2014 Herbicide Guide for Iowa Corn and Soybean Production

Weed management update for 2014

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Weed management in 2014 will continue to be more challenging regardless of the weather. Factors such as prevented planting, poor weed control in 2013, increasing populations of weeds with evolved herbicide resistances and recently, the discovery of Palmer amaranth in Iowa will make weed control decisions interesting and likely difficult. However, other factors such as grower and dealer attitudes, commercial promotional incentives, desire for simple and convenient tactics and perceived costs of more diverse alternative approaches to weed management programs are still primary considerations impacting weed control.

Increasing the diversity of weed management tactics will improve the consistency of weed control, mitigate herbicide-resistant weeds and increase profitability. However, these tactics will require more planning, time, and possibly higher initial costs; to effectively diversify weed management requires that fields be considered individually and possibly unique strategies developed for each field. All possible "tools" should be considered and as many as possible included in the weed management plan.

There is a long history demonstrating that simple and convenient approaches to pest management, and in particular weed management, will inevitably fail biologically and economically. The objectives of this paper are to provide an update of changes in the industry that may impact weed management decisions for 2014, review the state of herbicide resistant weeds in Iowa, provide some information about alternative weed management tactics and list some perspectives about weed management decisions.

Selected industry updates

Industry representatives were asked in late summer and early fall to provide information about their proprietary products, programs and new developments that would potentially impact weed management in 2014. Based on the responses, it is clear that the trend of no new herbicide mechanisms of action (MOA) continues. Furthermore, while there are a number of new herbicide premixtures now available, these represent combinations of older products. One thing that is consistent across the industry is to highlight using proprietary products to address the issues of evolved resistance to herbicides. Development of new genetically-engineered (GE) herbicide-resistant (HR) crop cultivars continues although the target herbicides for the new HR crops have been available for many years and to which waterhemp has already evolved resistance. Not all companies are represented in this update which reflects whether or not they accepted the opportunity to submit information. Inclusion of any product in this update does not imply endorsement nor does exclusion imply that the product is not recommended.

BASF has reported that a number of products are no longer available. Specifically, G-Max Lite and Guardsman Max herbicides are no longer formulated. Clearfield corn systems are essentially dead according to BASF-supplied information and Distinct is no longer labeled on corn. Armezon is labeled for application up to 45 days prior to harvest however cannot be applied to corn that is beyond the V8 growth stage. Outlook herbicide is now labeled to be applied postemergence to soybeans from emergence (cracking) to the fifth trifoliate

Contents

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WC-94 | Revised Dec 2013

weeds that have emerged will not be controlled by Outlook. This strategy will provide extended residual control of waterhemp, Palmer amaranth and grasses. If a preemergence application of Outlook is followed by a postemergence Outlook application, at least 14 days between applications should occur and the seasonal total of 24 ounces of Outlook should not be exceeded. The first Outlook application should be 8 to 16 ounces and 8 to 16 ounces (depending on the first application) for the second application. Zidua is now labeled for soybeans and can be applied preplant surface, preplant incorporated, preemergence and early postemergence (1st to the 3rd trifoliate). Sharpen can be used as a harvest aid/desiccant in soybeans.

Bayer CropScience has continued with an emphasis on better management of weeds and specifically are targeting herbicide-resistant weeds. Liberty herbicide in conjunction with Liberty Link corn and soybean, represents a good tactic to help manage weeds, particularly those that have evolved resistance to glyphosate. Bayer CropScience recommends that residual herbicides be used along with the Liberty and highlights the need for timely application on smaller weeds. In the Bayer CropScience "Respect the Rotation", the need for alternative tactics, integrated weed management, and timeliness of all weed management is stressed. Some growers, however, are looking to continue the type of management programs that were used in glyphosate-based systems. This is particularly a concern in the Mississippi Delta where a relatively high percentage of growers indicate plans to switch to Liberty Link crop cultivars and only apply Liberty as the sole weed management approach. This approach will inevitably result in weeds with evolved resistance to Liberty in a few years.

Cheminova is marketing Crusher which is a premixture of rimsulfuron and thifensulfuron-methyl, both Group 2 herbicides. Fall, preplant and preemergence applications are registered for corn while fall and preplant (30 days or more before planting) are registered for soybeans.

Dow AgroSciences is continuing to develop the 2,4-D-resistant corn and soybean cultivars. However, the anticipated deregulation has been delayed due to a required Environmental Impact Statement (see below). Also a number of new acetochlor products with and without atrazine are now available. Surpass NXT is a 7 pound per gallon acetochlor registered for all types of corn including seed corn, popcorn and sweetcorn. KeyStone NXT and KeyStone LA NXT are also registered for all types of corn with the amount of acetochlor and atrazine included in the premixture changing depending on the specific product. FulTime NXT is an encapsulated formulation of acetochlor and atrazine now available for application to all types of corn.

DuPont Crop Protection is anticipating the registration of Trivence herbicide for use in soybeans. Trivence is formulated as a water dispersible granule and contains chlorimuron ethyl, flumioxazin and metribuzin and may be applied preplant or preemergence up to three days after planting. Panoflex and Alluvex are now registered. Panoflex contains tribenuron methyl and thifensulfuron methyl, both Group 2 herbicides, is formulated as a water dispersible granule, and can be applied postharvest, fallow or preplant burndown prior to corn or soybeans. Alluvex is a water dispersible formulation of rimsulfuron and thifensulfuron-methyl that can be applied preplant, preemergence or a burndown treatment in field corn. DuPont also will be introducing a number of formulation and name changes for several existing products. Canopy will now formulated as a homogeneous blend of metribuzin and chlorimuron ethyl water dispersible granules and renamed Canopy NXT. Similarly, Breakfree herbicides will be renamed Breakfree NXT herbicides. DuPont is also stressing at plant, burndown and fall applications of their proprietary herbicides such as Basis Blend, Envive, Enlite, and Instigate. Refer to the labels for specific application details.

FMC has a new premixture called Authority Maxx which has a 16:1 ratio of sulfentrazone and chlorimuron ethyl compared to an 8:1 ratio in Authority XL. Solstice, which is a premixture of Cadet and mesotrione, will be registered for corn. Marvel is a premixture of fluthiacet methyl and fomesafen registered for preplant burndown and postemergence applications in soybean. Anthem which is a premixture of fluthiacet and pyroxasulfone will be labeled for soybeans and supplements the existing corn registration.

Makhteshim Agan of North America (MANA) will be marketing a number of herbicides in 2014. Pummel is a premixture of metolachlor and imazethapyr registered for soybeans. Rumble is a formulation of fomesafen registered for postemergence application to weeds in soybeans. Torment is a combination of fomesafen and imazethapyr that can be applied preplant, preemergence and postemergence in soybeans. Tailwind is a combination of metolachlor and metribuzin that is registered for preplant incorporated and preemergence application in soybean.

Monsanto continues to develop the dicamba-resistant soybean cultivars and new formulations of dicamba that are anticipated to reduce off-target drift attributable to volatilization. However, with the Environmental Impact Statement requirement, deregulation of the GE HR soybean cultivars is delayed (see below).

Syngenta is marketing Callisto GT for postemergence applications in glyphosate-tolerant corn. This product contains mesotrione and glyphosate. Lexar EZ and Lumax EZ are new premixtures of mesotrione, metolachlor atrazine and benoxacor (a safener) registered for corn. These two premixtures have different ratios of the three herbicides and are registered for all types of corn and grain sorghum. Label tank mixing guidelines for Gramoxone SL 2.0 have been modified; specifically, the order that the non-ionic surfactant is added has changed to be added prior to any herbicides. The label also now describes the addition of crop oil concentrates or methylated seed oils. Sequence (metolachlor plus glyphosate) is now registered in Iowa for use in corn.

Alternative tactics for herbicide-resistant and herbicide-sensitive weed management

There has been considerable discussion about developing more diverse weed management programs and most of the discussion has focused on improving control of weeds with evolved resistance(s) to herbicides (Table 1). However, the diversity that most growers are currently willing to consider primarily focuses on changing, adjusting or adding herbicides to the program. There has been considerable traction to the rotation of herbicides and including multiple herbicide MOAs, however there is not, in the opinion of the author, a good understanding of how to implement these tactics effectively (Arbuckle Jr. and Lasley, 2013; Norsworthy et al., 2012). In part, this lack of understanding is attributable to socio-economic issues (e.g., time management and perceived costs) but also because of poor or unclear communication by the industry that is compounded by a lack of understanding on the part of growers (e.g., recognizing the MOA of herbicide pre-mixtures, identifying herbicide resistance(s) in specific fields) (Owen, 2012).

Clearly, the discussion about alternative weed management should go beyond focusing only on herbicides. Consider that there are no truly new or novel tactics to manage weeds, just recycled or reinvented ideas. Integrated weed management has not changed in principle but has been redefined and revisited as deemed necessary to meet current crop production systems (Baldwin and Santelmann, 1980; Blackman, 1950; Green and Owen, 2011). An incomplete description of alternative weed management tactics follows; recognize the greater the diversity of tactics, the more successful the overall weed management program will be. Often, the combination of tactics will supplement each other resulting in considerably better management of weeds (De Bruin et al., 2005; DeVore et al., 2012; DeVore et al., 2013; Katsvairo and Cox, 2000b; Krutz et al., 2009).

Crop rotation

Historically, diverse crop rotations have demonstrated consistent positive impacts on weeds; weed population densities and biomass production are markedly reduced by crop rotations which provide diversity over time (Liebman and Dyck, 1993). Crop rotations can be supplemented by intercropping tactics which provides increased diversity spatially. Crop rotation impact weeds by creating a different environment by changing resource competition, soil disturbance and other aspect of the crop system resulting in an unstable situation for specific weeds that have proliferated in a system lacking crop rotation. However, the diversity of the crop rotation should consider the herbicide options available for all rotational crops.

Where herbicides are not used on specific crops in a diverse crop rotation system, the reduction of the weed seedbank may be lessened (Gulden et al., 2011). However for more complex the crop rotation schemes, one crop without an herbicide treatment may not negatively impact the overall reduced weed seedbank. Tillage used in a diverse crop rotation program impacts the effectiveness on weed management as well as the potential crop yield and overall economics of the system (Katsvairo and Cox, 2000a; Katsvairo and Cox, 2000b). Crop rotation as an herbicide-resistant weed management practice was reported to be somewhat effective, effective or very effective by 97% of the respondents to the 2013 Iowa Farm and Rural Life Poll (Arbuckle Jr. and Lasley, 2013).

Table 1. Assessment of current and alternative tactics to help manage weeds (Adapted from (Owen, 2001))

Tactic	Benefits	Risks	Relative effectiveness	Adoption rate
Herbicide MOA rotation	Reduced selection pressure, control of herbicide resistant weeds, greater diversity	Lack of new and available MOAs, phytotoxicity, limited weed spectrum of alternatives	Fair to excellent	High
Herbicide mixtures	Reduced selection pressure, improved control, broader weed spectrum, greater diversity	Poor activity on HR weed species, increased cost, potential phytotoxicity, use of reduced herbicide rates	Fair to excellent	High
Variable application rate and timing	Better control of target weeds, more efficient use of herbicides, fall applications for winter annuals	Reduced residual activity, poor application timing, more applications, selection for non-target site resistance	Fair	Medium
Adjusted herbicide rates	Better control of target species, longer residual activity	Increased target-site selection pressure with higher rates, increased non-target site selection with reduced rates	Excellent (high rates), Poor (reduced rates)	High
Precision application	Decreased herbicide use, reduced selection pressure	Increased application cost, weed maps unavailable, poor understanding of weed seedbank dynamics, variable control	Fair	Low
Primary tillage	Decreased selection pressure, greater diversity, consistent efficacy, depletion of weed seedbank	Increased time required, increased soil erosion, increased costs, more fuel used, supplemental tactics required	Good to excellent	Medium
Mechanical tactics	Decreased selection pressure, consistent efficacy, relatively inexpensive, greater diversity	Increased time required, possible increased soil erosion, increased costs, more fuel used, possible crop injury	Fair to good	Low
Crop selection/ rotation	Improved diversity, allow different herbicide options, reduced selection pressure	Economic risks of alternative rotation crops, rotation crops too similar to increase diversity, inconsistent impact on HR weeds, lack of research base	Fair to good	Low to high
Adjusted planting time	Improved efficacy on target weeds, reduced selection pressure	Requires alternative strategies, potential for yield loss, need for increased rotation diversity, useful for specific crops	Fair to excellent	Low
Adjusted seeding rate	Improved crop competitive ability, reduced selection pressure	Increased seed costs, potentially increased risk from other pests, increased intraspecific competition, reduced yields	Fair	Low to medium
Planting configuration	Improved crop competitive ability, reduced selection pressure	Limits mechanical tactics, equipment limitations, places emphasis on herbicides	Fair	Low to medium
Cover crops, mulches, intercrop systems	Greater diversity, improved competitive ability, reduced selection pressure, possible allelopathy	Inconsistent impact on HR weeds, poor understanding of the system and lack of research information, lack of good cover crops, need to manage the cover crop/ mulch	Fair to good	Low
Weed seedbank management	Reduced HR weed pressure, reduced selection pressure	Poor understanding about seed bank dynamics, need for aggressive tillage, emphasis on herbicides, high level of management skill required, need for novel equipment	Fair	Low to medium
Manipulation of nutrients	Improved crop competitive ability, efficient use of nutrients, lower nutrient costs, greater diversity	Poor research base, inconsistent results, potential for crop yield loss	Poor to fair	low
Flaming	Greater diversity, decreased selection pressure, relatively inexpensive equipment	Increased time required, increased costs, more fuel used, possible crop injury	Fair to good	low
Herbicide-resistant crops	Ability to use specific herbicides, no crop injury, control of existing specific herbicide resistances	Lack of diversity, increase selection pressure, concerns for non-target crops, possible limited weed spectrum	Fair to Excellent	Medium to high

Cover crops

Cover crops provide on farm and off farm benefits when they are included as a component of a crop production system (Snapp et al., 2005). The benefits provided by cover crops include, but are not limited to pest suppression, reduced soil erosion, improved water quality and better nutrient cycling. The costs of cover crops, reflecting both economic as well as time utilization cost, are important considerations when deciding the utility of cover crops (Snapp et al., 2005). There has been considerable interest in using cover crops as a component of a diversified weed management program to help control herbicide-resistant weeds, particularly in reduced tillage systems (Price and Norsworthy, 2013). However, results for weed efficacy are mixed and depend a lot on weed population density, cover crop species and other environmental and edaphic factors (De Bruin et al., 2005; Hayden et al., 2012; Price and Norsworthy, 2013).

Vetch (*Vicia villosa*) and rye (*Secale cereal*) suppressed winter annuals up to 98% in reduced tillage systems on loamy sand soils in Michigan (Hayden et al., 2012). Rye in experiments with high and low weed population densities demonstrated variable results; where low weed population densities existed, the properly managed rye cover crop had soybean yields equivalent to treatments with a two-pass herbicides. However when weed population densities were high, the rye cover crop did not provide adequate weed suppression making this system less profitable when compared to a conventional system of weed management (De Bruin et al., 2005).

The allelotoxin aspect of some cover crops needs further study but to date seems ephemeral at best (Price and Norsworthy, 2013). Cover crops were used by 16% of the Iowa growers to respond to a recent poll and they indicated that the practice was somewhat effective by 23% of the growers, effective by 29% and very effective by 11% of the growers who responded to this question (Arbuckle Jr. and Lasley, 2013).

Fall herbicide applications

Increasing problems with winter annual weeds (e.g., horseweed/marestail, henbit, field pennycress) and simple perennials (e.g., dandelion) which are well-adapted to the conservation tillage systems that dominate Iowa crop production has resulted in growers considering fall herbicide applications. Fall herbicide applications are also seen as a tactic that can improve time management in the spring when the time available for crop production can be limited, depending on the weather (Table 1). The number of companies who are promoting proprietary products for fall applications is increasing and the claims made to support these products are typically quite attractive with regard to the described benefits.

There are several keys to improving the success of a fall herbicide application but the most important factor is to establish reasonable and objective expectations. Some of the products are promoted to provide weed control well into the following spring; while this can occur, the certainty of spring residual control from a fall-applied herbicide is highly dependent on the spring weather. Thus, it is prudent to not expect much residual control in the spring following a fall herbicide application and plan accordingly for the spring weed management program.

Another important consideration is field history and knowledge about the weed infestations. In many instances, broadleaf weeds are the primary concern and thus 2,4-D may be the best herbicide to consider. A number of Group 2 herbicides are currently registered for fall applications; consider that Group 2 herbicide resistance is common in horseweed/marestail. Some Group 14 herbicides that provide contact activity on existing broadleaf weeds at the time of fall application may potentially may provide some residual control in the spring. Consider however that using these products may limit options in the spring.

Set objective expectations for fall herbicide applications, identify the target weeds, and determine how the fall applied herbicide fit into the weed management plans in the spring.

Tillage, mechanical, flaming and other novel tactics

The primary purpose of tillage, whether primary (e.g., moldboard plow) or secondary (e.g., cultivation, rotary hoe) in agriculture is to provide weed management (Table 1). The Iowa Farm and Rural Life Poll included questions about tillage, hand-weeding and mechanical tactics to manage herbicide-resistant weeds (Arbuckle Jr. and Lasley, 2013). Tillage as a practice to help manage herbicide-resistant weeds was reported by 74% of growers who responded to the questionnaire while only 25% reported to having used mechanical control tactics (Arbuckle Jr. and Lasley, 2013). However, these practices were generally reported to be effective for helping to manage herbicide-resistant weeds.

Multiple rotary hoeing was reported to be effective for weed management as was combining rotary hoe with flame cultivation in organic vegetable production (Taylor et al., 2012). Rotary hoes designed to handle high crop residues did not disturb the surface residue cover but were inconsistent with regard to weed control (Bates et al., 2012). High residue inter-row cultivators were reported to be very effective but did reduce surface residue cover which could increase the potential for soil erosion, depending on when the cultivation was accomplished and the developmental stage of the crop. Interestingly, using multiple mechanical tactics as well as herbicides provided a more complex weed management system but provided similar high yields and economic returns as the herbicide-intensive crop production systems (Bates et al., 2012).

Flaming has been demonstrated to be effective for a number of crops and a number of weed species. However, not unlike mechanical cultivation, timeliness requirements, actual time expenditure and energy consumption are critical considerations (Knezevic et al., 2009a; Ulloa et al., 2012; Ulloa et al., 2011a; Ulloa et al., 2010a; Ulloa et al., 2011b; Ulloa et al., 2010b; Ulloa et al., 2010c). Furthermore, the potential for crop injury from flaming is higher than with mechanical cultivation (Knezevic et al., 2009b).

Several innovations to improve weed management due to widespread herbicide resistance have come forward from Australia. One of these that has achieved considerable agricultural press is the Harrington Seed Destructor (Walsh et al., 2012). The goal of this equipment is to better manage the weed seedbank by destroying weed seeds during crop harvest. How widely adopted this technology is in Australia has not been determined but the equipment was developed for a small grain crop system and may not fit particularly well in Midwest crop production. Actually the concept is quite old as there were a number of grain harvesters that separated the weed seeds from the grain but they required that growers empty the weed seed reservoir; the weed seeds were typically fed to chickens and pigs – this was obviously a time of more diverse agriculture.

Current and new genetically-engineered herbicide-resistant crops

Many companies that previously had very active herbicide discovery programs have evolved to become "bioscience" companies and are attempting to improve weed management by introducing crops with genetically-engineered herbicide tolerance/resistance. There are a number of new GE HR crops currently being developed and grower interest is high (Green and Owen, 2011). The benefits of the crops are documented in numerous review papers and the risks addressed as appropriate (Green, 2012; Green and Owen, 2011) (Table 2).

Currently available genetically-engineered herbicide-resistant crops

Obviously, the primary GE HR crops have glyphosate resistance, although glufosinate resistance in the major row crops is also available and represents a good alternative. The adoption of currently available GE HR crops, particularly those with glyphosate resistance, has been for improved weed management (Table 1). Only 27% of the respondents to a recent questionnaire indicated that they had used crop cultivars resistant to herbicides other than glyphosate (Arbuckle Jr. and Lasley, 2013). The tactic was reported to be effective or very effective for weed management by 46% of the respondents.

Given the widespread evolution of resistance to glyphosate in many important weeds (e.g., waterhemp and Palmer amaranth), many people question the utility and sustainability of crop systems based on glyphosate and thus the current interest is on new GE HR crops. Glufosinate-resistant corn and soybean cultivars are available and in the south, growers have in many cases switched from glyphosate-resistant cultivars to glufosinate-resistant cultivars in an effort to manage Palmer amaranth problems. Unfortunately, many of the growers who are adopting glufosinate are also planning on using the same glufosinate use practices that they used with glyphosate. To not learn from history is to repeat it; without appropriate stewardship and the inclusion of alternative tactics to supplement glufosinate, glufosinate resistance in weeds will evolve quickly and thus put these growers in the same sinking boat that they now occupy with glyphosate.

New genetically-engineered herbicide-resistant crops

Crops with resistance to the auxin herbicides (Group 4), specifically the dicamba-resistant soybean and the 2,4-D resistant soybean, are seen by many as the answers to the wide-spread glyphosate resistance issues. What must be recognized is that these herbicides have different characteristics, limitations and liabilities that are very different than what agriculture has become accustomed over the last decade plus. These auxin-resistant crops will provide good opportunities to manage some glyphosate-resistant weeds but expectations must be set appropriately and an understanding of the potential issues (e.g., off-target movement, application timing restrictions) addressed to maximize the benefits and minimize the risks. The commercial introduction of the auxin-resistant crops has been delayed due to an Environmental Impact Assessment that was imposed May 13, 2013. It is important to take advantage of the delayed but highly anticipated commercial launch of these technologies by learning more about how to best utilize the technologies and the herbicides that will be used; objectively review the published benefits and evaluate the risks, and learn about the stewardship programs that the companies are developing to support these technologies.

Soybean cultivars with resistance to HPPD herbicides (Group 27) are also under development by Bayer Crop Science and Syngenta with collaborations with other companies. Bayer Crop Science in collaboration with MS Technologies has announced it is anticipated soybean cultivars with resistance to the HPPD inhibitor herbicide isoxaflutole (Balance) will be deregulated in time for planting in 2015. These soybean cultivars also have tolerance to glyphosate (Group 9).

Syngenta and Bayer Crop Science submitted petitions to the USEPA and the Canadian Pest Management Regulatory Agency in the spring 2013 for approval of the HPPD inhibitor herbicide mesotrione (Callisto) use on MGI herbicide-tolerant soybean cultivars. The MGI herbicide-tolerant soybean cultivars also have tolerance to isoxaflutole and glufosinate (Liberty – Group 10). Deregulation and commercial launch of the MGI herbicide-tolerant soybean cultivars is projected to be between 2015 and 2020.

A potential impediment to the utility of these HPPD inhibitor herbicide tolerant soybean cultivars in Iowa is the increasing presence of waterhemp with resistance to the HPPD-inhibitor herbicides (McMullan and Green, 2011). It is estimated that HPPD resistance in waterhemp may occur in 24% to 27% of Iowa soybean fields. These populations are likely to increase dramatically unless appropriate stewardship to protect these important herbicides is implemented soon.

Herbicide combinations and application rates

There has been considerable discussion about using more herbicide MOAs when creating a more diverse weed management program (probably better described as a more diverse herbicide management program) (Table 1). In the recently published Iowa Farm and Rural Life Poll, multiple herbicide MOAs used each season were reported by 71% of the respondents and 60% of the respondents reported using multiple MOAs in each herbicide application. Generally these practices were reported in a favorable light with regard to effectiveness (Arbuckle Jr. and Lasley, 2013).

It is critical that the different MOAs are identified; simply using a different herbicide from a different company does not provide diversity. Thus, and important tool to use to make sure that the herbicides selected represent different MOAs is the herbicide group number. Herbicide group numbers are present on most herbicide labels and will facilitate the development of a multi-year herbicide management program that allows the greatest amount of herbicide MOA diversity (Figure 1).

There are two possible ways that diversity of herbicides can be achieved; rotation of herbicide MOAs or combining herbicide MOAs. Combining herbicide MOAs is more effective at managing weeds and mitigating herbicide resistance than rotating herbicides (Beckie and Reboud, 2009). The key to understanding the use of herbicide MOAs is recognizing the selection pressure an herbicide imparts on weed populations.

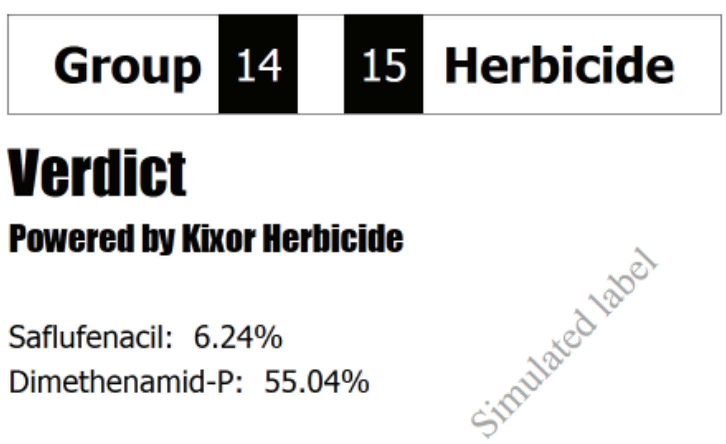

Figure 1. Example of a simulated herbicide label that includes herbicide group numbers designating the herbicide mode of action.

When combinations of herbicides are used, each application imparts multiple selection pressures instead of one source of selection that occurs when herbicide MOAs are rotated. Ideally, each herbicide application would include several herbicide MOAs and each herbicide would impart selection pressure that was the same as all other herbicides used in the mixture. However, the reality is herbicides used in mixtures will select weed populations differently which can eventually result in evolved resistance to the herbicide that imparts greater selection pressure (Diggle et al., 2003). Thus, it is critical to consider herbicide diversity in a planned long-term program in order to maintain diverse selection pressures on the weed populations.

One key to using herbicide combinations is to make sure that the MOAs are actually effective. It does no good to include an herbicide if it is not active on the target weed. For example, there are a number of herbicide premixtures that are advertised as being effective for managing herbicide resistance. However in many cases, the other herbicide MOA included in the premixture is a Group 2 product which generally is not effective on waterhemp, given the preexisting widespread Group 2 resistance.

Another key to consider is herbicide rate of application. While concerns for initial costs of herbicides often is the primary consideration for growers, unless full rates of herbicides are used, the additional cost of supplemental herbicide applications and resultant variable control is likely to cost more than the initial investment required to apply the herbicide at the full rate appropriate for the field situation. Also, reduced rates are also likely to contribute to the evolution of herbicide-resistant weed biotypes sooner than when full rates are used (Gressel, 2011).

Conclusions

Unless better management tactics are quickly adopted, herbicide resistance will continue to increase at an increasing rate in Iowa, and given that no new herbicide sites of action have been discovered in the last 25 years, the future is not particularly bright for herbicidal weed management tactics. While new genetically engineered crops will provide different tactics for weed management, consider that the herbicides that will be available for use on these crops are not new products and waterhemp populations with evolved resistances to these herbicides already exist. It is imperative to develop more diverse approaches for weed management. If greater diversity is not part of the future for Iowa agriculture, weed management specifically will become increasingly costly and difficult. History has proven time and again that simple and convenient approaches inevitably fail.

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Pest resistance: Overall principles and implications on evolved herbicide resistance in Iowa

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"And this, perhaps, might have been anticipated: for, as varieties, in order to become in any degree permanent, necessarily have to struggle with the other inhabitants of the country, the species which are already dominant will be the most likely to yield offspring which, though in some slight degree modified, will still inherit those advantages that enabled their parents to become dominant over their compatriots." (Darwin, 1859)

Introduction

The universal truths of the survival of the fittest and the inevitability that organisms will adapt to whatever environmental factors they encounter have been the most important management considerations to achieving success in agronomic endeavors since mankind transitioned from a hunter/gatherer existence to the agrarian society that has existed for more than six millennia. Predictions of the evolutionary adaptation of pests to the environment in which they exist were made more than 150 years ago (Darwin, 1859). More recent discussions about selective adaption or evolved resistance in pests were published as early as 1914 for insects, 1914 for diseases and 1950 for weeds, although the author suggests that earlier citations are undoubtedly available (Blackman, 1950; Jones, 1914; Melander, 1914). Natural selection and evolutionary adaptation will prevail and while there are evolutionary optimization models that provide insight into biological adaptations, it appears that the use of this knowledge has not resolved the agronomic problems to any great degree (Parker and Smith, 1990).

Unfortunately, there appears to be another universal truth that suggests that agriculture will not address pest adaptation (evolution) until the issues have gotten almost completely "out of hand" and are increasingly of great economic importance. Agricultural scientists and evolutionary biologists have attempted to join together and investigate an essential question about the success of future food production; are there strategies that can anticipate and manage to a degree, pest evolutionary responses (Gould, 1991). It is suggested that the correct answer to this question is a qualified yes. Indeed, pest responses to selection pressure can be anticipated but the strategies needed to resolve these adaptations are typically not effectively employed.

There are a number of reasons that agriculture has thus far been negligent in managing the inevitable evolution of pest resistances. Interestingly, most of the reasons appear to be other than biological considerations but rather reflect socio-economic aspects of modern agriculture (Mortensen et al., 2012). In most cases, when resistance in an important pest complex is scientifically announced, the industry as well as many growers and commodity associations first deny the existence of the resistant pests, then attempt to minimize the importance of the discovery by indicating the resistance is only an isolated event, and then criticize the scientist announcing the new pest resistance before they finally accept the existence of the pest resistance. By the time the validity of the pest resistance is accepted, the spread of the pest resistance complex is such that effective management is no longer a simple or inexpensive prospect.

Perhaps the most recent and glaring example of agriculture's inability, or perhaps better said, unwillingness to address the inevitability of pest resistance evolution is the recurrent issues of glyphosate resistance in weeds (Owen et al., 2011). However, there are other important historic examples of organisms adapting to agricultural practices. For example, soil microorganisms adapted to the recurrent use of the thiocarbamate herbicides causing the rapid degradation of these herbicides resulting in this herbicide family becoming of little value in Midwest agriculture (Obrigawitch et al., 1983).

Evolution of resistance in weeds

The first Fernhurst Lecture to the Royal Society of Arts in 1950 was dedicated to the selective toxicity of "weedkillers" and addressed the likelihood of evolved resistance in weeds to these pesticides (Blackman, 1950). Baker described how and why weeds can adapt to specific environments and crop production systems which provides some insight into the genetic diversity of weeds that contributes to their success in agriculture (Baker, 1974; Baker, 1991). Gressel and Segel (1978) modeled the evolution of herbicide resistance in weeds and described the implications of the selection of weeds for herbicide resistance

(Gressel, 1986; Gressel and Segel, 1978). All of these scientists provided a clear picture of why weeds are successful in agronomic systems and why agronomists must consider the adaptability and diversity of weeds if effective management is to be maintained.

Unfortunately, it is clear that agriculture has not profited from these astute descriptions and predictions with regard to evolved herbicide resistance and has continued to follow a course of action that inevitably resulted in escalating problems controlling weeds. Currently, there are 404 unique cases of herbicide-resistant weed biotypes reported globally (Heap, 2013). These biotypes occur in 220 weed species which are represented by 130 dicot and 90 monocot plant species. Resistance has evolved to 21 of 25 known herbicide sites of action and is increasing globally at an increasing rate (Heap, 2013).

Weed "mimicry" that allows them to be well-adapted to agricultural production systems takes on several forms but currently biochemical "mimicry" is of greatest concern. Weeds may evolved mutations at the herbicide target-site enzyme, evolve enhanced ability to metabolize the herbicide, impair the uptake and translocation of the herbicide or may sequester the herbicide thus limiting the amount of the product available to provide effective control of the target weed. These biochemical strategies and more were predicted for glyphosate as early as 1996 (Gressel, 1996).

A specific biochemical "mimicry" has become perhaps the most serious pest problem facing global agriculture. Specifically, evolved resistance in important weed species to glyphosate has become a major economic issue and is indirectly attributable to the unprecedented adoption of genetically-engineered (GE) glyphosate-resistant (GR) crops and the resultant diminished diversity of weed management tactics (Mortensen et al., 2012; Owen, 2008).

However, there are other examples of widespread evolved herbicide resistance in weeds that preceded the current glyphosate resistance issues (Gressel and Segel, 1978; LeBaron, 2008; Tranel and Wright, 2002). Evolved resistance to Group 2 herbicides was widespread and preceded glyphosate resistance; in fact concerns about ALS inhibitor herbicide resistance supported that adoption of the GR crops and Group 2 herbicide resistance concerns diminished with the commercial availability of GR corn, cotton and soybean (Tranel and Wright, 2002). Prior to Group 2 resistance, Group 5 resistance, primarily to atrazine, was a concern but the introduction of the Group 2 herbicides provided at least a partial solution to that widespread problem (LeBaron, 1991). Historically, new technologies have become available to resolve issues to older technologies. Unfortunately, there are no new technological solutions similar to glyphosate-based systems to resolve the current glyphosate-resistant problems as the new technologies themselves have specific concerns and problems.

Herbicide resistant weeds in Iowa

Weed population collections have been completed for 2011, 2012 and 2013 and are currently being processed for herbicide resistance in a project supported by the Iowa Soybean Association. Approximately 700 waterhemp (Amaranthus tuberculatus), horseweed/marestail (Conyza canadensis), and giant ragweed (Ambrosia trifida) weed populations were sampled across Iowa. Most Iowa Crop Reporting Districts (CRD) were well represented in these collections with the exception of the East Central CRD (Figure 1). An important consideration for the 2011 and 2012 collections was that the field sites were not selected randomly and in fact likely represent a worst case scenario with regard to weed populations with evolved resistance to herbicides. Thus, the lack of random selection

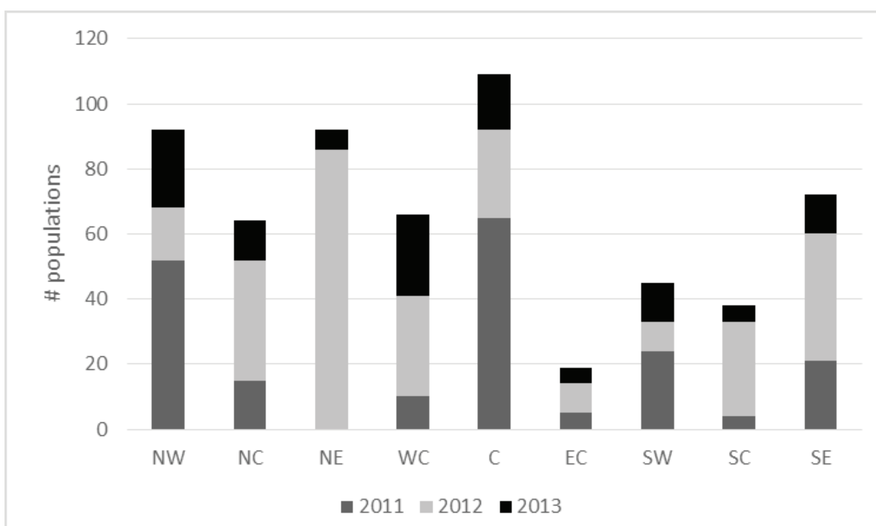

Figure 1. Weed populations collected in 2011, 2012, and 2013 by Iowa Crop Reporting District. Project supported by the Iowa Soybean Association.

precluded any ability to make an assessment about the relative frequency of herbicide resistance in Iowa soybean fields. In order to resolve this problem, 2013 weed population were collected from fields selected randomly across Iowa based on reported CRD soybean acres.

The key factors for fields to be included in the 2011 and 2012 weed population collections were whether or not the fields 1) were planted to soybean and 2) if there were weeds visible above the soybean canopy. Thus, a procedure was used in 2013 to estimate the percentage of all available Iowa soybean fields in 2011 and 2012 that were included in the weed population collections, relative to those fields in 2013 that were planted to soybean and had weeds visible above the canopy in September. From this evaluation, an estimation of herbicide resistance for all soybean fields was calculated.

The weed populations collected in 2011, 2012 and 2013 have been or will be screened for resistance to Group 2, 5, 9, 14 and 27 herbicides; the greenhouse evaluations of the 2011 waterhemp populations is about completed. The levels of herbicide resistance(s) detected in the 2011 waterhemp collections are surprisingly high (Figure 2). Group 2 resistance was detected in 97% of the populations assessed for the 1X Group 2 herbicide (imazethapyr) rate and 92% at the 4x rate. Group 5 (atrazine) resistance for the 2011 waterhemp populations sampled was 69% for both 1X and 4X while Group 9 (glyphosate) resistance was 65% and 34% of the waterhemp populations for the 1X and 4X rates, respectfully. Group 14 (lactofen) resistance was 16% and 13% for the 1X and 4X rates, respectively and

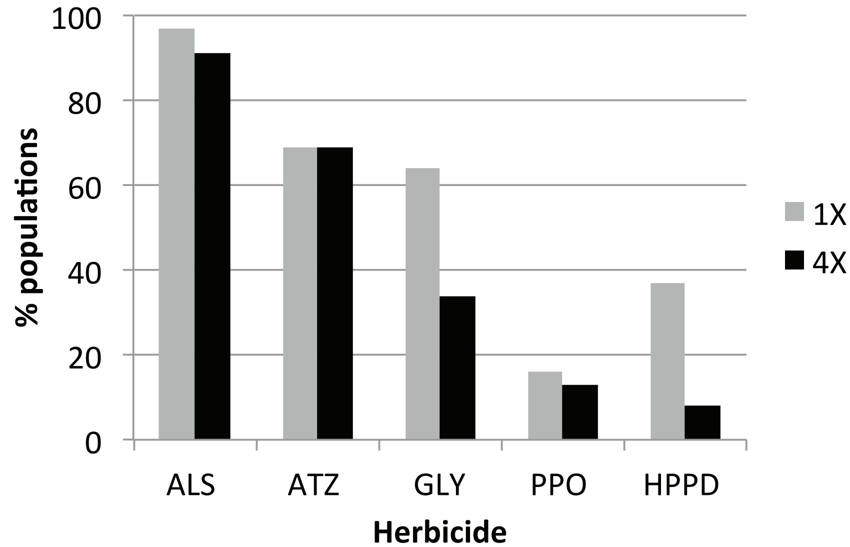

Figure 2. Assessment of herbicide resistance in 2011 waterhemp populations. Project supported by the Iowa Soybean Association.

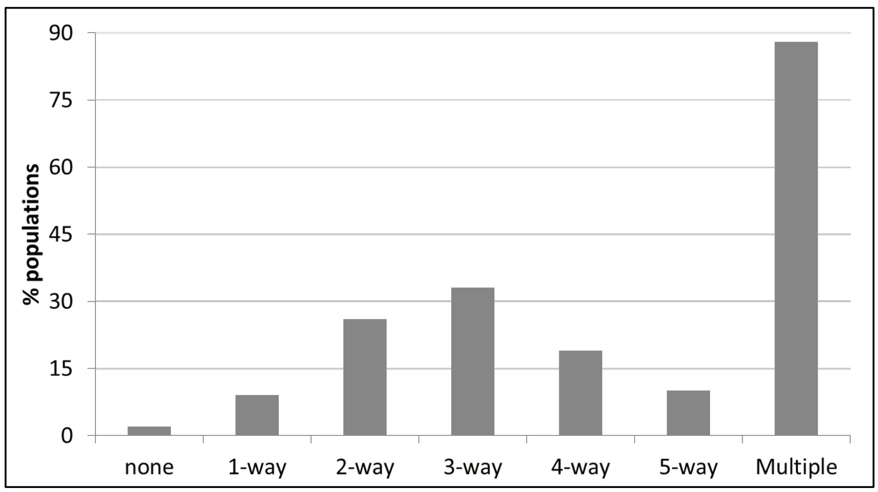

Figure 3. Multiple herbicide resistances in 2011 Iowa waterhemp populations. Project supported by the Iowa Soybean Association.

Group 27 (mesotrione) resistance was detected in 37% of the waterhemp populations at the 1X rate and 7% at the 4X rate (Figure 2). All herbicides were applied postemergence to waterhemp plants in the greenhouse that were 3 to 4 inches in height.

Using the statistics developed from the randomly selected 2013 fields that were planted to soybean and had weeds visible above the canopy, an estimate of the percentage of the Iowa soybean fields that have herbicide-resistant waterhemp populations was made. Based on this statistical assessment at the 95% confidence limit, Iowa soybean fields are likely to have "weeds visible above the canopy of soybean fields" 65% to 74% of the time and thus could be selected for an assessment of herbicide resistance(s) (Philip Dixon, personal communication).

Applying these statistics for the percentage of fields with "weeds visible above the soybean canopy" to the 2011 waterhemp collections and extrapolating this to estimate the herbicide resistance(s) for Iowa soybean fields, the Group 2 resistance for the 1X application rate is estimated to be present on 62% to 77% of Iowa soybean fields, Group 5 resistance on 44% to 51%, Group 9 resistance on 42% to 48%, Group 14 resistance on 10% to 12% and Group 27 resistance on 24% to 27% of the Iowa soybean fields.

All of the 2011 waterhemp populations were evaluated for evolved resistance to five herbicide groups and the assessments demonstrated that multiple herbicide resistance was found in 88% of the populations evaluated (Figure 3). This value represents an estimated 56% to 65% of the Iowa soybean fields that likely have waterhemp populations with multiple herbicide resistances based on the statistic generated from the randomly selected 2013 fields. Only 2% of the 2011 waterhemp populations evaluated did not demonstrate any herbicide resistance (Figure 3).

The most common multiple herbicide resistance was 3-way and was detected in 33% of the 2011 waterhemp populations evaluated. Between 21% and 24% of Iowa soybean fields based on the 2013 statistical program, are suggested to have waterhemp populations with 3-way herbicide resistance; the most common 3-way herbicide resistance is for Group 2, 5, and 9 herbicides (Figure 4).

Ten percent of the 2011 waterhemp populations evaluated demonstrated 5-way herbicide resistance and this problem is estimated to occur on 6% to 7% of Iowa soybean fields, again based on the 2013 random sample of fields with the inclusionary probability requirement of “weeds visible above the soybean canopy”.

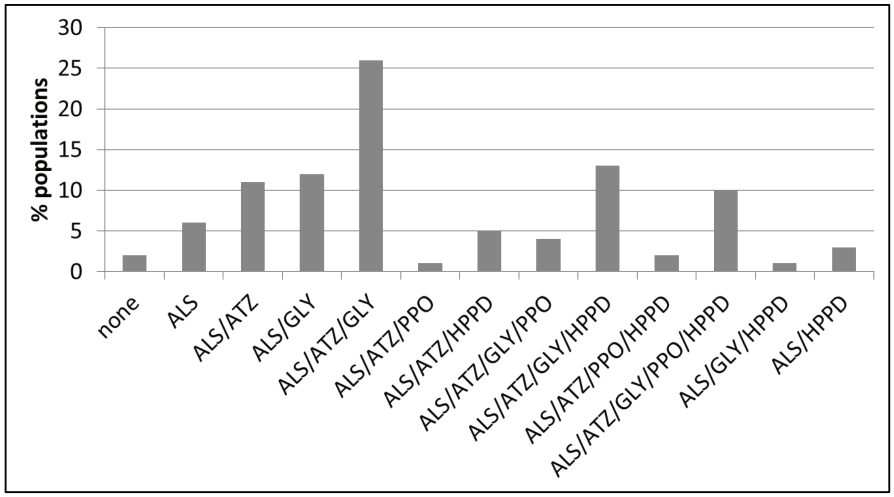

Figure 4. Assessment of herbicide resistance combinations in 2011 Iowa waterhemp populations. Project supported by the Iowa Soybean Association.

Conclusions

Given the tenets of evolutionary adaptation and the significant selection pressures imparted by agriculture on pest complexes, it should be no surprise that pest management is essentially a moving target. Unfortunately, biochemical mimicry within pest complexes occurs at a much faster rate than morphologically based mimicry. Also important is that fact that when biochemical adaptation (e.g., evolved pesticide resistance) within a species occurs, this trait will remain in the species even if management (e.g., a different pesticide) tactics change. Note that multiple herbicide resistances were detected in 88% of the 2011 waterhemp samples screened for resistance to five herbicide groups. In many of these waterhemp populations, the selection from Group 2 herbicides has not been imposed for a number of years, and the only tactic used for management was glyphosate. It is important to recognize that the herbicide resistances that were detected in the waterhemp populations are indicative that the population is transitioning from sensitive to resistant; few of the populations evaluated were homogeneous for either herbicide sensitivity or herbicide resistance.

The keys to addressing issues with pest adaptation is the reverse of what caused the evolutionary change; simple and recurrent tactics select quickly for traits in pests that overcome the tactic. Thus, increasing the diversity of tactics is essential. Recognize that there are no new strategies. For example, the same weed management practices that were developed and recommended more than thirty years ago are now being revisited (Baldwin and Santelmann, 1980; Norsworthy, 2013). Unless a more diverse crop production system is developed, pest evolution to pesticides will increase at an increasing rate.

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Palmer amaranth: ID, biology and management

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Palmer amaranth is native to the Southwestern United States, but its range has expanded over the past 50 years. The first documented occurrence in Iowa was this year, although with these infestations it is clear that the weed was initially introduced to the state prior to 2013. It has been a serious problem in the south, and gained national notoriety after developing resistance to glyphosate and devastating the cotton industry in the Southeast. This paper will review why the weed has garnered such attention and access the threat it poses to Iowa.

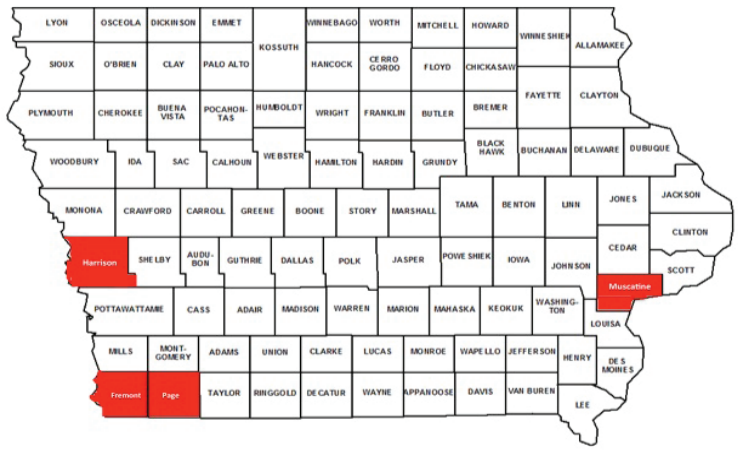

Figure 1. Known infestations of Palmer amaranth (Nov. 2013).

Identification

Our heavy reliance on glyphosate has led to complacency in weed identification. However, the ability to identify Palmer amaranth is critical since Iowa is at the initial stages of invasion (Figure 1). The best way to minimize the impact of Palmer amaranth is to identify new infestations quickly and initiate steps to prevent its establishment and spread.

Palmer amaranth is one of several weedy pigweed (Amaranthus) species found across Iowa. Prior to the 1980's redroot pigweed and smooth pigweed were our most common pigweed species, but since the late 1980's, waterhemp has been our number one pigweed. Less common weedy pigweeds of Iowa fields include Powell amaranth and spiny pigweed. At casual glance there are many similarities among the weedy pigweeds, but knowledge of what specifically to look for simplifies differentiating Palmer amaranth from the other pigweeds.

Upon encountering an unknown pigweed, the first trait to look for is hairs on the stem. Redroot pigweed, smooth pigweed and Powell amaranth have hairy (pubescent) stems; the hairs are most prominent on young branches. Palmer amaranth, waterhemp and spiny amaranth have hairless (glabrous) stems. Spiny amaranth can be differentiated from Palmer amaranth and waterhemp due to the presence of sharp spines at the point where leaves attach to the stem. These spines are up to ½ inch in length.

This leaves Palmer amaranth and waterhemp. With experience it may be possible to differentiate vegetative Palmer amaranth and waterhemp, but the diversity within both species can make this

Table 1. Vegetative characteristics of Palmer amaranth (PA) and waterhemp (WH).

Leaf shape	WH leaves tend to be long and narrow, whereas PA leaves are wider and ovate to diamond shaped.
Leaf petiole	Petioles on PA leaves are often longer than the leaf blade.
Leaf watermark	Some PA plants have a silverish watermark on the leaves, but this trait occasionally is found on WH.
Canopy shape	PA tend to have a relatively dense canopy compared to the open canopy of WH. PA often have a tight cluster of leaves that has been compared to a poinsettia at the apical meri-stem.
Leaf tip hair	A hair on the tip of PA leaves has been promoted as a reliable trait, but this hair is often present on WH.
Seedlings	The cotyledon stage of all of the Amaranthus species are difficult, if not impossible, to distinguish from each other.

unreliable at times. Vegetative traits used to differentiate the two species are listed in Table 1.

It is much easier to distinguish Palmer amaranth from waterhemp once the plants have produced flowers. Both species are dioecious, having separate male and female plants. Female plants can be easily identified by rubbing the inflorescences (seedheads) and looking for the presence of small, black seed. As with vegetative traits, the inflorescences of both species are highly variable. Palmer amaranth inflorescences tend to be thicker (up to 1" in diameter) than those of waterhemp (Figure 2), and terminal branches of Palmer amaranth are long, sometimes exceeding three feet in length. Male waterhemp plants sometimes have thick inflorescences that may be mistaken for Palmer amaranth.

Figure 2. Inflorescences of female Palmer amaranth (L) and waterhemp (R).

The flowers of the two species provide the most reliable way of differentiating Palmer amaranth and waterhemp. Many weeds, including the pigweeds, have very small flowers that are difficult for novices to find the flower parts used to identify a species. Fortunately, the flower parts used to separate Palmer amaranth from waterhemp are easy to locate and sufficiently different to eliminate subjectivity. There are differences in the male and female flowers of the species; female plants are easier to differentiate.

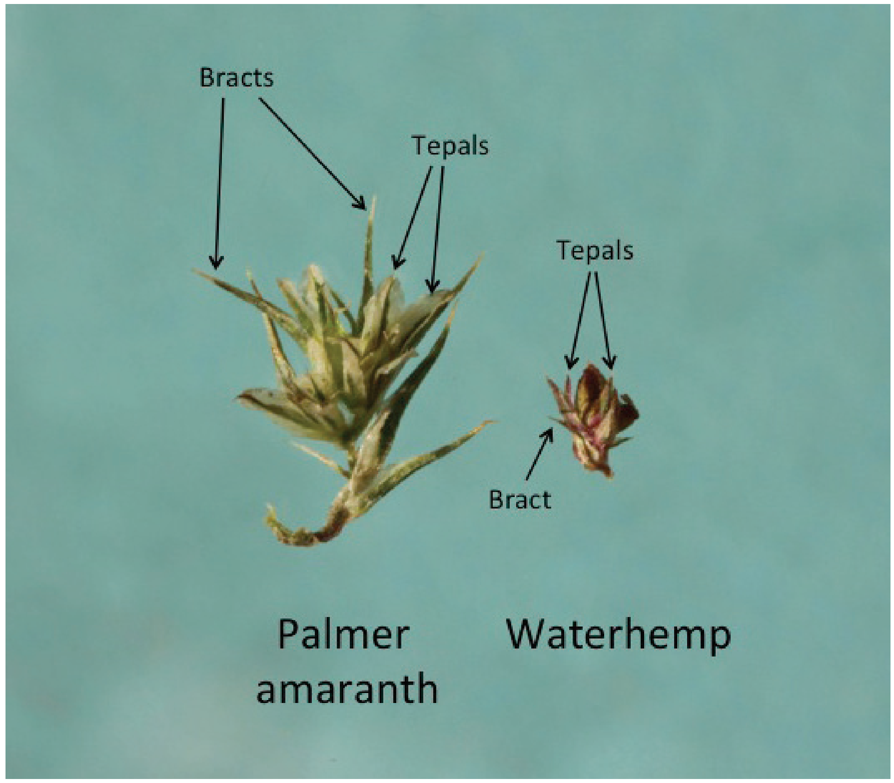

Figure 3. Female flowers of Palmer amaranth (L) and waterhemp (R).

Female flowers of pigweeds have three major components – bracts, tepals and the seed capsule. Bracts are modified leaves found at the base of flowers. Tepal is a term used to describe flower petals when the petals and sepals of the flower are indistinguishable. The seed capsule contains the seed. Male flowers have bracts, tepals and anthers (male parts that produce pollen). The anthers are relatively short-lived and fall from the male flowers when pollen shed is complete.

The distinguishing feature of Palmer amaranth is the large bract on female flowers (Figure 3). The bracts are green, up to ¼ inch in length, and extend well beyond the tepals and seed capsule. As the bracts mature they become sharp and make the seedheads painful to handle. There are five translucent tepals that surround the seed capsule, each with a dark green midrib. The bract on female waterhemp plants is less than 1/8 inch in length and there is one or no tepals. The seed capsule in waterhemp flowers extends beyond the bract and petal. While the flowers of Palmer amaranth are much larger than those of waterhemp, the seeds are only slightly larger.

Male Palmer amaranth flowers have five tepals that are nearly as long as the bract, the bract is slightly shorter than those on females. Male waterhemp flowers have five tepals that extend well beyond the bract.

The bracts on redroot pigweed, smooth pigweed and Powell amaranth are as long as those on Palmer amaranth. These bracts also become sharp as they mature, but are not as sharp as those of Palmer amaranth. There are two simple ways to distinguish redroot, smooth pigweed and Powell amaranth from Palmer amaranth. First, these three species are monoecious, meaning that all plants will produce seed. Second, and most important, the hairy stems of these monoecious species easily distinguish them from Palmer amaranth.

Biology

Like most weeds of our cropping system, Palmer amaranth is an annual that initiates growth each spring from seed present in the seedbank (Figure 4). Understanding factors that influence the fate of the weed at different phases of the life cycle is the key to developing successful weed management strategies.

Seedbank (A)

Seeds of Palmer amaranth possess dormancy and are relatively persistent in the seedbank. Once the weed gets established in a field management becomes a long-term problem. In Georgia, 12% of Palmer amaranth seed buried in the upper inch of the soil profile remained viable three years after burial. Seed persistence increased slightly with greater burial depths. In Iowa, 28% of waterhemp seed remained viable three years after burial. The greater persistence of waterhemp could be due to inherent differences between the two species, or differences in environment and soils of the two states. The shorter growing season in Iowa likely enhances seed persistence.

Emergence patterns strongly influence the problems a weed presents. The prolonged emergence of waterhemp contributes to its weediness since much of the waterhemp population emerges after residual herbicides have degraded or postemergence herbicides have been applied. Palmer amaranth also emerges for an extended period, at the Iowa infestations new seedlings were observed well into August. At optimum soil temperatures, emergence of Palmer amaranth was much more rapid than that of waterhemp.

Growth and competitiveness (B)

Palmer amaranth has gained recognition for two reasons: 1) its propensity for herbicide resistance, and 2) its rapid growth and competiveness. There is no evidence suggesting that it is any more adept at evolving herbicide resistance than waterhemp; however, it is clear that uncontrolled Palmer amaranth is more damaging to crop yields than other weedy pigweeds due to differences in growth habits.

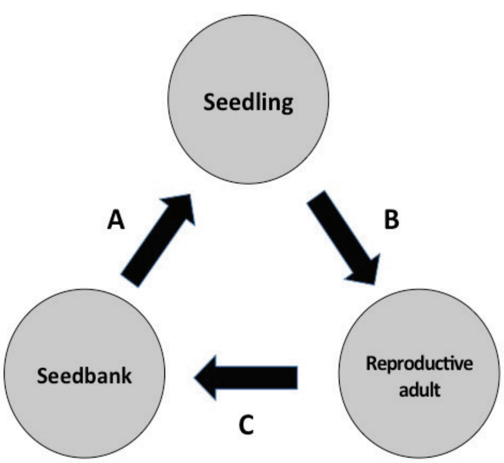

Figure 4. Stages of the annual life cycle.

One frequently cited characteristic of Palmer amaranth is its rapid growth rate, with reports of plants growing more than three inches in a single day. Kansas State University researchers reported Palmer amaranth height increased at twice the rate as redroot pigweed and more than 42% faster than waterhemp. This rapid growth results in a narrower application window for postemergence herbicide applications than with waterhemp, one of the factors complicating Palmer amaranth management. It is important to keep this rapid growth rate in perspective – seedling Palmer amaranth do not grow three inches in a day. These rapid growth rates occur when the plants are already at least four or five inches in height, well after the optimum application window for postemergence herbicides.

The greater growth rate of Palmer amaranth is largely due to how it allocates resources compared to the other species. Palmer amaranth puts more dry matter into leaves than the other species, resulting in a higher photosynthetic capacity. The dense canopy architecture of Palmer amaranth that facilitates its rapid growth is easily visible in many plants. The rapid growth and large biomass of Palmer amaranth make it much more damaging to crop yields than waterhemp or redroot pigweed. Palmer amaranth that emerged within a week of soybean planting reduced yields by 79% compared to 56% for waterhemp. In this research, Palmer amaranth that emerged 3 to 4 weeks after soybean planting did not impact yields. While late-emerging plants may not impact yields, they do contribute seed to the seedbank.

Seed production (C)

A primary weedy trait of pigweed species is prolific seed production. A single waterhemp plant can produce over 2 million seeds. This is accomplished by producing small seed. While seedlings of small-seeded species are more vulnerable to stresses (e.g. tillage, herbicides) than those of large-seeded species (e.g. velvetleaf, cocklebur), their high numbers increase the probability that some individuals will survive.

While Palmer amaranth produces more biomass per individual plant, researchers in Missouri reported no difference in the number of seed produced by individual waterhemp and Palmer amaranth plants. Waterhemp overcame the lower biomass compared to Palmer amaranth by converting a higher percentage of biomass to seed and producing slightly smaller seeds.

Palmer amaranth management

If there is a bright side to the threat posed by Palmer amaranth, it is that everyone involved in weed management in Iowa should be experienced at managing waterhemp. The tactics used to control waterhemp also are effective against Palmer amaranth. The primary differences in managing these two species are: 1) the rapid growth rate of Palmer amaranth creates narrower application windows for postemergence control tactics, and 2) control failures with Palmer amaranth carry a larger yield penalty than with waterhemp.

Both Palmer amaranth and waterhemp are prone to evolving herbicide resistance when herbicides are used in ways that result in significant selection pressure (Table 2). A Palmer amaranth population in Kansas was recently documented to be resistant to three Herbicide Groups: 3, 5 and 27. The resistance profiles of the Palmer amaranth biotypes present in Iowa are unknown at this time. As selection pressure from herbicides continues, more types and combinations of multiple herbicide resistant populations will evolve.

Steps for effective Palmer amaranth management

1) Prevention. It is unlikely that Palmer amaranth will be stopped from spreading in Iowa; however, the rate that it moves into new fields can be limited. This requires improved weed identification skills and better scouting. When new infestations are identified steps should be implemented to prevent seed production (e.g. hand weeding, etc.) and limit movement of seed from infested areas to clean fields. Control Palmer amaranth growing in fencelines, roadsides and other non-crop areas. At current Iowa infestations there was more Palmer amaranth present in non-crop areas than in the adjacent crop fields. Combines are the most efficient seed disseminator ever developed, whenever possible harvest infested fields last to limit spread of seed.

2) Start clean. Make sure all Palmer amaranth is killed before planting the crop. It is probably safe to assume that most Palmer amaranth found in Iowa will be resistant to glyphosate, so use alternative herbicides (e.g. 2,4-D; Liberty, etc.) in burndown applications for no-till fields. In tilled fields, ensure that the preplant tillage completely kills all established weeds.

3) Full rates of effective preemergence herbicides. Due to the rapid growth rate of Palmer amaranth, effective preemergence herbicides are essential to effective management. Herbicide Group 3 (dinitroanilines), 5 (triazines), 15 (amides) and 27 (HPPD inhibitors) herbicides provide the crop a head start on Palmer amaranth. This allows postemergence herbicides to be applied later in the season when the crop canopy will be able to reduce weed establishment following the application.

4)Timely postemergence applications. Timing is everything. Prior to the spread or resistant biotypes, delayed applications of postemergence herbicides to too large of waterhemp was the number one cause of control failures of this weed. Due to the rapid growth of Palmer amaranth, this will be an even greater problem with Palmer amaranth. Applications should be targeted for weeds that are less than three inches in height.

5) Include residual herbicides with postemergence applications. The prolonged emergence pattern of Palmer amaranth allows significant establishment of plants after

Table 2. Documented herbicide resistances in Palmer amaranth and waterhemp.

Herbicide			
Group Number	**Examples**	**Palmer amaranth**	**Waterhemp**
2	Classic, Pursuit	X	X
3	Treflan, Prowl	X	
4	2,4-D; dicamba		X
5	atrazine	X	X
9	glyphosate	X	X
14	Valor, Reflex		X
27	Callisto, Laudis	X	X

postemergence applications. While these late-emerging weeds may not impact yields, they increase the size of the seedbank. Several residual herbicides are registered for postemergence use in corn and soybean and provide an effective management option for late-emerging Palmer amaranth.

6) Use a diversity of herbicide groups. Relying on a single herbicide program repeatedly will result in rapid selection of new herbicide resistant biotypes. Use multiple herbicide groups that are effective against pigweed species and rotate groups over time.

7) Use cultural and mechanical practices. Relying only on herbicides, regardless of how well they are managed, will eventually result in the selection of resistant biotypes. Consider all practices that enhance the competitiveness of the crop (row spacing, planting population, planting date, etc.) and use mechanical practices where feasible.

Summary

It is unclear how big an impact Palmer amaranth will have in Iowa, but we know it is a formidable foe and the threat should be taken seriously. The impact of Palmer amaranth on the cotton industry is well documented, but there is no reason why the weed should cause such damage here. A greater diversity of herbicides is available for use in corn and soybean than for cotton. By taking advantage of this variety the speed that weeds adapt to herbicides is reduced. In addition, Iowa has some of the most productive soils in the world. Good soils provide a highly competitive crop that greatly enhances the effectiveness of all control tactics. It is interesting that all but one of the current Palmer amaranth infestations in Iowa are located on sands or other atypical soils for Iowa. This suggests that perhaps Palmer amaranth is not yet well adapted to competing on our more productive soils. Increased vigilance to identify new infestations, taking appropriate actions to minimize the establishment and spread of new infestations, and implementing diversified weed management programs will minimize the impact that Palmer amaranth has on corn and soybean production in Iowa.

Corn Herbicide Effectiveness Ratings[1]

Weed response to selected herbicides

E = excellent   G = good
F = fair   P = poor

	Grasses						Broadleaves									Perennials		
	Crop tolerance	Crabgrass	Fall panicum	Foxtail	Woolly cupgrass	Shattercane[2]	Amaranthus spp.[2,4,5,6]	Black nightshade	Cocklebur[2]	Common ragweed	Giant ragweed[2,4]	Lambsquarter	Smartweed	Sunflower[2]	Velvetleaf	Canada thistle	Quackgrass	Yellow nutsedge
Preplant/Preemergence																		
Atrazine	E	F	P	F	P	P	E	G	G	E	F-G	E	E	G	G	P	F	F
Balance Flexx	E	G	F-G	G	G-E	F-G	G-E	F	P-F	F-G	P	G	G-E	F	G-E	P	P	G
Breakfree, Degree, Harness, Surpass, Topnotch, etc	E	E	E	E	F-G	F-G	G	G	P	P	P	P-F	P-F	P	P	P	P	G
Callisto	E	P	P	P	P	P	G-E	G-E	F-G	F-G	F	E	F-G	G-E	E	P	P	P
Cinch,, Dual II Magnum, Outlook, Zidua, etc	E	E	E	E	F	F	F-G	G	P	P	P	P	P	P	P	P	P	G
Hornet WDG	G	P	P	P	P	P	G-E	F-G	G	G	G	G	G-E	G-E	G	P	P	P
Linex/Lorox	G	P-F	P-F	P	P	P	G-E	F	F	G	P-F	G-E	G-E	F	F	P	P	P
Pendimax, Prowl, etc	F-G	G-E	G-E	G-E	G	G	G	P	P	P	P	G-E	F	P	P-F	P	P	P
Python	G	P	P	P	P	P	E	F-G	F	G	F	F-G	G-E	F-G	G-E	P	P	P
Sharpen (Kixor)	G	P	P	P	P	P	G-E	G-E	G	G	G	G-E	G	G-E	G-E	P	P	G
Postemergence																		
Accent Q, Steadfast Q	G-E	P	G	G-E	G-E	E	G	P	F	P	P	P	G	P	F	F	G	F
Aim	G	P	P	P	P	P	F-G	G	P	P	F	G	P	P	E	P	P	P
Armezon, Impact	G-E	F-G	F	G	F	F	G-E	G-E	G-E	G	G	G	G	E	E	P	P	P
Atrazine	G	F	P	F	P	P	E	E	E	E	G	E	E	E	E	F*	F	G
Basagran	E	P	P	P	P	P	P	P	E	E	F	P	E	G	G-E	G*	P	G*
Basis, Basis Blend	F	F	F-G	G	F	G	G	P	F	F	P	G-E	G-E	G-E	G	P	G	P
Banvel, Clarity, etc	F-G	P	P	P	P	P	G-E	G	E	G-E	E	G	E	G	F-G	G*	P	P
Beacon	G	P	F-G	P-F	P	E	E	G	G	G	E	P	G	G	F-G	F-G*	G	F
Buctril	G	P	P	P	P	P	G	G-E	E	E	G	G-E	G-E	E	G	P	P	P
Callisto	G-E	P	P	P	P	P	E	E	G-E	F	G	G	E	G-E	E	P	P	P
Equip	F-G	P	G	G-E	F-G	E	G	E	E	E	G	G	E	E	G-E	G*	G	P
Glyphosate (Roundup, Touchdown)[3]	E	E	E	G-E	E	E	G-E	F-G	E	E	G-E	G	E	E	G	G	G-E	F
Hornet WDG	G	P	P	P	P	P	G-E	F	E	E	G-E	F	G-E	E	G-E	G	P	P
Liberty[3]	E	E	G	G-E	E	E	G	E	E	E	G	G	E	E	E	F-G	G	P
Laudis	G-E	F-G	F	G-E	F-G	F-G	E	G-E	G-E	G	G	G	G	E	E	P	P	P
NorthStar	G	P	F-G	F	P	E	F-G	G	E	E	E	G	E	E	G	F-G	G	F
Option	G	P	G	G-E	F-G	E	G	E	F	F	P	P	P	G	G	P	G	P
Permit, Halomax, etc	G	P	P	P	P	P	E	P	G-E	G-E	G	P	G-E	E	E	P	P	G
Resolve	F	F	F-G	G	F	G	G	P	F	F	P	G-E	G	P	F-G	F	G	F
Resource	G-E	P	P	P	P	P	G	P	F	F-G	P	F	P	P	E	P	P	P
Status	F-G	P	F	F	P	F	G-E	G	E	G-E	G	G	E	G	G	G*	P	P
Yukon	F-G	P	P	P	P	P	G	G	G-E	G-E	G	G	G-E	E	E	P	P	G
2,4-D	F	P	P	P	P	P	G	F	E	G	G-E	G	F	G	G	F*	P	P

This chart should be used only as a guide. Ratings of herbicides may be higher or lower than indicated depending on soil characteristics, managerial factors, environmental variables, and rates applied. The evaluations for herbicides applied to the soil reflect appropriate mechanical weed control practices.

[1]Ratings are based on full label rates. Premix products containing ingredients marketed as single a.i. products may not be listed in this table.
[2]ALS-resistant biotypes of these weeds have been identified in Iowa. These biotypes may not be controlled by all ALS herbicides.
[3]Use only on designated resistant hybrids.
[4]Glyphosate-resistant biotypes of these weeds have been identified in Iowa. These biotypes may not be controlled by glyphosate.
[5]PPO-resistant biotypes of common waterhemp have been identified in Iowa. These biotypes may not be controlled by PPO inhibitor herbicides.
[6]HPPD-resistant biotypes of common waterhemp have been identified in Iowa. These biotypes may not be controlled by HPPD herbicides.
*Degree of perennial weed control is often a result of repeated application.

Soybean Herbicide Effectiveness Ratings[1]

Weed response to selected herbicides
E = excellent G = good
F = fair P = poor

	Grasses						Broadleaves									Perennials		
	Crop tolerance	Crabgrass	Fall panicum	Foxtail	Woolly cupgrass	Shattercane[2]	Amaranthus spp.[2,4,5,6]	Black nightshade	Cocklebur[2]	Common ragweed	Giant ragweed[2,4]	Lambsquarter	Smartweed	Sunflower[2]	Velvetleaf	Canada thistle	Quackgrass	Yellow nutsedge
Preplant/Preemergence																		
Authority/Spartan	G	P-F	P	P-F	P	P	E	E	F	F	F	G-E	F	P	F-G	P	P	F-G
Cinch, Dual II Magnum, INTRRO, Frontier, Warrant, Zidua	E	E	E	E	F	F	F-G	G	P	P	P	P	P	P	P	P	P	P
Command	E	G-E	G-E	E	F	F	P	F	F	G	P	G-E	G	F	E	P	P	P
FirstRate/Amplify	G-E	P	P	P	P	P	F-G	P	G	G-E	G-E	G	G-E	G	F-G	P	P	F-G
Linex/Lorox	F	P-F	P-F	P	P	P	G-E	F	F	G	P-F	G-E	G-E	F	F	P	P	P
Pendimax, Prowl, Sonalan, Treflan, etc	G-E	E	E	E	E	G-E	G	P	P	P	P	G	F	P	P	P	P	P
Pursuit	G	F-G	F	F-G	P-F	G	F-E	G-E	F	G	F	G	G-E	F-G	G	P	P	P
Python	E	P	P	P	P	P	E	F	F	F	P	F-G	G-E	F	E	P	P	P
Sencor, TriCor, etc	F-G	P	P	P-F	P	P	E	F	F	E	P	E	E	F-G	G-E	P	P	P-F
Sharpen	G	P	P	P	P	P	G-E	G-E	G	G	G	G-E	G	G-E	G-E	P	P	P
Valor SX	F-G	P-F	P-F	P-F	P	P	G-E	E	F	G	F	G-E	F	P	F	P	P	P
Postemergence																		
Assure II, Fusilade DX, Fusion, Poast Plus, Select, etc.	E	E	E	E	E	E	P	P	P	P	P	P	P	P	P	P	G-E*	P
Basagran	E	P	P	P	P	P	P-F	P-F	E	E	F	P	E	G	G-E	G*	P	G*
Blazer	F-G	P	P	F	P	F	E	G	F	G	F	F	E	F	F	F	P	P
Classic	G	P	P	P	P	P	E	P	E	G-E	F	P	G-E	E	G-E	F	P	G-E
Cobra/Phoenix	F-G	F	P	P	P	P	E	G	G-E	E	F-G	F	G	G	F	F	P	P
FirstRate/Amplify	G	P	P	P	P	P	P	P	G-E	E	E	P	G	E	G	P	P	P
Glyphosate (Roundup, Touchdown)[3]	E	E	G-E	E	E	E	G-E	F-G	E	E	G-E	G	E	E	G	G	G-E	F
Harmony	F	P	P	P	P	P	E	P	F	F	P	G-E	G-E	G-E	G	P	P	P
Liberty	E	E	G	G-E	E	E	G	E	E	E	G	G	E	E	E	F-G	G	F
Pursuit	G	G	G	F-G	F	E	F-G	E	G-E	G	F	P-F	E	G	G-E	F	P	P
Raptor	G	G-E	G-E	G-E	G	E	F-G	E	G-E	G	G	G	E	E	G-E	F	F	F
Reflex/Flexstar, Rumble	F-G	P	P	P	P	P	E	F-G	F	G	G	F	G-E	F	F	P-F	P	P
Resource	G-E	P	P	P	P	P	G	P	F	F-G	P	F	P	P	E	P	P	P

[1]Ratings in this table are based on full label rates. Premix products containing ingredients marketed as single a.i. products may not be included in this table.
[2]ALS-resistant biotypes have been identified in Iowa. These biotypes may not be controlled by all ALS products.
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[4]Glyphosate-resistant biotypes of these weeds have been identified in Iowa. These biotypes may not be controlled by glyphosate.
[5]PPO-resistant biotypes of common waterhemp have been identified in Iowa. These biotypes may not be controlled by PPO inhibitor herbicides.
[6]HPPD-resistant biotypes of common waterhemp have been identified in Iowa. These biotypes may not be controlled by HPPD herbicides.
*Degree of perennial weed control is often a result of repeated application.
This chart should be used only as a guide. Ratings of herbicides may be higher or lower than indicated depending on soil characteristics, managerial factors, environmental variables, and rates applied. The evaluations for herbicides applied to the soil reflect appropriate mechanical weed control practices.

Grazing and haying restrictions for herbicides used in grass pastures

			Beef and Non-Lactating Animals			Lactating Dairy Animals	
Herbicide	A.I.	Rate/A	Grazing	Hay harvest	Removal before slaughter	Grazing	Hay harvest
Ally		0.1 - 0.3 oz	0	0	0	0	0
Clarity and many others	dicamba	Up to 1 pt	0	0	30 days	7 days	37 days
		1 - 2 pt	0	0	30 days	21 days	51 days
		2 - 4 pt	0	0	30 days	40 days	70 days
		4 - 16 pt	0	0	30 days	60 days	90 days
Chaparral	aminopyralid + metsulfuron methyl	1 - 3.3 oz	0	7 days	0	0	0
Cimarron Max (co-pack)	metsulfuron methyl + dicamba + 2,4-D	0.25-1 oz A + 1-4 pt B	0	0	30 days	7 days	37 days
Cimarron X-Tra	metsulfuron methyl + chlorsulfuron	0.1 - 1.0 oz	0	0	0	0	0
Crossbow	triclopyr + 2,4-D	1 - 6 qt	0	14 days	3 days	Growing season	Growing season
Escort XP	metsulfuron methyl	Up to 1.7 oz	0	0	0	0	0
		1.7 - 3.3 oz	NA	3 days	NA	NA	3 days
ForeFront HL	aminopyralid + 2,4-D	1.2 - 2.1 pt	0	7 days	0	0	7 days
Grazon P&D	picloram + 2,4-D	3 - 4 pt	0	0	0	7 days	30 days
Milestone	aminopyralid	3 - 7 oz	0	0	0	0	0
Overdrive	dicamba + diflufenzopyr	4 - 8 oz	0	0	0	0	0
PastureGard HL	triclopyr + fluroxypyr	1 - 1.5 pt	0	14 days	3 days	1 year	1 year
Rave	dicamba + triasulfuron	2 - 5 oz	0	37 days	30 days	7 days	37 days
Redeem R&P	triclopyr + clopyralid	1.5 - 4 pt	0	14 days	3 days	Growing season	Growing season
Remedy Ultra	triclopyr	1 - 2 qt	0	14 days	3 days	Growing season	Growing season
Surmount	picloram + fluroxypyr	1.5 - 6 pts	0	7	3	14	7
Tordon 22K	picloram	< 2 pts	0	0	3	14	14
		> 2 pts	0	14	3	14	14
Weedmaster	dicamba + 2,4-D	1-4 pts	0	37 days	30 days	7 days	37 days
2,4-D (many tradenames) Uses may vary among products	2,4-D	2-4 pt 4 lb/G	0	30 days	3 days	7 days	30 days

Herbicide Package Mixes

The following table provides information concerning the active ingredients found in prepackage mixes, the amount of active ingredients applied with a typical use rate, and the equivalent rates of the individual products.

Corn Herbicide Premixes or Co-packs and Equivalents

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Alluvex WSG	2	16.7% rimsulfuron	1.5 oz	0.25 oz rimsulfuron	0.5 oz Harmony SG
	2	16.7% thifensulfuron		0.25 oz thifensulfuron	1.0 oz Resolve SG
Anthem	15	2.087 lb pyroxasulfone	10 oz	2.6 oz pyroxasulfone	3.1 oz Zidua
	14	0.063 lb fluthiacet-methyl		0.08 fluthiacet	0.7 oz Cadet
Anthem ATZ	5	4 lb atrazine	2 pt	1 lb atrazine	2 pt atrazine 4L
	15	0.485 lb pyroxasulfone		0.12 lb pyroxasulfone	2.25 oz Zidua
	14	0.014 lb fluthiacet		0.004 lb fluthiacet	0.6 oz Cadet
Basis Blend	2	20% rimsulfuron	0.825 oz	0.167 oz rimsulfuron	0.67 Resolve
	2	10% thifensulfuron		0.083 oz thifensulfuron	0.16 oz Harmony
Bicep II MAGNUM, Cinch ATZ	15	2.4 lb S-metolachlor	2.1 qt	1.26 lb S-metolachlor	21 oz Dual II MAGNUM
	5	3.1 lb atrazine		1.63 lb atrazine	52 oz Aatrex 4L
Bicep Lite II MAGNUM	15	3.33 lb S-metolachlor	1.5 qt	1.24 lb S-metolachlor	21 oz Dual II MAGNUM
	5	2.67 lb atrazine		1.00 lb atrazine	32 oz atrazine 4L
Breakfree NXT ATZ	15	3.1 lb acetochlor	2.7 qt	2.1 lb acetochlor	2.4 pt Breakfree NXT
	5	2.5 lb atrazine		1.7 lb atrazine	3.4 pt atrazine 4L
Breakfree NXT Lite	15	4.3 lb acetochlor	2.0 qt	2.2 lb acetochlor	2.5 pt Breakfree NXT
	5	1.7 lb atrazine		0.85 lb atrazine	1.7 pt atrazine 4L
Bullet 4ME	15	2.5 lb alachlor	4.0 qt	2.5 lb alachlor	2.5 qt Micro-Tech 4ME
	5	1.5 lb atrazine		1.5 lb atrazine	1.5 qt atrazine 4L
Callisto GT	9	3.8 lb glyphosate	2 pt	0.95 lb glyphosate	1.8 pt Touchdown
	27	0.38 lb mesotrione		0.095 lb mesotrione	3.04 oz Callisto
Callisto Xtra	27	0.5 lb mesotrione	24 fl oz	0.09 lb mesotrione	3.0 oz Callisto
	5	3.2 lb atrazine		0.6 lb atrazine	1.2 pt Aatrex 4L
Capreno	2	0.57 lb thiencarbazone	3.0 oz	0.01 lb thiencarbazone	-
	27	2.88 lb tembotrione		0.068 lb tembotrione	2.5 oz Laudis
Cinch ATZ	15	2.4 lb S-metolachlor	2.1 qt	1.26 lb S-metolachlor	21 oz Dual II Magnum
	5	2.67 lb atrazine		1.63 lb atrazine	3.25 pt atrazine 4L

Corn Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Corvus	27	1.88 lb isoxaflutole	5.6 oz	1.3 oz isoxaflutole	5.1 oz Balance Flexx
	2	0.75 lb thiencarbazone		0.5 oz thiencarbazone	
Crusher 50 WDF	2	25% rimsulfuron	1 oz	0.25 oz rimsulfuron	1 oz Resolve SG
	2	25% thifensulfuron		0.25 oz thifensulfuron	0.5 oz Harmony SG
Degree Xtra	15	2.7 lb acetochlor	3 qt	2 lb acetochlor	36.6 oz Harness 7E
	5	1.34 lb atrazine		1 lb atrazine	1 qt atrazine 4L
Distinct 70WDG	19	21.4 % diflufenzopyr	6 oz	1.3 oz diflufenzopyr	1.3 oz diflufenzopyr
	4	55.0% dicamba		3.3 oz dicamba	6 oz Banvel
Expert 4.9SC	15	1.74 lb S-metolachlor	3 qt	1.3 lb S-metolachlor	1.4 lb Dual II Mag.
	5	2.14 lb atrazine		1.61 lb atrazine	1.6 qt Aatrex 4L
	9	0.74 lb ae glyphosate		0.55 lb ae glyphosate	1.5 pt Glyphosate 3L
Fierce	14	33.5% flumioxazin	3 oz	1 oz flumioxazin	2 oz Valor
	15	42.5% pyroxasulfone		1.28 oz pyroxasulfone	1.5 oz Zidua
FulTime NXT	15	2.7 lb acetochlor	3 qt	2.0 lb acetochlor	2.5 pt Surpass 6.4EC
	5	1.34 lb atrazine		1.0 lb atrazine	2.0 pt atrazine 4L
Halex GT	15	2.09 lb *S*-metolachlor	3.6 pt	0.94 lb *S*-metolachlor	1.0 pt Dual II Magnum
	27	0.209 lb mesotrione		0.09 lb mesotrione	3.0 oz Callisto
	9	2.09 lb glyphosate		0.94 lb glyphosate ae	24 oz Touchdown HiTech
Harness Xtra	15	4.3 lb acetochlor	2.3 qt	2.5 lb acetochlor	2.9 pt Harness 7E
	5	1.7 lb atrazine		0.98 lb atrazine	1 qt atrazine 4L
Harness Xtra 5.6L	15	3.1 lb acetochlor	3 qt	2.325 lb acetochlor	42.5 oz Harness 7E
	5	2.5 lb atrazine		1.875 lb atrazine	1.9 qt atrazine 4L
Hornet WDG	2	18.5% flumetsulam	5 oz	0.924 oz flumetsulam	1.15 oz Python WDG
	4	60% clopyralid		0.195 lb clopyralid	6.68 oz Stinger 3S
Integrity	14	6.24% saflufenacil	13 oz	0.058 lb saflufenacil	2.6 oz Sharpen
	15	55.04% dimethenamid		0.5 lb dimethenamid	10.9 oz Outlook
Instigate	2	4.17% rimsulfuron	6.0 oz	0.25 oz rimsulfuron	1.5 oz Resolve
	27	41.67% mesotrione		2.5 oz mesotrione	5 oz Callisto
Keystone NXT	15	3.1 lb acetochlor	2.0 qt	1.55 lb acetochlor	1.9 pt Surpass 6.4E
	5	2.5 lb atrazine		1.25 lb atrazine	2.5 pt Aatrex 4L
Keystone LA NXT	15	4.3 lb acetochlor	2.0 qt	2.15 lb acetochlor	2.7 pt Surpass 6.4E
	5	1.7 lb atrazine		1.25 lb atrazine	1.7 pt Aatrex 4L

Corn Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Lariat 4L	15	2.5 lb alachlor	4 qt	2.5 lb alachlor	2.5 qt Lasso 4E
	5	1.5 lb atrazine		1.5 lb atrazine	1.5 qt atrazine 4L
Lexar EZ	15	1.74 lb S-metolachlor	3.5 qt	1.52 lb S-metolachlor	1.6 pt Dual II Mag.
	5	1.74 lb atrazine		1.52 lb atrazine	3 pt Aatrex 4L
	27	0.224 lb mesotrione		0.196 lb mesotrione	6.27 oz Callisto
Lumax EZ	27	0.268 lb mesotrione	3 qts	0.2 lb mesotrione	6.4 oz Callisto
	15	2.68 lb S-metolachlor		2.0 lb S-metolachlor	2 pt Dual II MAGNUM
	5	1.0 lb atrazine		0.75 lb atrazine	0.75 qt Aatrex 4L
Medal 11 AT	5	3.1 lb atrazine	2.1 qts	1.63 lb atrazine	2 qt Aatrex 4L
	15	2.4 lbs S-metolachlor		1.26 lb S-metolachlor	1.3 pt Dual II MAGNUM
NorthStar	2	7.5% primisulfuron	5.0 oz	0.375 oz primisulfuron	0.5 oz Beacon 75SG
	4	43.9% dicamba		2.20 oz dicamba	4.0 oz Banvel 4L
Optill	14	17.8% saflufenacil	2.0 oz	0.35 oz saflufenacil	1 oz Sharpen
	2	50.2% imazethapyr		1 oz imazethapyr	4 oz Pursuit AS
Panoflex 50 WSG	2	40% tribenuron	0.5 oz	0.2 oz tribenuron	0.2 oz tribenuron
	2	10% thifensulfuron		0.05 oz thifensulfuron	0.1 oz Harmony SG
Prequel 45% DF	2	15% rimsulfuron	2 oz	0.3 oz rimsulfuron	1.2 oz Resolve SG
	27	30% isoxaflutole		0.59 oz isoxaflutole	1.2 oz Balance Pro
Priority	14	12.3% carfentrazone	1.0 oz	0.008 lb carfentrazone	0.5 oz Aim
	2	50% halosulfuron		0.032 lb halosulfuron	0.68 oz Permit
Realm Q	2	7.5% rimsulfuron	4 oz	0.3 oz rimsulfuron	1.2 oz Resolve SG
	27	31.25% mesotrione		1.25 oz mesotrione	2.5 oz Callisto
Require Q	2	0.062 lb rimsulfuron	4 oz	0.016 lb rimsulfuron	0.064 lb Resolve SG
	4	0.481 lb dicamba		0.12 lb dicamba	0.24 pt Clarity/Banvel
Resolve Q	2	0.184 lb rimsulfuron	1.25 oz	0.0143 lb rimsulfuron	0.057 lb Resolve DF
	2	0.04 lb thifensulfuron		0.0031 lb thifensulfuron	0.006 lb Harmony SG
Sequence	9	2.25 lbs glyphosate	4 qt	1.12 lbs glyphosate	28 oz Touchdown
	15	3 lbs S-metolachlor		1.5 lbs S-metolachlor	26 oz Dual II MAGNUM
Shotgun 3.25L	5	2.25 lb atrazine	2 pt	0.56 lb atrazine	1.12 pt atrazine 4L
	4	1 lb 2,4-D		0.25 lb a.e. 2,4-D	0.53 pt Esteron 99 3.8E
Spirit 57WG	2	14.25% prosulfuron	1 oz	0.1425 oz prosulfuron	0.25 oz Peak 57WG
	2	42.75% primisulfuron		0.4275 oz primisulfuron	0.57 oz Beacon 75SG

Corn Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Status 56WDG	19	17.1 % diflufenzopyr	5 oz	0.05 oz diflufenzopyr	0.05 oz diflufenzopyr
	4	44% dicamba		0.125 oz dicamba	4 oz Banvel
Steadfast Q	2	25.2% nicosulfuron	1.5 oz	0.37 oz nicosulfuron	0.68 oz Accent Q
	2	12.5% rimsulfuron		0.19 oz rimsulfuron	0.76 oz Resolve DF
SureStart SE/Tripleflex	15	3.75 lb acetochlor	2.0 pt	0.94 lb acetochlor	1.2 pt Surpass 6.4E
	4	0.29 lb clopyralid		1.2 oz clopyralid	3.2 oz Stinger 3S
	2	0.12 lb flumetsulam		0.48 oz flumetsulam	0.6 oz Python WDG
Surpass 100 5L	15	3 lb acetochlor	2.5 qt	1.88 lb acetochlor	1.18 qt Surpass 6.4E
	5	2 lb atrazine		1.25 lb atrazine	1.25 qt atrazine 4L
Verdict	14	6.24% saflufenacil	14 oz	0.992 oz saflufenacil	2.8 oz Sharpen
	15	55.04% dimethenamid-P		0.547 lb dimethenamid-P	11.7 oz Outlook
WideMatch 1.5EC	4	0.75 lb fluroxypyr	1.3 pt	0.125 lb fluroxypyr	10.6 oz Starane 1.5E
	4	0.75 lb clopyralid		0.125 lb clopyralid	5.3 oz Stinger 3S
Yukon	2	12.5% halosulfuron	4 oz	0.031 lb halosulfuron	0.66 oz Permit
	4	55% dicamba		0.125 lb dicamba	4.0 oz Banvel
Zemax	15	3.34 lb s-metolachlor	2 qt	1.67 lb s-metolachlor	1.7 pt Dual II Magnum
	27	0.33 lb mesotrione		0.17 lb mesotrione	5.4 oz Callisto

Soybean Herbicide Package Mixes or Co-packs and Equivalents

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Authority Assist	14	33.3% sulfentrazone	10 oz	3.3 oz sulfentrazone	5.6 oz Authority 75DF
	2	6.67% imazethapyr		0.67 oz imazethapyr	3.4 oz Pursuit AS
Authority Elite	14	7.55% sulfentrazone	25 oz	2.24 oz sulfentrazone	3 oz Authority 75DF
	15	68.25% s-metolachlor		1.26 lb s-metolachlor	1.3 pt Dual II MAGNUM
Authority First/Sonic	14	6.21% sulfentrazone	8.0 oz	0.31 lb sufentrazone	6.6 oz Authority 75DF
	2	7.96% cloransulam-methyl		0.04 lb cloransulam-methyl	0.76 oz FirstRate
Authority MAXX	14	62.12% sulfentrazone	7 oz	4.3 oz sulfentrazone	5.7 oz Authority 75DF
	2	3.88% chlorimuron		0.28 oz chlorimuron	1.1 oz Classic 25DF
Authority MTZ	14	18% sulfentrazone	16 oz	0.18 lb sulfentrazone	3.8 oz Authority 75DF
	5	27% metribuzin		0.27 lb metribuzin	0.54 pt Sencor 4L

Soybean Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Authority XL	14	62.2% sulfentrazone	8 oz	5.0 oz sulfentrazone	6.6 oz Authority 75DF
	2	7.8% chlorimuron		0.6 oz chlorimuron	2.4 oz Classic
Boundary 7.8EC	15	5.2 lbs s-metolachlor	2.1 pt	1.4 lb s-metolachlor	1.5 pt Dual II MAG.
	5	1.25 lbs metribuzin		0.3 lb metribuzin	6.4 oz Sencor 75DF
Canopy 75DF	2	10.7% chlorimuron-ethyl	6 oz	0.5 oz chlorimuron	2.0 oz Classic 25DF
	5	64.3% metribuzin		3 oz metribuzin	4.0 oz metribuzin 75DF
Canopy EX	2	22.7% chlorimuron	1.5 oz	0.34 oz chlorimuron	1.36 oz Classic
	2	6.8% tribenuron		0.10 oz tribenuron	0.10 oz tribenuron
Crusher	2	25% rimsulfuron	1 oz	0.25 oz rimsulfuron	1.0 oz Resolve DF
	2	25% thifensulfuron		0.25 oz thifensulfuron	0.5 oz Harmony SG
Enlite 47.9DG	14	36.2% flumioxazin	2.8 oz	1.0 oz flumioxazin	2.0 oz Valor
	2	8.8% thifensulfuron		0.25 oz thifensulfuron	0.5 oz Harmony SG
	2	2.8% chlorimuron ethyl		0.08 oz chlorimuron ethyl	0.32 oz Classic 25 DF
Envive 41.3DG	14	29.2% flumioxazin	5.3 oz	1.5 oz flumioxazin	3.0 oz Valor
	2	2.9% thifensulfuron		0.15 oz thifensulfuron	0.3 oz Harmony SG
	2	9.2% chlorimuron ethyl		0.49 oz chlorimuron ethyl	2.0 oz Classic 25DF
Extreme	2	1.8% imazethapyr	3 pt	0.064 lb imazethapyr	1.44 oz Pursuit DG
	9	22% glyphosate		0.75 lb glyphosate	24 oz Roundup
Fierce 76% WDG	2	33.5 % flumioxazin	3 oz	1.0 oz flumioxazin	2.0 oz Valor
	15	42.5% pyroxasulfone		1.28 oz pyroxasulfone	1.5 oz Zidua
Flexstar GT 3.5	14	0.56 lb fomesafen	3.5 pt	0.245 lb fomesafen	16 oz Flexstar
	9	2.26 lb glyphosate		1.0 lb glyphosate	26 oz Touchdown HiTech
FrontRow	2	flumetsulam	5 acres/pkg	0.15 oz flumetsulam	0.12 oz Python 80WDG
	2	chloransulam		0.25 oz chloransulam	0.3 oz FirstRate 84WDG
Fusion 2.67E	1	2 lb fluazifop	8 fl oz	0.125 lb fluazifop	8 fl oz Fusilade DX 2E
	1	0.67 lb fenoxaprop		0.042 lb fenoxaprop	8 fl oz Option II 0.67E
Gangster (co-pack)	14	51% flumioxazin	3.6 oz	1.5 oz flumioxazin	3.0 oz Valor
	2	84% chloransulam		0.5 oz chloransulam	0.6 oz FirstRate
Marvel	14	1.2% fluthiacet	5 oz	0.075 oz fluthiacet	0.66 oz Cadet
	14	30.08% fomesafen		1.8 oz fomesafen	0.5 pt Flexstar
OpTill	14	17.8% saflufenacil	2 oz	0.35 oz saflufenacil	1 oz Sharpen
	2	50.2% imazethapyr		1.0 oz imazethapyr	4 oz Pursuit AS

Soybean Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Panoflex 50% WSG	2	40% tribenuron	0.5 oz	0.2 oz tribenuron	0.2 oz tribenuron
	2	10% thifensulfuron		0.05 oz thifensulfuron	0.1 oz Harmony SG
Prefix	15	46.4% S-metolachlor	2 pt	1.09 lb S-metolachlor	1.14 pt Dual Magnum
	14	10.2% fomesafen		0.238 lb fomesafen	0.95 pt Reflex
Pummel	15	5.0 lb metolachlor	2 pt	1.25 lb metolachlor	2.6 pt Dual II MAGNUM
	2	0.25 lb imazethapyr		0.063 lb imazethapyr	4 oz Pursuit
Pursuit Plus 2.9E	2	0.2 lb imazethapyr	2.5 pt	0.063 lb imazethapyr	4.0 oz Pursuit 2S
	3	2.7 lb pendimethalin		0.84 lb pendimethalin	2.00 pt Prowl 3.3E
Sequence 5.25L	15	3.0 lb S-metolachlor	3 pt	1.13 lb S-metolachlor	1.2 pt Dual Magnum
	9	2.25 lb glyphosate		0.84 lb ae glyphosate	26 oz Touchdown
Sonic	14	6.21% sulfentrazone	8.0 oz	0.361 lb sulfentrazone	6.6 oz Authority 75DF
	2	7.96% cloransulam-methyl		0.04 lb cloransulam-methyl	0.76 oz FirstRate
Storm 4S	6	2.67 lb bentazon	1.5 pt	0.50 lb bentazon	1 pt Basagran 4S
	14	1.33 lb acifluorfen		0.25 lb acifluorfen	1 pt Blazer 2S
Synchrony NXT	2	21.5% chlorimuron	0.5 oz	0.11 oz chlorimuron	0.44 oz Classic 25DF
	2	6.9% thifensulfuron		0.034 oz thifensulfuron	0.068 oz Harmony SG
Tailwind	15	5.25 lb metolachlor	2 pt	1.3 lb metolachlor	2.7 pt Dual II MAGNUM
	5	1.25 lb metribuzin		0.31 lb metribuzin	0.62 pt Sencor 4F
Torment	14	2.0 lb fomesafen	1 pt	0.25 lb fomesafen	2.1 pt Flexstar
	2	0.5 lb imazethapyr		0.063 lb imazethapyr	4 oz Pursuit
Trivence WDG	2	3.9% chlorimuruon-ethyl	10 oz	0.39 oz chlorimuron	1.6 oz Classic 25DF
	14	12.8% flumioxazin		1.28 oz flumioxazin	2.5 oz Valor
	5	44.6% metribuzin		4.46 oz metribuzin	6 oz Sencor 75DF
Valor XLT	14	30.3% flumioxazin	3 oz	0.056 lb flumioxazin	1.76 oz Valor
	2	10.3% chlorimuron ethyl		0.019 lb chlorimuron	1.24 oz Classic

Herbicide Sites of Action

Herbicides kill plants by binding to a specific protein and inhibiting that protein's function. This protein is referred to as the herbicides site of action. Utilizing herbicide programs that include several different sites of action is a key step in managing herbicide resistant weeds.

A numbering system has been developed that makes it easier for farmers to evaluate their herbicide program in terms of site of action diversity. Each herbicide site of action is assigned a Group Number (Table 1), and this Group Number is typically found on the first page of most herbicide labels. Simply including multiple sites of action is not sufficient in fighting herbicide resistance in weeds, but rather the different sites of action must be effective against problem weeds such as waterhemp and giant ragweed.

Table 1. Herbicide classification by Group Number and site of action

Group No.	Site of Action (mode of action)
1	ACC-ase (lipid synthesis)
2	ALS (amino acid synthesis)
3	Tubulin (cell division)
4	Auxin binding site (synthetic auxin)
5	D1 protein (Photosystem II inhibition)
6	D1 protein (Photosystem II inhibition)
9	EPSPS (shikimic acid pathway inhibition)
10	Glutamine synthetase (photosynthesis inhibition)
13	DPX synthase (carotene synthesis)
14	PPO (chlorophyll synthesis)
15	Unknown (LC fatty acid synthesis)
19	Auxin transport
22	Photosystem I
27	HPPD (carotene synthesis)

Table 2. Active ingredients and Group Numbers of single ingredient products.

Trade name	Group No.	Active Ingredient
2,4-D	4	2,4-D
Accent	2	nicosulfuron
Aim	14	carfentrazone
Assure II	1	quizalofop
atrazine	5	atrazine
Autumn	2	iodosulfuron
Balance Flexx	27	isoxaflutole
Banvel/Clarity	4	dicamba
Basagran	6	bentazon
Beacon	2	primisulfuron
Buctril	6	bromoxynil
Cadet	14	fluthiacet-ethyl
Callisto	27	mesotrione
Classic	2	chorimuron
Cobra	14	lactofen
Command	13	clomazone
Dual	15	metolachlor
Express	2	tribenuron
FirstRate	2	cloransulam
FlexStar/Reflex	14	fomasafen
Fusilade DX	1	fluazifop
Gramoxone SL	22	paraquat
Harmony	2	thifensulfuron
Harness/Surpass	15	acetochlor
Impact/Armezon	27	topramezone
IntRRo	15	alachlor
Laudis	27	tembotrione
Liberty/Ignite	10	glufosinate
Lorox	7	linuron
Option	2	foramsulfuron
Outlook	15	dimethenamid
Peak	2	prosulfuron
Permit	2	halosulfuron
Poast	1	sethoxydim
Prowl	3	pendimethalin
Pursuit	2	imazethapyr
Python	2	flumetsulam
Raptor	2	imazamox
Resolve	2	rimsulfuron
Resource	14	flumiclorac
Roundup	13	glyphosate
Scepter	2	imazaquin
Select	1	clethodim
Sencor	5	metribuzin
Sharpen	14	saflufenacil
Sonalan	3	ethalfluralin
Spartan/Authority	14	sulfentrazone
Stinger	4	clopyralid
Treflan	3	trifluralin
UltraBlazer	14	acifluorfen
Valor	14	flumioxazin
Warrant	15	acetochlor
Zidua	15	pyroxasulfone
Only sold in premix	2	thiencarbazone
Only sold in premix	19	diflufenzopyr
Only sold in premix	1	fenoxaprop

Table 3. Active ingredients and group numbers of herbicide premixes.

Tradename	Group No.	Active Ingredients
Alluvex	2, 2	rimsulfuron, thifensulfuron
Anthem	14, 15	fluthiacet, pyroxasulfone
Anthem ATZ	5, 14, 15	atrazine, fluthiacet, pyroxasulfone
Authority Assist	2, 14	imazethapyr, sulfentrazone
Authority Elite	14, 15	sulfentrazone, metolachlor
Authority MTZ	5, 14	metribuzin, sulfentrazone
Authority XL	2, 14	chlorimuron, sulfentrazone
Autumn Super	2, 2	iodosulfuron, thiencarbazone
Basis Blend	2, 2	rimsulfuron, thifensulfuron
Bicep	5, 15	atrazine, metolachlor
Breakfree NXT ATZ, Breakfree NXT Lite	5, 15	atrazine, acetochlor
Callisto GR	9, 27	Glyphosate, mesotrione
Callisto Xtra	5, 27	atrazine, mesotrione
Canopy	2, 5	chloriuron, metrbuzin
Canopy EX	2, 5	chlorimuron, tribenuron
Capreno	2, 27	thiencarbazone, tembotrione
Corvus	2, 27	thiencarbazone, isoxaflutole
Crusher	2, 2	Rimsulfuron, thifensulfuron
Degree Xtra	5, 15	atrazine, acetochlor
Enlite	2, 2, 14	chlorimuron, thifensulfuron, flumioxazin
Envive	2, 2, 14	chloriuron, thifensulfuron, flumioxazin
Expert	5, 9, 15	atrazine, glyphosate, metolachlor
Extreme	2, 9	imazethapyr, glyphosate
Fierce	14, 15	flumioxazin, pyroxasulfone
Fierce XLT	2, 14, 15	chlorimuron, flumioxazin, pyroxasulfone
Flexstar GT	9, 14	glyphosate, fomesafen
FulTime NXT	5, 15	atrazine, acetochlor
Fusion	1, 1	fenoxaprop, fluazifop
Gangster	2, 14	cloransulam, flumioxazin
Halex GT	9, 15, 27	glyphosate, metolachlor, mesotrione
Harness Xtra	5, 15	atrazine, acetochlor
Instigate	2, 27	rimsulfuron, mesotrione
Keystone NXT, Keystone LA NXT	5, 15	atrazine, acetochlor
Lexar EZ	5, 15, 27	atrazine, metolachlor, mesotrione
Lumax EZ	5, 15, 27	atrazine, metolachlor, mesotrione
Marksman	4, 5	dicamba, atrazine
Marvel	14,14	Fluthiacet, fomesafen
Northstar	2, 4	primisulfuron, dicamba
Optill	2, 14	imazethapyr, saflufenacil
Panoflex	2, 2	Tribenuron, thifensulfuron
Permit Plus	2, 2	halosulfuron, thifensulfuron
Priority	2, 14	halosulfuron, carfentrazone
Prefix	14, 15	fomesafen, metolachlor
Prequel	2, 27	rimsulfuron, isoxaflutole
Pummel	2, 15	Imazethapyr, metolachlor
Pursuit Plus	2, 3	imazethapyr, pendimethalin
Realm Q	2, 27	rimsulfuron, mesotrione
Resolve Q	2, 2	rimsulfuron, thifensulfuron
Require Q	2, 4	rimsulfuron, dicamba
Sequence	9, 15	glyphosate, metolachlor
Sonic	2, 14	cloransulam, sulfentrazone
Spirit	2, 2	primisulfuron, prosulfuron
Status	4, 19	dicamba, diflufenzopyr
Steadfast Q	2, 2	nicosulfuron, rimsulfuron
Surestart	2, 4, 15	flumetsulam, clopyralid, acetochlor
Synchrony	2, 2	chlorimuron, thifensulfuron
Tailwind	5, 15	Metribuzin, metolachlor
Torment	2, 14	Imazethapyr, formesafen
Triple Flex	2, 4, 15	flumetsulam, clopyralid, acetochlor
Trivence	2, 5, 14	Chlorimuron, metribuzin, flumioxazin
Valor XLT	2, 14	chlorimuron, flumioxazin
Verdict	14, 15	saflufenacil, dimethenamid
Yukon	2, 4	halosulfuron, dicamba
Zemax	15, 27	metolachlor, mesotrione

Herbicide Site of Action and Typical Injury Symptoms

Herbicides kill plants by disrupting essential physiological processes. This normally is accomplished by the herbicide specifically binding to a single protein. The target protein is referred to as the herbicide "site of action". Herbicides in the same chemical family (e.g. triazine, phenoxy, etc.) generally have the same site of action,. The mechanism by which an herbicide kills a plant is known as its "mode of action." For example, triazine herbicides interfere with photosynthesis by binding to the D1 protein which is involved in photosynthetic electron transfer. Thus, the site of action for triazines is the D1 protein, whereas the mode of action is the disruption of photosynthesis. An understanding of herbicide mode of action is essential for diagnosing crop injury or off-target herbicide injury problems, whereas knowledge of the site of action is needed for designing weed management programs with a low risk of selecting for herbicide-resistant weed populations.

The Weed Science Society of America (wssa.net) has developed a numerical system for identifying herbicide sites of action by assigning group numbers to the different sites of action. Certain sites of action (e.g., photosystem II inhibitors) have multiple numbers since different herbicides may bind at different locations on the target enzyme (e.g. photosystem II inhibitors) or different enzymes in the pathway may be targeted (e.g., carotenoid synthesis). The number following the herbicide class heading is the WSSA classification. Most manufacturers are including these Herbicide Groups on herbicide labels to aid development of herbicide resistance management strategies. Prepackage mixes will contain the Herbicide Group numbers of all active ingredients.

ACCase Inhibitors – 1

The ACCase enzyme is involved in the synthesis of fatty acids. Three herbicide families attack this enzyme although there are two commonly associated with this site of actin. Aryloxyphenoxypropanoate (commonly referred to as "fops") and cyclohexanedione (referred to as "dims") herbicides are used postemergence, although some have limited soil activity (e.g., fluazifop). ACCase inhibitors are active only on grasses, and selectivity is due to differences in sensitivity at the site of action, rather than differences in absorption or metabolism of the herbicide. Most herbicides in this class are translocated within the phloem of grasses. The growing points of grasses are killed and rot within the stem. At sublethal rates, irregular bleaching of leaves or bands of chlorotic tissue may appear on affected leaves. Resistant weed biotypes have evolved following repeated applications of these herbicides. An altered target site of action and metabolism of these herbicides have been determined as responsible for the resistance.

ALS Inhibitors – 2

A number of chemical families interfere with acetolactate synthase (ALS), an enzyme involved in the synthesis of the essential branched chain amino acids (e.g., valine, leucine, and isoleucine). This enzyme is also called acetohydroxyacid synthaes (AHAS). These amino acids are necessary for protein biosynthesis and plant growth. Generally, these herbicides are absorbed by both roots and foliage and are readily translocated in the xylem and phloem. The herbicides accumulate in meristematic regions of the plant and the herbicidal effects are first observed there. Symptoms include plant stunting, chlorosis (yellowing), and tissue necrosis (death), and are evident 1 to 4 weeks after herbicide application, depending upon the dose, plant species and environmental conditions. Soybeans and other sensitive broad-leaf plants often develop reddish veins visible on the undersides of leaves. Symptoms in corn include reduced secondary root formation, stunted, "bottle-brush" roots, shortened internodes, and leaf malformations (chlorosis, window-pane appearance). However, symptoms typically are not distinct or consistent. Factors such as soil moisture, temperature, and soil compaction can enhance injury or can mimic the herbicide injury. Some ALS inhibiting herbicides have long soil residual properties and may carry over and injure sensitive rotational crops. Herbicide resistant weed biotypes possessing an altered site of action have evolved after repeated applications of these herbicides. Resistance to the ALS inhibitor herbicides attributable to metabolism has also been identified in weeds.

Microtubule Inhibitors – 3

Dinitroaniline (DNA) herbicides inhibit cell division by interfering with the formation of microtubules through inhibition of tubulin polymerization. Dinitroaniline herbicides are soil-applied and absorbed mainly by roots. Very little herbicide translocation in plants occurs, thus the primary herbicidal effect is on root development. Soybean injury from DNA herbicides is characterized by root pruning. Roots that do develop are typically thick and short. Hypocotyl swelling also occurs and the hypocotyl may be brittle and easily snapped at the ground level. The inhibited root growth causes tops of plants to be stunted. Corn injured by DNA carryover demonstrates root pruning and short, thick roots. Leaf margins may have a reddish color. Since DNAs are subject to little movement in the soil, such injury is often spotty due to localized concentrations of the herbicide. Early season stunting from DNA herbicides typically does not result in significant yield reductions.

Synthetic Auxins – 4

Several chemical families cause abnormal root and shoot growth by upsetting the plant hormone (i.e., auxin) balance. This is accomplished by the herbicides binding to the auxin receptor site. These herbicides are primarily effective on broadleaf species, however some monocots are also sensitive. Uptake can occur through seeds or roots with soil-applied treatments or leaves when applied postemergence. Synthetic auxins translocate throughout plants and accumulate in the active meristems. Corn injury may occur in the form of onion leafing, proliferation of roots, or abnormal brace root formation. Corn stalks may become brittle and breakage at the nodes following application is possible; this response usually lasts for 7 to 10 days following application. The potential for injury increases when applications are made over the top of the plants to corn larger than 10 to 12 inches in height. Soybean injury from synthetic auxin herbicides is characterized by cupping, strapping and crinkling of leaves. Soybeans are extremely sensitive to dicamba; however, early season injury resulting only in leaf malformation usually does not negatively affect yield potential. Soybeans occasionally develop symptoms characteristic of auxin herbicides in the absence of these herbicides. This response is poorly understood but usually develops during periods of rapid growth, low temperatures or following stress from other postemergence herbicide applications. Some dicamba formulations have a high vapor pressure and may move off target due to volatilization.

Photosystem II Inhibitors – 5, 6, 7

Several families of herbicide bind to a protein involved in electron transfer in Photosystem II (PSII). These herbicides inhibit photosynthesis, which may result in inter-veinal yellowing (chlorosis) of plant leaves followed by necrosis (death) of leaf tissue. Highly reactive compounds formed due to inhibition of electron transfer cause the disruption of cell membranes and ultimately plant death. When PSII inhibitors are applied to the leaves, uptake occurs into the leaf but very little movement out of the leaf occurs. Injury to corn may occur as yellowing of leaf margins and tips followed by browning, whereas injury to soybean occurs as yellowing or burning of outer leaf margins. The entire leaf may turn yellow, but veins usually remain somewhat green (inter-veinal chlorosis). Lower leaves are first and most affected, and new leaves may be unaffected. Triazine (Group 5) and urea (Group 7) herbicides generally are absorbed both by roots and foliage, whereas benzothiadiazole (Group 6) and nitrile (Group 6) herbicides are absorbed primarily by plant foliage. Triazine-resistant biotypes of several weed species have been confirmed in Iowa following repeated use of triazine herbicides. Although the other PSII herbicides attack the same target site, they bind on a different part of the protein and remain effective against triazine-resistant weeds. Triazine resistance is due to an altered target site and examples of metabolic resistance also have been identified.

Photosystem I Inhibitors - 22

Herbicides in the bipyridilium family rapidly disrupt cell membranes, resulting in wilting, necrosis and tissue death. They capture electrons moving through Photostystem I (PSI) and produce highly destructive secondary plant compounds. Very little translocation of bipyridilium herbicides occurs due to loss of membrane structure. Injury occurs only where the herbicide spray contacts the plant. Complete spray coverage is essential for weed control. The herbicide molecules carry strong positive charges that cause them to be very tightly adsorbed by soil colloids. Consequently, bipyridilium herbicides have no significant soil activity. Injury to crop plants from paraquat drift occurs in the form of spots of dead leaf tissue wherever spray droplets contact the leaves. Typically, slight drift injury to corn, soybeans, or ornamentals from a bipyridilium herbicide does not result in significant growth inhibition.

Protoporphyrinogen Oxidase (PPO) Inhibitors – 14

Group 14 herbicides inhibit an enzyme involved in synthesis of a precursor of chlorophyll; the enzyme is referred to as PPO. Plant death results from destruction of cell membranes due to formation of highly reactive compounds. Postemergence applied diphenyl ether herbicides (e.g., aciflurofen, lactofen) kill weed seedlings are contact herbicides with little translocation. Thorough plant coverage by the herbicide spray is required. Applying the herbicide prior to prolonged cool periods or during hot, humid conditions will result in significant crop injury. Injury symptoms range from speckling of foliage to necrosis of whole leaves. Under extreme situations, herbicide injury has resulted in the death of the terminal growing point, which produces short, bushy soybean plants. Most injury attributable to postemergence diphenyl ether herbicides is cosmetic and does not affect yields. The aryl triazolinones herbicides are absorbed both by roots and foliage. Susceptible plants emerging from soils treated with these herbicides turn necrotic and die shortly after exposure to light. Soybeans are most susceptible to injury if heavy rains occur when beans are cracking the soil surface.

Carotenoid synthesis inhibitors –13, 27

Herbicides in these families inhibit the synthesis of the carotene pigments. Inhibition of the carotene pigments results in loss of chlorophyll and bleaching of foliage at sublethal doses. Plant death is due to disruption of cell membranes. Several different enzymes in the synthesis of carotenoids are targeted by herbicides. Clomozone (Command) inhibits DOXP (Group 13), whereas the other bleaching herbicides used in corn (Callisto, Balance Flexx, Laudis, Impact) inhibit HPPD (Group 27). The HPPD inhibiting herbicides are xylem mobile and absorbed by both roots and leaves, they are used both preemergence and postemergence. Resistance to the Group 27 herbicides has evolved in waterhemp and is attributable to metabolism of the herbicide.

Enolpyruvyl Shikimate Phosphate Synthase (EPSPS) Inhibitors – 9

Glyphosate is a substituted amino acid (glycine) that inhibits the EPSPS enzyme. This enzyme is a component of the shikimic acid pathway, which is responsible for the synthesis of the essential aromatic amino acids and numerous other compounds. Glyphosate is nonselective and is tightly bound in soil, so little root uptake occurs under normal use patterns. Applications must be made to plant foliage. Translocation occurs out of leaves to all plant parts including underground storage organs of perennial weeds. Translocation is greatest when plants are actively growing. Injury symptoms are fairly slow in appearing. Leaves slowly wilt, turn brown, and die. Sub-lethal rates of glyphosate sometimes produce phenoxy-type symptoms with feathering of leaves (parallel veins) and proliferation of vegetative buds, or in some cases cause bleaching of foliage. Resistance to glyphosate has evolved in a number of important weed species (e.g., waterhemp, giant ragweed, Palmer amaranth). Several mechanisms have been identified that confer resistance to glyphosate in weeds.

Glutamine Synthetase Inhibitors – 10

Glufosinate (Liberty) inhibits the enzyme glutamine synthetase, an enzyme that incorporates ammonium in plants. Although glutamaine synthetase is not involved directly in photosynthesis, inhibition of this enzyme ultimately results in the disruption of photosynthesis. Glufosinate is relatively fast acting and provides effective weed control in three to seven days. Symptoms appear as chlorotic lesions on the foliage followed by necrosis. There is limited translocation of glufosinate within plants. Glufosinate has no soil activity due to rapid degradation in the soil by microorganisms. Libery is nonselective except to crops that carry the Liberty Link gene. To date, there are only two weed species with evolved resistance to glufosinate and resistance has not be identified in Iowa.

Fatty acid and lipid synthesis inhibitors – 8

The specific site of action for the thiocarbamate herbicides (e.g., EPTC, butylate) is unknown, but it is believed they may conjugate with acetyl coenzyme A and other molecules with a sulfhydryl moiety. Interference with these molecules results in the disruption of fatty acid and lipid biosynthesis, along with other related processes. Thiocarbamate herbicides are soil applied and require mechanical incorporation due to high volatility. Leaves of grasses injured by thiocarbamates do not unroll properly from the coleoptiles, resulting in twisting and knotting. Broadleaf plants develop cupped or crinkled leaves.

Very long chain fatty acid synthesis inhibitors (VLCFA) –15

Several chemical families (acetamide, chloroacetamide, oxyacetamide, pyrazole and tetrazolinone) are reported to inhibit biosynthesis of very long chain fatty acids. VLCFA are believed to play important roles in maintaining membrane structure. These herbicides disrupt the germination of susceptible weed seeds but have little effect on emerged plants. They are most effective on annual grasses, but have activity on certain small-seeded annual broadleaves. Soybean injury occurs in the form of a shortened mid-vein in leaflets, resulting in crinkling and a heart-shaped appearance. Leaves of grasses, including corn, damaged by these herbicides fail to unfurl properly, and may emerge underground.

Auxin Transport Inhibitors – 19

Diflufenzopyr (Status) has a unique mode of action in that it inhibits the transport of auxin, a naturally occurring plant-growth regulator. Diflufenzopyr is sold only in combination with dicamba and is primarily active on broadleaf species, but it may suppress certain grasses under favorable conditions. Diflufenzopyr is primarily active through foliar uptake, but it can be absorbed from the soil for some residual activity. Injury symptoms are similar to other growth regulator herbicides. Status (dicamba + diflufenzopyr) includes a safener to improve crop safety.

ACCase inhibitor	
aryloxyphenoxy-propanoate	
Assure II, others	quizalofop-p-ethyl
Fusilade DX	fluazifop-p-butyl
Fusion	fluazifop-p-butyl + fenoxaprop
Hoelon	diclofop
cyclohexanediones	
Poast, Poast Plus	sethoxydim
Select, Section, Arrow, others	clethodim

ALS inhibitors	
imidazolinones	
Pursuit	imazethapyr
Raptor	imazamox
Scepter	imazaquin
sulfonanilides	
FirstRate, Amplify	chloransulam
Python	flumetsulam
sulfonylureas	
Accent	nicosulfuron
Ally, Cimarron	metsulfuron
Beacon	primisulfuron
Classic	chlorimuron
Express	tribenuron
Harmony GT	thifensulfuron
Permit, Halofax	halosulfuron

Microtubule inhibitor	
dinitroanilines	
Balan	benefin
Prowl H_20, Pentagon, Pendimax, Framework, others	pendimethalin
Sonalan	ethalfluralin
Surflan	oryzalin
Treflan, Trust, others	trifluralin

Synthetic auxin	
benzoic	
Banvel, Clarity, Sterling Blue, others	dicamba
phenoxy	
many	MPCA
many	2,4-D
Butyrac, Butoxone	2,4-DB
pyridines	
Remedy Ultra, Pathfinder II, many others	triclopyr
Milestone	aminopyralid
Stinger, Transline	clopyralid
Tordon	picloram

Photosystem II inhibitors	
benzothiadiazole	
Basagran	bentazon
nitriles	
Buctril, others	bromoxynil
triazines	
AAtrex, others	atrazine
Evik	ametryn
Princep	simazine
Sencor	metribuzin
ureas	
Karmex	diuron
LInex, Lorox	linuron

Photosystem I inhibitors	
Diquat, Reward	diquat
Gramoxone Max	paraquat

Protoporphyrinogen Oxidase (PPO) inhibitors	
aryl triazolinones	
Aim	carfentrazone
Authority, Spartan	sulfentrazone
diphenyl ethers	
Blazer, UltraBlazer	acifluorfen
Cobra, Phoenix	lactofen
ET, Vida	pyraflufen
Flexstar, Reflex	fomesafen
Goal	oxyfluorfen
phenylphthalimides	
Resource	flumiclorac
Valor	flumioxazin
pyrimidinedione	
Sharpen (Kixor)	saflufenacil
other	
Cadet	fluthiacet

Enolpyruvyl shikimate phosphate synthase (EPSPS) inhibitors	
Roundup, Touchdown, others	glyphosate

Glutamine synthetase inhibitors	
Liberty, Ignite	glufosinate

Hydroxyphenyl pyruvate dioxygenase (HPPD) inhibitors	
Balance Flexx	isoxaflutole + safener
Callisto	mesotrione
Armezon/Impact	topramezone

Diterpene inhibitors	
Command	clomazone

Auxin transport inhibitors	
Distinct, Status	diflufenzopyr + dicamba

Lipid synthesis inhibitors	
amides or acetanilides	
Degree, Harness, Surpass, Warrant	acetochlor
Dual II MAGNUM, Cinch, Medal, Charger Max, others	s-metolachlor + safener
Frontier, Outlook, Commit, others	dimethenamid
Lasso, Intrro, MicroTech	alachlor
Zidua	pyroxasulfone

Prepared by Micheal D. K. Owen and Robert Hartzler, Extension weed specialists, Department of Agronomy, Iowa State University. Design by Brent Pringnitz, Agriculture and Natural Resources Program Services. Common chemical and trade names are used in this publication. The use of trade names is for clarity by the reader. Due to the large number of generic products available ISU is not able to include all products. Inclusion of a trade name does not imply endorsement of that particular brand of herbicide and exclusion does not imply non-approval.

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