

Weed management update for 2018 and beyond: The more things change...

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Introduction

Again there are no new herbicides with novel mechanisms of action and none are anticipated in the near future. Weed management issues were very evident in 2017 and weed populations with evolved resistance(s) to herbicides continued to escalate statewide. Palmer amaranth populations have been identified in many new Iowa counties and it is likely that populations will eventually be identified in all Iowa counties. Weed management remains a major concern for Iowa agriculture and addressing these burgeoning problems requires greater diversity of tactics beyond herbicides.

Most herbicide labels now include sections describing management of herbicide-resistant (HR) weeds. These sections describe various best management practices (BMPs) which are important for the diversification of weed management programs. Typically, there is a statement that suspected HR weed populations should be reported to the company for investigation. It is hopeful that the BMPs as suggested on most herbicide labels will gain traction and more growers will adopt more diverse tactics to manage weeds.

New HR crops represent a continuation of herbicide-based weed management and evolved resistance to the concomitant herbicides may already be evident. With dicamba-tolerant soybeans, the new dicamba formulations represent challenges for managing off-target dicamba movement. Given the problems with dicamba movement attributable to particle drift during application and movement after application from volatilization, it is clear that adoption of the dicamba-based technology incurs greater risk than past herbicide technologies.

The off-target movement of dicamba is complex and involves a number of factors, some that can be addressed with better application techniques. Factors such as nozzle type, boom height, application speed, wind speed, and direction can be addressed by applicators. Other factors such as the inherent chemical characteristics of dicamba, the high sensitivity of susceptible soybean cultivars and other non-target plants, the effects of rain, temperature, relative humidity, and inversions, not just the day of application but for several days following application, cannot be addressed by applicators and increase the risk of adopting the dicamba-based technology.

The Environmental Protection Agency (EPA) added new regulatory action on the XtendiMax with VaporGrip Technology, Engenia, and FeXapan with VaporGrip Technology labels in an attempt to address the widespread off-target issues in 2017. These label changes include classifying these herbicides as Restricted Use Products (RUP) thus permitting only certified applicators with special training to better apply dicamba products. Dicamba-specific training will be required. Applicators will be required to keep extensive records for two years and these records must be made available to the Iowa Department of Agriculture and Land Stewardship, the USDA and EPA upon request. Applicators must also keep the receipts for dicamba purchases. Application parameters have been modified; applications can now be made from sunrise to sunset and wind speed during application is now restricted to 3-10 mph. Label language regarding sprayer cleanout and proximity of susceptible crops with regard to dicamba-treated fields have been expanded. We feel these label changes are appropriate, but are concerned that they do not address the issue of off-target movement due to volatilization. See the specific dicamba product labels for specific information about the changes.

The need for different technologies to address the burgeoning problem of HR weeds must be considered

in relation to the risks associated with the technology. Preemergence applications of dicamba with dicamba-resistant soybean represent the least risky use strategy and is recommended. Early postemergence applications in May, when temperatures are typically relatively cooler, have greater risk than the soil applications. The greatest risk from dicamba-based weed management is postemergence applications in June and later. We do not recommend using the dicamba-based weed management at this time due to the greater risk of off-target movement.

Regardless of pending changes in herbicides and crop traits, weed management diversification beyond herbicides must be considered in order to support the tools currently available to farmers. Iowa agriculture will not be able to resolve weed management issues by simply spraying herbicides. What follows is a summary of the limited changes in the industry for 2018; the information should not be considered all encompassing. What follows is a summary of the limited changes in the industry for 2018; the information should not be considered all encompassing.

Selected industry updates

AMVAC

Parazone 3SL herbicide (paraquat) is now available from AMVAC. Parazone 3SL is a HG22 and the formulation contains stenching (odor) and emetic materials. The label is similar to other paraquat herbicides.

BASF

Engenia herbicide was approved for use in 2017. Engenia is a 5 lb ai/gal formulation of N,N-Bis (3-aminopropyl) methylamine [BAPMA] salt of dicamba. The main label specifies uses in asparagus, CRP, corn, cotton, fallow cropland, farmstead turf (non-cropland) and sod farms, grass grown for seed, pasture, hay, rangeland, and farmstead (non-cropland), proso millet, small grain, sorghum, soybean and sugarcane. A supplemental label allows use of Engenia in dicamba-tolerant soybeans. Application can be made preplant, preemergence or postemergence. Maximum application rate (per application) is 12.8 oz/A. Combined applications per season may not exceed a maximum rate of 51.2 oz/A, e.g. two 12.8 oz/A applications to the soil (preplant and preemergence) and two 12.8 oz/A applications post. Approved nozzles, adjuvants and tank mix partners can be found at <http://agproducts.basf.us/campaigns/engenia/tankmixselector>.

Zidua SC herbicide (HG 15) will be available for the 2018 growing season. The water-based suspension concentrate formulation contains 4.17 lbs. of pyroxasulfone per gallon. The label allows preplant surface, preplant incorporated, preemergence or post emergence applications in both corn and soybeans. Use rates in corn range from 1.75 to 6.50 oz/A and from 1.75 to 5.75 oz/A in soybean. Use rates are based on soil texture and application timing.

FIFRA 24(c) Special Local Needs Label allows applications of Zidua herbicide for control of Palmer Amaranth in established federal Conservation Reserve Program (CRP) fields. The label specifies both preemergence and early postemergence applications. Application rate range is from 1.0 to 4.0 oz/A depending on soil texture and application timing. This label is for distribution and use only in the state of Iowa.

Dow Agroscience

Corn hybrids with 2,4-D (HG4) resistance (Enlist corn) are globally deregulated for the 2018 crop season. Enlist corn will tolerate applications of conventional corn herbicides and carry herbicide tolerance to glyphosate and Enlist Duo and Enlist One herbicides.

Enlist Duo (HG4 and 9) is registered and available for non-Enlist corn and soybean as preplant burndown

and preemergence (corn) and preplant burndown (soybeans). Enlist Duo is a premix of 2,4-D choline and glyphosate with Colex-D technology. Enlist Duo is also labeled for use on Enlist corn in 2018, but not available for postemergence use until the Enlist soybeans or E3 soybeans are approved by China. Enlist Duo has less potential for volatilization than other HG4 formulations but care should be taken to avoid conditions that may cause off-target movement. The Enlist Duo label describes appropriate nozzles for application, buffer requirements, and specific application techniques. Enlist Duo can be tank mixed with many surfactants and additives including AMS. Refer to <http://www.enlist.com/en/approved-tank-mixes> to confirm a given product or nozzle is approved. Herbicide-resistant weed management requirements are also included in the Enlist Duo label.

Enlist One (HG4) is a registered herbicide for the control of annual and perennial weeds for use on non-Enlist corn and soybeans as a preplant burndown, preemergence (corn) and preplant burndown (soybeans). Enlist One is also labeled on Enlist corn in 2018, but not available for postemergence use until the Enlist soybeans or E3 Soybeans are approved by China. Enlist One herbicide contains 3.8 lb ai/gal of 2,4-D choline with Colex-D technology and was developed to give greater flexibility in herbicide tank mix partners to combat hard to control and herbicide-resistant weeds in Enlist corn and soybean. Enlist One has a use rate of 1.5 to 2.0 pints/A and can be applied to Enlist corn from preplant to V8 growth state or 30 inches tall as an over the top application. Corn taller than 30 inches and less than 48 inches requires the use of drop nozzles. The Enlist One label describes appropriate nozzles for application, buffer requirements, and specific application techniques. Enlist One has the ability to be tank mixed with various surfactants, additives, and herbicides: refer to www.enlisttankmix.com to confirm a given product or nozzle is approved. Herbicide-resistant weed management requirements are also included in the Enlist One label.

Elevore (HG4) herbicide will be launched in 2018 for preplant burndown control of annual broadleaf weeds with an emphasis on winter annuals like horseweed/marestail, henbit, purple deadnettle and early spring annuals like common ragweed and common lambsquarters. Elevore contains 0.572 lbs of halauxifen acid per gallon and is applied at 1.0 oz/A 14 days prior to planting for corn and soybeans. Refer to <http://client.dow.com/elevoretankmix> to determine the herbicides available for tank mixtures with Elevore. Herbicide-resistant weed management requirements are also included in the Elevore label.

DuPont

EverpreX (HG 15) is a 7.62 EC formulation of s-metolachlor that is labeled for corn and soybeans. This product can be applied in the fall, early preplant, preplant incorporated, preemergence and postemergence for residual weed control. Note that the postemergence application does not control emerged weeds so if weeds are present at the time of application, a tankmixture with products that provides control of emerged weeds is needed. EverpreX will provide control of annual grasses and some small-seeded annual broadleaf weeds.

Revulin Q (HG 2 and 27) is a prepackage mixture of nicosulfuron (HG 2) and mesotrione (HG 27). Label changes for 2018 include the addition of COC and AMS for applications to popcorn and sweet corn, the addition of topramezone (HG 27) (e.g., Impact and Armezon) as a tank mix partner, and ability to apply Revulin Q aerially. Popcorn and sweet corn may now be replanted immediately after a Revulin Q application (see the Rotational Crops Guideline) and new sections describing cover crops and a field bioassay are included on the label. Cover crops can be planted into Revulin Q-treated fields as long as the cover crops are not grazed by livestock or harvested for forage or food. However, not all cover crops have been evaluated for sensitivity to Revulin Q so there may be a risk of injury to the cover crop. The field bioassay of the Revulin Q label describes how to assess the potential for cover crop injury from the herbicide.

Monsanto

Harness MAX herbicide (HG 15 and 27) is a premixture of acetochlor (HG 15) and mesotrione (HG

27) and available for preplant, preemergence and postemergence use in field corn, seed corn and yellow popcorn. Postemergence applications of Harness MAX can be made to corn up to 11 inches in height. Harness MAX will provide excellent control of annual small-seeded broadleaf and grass weeds as well as postemergence control of some large-seeded broadleaf weeds.

Nufarm

Panther Pro (HG 5, 14 and 2) contains 3 lbs metribuzin, 0.67 lbs flumioxazin, and 0.56 lbs imazethapyr per gallon and the use rate on soybeans is 12 to 15 fluid oz/A. The amount of metribuzin (0.28 to 0.35 lb a.i./A) is a bit higher than many other premixtures with metribuzin and may provide soil residual as well as contact activity. Panther Pro is restricted from use on sand soils (regardless of O.M.) as well as sandy loams or loamy sands containing less than 2% organic matter. Panther Pro is labeled for burndown/fallow uses as well as soybean preplant and preemergence uses. Panther Pro is very effective on many annual broadleaf weeds such as common lambsquarters, waterhemp and others as well as foxtail species and other annual grass weeds. Panther Pro provides excellent burndown of many seedling broadleaf weeds less than 4 inches in height but the addition of glufosinate, glyphosate or paraquat will help with the control of emerged grasses. Either a crop oil concentrate or methylated seed oil which contains at least 15% emulsifiers and 80% oil or a non-ionic surfactant at 0.25% v/v, may be used when applying Panther Pro as part of a burndown program.

Syngenta

There are numerous modifications on the labels of existing Syngenta proprietary products (i.e., typos for the emergency telephone number on the Acuron label). These changes pertinent for Iowa can be found on the Acuron Flexi, Acuron, Dual Magnum, Evik DF, Flexstar, Fusilade DX, Gramoxone SL, Halex GT, Reflex, and Sequence herbicide labels.

Valent

Valor EZ is a 4 lb ai/gal liquid flumioxazin formulation (HG14) registered for use in corn and soybean. Valor EZ can be applied 7 to 30 days prior to corn planting and can be applied preplant and preemergence to soybeans. The preemergence application can be made up to 3 days after soybean planting. Valor EZ may also be used as part of a fall burndown program, however it is recommended that this product be tank-mixed with 2,4-D or dicamba (HG4) or glyphosate (HG9) herbicides if weeds are present at the time of application. Refer to the Valor EZ label for all use rates and restrictions.

There do not appear to be significant changes in the proprietary products from Bayer Crop Science, FMC and Winfield.

Iowa survey of herbicide-resistant weeds

Weeds with evolved resistance to herbicides are widely distributed in Iowa. Currently there are 10 weed species identified with evolved resistance to herbicides (Table 1). It is important to recognize that reporting herbicide resistance is voluntary and may not reflect the actual situation, particularly for weed populations with multiple resistances. Waterhemp populations have been reported in Nebraska with evolved resistance to HG 4 herbicides and common sunflower populations have evolved resistance to HG 9. Iowa horseweed/marestail populations have evolved resistance to HG 2 and 5, but this has not been reported to the International Survey of Herbicide Resistant Weeds (<http://www.weedscience.com>). Similarly, giant ragweed populations in Iowa have evolved resistance to HG 27. Importantly, the evolution of herbicide resistance continues to increase in Iowa and herbicide resistant weed population densities in specific fields are increasing, thus becoming an economic concern.

In 2010, the Iowa Soybean Association requested that the Iowa State University weed science program survey soybean fields in Iowa to gain a better understanding of the herbicide resistance problem. The task became much greater than originally proposed and has just recently been completed. Approximately 900 waterhemp populations were sampled in Iowa (Figure 1). While the information is dated, and likely under-reports resistance to HG 14 and HG 27, the information provides a comprehensive picture of herbicide resistance in Iowa for waterhemp. Giant ragweed and horseweed/marestail populations sampled will be completed next but the number of fields with these weeds is considerably less than those with waterhemp.

Table 1. Weed species with evolved herbicide resistance in Iowa.

Date reported	Weed species (<i>Latin binomial</i>)	Herbicide site of action reported in Iowa	Multiple herbicide resistances reported in Iowa
1985	Kochia (<i>Kochia scoparia</i>)	5	No
1989	Common lambsquarters (<i>Chenopodium album</i>)	5	No
1990	Pennsylvania smartweed (<i>Polygonum pennsylvanicum</i>)	5	No
1992	Giant foxtail (<i>Setaria faberi</i>)	5	Yes (HG1 in 1994)
1993	Tall waterhemp (waterhemp) (<i>Amaranthus tuberculatus</i>)	2	Yes (HG5 in 1996, HG 14, 9, and 27 in 2009)
1995	Common cocklebur (<i>Xanthium strumarium</i>)	2	No
1997	Common sunflower (<i>Helianthus annuus</i>)	2	No
1998	Shattercane (<i>Sorghum bicolor</i>)	2	No
2000	Giant ragweed (<i>Ambrosia trifida</i>)	2	Yes (HG 9 in 2009 and HG 27 in 2016)
2011	Horseweed/marestail (<i>Conyza canadensis</i>)	9	No

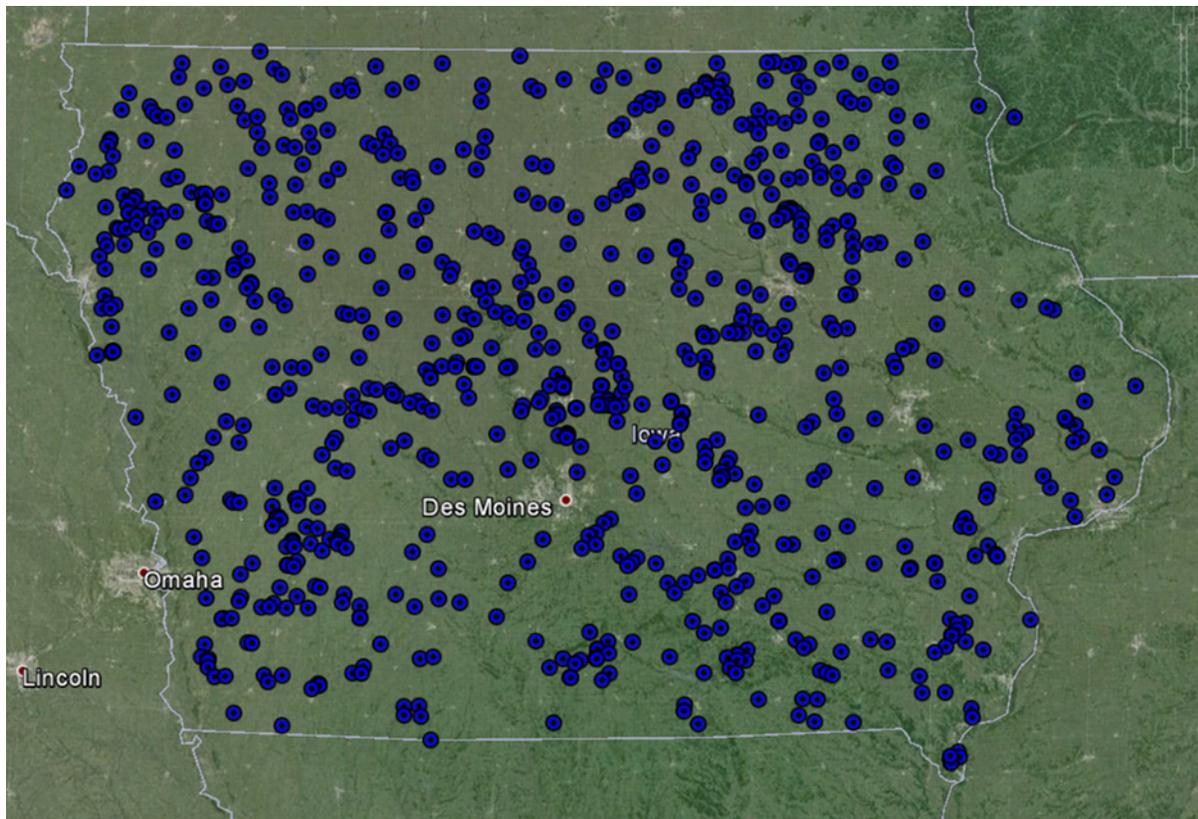


Figure 1. Sample collection locations in Iowa, 2011-2013.

Methods used

The original idea was to arbitrarily sample soybean fields that had weeds visible above the canopy in August and September. Approximately 300 soybean fields were sampled in 2011 and 2012. This approach increased the likelihood that the escaped weeds were resistant to herbicides but no information about the herbicide use history was collected. The GPS coordinates of the fields were recorded so return visits were possible.

It was decided that a random selection of fields would provide more useful and predictive information about evolved herbicide resistance. Thus in 2013, a procedure was developed that provided the prediction of herbicide resistance at the 95% confidence interval in any Iowa soybean field. This procedure used the number of soybean acres reported in each county to determine how many fields should be sampled in order to provide an estimate of herbicide resistance. Collaboration with the Iowa State University Department of Statistics and the Geographic Information Systems laboratory resulted in identifying the GPS coordinates of 400 fields that would be visited. Using the same two inclusionary principles as the 2011 and 2012 collections (e.g., soybean field and weeds visible above the canopy), weeds were collected and screened to allow predictions of herbicide resistance at the 95% confidence interval. Approximately 900 waterhemp populations were sampled for the project (Figure 1).

Several female waterhemp plants were collected from each field, GPS coordinates of the fields were recorded and samples were dried for a number of days. Seeds were threshed by hand, cleaned, and samples were wet-chilled for several weeks to break dormancy. Seed samples were then air-dried and seeds planted and grown in the greenhouse until plants were approximately 3-4 inches tall, at which time they were treated with a herbicide. Herbicide treatments included an HG 2 herbicide (Pursuit), an HG 5 herbicide

(atrazine), an HG 9 herbicide (Roundup), an HG14 herbicide (Cobra), and an HG 27 herbicide (Callisto). All herbicides were applied at label rates with adjuvants included as suggested in the herbicide labels. Nine waterhemp plants from each population were evaluated for control for each herbicide group and populations were evaluated for all five herbicide groups.

Herbicide response was visually assessed on a scale of 0-100 where 0 response indicated no herbicide affect and 100 indicated plant death. Populations were determined to be resistant if the averaged herbicide response was 80% or less when compared to a waterhemp population known to be sensitive to all herbicide groups.

Results

The herbicide groups included in the survey were chosen as they represent the most commonly used herbicides in Iowa. The levels of herbicide resistance found were surprisingly high for the five herbicide groups evaluated. However, given the years these herbicides have been used in Iowa, often in both corn and soybean, and the inevitability of evolved herbicide resistance, perhaps it is not that surprising. It should be recognized that the waterhemp populations in most fields that fulfilled the inclusionary principles were relatively low in population density and often represented scattered patches and individual plants. Given the ability of waterhemp to produce high seed numbers, it is possible that the population density may increase quickly in these fields unless appropriate management tactics are adopted.

Resistance to ALS inhibitor herbicides (HG 2) in waterhemp is widely distributed and represents virtually all fields in Iowa based on the 2013 evaluation (Figure 2). While one ALS herbicide was used in the screen (Pursuit), waterhemp demonstrates cross-resistance to all HG 2 herbicides regardless of application technique. Thus, HG 2 herbicides are not effective in managing waterhemp in Iowa. While waterhemp populations may not be homozygous for the resistance trait, the sensitive waterhemp in these populations is likely a minor component, given the historic use of HG 2 herbicides.

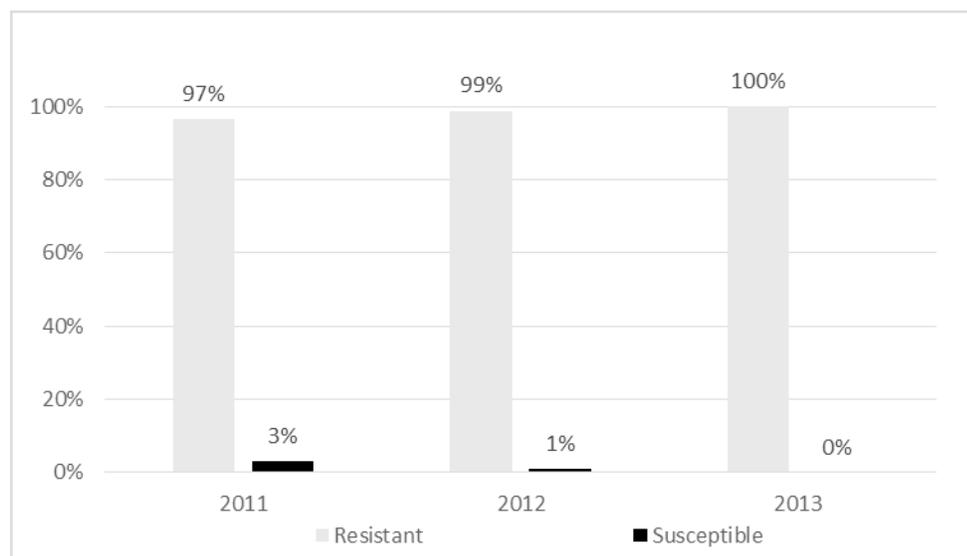


Figure 2. Evolved resistance in waterhemp to ALS herbicides (HG 2) in Iowa 2011-2013.

Atrazine was used as the representative HG 5 herbicide. There is some difference in opinion whether waterhemp with evolved resistance to atrazine behaves similarly to other HG 5 herbicides such as an asymmetric triazine such as metribuzin. Preliminary research suggests that these HG 5 herbicides may

still be effective to control waterhemp with evolved resistance to the symmetric triazine herbicides (e.g., atrazine) (Owen, data unreported). Given the continued use of atrazine for many decades, it is not surprising that evolved resistance in waterhemp is so widely distributed in Iowa (Figure 3). Historically, HG 5 herbicide was target site-based and incurred a fitness penalty to the resistant populations (LeBaron 1991). However, with the changes in atrazine usage, application rates have declined considerably which, considering the fitness penalty, should result in the decline of HG 5 biotypes. However, reduced herbicide rates facilitate the evolution of herbicide resistance and metabolic HG 5 resistance has been reported in waterhemp (Gressel 2011; Huffman et al. 2015). Based on the 2013 waterhemp collection, at the 95% confidence interval 97% of the fields in Iowa have detectable resistance to HG 5.

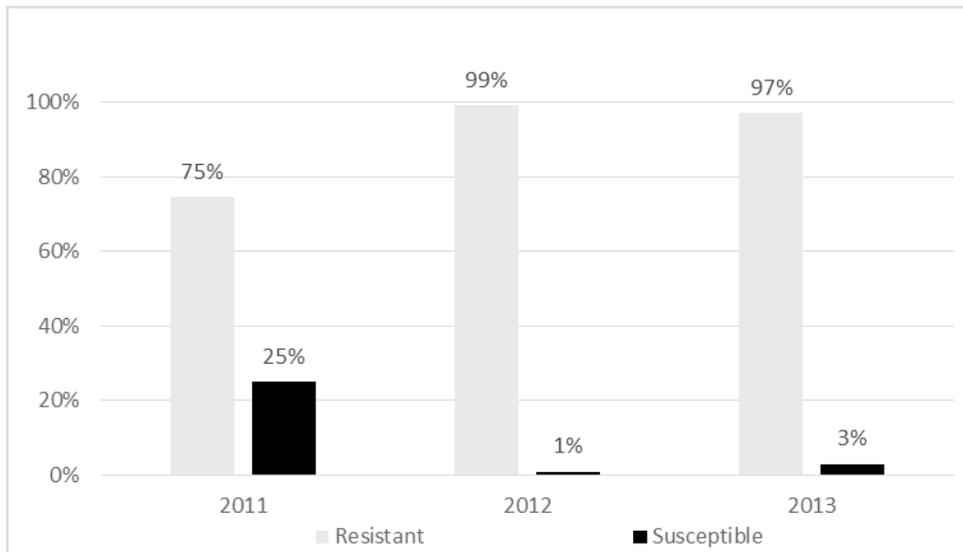


Figure 3. Evolved resistance in waterhemp to PSII herbicides (HG 5) in Iowa 2011-2013.

The adoption of crop cultivars with genetically-engineered tolerance to glyphosate in the mid-1990s was arguably the most important change in agriculture since the introduction of the moldboard plow. Despite the public concerns about technology, the benefits outweigh the risks (Duke and Powles 2008). However, the evolution of resistance to glyphosate has also changed agriculture and has benefited from the resurgence of the importance of weed management (Chatham et al. 2015). Glyphosate has been used on most of the Iowa corn and soybean acres for more than a decade and the inevitable evolution of glyphosate resistance is wide-spread and is predicted to be in 98% of the fields in Iowa (Figure 4). The occurrence of glyphosate resistance increased from 2011-2013 and it is unlikely that glyphosate resistance in waterhemp will decline even if other technologies are adopted.

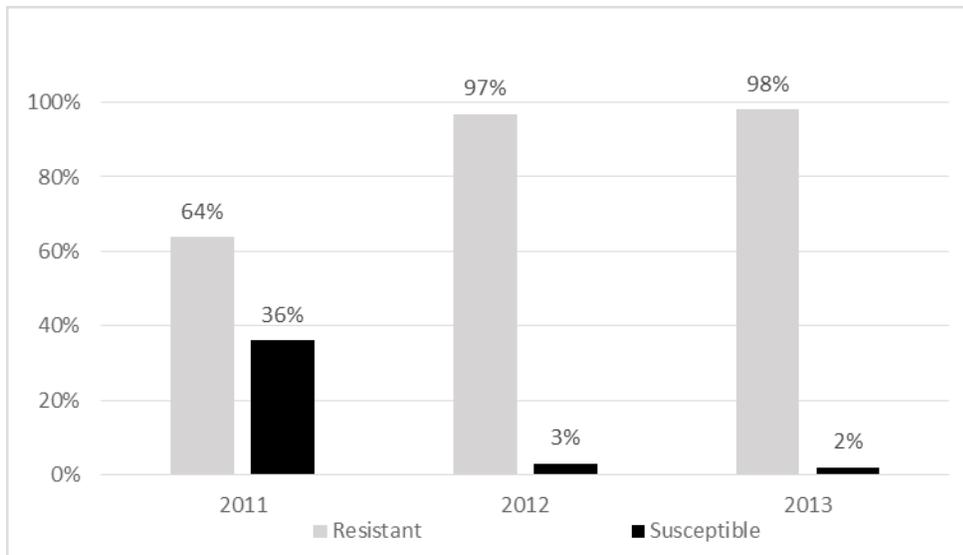


Figure 4. Evolved resistance in waterhemp to glyphosate (HG 9) in Iowa 2011-2013.

The evolution of HG 14 resistance did not change during the course of this survey (Figure 5). However, given the increased importance of HG 14 herbicides to control glyphosate-resistant waterhemp, it is likely that these data greatly underestimate the occurrence of HG 14 resistance in waterhemp (Thinglum et al. 2011). This herbicide group is seen as the only selective postemergence option in soybean weed control despite the phytotoxicity these herbicides cause. The use of HG 14 herbicides as soil-applied treatments has also increased. The increased use of HG 14 herbicides will result in more waterhemp populations with resistance. (Wuerffel et al. 2015)

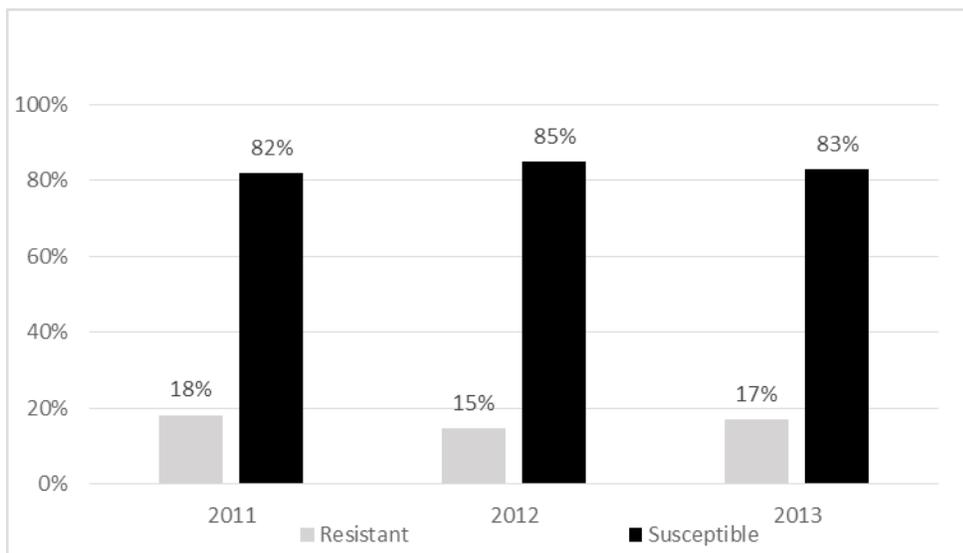


Figure 5. Evolved resistance in waterhemp to PPO inhibitor herbicides (HG 14) in Iowa 2011-2013.

The last new herbicide mechanism of action commercially introduced was the HG 27 herbicides almost 30 years ago. These herbicides have been widely used in corn, and as a result evolved resistance to HG

27 herbicides is widely distributed in Iowa (Figure 6). It is suggested that these data underestimate the occurrence of HG 27 resistance given the increased use of these products since the survey ended. Resistance to the HG 27 herbicides is reported to be due to metabolism (Huffman et al. 2015). Recent research conducted at Iowa State University has verified that HG 27 is dominant or semi-dominant and polygenic with the number of genes involved with the metabolic resistance increasing with the herbicide rate (Kohlhase, unreported). The polygenic nature of HG 27 resistance may make management in the field more difficult. Further, the frequency of HG 27 resistance brings into question how effective the anticipated HG 27 resistance in soybean cultivars will be at supporting weed management.

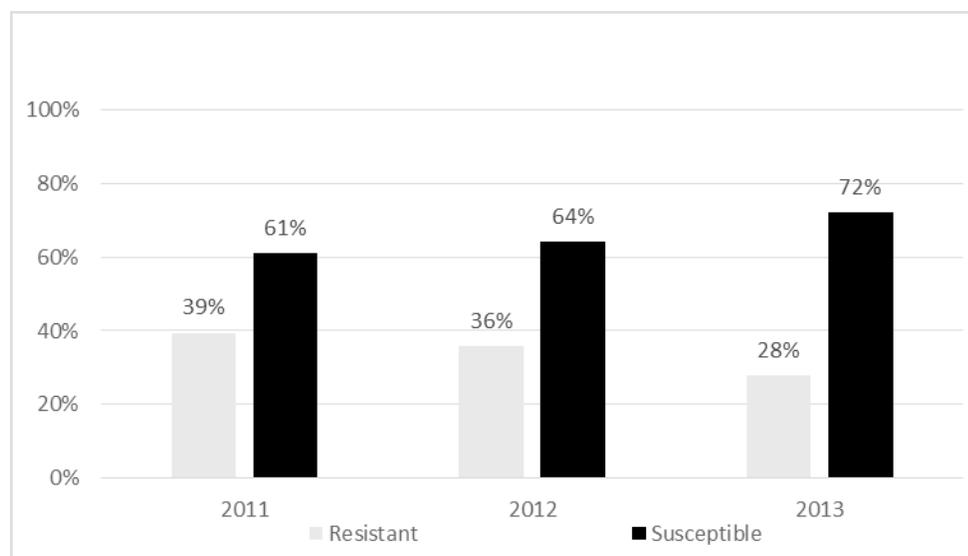


Figure 6. Evolved resistance in waterhemp to HPPD inhibitor herbicides (HG 27) in Iowa 2011-2013.

A problem with herbicide resistance in waterhemp is there does not appear to be a fitness penalty associated with the resistance (Wu et al. 2017). As a result, the resistance trait is likely to be conserved even if the herbicide is not used. New evolved resistances will be added to previously evolved resistance (Patzoldt et al. 2005). Given the dearth of new herbicide mechanisms of action, multiple resistances in waterhemp dramatically increased the difficulty of management. Multiple herbicide resistances in Iowa waterhemp populations is the norm (Figure 7). Waterhemp populations with resistance to three herbicide groups increased over the course of this study, and in 2013 69% of the waterhemp populations demonstrated three-way resistance. This estimate is correct at the 95% confidence interval. Not surprising is the observation that the most common three-way resistance are for HG 2, HG 5, and HG 9, the most commonly used herbicide groups. Resistance to four herbicide groups and five herbicide groups (all the herbicide groups used in the screen) did not change over the course of the study with four-way resistance more commonly detected than five-way resistance. Management of multiple herbicide resistant waterhemp is a significant challenge for farmers.

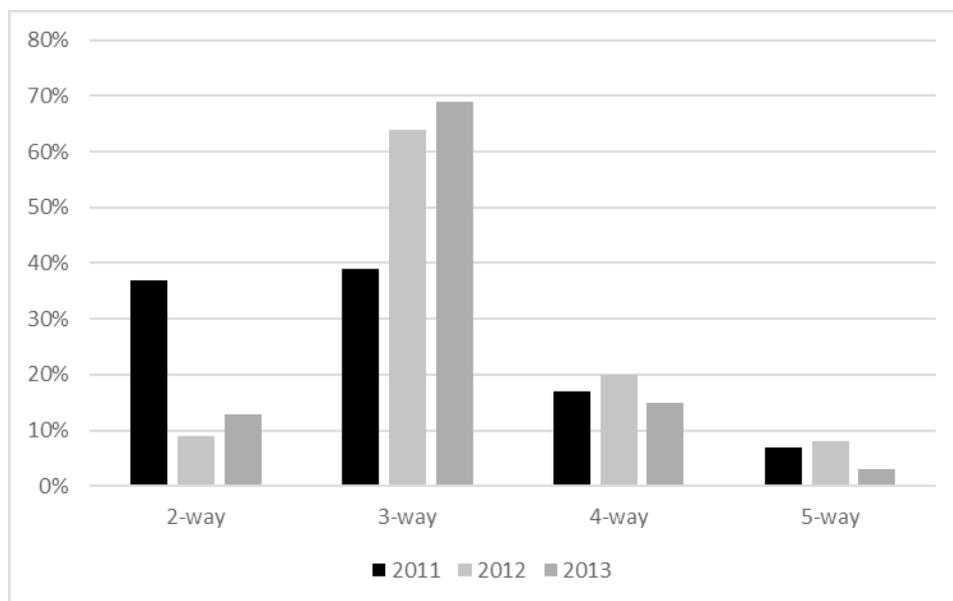


Figure 7. Evolved multiple resistance in waterhemp to in Iowa 2011-2013.

Conclusion

Regardless of pending changes in herbicides and crop traits, weed management diversification beyond herbicides must be considered in order to support the tools currently available to farmers. Iowa agriculture will not be able to resolve weed management issues by simply spraying herbicides. The new dicamba formulations must be used cautiously and with considerable attention to detail. While dicamba provides broadleaf weed control in dicamba-tolerant soybean cultivars, there is also risk of off-target movement.

With regards to herbicide-resistant weeds, it is important to understand that most of the fields from which waterhemp populations were collected were transitioning from sensitive to resistant and the population density of waterhemp found was likely lower than the level that would be recognized by a farmer and cause a major concern. Nevertheless, the levels of HR detected suggests that unless remediation is initiated, wide resistance to herbicides in Iowa waterhemp populations will likely increase. Despite farmers' desires to have available a new herbicide, it is impossible to spray the problem of herbicide resistance in waterhemp away. The only solution is the judicious use of herbicides and adoption of greater diversity of weed management tactics (Owen 2016; Owen et al. 2015).

The path forward

The need for better weed management continues to be a critical concern for Iowa agriculture. However, despite the widespread occurrence of herbicide resistance in waterhemp, giant ragweed, and horseweed/marestail, most fields in Iowa are in a position to allow continued effective weed control if farmers will diversify their tactics. The thoughtful choice of herbicides with still-effective mechanisms of action is critically important, however, given that most waterhemp populations have evolved multiple resistances, knowing which herbicide mechanisms of action are still effective is a major challenge. The drought of new herbicides in the developmental pipeline continues to be a major problem and the long-term forecast for new herbicides with novel mechanisms of action is not bright. While new herbicide-resistant crop cultivars are available, the herbicides for those cultivars already have resistant weed populations. Clearly, issues in

weed management continue to be increasingly complex, and there are no simple and convenient answers despite what product marketing might suggest. The problems of off-target dicamba represents a major problem for agriculture and there does not appear to be a clear answer to these issues.

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