST herbicides other than glyphosate or PRE herbicides, respectively (Figure 6). Though kochia control with PRE herbicides was rated slightly more effective than that with POST herbicides (57 vs. 50%), at least one-fourth reported PRE herbicides were effective no more than half the time. In comparison, tillage was used on a much

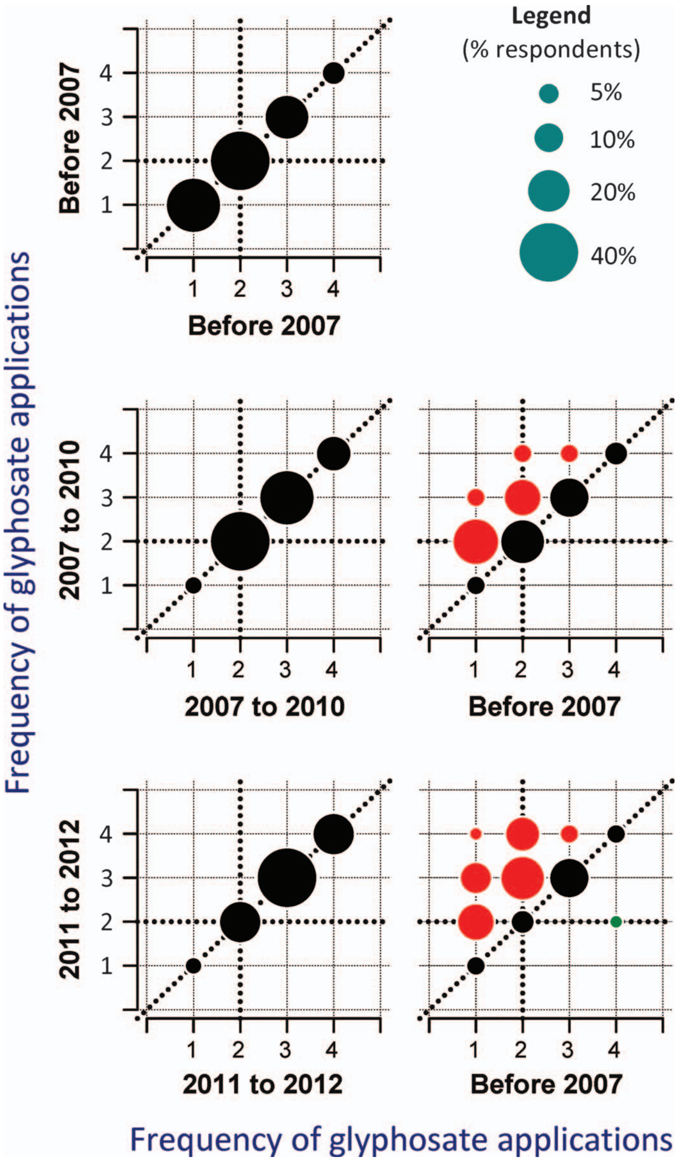

Figure 4. Glyphosate use frequency in fallow fields in western Kansas reported by crop consultants ($n = 47$). Both axes are glyphosate use frequency per season and circles represent percentage of respondents in proportion to circle size in the legend. Circles above the diagonal line indicate increased glyphosate application frequency during the survey period in Y-axis compared to that during the survey period in X-axis and vice versa for the green circles below the diagonal line. Black circles indicate no change in the frequency of glyphosate application during the both survey periods. (Color for this figure is available in the online version of this paper.)

lower percentage of fields than herbicides, but was reported to be the most effective method in controlling kochia. Though tillage was the least-used control method, its use was higher than expected and might indicate failure to control kochia with herbicides. Nevertheless, there is

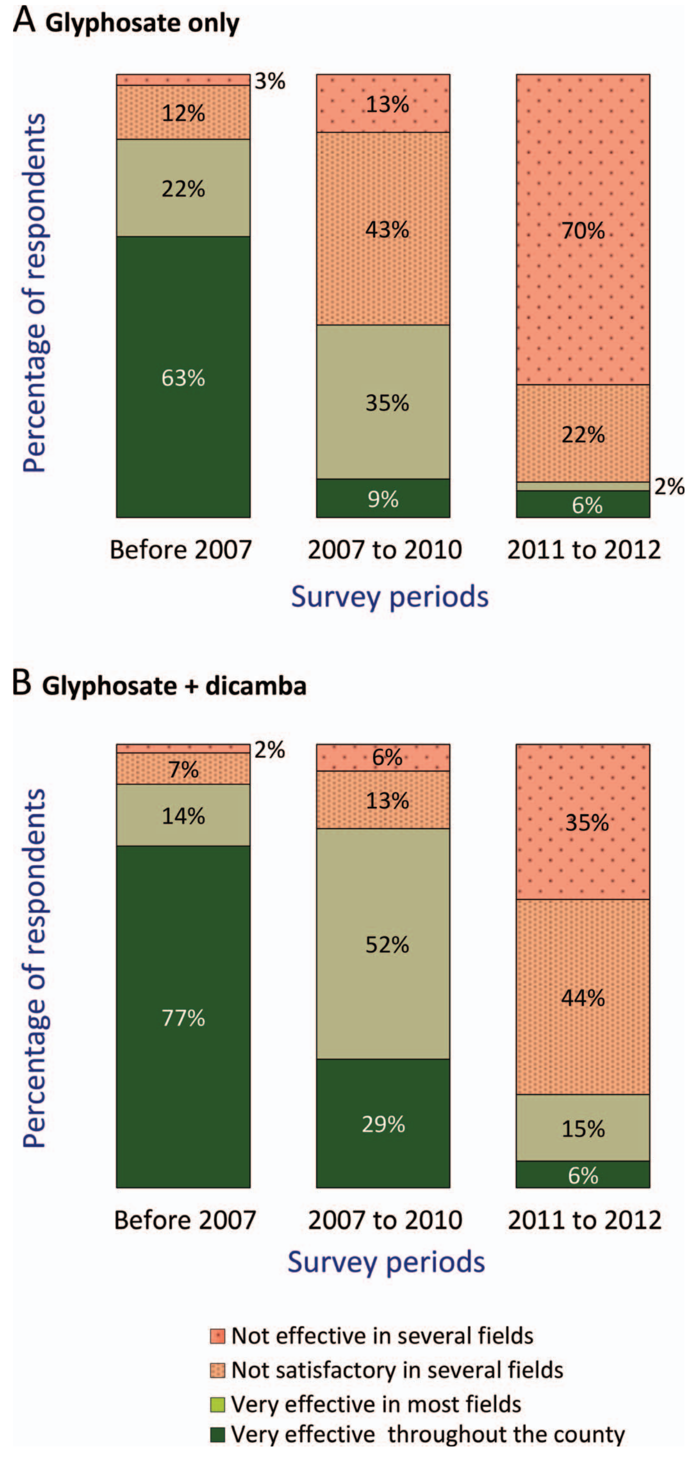

Figure 5. Efficacy of glyphosate with and without dicamba in controlling kochia as reported by crop consultants. (A) Efficacy of glyphosate-only applications ($n = 41$, before 2007; $n = 46$, 2007 to 2010; $n = 50$, 2011 to 2012), and (B) efficacy of glyphosate plus > 0.25 kg ae ha^{-1} dicamba applications ($n = 43$, before 2007; $n = 48$, 2007 to 2010; $n = 52$, 2011 to 2012). (Color for this figure is available in the online version of this paper.)

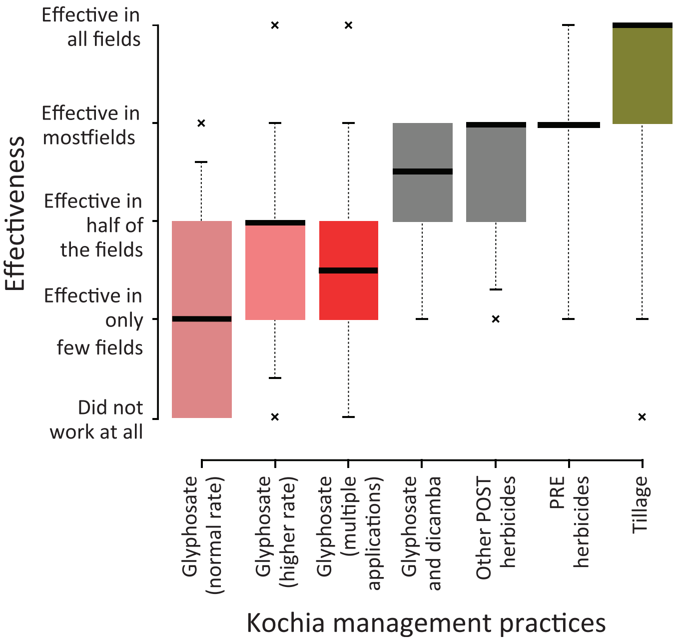

Figure 6. Effectiveness of management practices employed to control kochia during 2011 to 2012 reported by crop consultants ($n = 46$ to 52). Glyphosate rates of 0.79 to 0.95 kg ae ha^{-1} were condidered as nomal rates. The box plots show the upper quartile (Q3), lower quartile (Q1), and the median. The median is identified by a line inside the box. The length of the box represents the interquartile range (middle 50% of values). The vertical lines are the full range of values in the data except outliers. X indicates outlier response. (Color for this figure is available in the online version of this paper.)

growing concern over loss of soil and water conservation gains, and farm profitability and sustainability due to potential increase in use of tillage for controlling herbicide-resistant weeds (CAST 2012).

Survey respondents were also asked to narratively identify the most effective kochia management practice(s) used in 2012 not commonly used in prior years (responses not shown). It is logical to assume the responses provided reflect reactive rather than proactive kochia management. Most respondents reported use of a wide array of PRE herbicides applied in February to early April followed by POST herbicide applications. In a large majority of cases, sequential applications of PRE and POST herbicides were effective, especially those herbicides that provided overlapping soil residual and multiple modes of action. In most instances the cost of such herbicide programs is considerably higher compared to the cost of using glyphosate alone. Growers' primary concern in implementing herbicide resistance management practices in GR cropping system was the cost involved (Givens et al. 2011).

The rapid and dramatic decline in effective kochia control with glyphosate in Kansas emphasizes the need for growers to adopt weed resistance best management practices (BMPs) despite the added costs and reduced short-term profitability. This conclusion is in agreement with that of Weirich et al. (2011), that adoption of BMPs is required to maintain the same level of return as before on-farm occurrence of weed resistance. Diversifying weed management practices will help reduce the risk of kochia populations evolving resistance to additional herbicide modes of action. In the light of increasing occurrence of GR kochia throughout the Great Plains region, results of this survey will be useful to extension specialists, researchers, policy makers, and agro-industries for more focused information delivery and in developing BMP recommendations for GR kochia management in the Great Plains.

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