# **2015 Herbicide Guide for Iowa Corn and Soybean Production**

# Weed management update for 2015

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# Introduction

Environmental conditions of 2013 resulted in delayed herbicide applications and drought later in the summer. 2014 saw an increased use of "alternative" herbicides and cool, wet conditions. These factors contributed to interesting occurrences in recent weed management.

Herbicide carryover was seen in several products, some products provided evidence why farmers preferred using glyphosate alone, and herbicide-resistant weed populations continued to evolve. It appears the message of diversity in herbicide resistance management is gaining traction. The focus is primarily on herbicides, though, which is the reason herbicide resistance became such a big issue. There is a need to expand the acceptance of diversity in weed management.

# Selected industry updates

**ADAMA** (formerly MANA) Latir is a premix of flumioxazin (herbicide group 14 - HG14) and imazethapyr (HG2) for preplant/preemergence applications in soybean. It is labeled at rates of 3.2 to 4.25 oz/A. Pummel is a premix of metolachlor (HG15) and imazethapyr (HG2) for preplant/preemergence use in soybean. Use rate ranges from 1.6 to 2.0 pt/A. Torment is a premix containing fomesafen (HG14) and imazethapyr (HG2) labeled for preplant/ preemergence/ postemergence application in soybean. Use rates range from .75 to 1 pt/A.

**BASF** The Sharpen (HG14) label now allows use as a harvest aid and desiccant for soybean. The use rate for this purpose is 1 to 1.5 oz/A and can be applied when >65% of pods are brown and >70% leaf drop, or when seed moisture is < 30%. No data is available to establish how effective it would be on enhancing dry down of waterhemp, the biggest potential target for this use in Iowa.

**Bayer CropSciences** is planning to introduce DiFlexx for the 2015 season. The label is pending at this time. DiFlexx contains dicamba (HG4) and the safener cyprosulfamide. It will be labeled for both preemergence and post applications up to the V9 stage. Use rates are 6 to 16 fl oz/A, and it will be registered for field, white, seed and popcorn.

Balance GT soybean were deregulated by the USDA in the summer of 2013, but commercial release will not be until 2016. The soybean are resistant to isoxaflutole (HG27) and glyphosate (HG9). Balance Bean is a formulation of isoxaflutole pending registration for use on soybean with the Balance GT trait.

**Cheminova** Bestow (25% rimsulfuron – HG2) replaces Solida for use in corn. Solida is still labeled for use on specialty crops. Harrow is a mixture of 50% rimsulfuron (HG2) and 50% thifensulfuron (HG2) for preplant/preemergence/ postemergence applications in corn. Statement is a premix of metolachlor (HG15) and fomesafen (HG14) for preplant/ preemergence applications in soybean.

**Dow AgroSciences** The Enlist trait providing resistance to 2,4-D (HG4) in soybean was approved by the USDA in September, 2014 and the EPA recently registered Enlist Duo, a premix of glyphosate (HG9) and 2,4-D choline (HG4). Full launch of the product line will be delayed until the trait is approved overseas.

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**DuPont** Afforia is a recently registered premix of flumioxazin (HG14). thifensulfuron (HG2) and tribenuron (HG2) for preplant applications in soybean. It provides burndown and residual control. Use rates range from 2.5 to 3.75 oz/A. Revulin Q is a premix of nicosulfuron (HG2), mesotrione (HG27) and a safener for postemergence use in corn. Registration is anticipated early in 2015. Use rates will be 3.4 to 4.0 oz/A. The use rate for Enlite {chlorimuron (HG2), flumioxazin (HG14) and thifensulfuron (HG2)} has been changed from 2.8 oz/A to a range of 2.8 to 4.25 oz/A.

**FMC** Solstice was introduced in 2014 and is a premix of mesotrione (HG27) and fluthiacet (HG14). It is labeled for postemergence use in corn at rates of 2.5 to 3.15 oz/A up to the V8 growth stage. Authority Elite was introduced in 2014 and is a premix of sulfentrazone (HG14) and S-metolachlor (HG15). It is labeled for preplant/preemergence applications in soybean at rates between 19 and 38.7 fl oz/A.

**Monsanto** TripleFlex II contains the same concentrations of acetochlor (HG15), flumetsulam (HG2) and clopyralid (HG4) and same use rates as the original formulation. It contains a new safener and has improved stability. Monsanto has introduced two products containing flumioxazin (HG14), Rowel and Rowel FX. The labels are equivalent to Valor and Valor XLT.

**NuFarm** Spitfire is a combination of dicamba and 2,4-D ester (both HG4). It is labeled for preplant and preemergence applications in corn, preplant applications in soybean,

and for use in pastures, CRP and general farmstead applications. It is an ester formulation of the Weedmaster product line with a lower rate of dicamba. Cheetah contains glufosinate (HG10) at the same concentration present in Liberty. Registration for use on LL soybean is anticipated for 2015 and LL corn for 2016. Cheetah Max is a premix of glufosinate (HG10) and fomesafen (HG14). It is labeled for preplant/preemergence applications in soybean and postemergence applications in LL soybean.

Syngenta Callisto GT is a premix of mesotrione (HG27) and glyphosate (HG9). It is labeled for postemergence applications in glyphosate resistant corn at a rate of 2 pt/A. Callisto (HG27) is now cleared for aerial applications in corn. A minimum of 2 gal/A carrier must be used. Sequential applications of a pre- and postapplication of Dual II Magnum are now allowed in soybean. The combined rate is not to exceed 2.5 pt/A. The V3 restriction for post-application in soybean has been removed and replaced by a 90 day preharvest interval (PHI) on both the Dual II Magnum and Prefix labels. Sequence is a premix of S-metolachlor (HG15) and glyphosate (HG9) labeled for preplant and preemergence application in corn and soybean, and may also be applied postemergence in glyphosate resistant corn and soybean. Syngenta is anticipating registration of Acuron for 2015. It contains the same actives as Lumax {(S-metolachlor (HG15), mesotrione (HG27), atrazine (HG5)} plus the new group 27 a.i. bicyclopyrone.

**UPI** Broadloom is a product containing bentazon (HG6) for postemergence broadleaf control in corn and soybean. Satellite is an encapsulated formulation of pendimethalin (HG3) for use in corn, soybean and alfalfa.

**Valent** Fierce XLT recently obtained federal registration for pre-weed control in soybean. It is a premix of flumioxazin (HG14), pyroxasulfone (HG15) and chlorimuron (HG2).

# Herbicide crop responses and carryover

Another wet spring in 2014 complicated weed management by compressing the time available for planting and applying herbicides. However, fewer growers chose to skip the preemergence herbicide applications in 2014 than in previous years and reduced the problems with weed escapes later in the season. Probably the biggest issue in 2014 was widespread crop response from pre-emergence herbicides, particularly in soybean.

The increase in unfavorable crop response was due to a combination of increased acres treated with preemergence herbicides, an increase in actual use rates applied, and the cool, wet conditions early in the growing season which caused stress on the developing crop. The potential for crop response is determined by: 1) the inherent tolerance of the crop to the herbicide, 2) the amount of herbicide the crop is exposed to, and 3) the vigor of the crop. Another factor that may be important is the herbicide applied during the past year. Information regarding crop tolerance is available in the Herbicide Effectiveness

Rating Tables provided in WC 94. With some herbicides there may be differences in relative tolerance among corn hybrids or soybean varieties. Some seed companies provide information on the relative tolerance of their products to various herbicides. In most situations the range of tolerance within a crop is relatively small compared to the influence environment can have on crop tolerance.

Herbicide exposure to the crop is also influenced by the herbicide rate applied, uniformity of application (i.e. sprayer overlaps), and availability of the herbicide to the developing crop. For preemergence herbicides, availability is determined primarily by soil characteristics and soil moisture. In most Iowa soils, soil organic matter is primarily responsible for herbicide adsorption which reduces herbicide availability to the crop. Herbicide availability increases as soil organic matter decreases. Thus, risk of an unfavorable crop response increases in eroded areas or other areas of a field with low soil organic matter. The amount of herbicide available for absorption by plants also increases with soil moisture since excess water displaces herbicide from the soil adsorptive sites, therefore increasing the amount of herbicide in solution and the potential for an unfavorable crop response. Saturated soils early in the spring of 2014 resulted in much greater availability of soilapplied herbicides than what typically occurs in growing seasons.

Finally, most crops gain their selectivity to herbicides via their ability to rapidly metabolize the herbicide before it reaches the site of action. Environmental conditions that stress a crop reduce herbicide metabolism and increase the potential for an unfavorable crop response. The prolonged periods of saturated soils this spring increased herbicide availability while reducing the ability of the crop to metabolize the herbicide. The combination of increased use of preemergence herbicides, increased herbicide availability, and reduced crop vigor created a scenario where the number of fields with significant unfavorable crop response should not be a surprise. In some fields crop stands were not reduced and the plants recovered relatively quickly, thus yield potential was less likely affected. Undoubtedly, there were some fields where the problems persisted and yields were reduced.

# Specific herbicides causing crop responses

The most common unfavorable crop response from preemergence herbicides observed in 2014 was from HG 14 herbicides applied in soybeans. A number of products were found to cause unfavorable soybean response including sulfentrazone (e.g., Authority products), saflufenacil (e.g., OpTill) and flumioxazin (e.g., Fierce). It is possible that products included in some of the pre-mixtures that have the HG 14 herbicides listed may have contributed to the issues. However, a major factor was the environmental conditions. Cool soils and rains that splashed soil containing the HG 14 products was likely an important factor in the crop response. Soybean stand reductions were observed and replanting did occur. Soybean yields were affected in some fields.

### Herbicide carryover

A number of instances of HG 2 (e.g., chlorimuron) and HG 14 (e.g., fomesafen) carryover to corn were observed in 2014. Again, environmental conditions were a primary factor; not just the 2014 conditions but also those that occurred in 2013. Postemergence herbicide applications to soybeans in 2013 were delayed due to wet conditions early in the spring. Dry conditions that followed did not provide a good opportunity for the herbicides to degrade. As a result, sufficient carryover herbicide was available to the corn in 2014 to cause an unfavorable response. The response was likely enhanced by the cool, wet conditions under which the corn was developing. Another factor that may have contributed was the HG 2 herbicide applied preemergence to the corn this spring. If the product included an HG 2 herbicide, the crop response to the previously applied HG 2 herbicide was exacerbated.

In the case of fomesafen, the late application in 2013 and the unique conditions did not favor the degradation of the herbicide, in concert with the 2014 corn crop conditions that resulted in a carryover response.

# Herbicide-resistant weeds

Herbicide resistance continues to be a major topic in agriculture and has the attention of politicians in Washington, DC. Secretary of Agriculture Vilsack issued a proclamation about the importance of herbicide-resistant weeds and indicated that the new herbicidetolerant crop cultivars were important tools to help combat this problem. The Weed Science Society of America sponsored a second Herbicide Resistance Summit hosted by the National Academy of Sciences in Washington DC and the event was extremely well-received. The United Soybean Board has developed the "Take Action" campaign and the Iowa Soybean Association has also been very aggressive about the need for improved herbicide-resistant weed management. There is, however, a need for research and education to better address the issue of herbicide resistance. Also, based on anecdotal information, farmers recognize that herbicide resistance is a major concern, but are reticent to do anything about it on their farms until it becomes a serious problem.

There was a greater adoption of alternative herbicides in Iowa, which may have slowed the rate of herbicide resistance evolution, but the problem is still very prevalent across the state. No new weed species with herbicide resistance have been identified, but the three that are most troublesome are serious enough. Waterhemp continues to be the biggest problem in the state and giant ragweed populations are expanding. Marestail/horseweed is still a major problem in the south and southwest where most of the notillage production is practiced. All three of these weeds have resistant populations to glyphosate (HG 9) and ALS inhibitor herbicides (HG 2), and many of the populations have multiple resistances.

The HG14 herbicides (PPO inhibitors) have been used more widely and often recurrently. While HG 14 resistance occurs at a low percentage of the Iowa fields, increasing use will likely result in more HG 14 resistance. This is a serious problem. The only herbicide group that can be applied postemergence in soybeans other than glufosinate (HG 10) is the HG 14 products. If resistance to these herbicides becomes widespread such as it is in Illinois, soybean weed management in Iowa will be in trouble.

Greater diversity of tactics is needed to combat herbicide-resistant weeds. Rotation of herbicide mechanisms of action is beneficial, but inclusion of multiple **effective** herbicide mechanisms of action for every herbicide application is a much more robust tactic. True diversification in weed management requires the inclusion of nonherbicidal tactics. Cultural tactics such as crop rotation, narrowrow spacing and the inclusion of cover crops reduce the selection pressure on weeds placed by herbicides. Mechanical weed control is an important option for Iowa farmers to use in the management of herbicide-resistant weeds and the benefits and risks should be evaluated to determine if mechanical tactics have a fit in specific fields.

## Assessment of herbicide pre-mixtures

Herbicide pre-mixtures of two or more active ingredients have been a major part of herbicidebased weed management. As more herbicides move off patent, companies are creating more pre-mixtures to support their proprietary product lines. In general, the benefits of the premixtures reflect the convenience of not having to mix several herbicides together, which requires knowing the proper mixing procedures, pre-wetting and other potentially time-consuming and difficult tasks. The risks of using herbicide pre-mixtures include having only one rate of the component herbicides available. The rates of the component herbicides may not be the best rate for specific field situations. Furthermore, companies will often look at the economics of the component products as an important criteria when they determine the rates included in the pre-mixture.

Generally the herbicide rates in a pre-mixture will be lower than labeled as a single product. As such. the rates of the herbicides in the pre-mixture may not be the best choice for specific fields or weed infestations, particularly if the weeds have evolved herbicide resistance. For example, Authority Elite is a pre-mixture of sulfentrazone and s-metolachlor. HG 14 and HG 15 herbicides, respectively. This pre-mixture would be a good choice to manage waterhemp with resistance to HG 2 and HG 9 herbicides except that the rates of the component herbicides are approximately 1/2 the labeled rates for Spartan and Dual Magnum.

Given the extended germination period for waterhemp, the reduced rates of herbicides in this premixture would not provide the needed residual control. Please note that many of the herbicide pre-mixtures available for corn and soybean have reduced herbicide amounts compared to the individual products. It is important to review the pre-mixtures and determine if the rates of the component herbicides are high enough to provide the desired weed control.

Another concern about available herbicide pre-mixtures is they are often advertised as a good tactic to manage herbicide-resistant weeds based on the fact that they have two or more herbicide groups included in the product. Given the prevalence of waterhemp with evolved resistance to HGs 2, 5 and 9, it is important to know the susceptibilities of the targeted waterhemp populations as well as the herbicide groups included in the pre-mixtures under consideration.

HG 2 herbicides (e.g., imazethapyr and chlorimuron) are essentially useless for waterhemp control in Iowa. Resistance to HG 5 (e.g., atrazine) and HG 9 (e.g., glyphosate) herbicides in waterhemp occurs in about half of the fields in Iowa and often the waterhemp populations will have multiple resistances to several herbicide groups. Knowing the herbicide groups included in the pre-mixtures as well as the herbicide resistance profile of the target weed population is critically important when developing an effective herbicide program.

# Assessment of new GE crop traits for weed management

The genetically engineered trait for tolerance to 2,4-D (HG 4) (Dow AgroSciences) is now deregulated and available for commercial sales. Also, the herbicide system developed for the traits is labeled. However, globally, the trait is not yet accepted by major markets. As a result, it is unclear how widely available the Enlist series of crops will be in 2015. The genetically engineered trait for tolerance to dicamba (HG 4) (Monsanto and BASF) is not deregulated at this time but deregulation is anticipated early in 2015. The dicamba-based technologies are not likely to be commercially available in 2015. The HPPD (HG 27) tolerance for soybean (Bayer CropScience and Syngenta) are still under development and will not be available in 2015. Commercialization of these soybean cultivars is likely several years in the future.

These new HG 4 traits represent useful tools for weed management and are important to help better manage evolved herbicide resistances in many important weeds such as waterhemp. However, despite the development of improved herbicide formulations and stewardship programs by the companies, there are still risks attributable to off-target movement from physical drift and to a lesser extent volatilization drift. An important concern reflects the contamination of spray tanks and nurse tanks and whether current sanitary procedures (e.g., triple rinse) will be effective or actually employed by applicators.

Another concern is with farmer expectations and willingness to adopt the stewardship programs developed by the companies. While the auxin herbicides (HG 4) are active on target weeds such as waterhemp, the level of control that they will consistently provide is likely lower than farmer expectations These traits and herbicides are not the answer to herbicide-resistant waterhemp but rather should be considered a component of a more diverse weed management program. It is important to remember that waterhemp has already demonstrated the ability to evolve resistance to the HG 4 herbicides.

# Community-based weed management – is this a possibility?

Herbicide-resistant weeds continue to be a problem in Iowa and are widely distributed across the landscape. Efforts to manage the herbicide-resistant weed problem have been historically based on the efforts of individual farmers and generally have not been as successful as desired. Survey information suggests that often the individual feels his or her efforts are overwhelmed by the lack of efforts by others and as a result, does not move forward with a diversified weed management plan. Also, the primary if not sole approach to managing herbicideresistant weeds continues to be with herbicides. Given the existence of waterhemp populations with multiple resistances, an approach that is strictly based on herbicides has little chance of durable success. Herbicide-resistant weeds are an example of a common pool resource: if an individual in the area has herbicide-resistant weeds, those weeds have the potential to impact everyone in the area. Thus, efforts need to be organized within the community and supported by the community.

In order for community-based weed management to work, the leadership must be local and the individuals participating must be dedicated to an agreed upon goal. Information and economic support of the community-based program will likely be external (i.e., Cooperative Extension Service) but the local effort is of paramount importance. The local leadership will establish the "boundaries" of the community, set up how local fields (the community) will be monitored and managed, and provide the momentum to keep the program functioning and possibly expanding in scope.

However, initiating a new concept like community-based weed management on herbicide-resistant weeds in Iowa is daunting and likely impossible to sustain. Measurement of success metrics would be difficult, at best, given the ubiquitous nature of herbicideresistant weeds across the Iowa landscape. A community-based management pilot program directed at Palmer amaranth should have a greater chance of success given the currently isolated and rare infestations that have been identified in Iowa. A study is currently underway to evaluate the feasibility of a pilot communitybased Palmer amaranth project in specific locations. It is hoped that the pilot project can be established in 2015 at yet-to-be identified communities.

### Palmer amaranth update

Palmer amaranth was confirmed in Harrison, Fremont, Page and Muscatine counties in 2013. A suspected infestation in Davis County turned out to be spiny amaranth rather than Palmer amaranth. Two different infestations were found in Lee County this year. We suspect there are more unknown infestations than those that have been reported. As might be expected, some of the growers with Palmer amaranth infestations are making good efforts at eradicating the invader before it becomes a permanent component of the weed community, but others are treating it like any other weed.

# Cover crops, weeds, and herbicides

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The Iowa Nutrient Reduction Strategy and other factors have increased interest in fitting cover crops into Iowa's cropping systems. The benefits of cover crops are well documented and include reducing erosion, nutrient losses, and soil compaction. Legume cover crops such as hairy vetch may contribute nitrogen via biological fixation. The extended period of plant growth during times when soil is often left bare is also beneficial for overall soil health. Finally, cover crops can complement weed management programs by suppressing the establishment of weeds. This paper will focus on the interactions between cover crops, weeds and current weed management programs.

# Weed suppression

The ability of cover crops to suppress weeds is well documented, with the majority of research using cereal rye as the cover crop. While many people attribute the weed suppression of rye to the release of allelopathic chemicals, research has shown the primary factor affecting weed growth is the physical barrier of rye on the soil surface. In order for cover crops to contribute to weed management, they must be managed in a way that maximizes accumulation of biomass. Iowa's relatively short growing season compared to other areas where cover crops are more commonly used has a major impact on the contribution of cover crops to weed management.

We evaluated the effect of cereal rye planting dates and seeding rates on the ability of rye to suppress lambsquarters and waterhemp. Rye was planted in mid-September and mid-October of 2012 and 2013 at rates ranging from 0.5 to 4 bu/A. The rye was terminated the first week of May with glyphosate, and then weed establishment was measured throughout the growing season. Seeding rate did not affect rye biomass at the time of termination in either year; however, planting date had a large effect on biomass levels. Rye biomass from October planting dates was less than 500 lb/A regardless of seeding rate, whereas September planting dates produced approximately 3200 lb/A of rye biomass (Table 1).

High levels of rye associated with the September seeding dates resulted in a 15% reduction in lambsquarters emergence, but more than doubled waterhemp densities (Table 1). In contrast, low levels of rye in the October seeding dates increased emergence of both species, although the effect on waterhemp was much less than seen with high levels of rye residue. The failure of rye to suppress weeds is not surprising based on the quantity of rye biomass produced. Other researchers have reported that at least 9000 lb/A of biomass is needed to consistently reduce weed establishment. Increasing seeding rates to excessive amounts (4 bu/A) failed to increase biomass at termination. This is likely due to tillering of rye compensating for differences in plant stands.

The high levels of rye with September seeding dates caused a small reduction in lambsquarters establishment, but more than doubled the density of waterhemp. This difference between the species is likely due to their respective emergence patterns. Lambsquarters is an early-emerging weed, thus its peak emergence period occurred before or shortly after termination of the rye. Waterhemp is a lateemerging weed, so much of the rye biomass had degraded by the time of waterhemp's peak emergence. The rye that remained at this time apparently created a more favorable environment for germination and establishment of waterhemp.

The presence of rye residue resulted in prolonged emergence patterns of waterhemp in both years, whereas lambsquarters emergence was extended only in 2014. The high levels of rye associated with September planting dates

**Table 1.** Effect of cereal rye cover crop biomass on establishment of two summer annual weeds.

Rye seeding date	Avg rye biomass	Lambsquarter	Waterhemp
	lb/A	% emer	gence <sup>1</sup>
Control	-	7.3	4.4
October	400	9.7	5.8
September	3200	6.3	10.8

<sup>1</sup>Data are means of 2013 and 2014 emergence counts. The seeding dates are averaged over multiple seeding rates.

delayed emergence of waterhemp by two to three weeks, whereas with lambsquarters the time until 50% emergence was delayed by four weeks in 2014. The shift in waterhemp emergence is illustrated in Figure 1. Delayed emergence of weeds reduces their competitiveness but prolongs the time period in which control efforts need to be implemented.

### **Terminating cover crops**

Successful management of cover crops requires that they be killed prior to or at the time of planting the primary crops. The primary means of termination are winterkill, mowing, tillage and herbicides. Oats and radish are two cover crops that are killed by freezing temperatures and do not require management in the spring. Cereal



**Figure 1.** Effect of cereal rye cover crop on the emergence pattern of waterhemp. 2014. M. Anderson. ISU.

While it is well documented that rve cover crops can suppress weeds. Iowa's relatively short growing season is likely to minimize the contribution of cover crops to weed management. Allowing a rye cover crop to accumulate sufficient biomass to consistently suppress weeds would require planting dates for corn and soybean to be delayed until mid- to late-May. Although cover crops may not reduce weed populations when managed in a manner that allows maximum corn and soybean yield potential, there are many other benefits associated with their inclusion in corn and soybean production.

rye is the most commonly planted cover crop in Iowa because of its consistent establishment and rapid growth. Glyphosate is the primary herbicide used to kill rye. Problems with terminating rye are usually associated with the cool temperatures that occur in early spring or the advanced stage of rye development at termination. Both issues are difficult to manage, but using full rates of glyphosate, increasing spray volume to improve coverage and including appropriate spray additives can minimize problems associated with the performance of glyphosate. Tank mixing other herbicides with

glyphosate can reduce glyphosate effectiveness, especially if the tankmix partner has significant foliar activity.

# Effect of residual herbicides on cover crop establishment

The use of preemergence herbicides has increased in recent years due to the spread of herbicide resistant weeds. Many of these products are persistent in the environment, and toxic concentrations may remain in the soil at the time of cover crop establishment in the fall. While herbicide labels provide information on restrictions regarding rotational crops, these recommendations generally are not written with cover crops in mind.

The first thing to consider when evaluating the effect of herbicides on cover crops is the potential use of the cover crop. If there is any possibility that the cover crop will be grazed or harvested for forage, all restrictions regarding rotational crops must be followed. If a cover crop is only being used for conservation purposes, then the grower can choose to plant a cover crop that is prohibited on the label. However, the grower accepts all responsibility if the herbicide interferes with establishment of the cover crop in this situation.

The potential for herbicides used earlier in the season to prevent successful establishment of cover crops is an important consideration. The threat posed by a herbicide is determined by sensitivity of the cover crop species, rate of herbicide applied, date of application and environmental conditions throughout the growing season and during cover crop establishment. Late herbicide applications and dry growing seasons will increase the potential for crop injury. The relatively short time period for establishment of cover crops prior to the onset of cool fall temperatures and dormancy increases the risk that herbicides pose to these plants.

We evaluated the response of five cover crop species to several persistent herbicides commonly used in Iowa corn and soybean production. All experiments were conducted in the greenhouse, so the studies provide information on the relative tolerance of the cover crops to the herbicides rather than an assessment of actual risk to cover crop establishment under field conditions. Herbicides were sprayed at rates from  $\frac{1}{8}$  to  $\frac{1}{2}$  of the label rate, incorporated into the soil, cover crops were seeded and then injury was evaluated for four weeks.

Results of the greenhouse trials are summarized in Table 2. The ratings are based on visual injury and cover crop dry weights. Radish was the most sensitive of the cover crops evaluated, with significant injury occurring with all herbicides except Dual II Magnum. Cereal rye was the most tolerant of the cover crops, with injury observed with atrazine, Corvus and Prowl H2O. Hornet caused serious injury to plant death on the three broadleaf species, whereas Corvus® affected the growth and vigor of all species.

### Summary

There are many benefits associated with inclusion of cover crops into the corn/soybean cropping systems that dominate the Iowa landscape. The limited period of active growth in the fall following crop harvest and in the spring prior to planting reduces the amount of biomass the cover crop accumulates compared to other areas of the country where cover crops have been used more frequently. The low levels of biomass will reduce the contribution of cover crops to weed management, but other beneficial contributions of cover crops are still achieved. Cereal rye has a relatively high tolerance to the herbicides commonly used in corn and soybean, and under most situations its establishment should not be affected by the herbicides used earlier in the growing season. Other cover crop species are more sensitive to herbicides, and the potential impacts of herbicides on their establishment should be considered. Finally, if cover crops may be harvested for forage or grazed, all restrictions regarding rotational crops must be followed.

Herbicide	Group No.	1X Rate	Cereal rye	Oat	Hairy vetch	Lentil	Radish
Corn products					— Injury Potential <sup>1</sup> ·		
Atrazine 90DF	5	1.1 lb	2	2	2	2	2
Dual II Magnum	15	1.5 pt	1	1	1	1	1
Balance Flexx	27	5 fl oz	1	1	2	2	3
Callisto	27	3 fl oz	1	1	1	2	2
Laudis	27	3 fl oz	1	1	2	2	2
Corvus	2, 27	5.6 fl oz	2	2	2	2	3
Hornet WDG	2, 4	5 oz	1	1	3	3	3
Soybean products							
Classic	2	1 oz	1	1	1	1	2
Pursuit	2	4 fl oz	1	1	1	1	2
Prowl H <sub>2</sub> O	3	3 pt	2	2	1	1	1
Reflex	14	1.25 pt	1	1	1	1	2

**Table 2.** Relative tolerance of several cover crop species to herbicides commonly used in corn and soybean production. Injury potential ratings are based on greenhouse trial.

<sup>1</sup>Injury Potential: 1 = little or no risk; 2 = some risk depending upon herbicide rate and environmental factors; 3 = high potential for injury affecting cover crop establishment.

			Grass	S						Broa	dleaves					Per	ennials	
Weed response to selected herbicides E = excellent G = good F = fair P = poor	eoneralot qorJ	crabgrass	muoineq Ile <del>1</del>	listxo7	cnbâtass woony	Shattercane <sup>2</sup>	autinsnamA <sup>8,2,4,5</sup> .qqs	absdzthgin bidzthgin	Cocklebur <sup>2</sup>	ragweed common	uann ragweed²₄	Lambsquarter	Smartweed	Sunflower²	îsəltəvləV	eltzidt ebeneO	Guackgrass	yatiow Yellow
Preplant/Preemergence																		
Atrazine	ш	ш	4	ш	д.	Ь	ш	ŋ	ŋ	ш	9.,	ш	ш	9	9	۵.	ш	ш
Balance Flexx	ш	IJ	5-G	IJ	- -	9.	G-E	ш	ц- -	9.,	Ч	9	ų	ш	G-E	۵	4	9
Breakfree, Degree, Harness, Surpass NXT, etc	ш	ш	ш	ш	- 9.,	9-	9	IJ	٩	۵	٩	н - Е	Ļ	۵.	٩	۵.	۵	G
Callisto	ш	۹	٩	Ч	Ч	Ь	о-Е	щ	9	9.,	ш	ш	Ö	щ	ш	۹	4	۵
Cinch,, Dual II Magnum, Outlook, Zidua, etc	ш	ш	ш	ш	ш	ш	F-G	IJ	۵.	۵.	٩	۵	۵.	۵	٩	۵.	۵	G
Hornet WDG	ŋ	۵	۵	4	4	Ь	<u>е-</u> Е	9.,	9	ŋ	9		ų	щ	Ð	۵	4	٩
Linex/Lorox	IJ	Р-F	Р-F	٩	٩	Ъ	<u>Ө-Е</u>	ш	ш	IJ	) T-0		ų	ш	ш	۵.	4	۵.
Pendimax, Prowl, etc	Ð-1	<u>-Е</u>	<u>Ө</u> -Е	щ Ц	ŋ	IJ	9	4	Ч	д	P	ш	ш	Ъ	Р-F	۹	4	۵.
Python	IJ	۵.	4	٩.	д.	Ч	ш	9.,	ш	ŋ	ш	9.5	ų	g	G-E	۵.	4	۵.
Sharpen (Kixor)	G	۹	٩	4	4	Ъ	<u>е-</u> Е	щ	9	9	9	щ		щ	G-E	۵.	۹	G
Postemergence																		
Accent Q, Steadfast Q	<u>6-Е</u>	۹	9	- - - - - - - - - - - - - - - 	щ	Ш	9	Ч	ш	Ч	Ч	Ч	9	Ъ	ц	ш	9	щ
Aim	9	۹.	4	4	4	а.	F-G	5	4	4	ш	9	4	۵.	ш	۵.	٩	۵.
Armezon, Impact	<u>6-Е</u>	F-G	щ	ŋ	ш	ц	е-е	- Ц Ц	щ	ŋ	9	9	G	ш	ш	۵	۵	٦
Atrazine	IJ	ш	۵.	ш	۵	Ч	ш	ш	ш	ш	9	ш	ш	ш	ш	*	ш	G
Basagran	ш	۵	۵	4	4	Ч	۵	۲	ш	ш	ш	Р.	ш	9	G-E	*9	4	*5
Basis, Basis Blend	ш	ш	F-G	9	ш	0	9	4	ш	ш	۵	Ш-	щ	щ	9	۵.	9	٩.
Banvel, Clarity, etc	Ð-1	۵	۵	Р.	Ч	Ь	<u>6-Е</u>	ŋ	ш	щ	ш	9	ш	9	F-G	*9	4	٩
Beacon	ŋ	۵.	F-G	ц.	д.	Ш	ш	ŋ	ŋ	ŋ	ш	д.	c J	9	F-G	F-G*	ŋ	ш
Buctril	9	٩.	٩	Ч	Ч	Ь	9	щ Н	ш	ш	9		ų	ш	9	۹.	4	۵.
Callisto	G-E	٩.	٩	4	4	Ь	ш	ш	п-6	ш	9	9	Ш	щ	Ш	٩.	Ъ	٩
Equip	F-G	۵.	9	щ Ш	9	Е	9	ш	ш	ш	9	9	ш	ш	G-E	*9	9	٩
Glyphosate (Roundup, Touchdown) <sup>3</sup>	ш	ш	ш	<u>-Е</u>	ш	Е	G-E	9'-	ш	) Ш	п-6	9	ш	ш	9	9	G-E	щ
Hornet WDG	G	۵.	٩	4	4	Ь	G-E	ш	ш	) Ш	ц.	E L	ų	ш	G-E	G	4	۲
Liberty <sup>3</sup>	ш	ш	9	Э-Е	ш	Е	Ð	ш	ш	ш	Ð	Ð	ш	ш	ш	5-G	9	٩
Laudis	<u>6-</u> Е	F-G	щ	щ	- 9.,	9	ш	- щ	щ	ŋ	9	ŋ	5	ш	ш	۵	4	٩
NorthStar	9	٩.	Đ-J	ш	۹	ш	F-G	ŋ	ш	ш	ш	Ð	ш	ш	Ð	5-G	9	ш
Option	ŋ	۵.	9	щ	9.,	Е	ŋ	ш	ш	ш	Ч	Ъ	۵	ŋ	9	۵	9	۵.
Permit, Halomax, etc	9	۵.	٩	4	4	Ь	ш	ے د	— ш.	щ	9	ۍ د	щ	ш	Ш	۵.	٩	G
Resolve	ш	ш	F-G	G	ш	9	ŋ	4	ш	ш	۵	щ	G	4	F-G	ш	9	щ
Resource	<u>-Е</u>	۵.	٩	д	д	Ь	9	д	ш	9.,	д	ш	д	Р.	Ш	۵.	4	۵.
Status	Ð-1	۹	щ	ш	д	ц	<u> Ө-Е</u>	ŋ	ш	щ	9	ŋ	ш	G	9	*9	4	۵.
Yukon	9-1	۵.	۵	٩	۵	Ъ	ŋ	IJ	- Ш	ш	9	0	ų	ш	ш	۵	۵	G
2,4-D	ш	٩	۵	Ч	д	Ь	9	ш	ш	9	щ Н	ŋ	ш	ŋ	9	*L	4	٩
This chart should be used only as a guide. Ratings of herbicides may be higher or	r lower than ii	ndicated dep	cending on sc	il character	istics, mana	gerial factors, envir	onmental vai	iables, and	rates applie	d. The eval	lations for h	erbicides ap	plied to the	soil reflec	t appropriate mech	anical weed	control prac	tices.
Ratings are based on full label rates. Premix products containing ingredients n ALS-resize biotypes of these weeks have been identified in lowa. These bio allow conternation devices builds.	narketed as s otypes may no	ingle a.i. pr. ot be contro	oducts may n lled by all AL:	ot be listed S herbicide:	in this table	.049 .090.	resistant bic D-resistant b	types of co iotypes of c	mmon wate ommon wa	themp have terhemp have	e been iden ve been ide	ified in low ntified in lov	ı. These bi va. These t	otypes may iotypes m	y not be controlled   ay not be controllec	y PPO inhib h HPPD h	itor herbicic erbicides.	les.
·ose only on designateu resistant invortus. 4Glyphosate-resistant biotypes of these weeds have been identified in lowa. Th	rese biotypes	: may not be	controlled b	r glyphosat	ci.	ĥan.	ee or berein	lial weeu c	DITEOLIS ULL	en a resurr	JT repeateu	аррисации.						

**Corn Herbicide Effectiveness Ratings<sup>1</sup>** 

Soybean Herbicide E	ffe	ctiv	/en	ess	Rat	ings <sup>1</sup>										
			Grass	Se					Broadle	aves				Per	ennials	
Weed response to selected herbicides E = excellent G = good F = fair P = poor	eonerelot qorD	Crabgrass	mupineq lle7	listxo7	Shattercane <sup>2</sup> vvooliy cupgrass	<sup>a.e.e.</sup> .qqs suffnersmA	Black nightshade	-10041000	6iant rauweed <sup>2,4</sup>	Lambsquarter	Smartweed	Sunflower <sup>2</sup>	îs∋itəvləV	əltzidt ebeneJ	Guackgrass	9gbəstun wolləY
Preplant/Preemergence																
Authority/Spartan	IJ	Ъ-F	۵.	Р-F	۵.	ш	ш			Ц-Ю	ш	۵.	F-G	۵.	۵.	9
Cinch, Dual II Magnum, INTRRO, Frontier, Warrant, Zidua	ш	ш	ш	ш	ш Ц	- - -	5		<u>م</u>	۵	۹-	۹-	4	۵	4	4
Command	ш	<u>е</u> -Е	<u>Ө-Е</u>	ш	ш	۵.	L.		•	<u>н</u> -9	9	ш	ш	۵.	۵.	۵.
FirstRate/Amplify	<u> Ө-Е</u>	٩	۹	۲	ط ط	F-G	۵	G	н Ц	9	Ц 9-Ц	9	F-G	۵	۵	94
Linex/Lorox	ш	Ъ-F	Ъ-Р	۵	۵.	G-E	ш		-	Ц- 9-Е	ц 9	щ	ш	۵.	۵.	4
Pendimax, Prowl, Sonalan, Treflan, etc	<u> 9-Е</u>	ш	ш	ш	Е <u>6-</u> Е	9	д.		-	IJ	щ	٩	4	٩	4	۲
Pursuit	IJ	9-4	ш	F-G	-F G	F-E G	щ		ш.	9	ц 9	9-J	9	۵.	۵.	4
Python	ш	۹	٩	д.	ط ط	ш	ш		₫	F-G	<u>-</u> Е	ш	ш	٩	٩	٦
Metribuzin, Sencor, TriCor, etc	6-G	۵.	۵	Р-F	- -	Ш	ш		₽	ш	ш	9-1 1	G-E	٦	۵	Р-F
Sharpen	9	٩	٩	Ъ	ط ط	ш	ш		ш. 	ш	ш	щ	щ	٦	٩	٩
Valor SX	F-G	٩	۵.	٩	<u>م</u>	G-E	ш	0	ш.	G-E	ш	٩	щ	ፈ	۵.	٩
Postemergence																
Assure II, Fusilade DX, Fusion, Poast Plus, Select, etc.	ш	ш	ш	ш	ш	٩	۵		₽	₽	۹-	۹-	٩	٦	е-Е	٩
Basagran	ш	۹	۹	д.	- -	Р-F	ц.		ш. 	۹.	ш	9	G-E	*9	۵	* 9
Blazer	F-G	٩	۹	ш	ц	ш	9		Ľ	ш	ш	щ	ш	щ	۹	۲
Classic	ŋ	٦	٩-	۵	ط ط	ш	4	6	щ	۵.	Ц- 9-	ш	G-E	щ	۵_	щ
Cobra/Phoenix	F-G	щ	۹	д.	Ч Ч	ш	9	ų		ш.	9	9	ш	ш	۹	٩
FirstRate/Amplify	G	۹	۹	д.	- -	4	P	ų	ш	۹.	9	ш	9	٦	۵	٩
Glyphosate (Roundup, Touchdown) <sup>3</sup>	ш	ш	<u> Ө-Е</u>	ш	ш	G-E F	Ģ		-9	9	ш	ш	9	9	G-E	ш
Harmony	ш	۵.	۹	д.	4	ш	д.		<u>م</u>	G-E	<u>-</u> Е	<u>-е</u>	9	٦	۹	٩
Liberty	ш	ш	9	G-E	ш	9	ш		9	IJ	ш	ш	ш	F-G	9	ш
Pursuit	ŋ	9	9	F-G	ш	F-G	E G	ų	ш.	Р-F	ш	9	G-E	ш	۹	4
Raptor	9	<u> Ө-Е</u>	<u> Ө-Е</u>	G-E	Э	F-G	E G	) -	9	9	ш	ш	G-E	ш	щ	ш
Reflex/Flexstar, Rumble, Dawn, Rhythm	F-G	۹	٩	٩	- -	ш	Ģ		9	ш	<u>Ө</u> -Е	щ	ш	P-F	۵	4
Resource	G-E	Р	Ч	Ь	P P	9	Ь	Ξ.	G P	F	٦	٦	Е	Р	Ь	Ч
Aatings in this table are based on full label rates. Premix products conta ALS-resistant biotypes have been identified in Iowa. These biotypes ma	aining ingre ay not be co	edients ma ontrolled k	arketed as y all ALS <sub>I</sub>	single a.i. products.	oroducts may	not be included in this t	able.									

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<sup>3</sup>Use only on appropriate resistant varieties. <sup>4</sup>Gynostaet-resistant blockpes of these weeds have been identified in lowa. These blocypes may not be controlled by PPO inhibitor herbicides. <sup>4</sup>Gynostaet-resistant blockpes of common waterhemp have been identified in lowa. These blocypes may not be controlled by PPO inhibitor herbicides. <sup>4</sup>HPPD-resistant blockpes of common waterhemp have been identified in lowa. These blocypes may not be controlled by HPPD herbicides. <sup>4</sup>HPPD-resistant blockpes of common waterhemp have been identified in lowa. These blocypes may not be controlled by HPPD herbicides. <sup>4</sup>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.

						)	
			Beef a	ind Non-Lactat	ing Animals	Lactating Da	iry Animals
Herbicide	A.I.	Rate/A	Grazing	Hay harvest	Removal before slaughter	Grazing	Hay harvest
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	0	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
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	30 days	3 days	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	7 days	30 days	7 days	7 days
2,4-D (many tradenames) Restrictions may vary among products	2,4-D	2-4 pt 4 lb/G	0-7 days	0-30 days	3 days	7-14 days	30 days

# Grazing and haying restrictions for herbicides used in grass pastures

# **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.

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,	15	2.4 lb S-metolachlor	2.1 qt	1.26 lb S-metolachlor	21 oz Dual II MAGNUM
CINCH AIZ, Medal II AI	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
Cinch ATZ Lite	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
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
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

### **Corn Herbicide Premixes or Co-packs and Equivalents**

Herbicide	Group	Components (a.i./gal or % a.i.)	lf you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
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
Enlist Duo	4	1.6 lb ae 2,4-D choline salt	4 pt	0.8 lb ae 2,4-D	26 oz 2,4-D 4A
	9	1.7 lb ae glyphosate		0.85 lb ae glyphosate	24 oz Roundup WMax
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
Keystone LA NX I	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
Keystone NXT	5	2.5 lb atrazine		1.875 lb atrazine	1.9 qt atrazine 4L
Hornet WDG	2	18,5% flumetsulam	5 07	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
0 /	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
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
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

# Corn Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	lf you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Optill	14	17.8% saflufenacil	2 oz	0.35 oz saflufenacil	1 oz Sharpen
	2	50.2% imazethapyr		1 oz imazethapyr	4 oz Pursuit
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
Resolve Q	2	18.4% rimsulfuron	1.25 oz	0.23 oz rimsulfuron	0.9 oz Resolve DF
	2	4.0% thifensulfuron		0.05 oz thifensulfuron	0.1 oz Harmony SG
Revulin Q	27	36.8% mesotrione	4 oz	1.5 oz mesotrione	3 oz Callisto
	2	14.4% nicosulfuron		0.58 oz nicosulfuron	1.1 oz Accent Ω
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
Solstice	27	3.78 lb mesotrione	3.15 oz	0.093 lb mesotrione	3 oz Callisto
	14	0.22 lb fluthiacet-methyl		0.0053 lb fluthiacet-m	0.75 oz Cadet
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
Spitfire	4	0.5 lb dicamba acid	2 pt	0.12 lb ae dicamba	3.8 oz Banvel
	4	3.07 lb ae 2,4-D ester		0.77 lb ae 2,4-D	26 oz 2,4-D 4E
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 II/Tripleflex II	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
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

# Corn Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	lf you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
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

# Corn Herbicide Package Mixes (continued)

# Soybean Herbicide Package Mixes or Co-packs and Equivalents

Herbicide	Group	Components (a.i./gal or % a.i.)	lf you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Afforia	14	40.8% flumioxazin	3 oz	1.22 oz flumioxazin	2.4 oz Valor SX
	2	5.0% thifensulfuron		0.15 oz thifensulfuron	0.3 oz Harmony
	2	5.0% tribenuron		0.15 oz tribenuron	0.3 oz Express
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	0.36 lb Metribuzin 75DF
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	0.4 lb Metribuzin 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	0.25 lb 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
Cheetah Max	10	2 lb glufosinate	34 oz	0.53 lb glufosinate	29 fl oz Liberty
	14	1 lb fomesafen		0.27 lb fomesafen	18 oz Flexstar

Herbicide	Group	Components (a.i./gal or % a.i.)	lf you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
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
Enlist Duo	4	1.6 lb ae 2,4-D choline salt	4 pt	0.8 lb ae 2,4-D	26 oz 2,4-D 4A
	9	1.7 lb ae glyphosate		0.85 lb ae glyphosate	24 oz Roundup WMax
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	3.5 oz	1.0 oz flumioxazin	2.0 oz Valor
	2	2.9% thifensulfuron		0.10 oz thifensulfuron	0.2 oz Harmony SG
	2	9.2% chlorimuron ethyl		0.32 oz chlorimuron ethyl	1.3 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	14	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
Fierce XLT	14	24.5% flumioxazin	4 oz	1.0 oz flumioxazin	2 oz Valor
	15	31.2% pyroxasulfone		1.28 oz pyroxasulfone	1.5 oz Zidua
	2	6.7% chlorimuron		0.25 oz chlorimuron	1 oz Classic DF
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
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, Surveil	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
Harrow	2	50% rimsulfuron	0.5.07	0 25 oz rimsulfuron	1 oz Matrix SG
	2	25% thifensulfuron	0.0 01	0.12 oz thifensulfuron	0.25 oz Harmony SG
Latir	14	31.5% flumioxazin	3.2 oz	1 oz flumioxazin	2 oz Valor
	2	23.5% imazethapyr	0.2 02	0.75 oz imazethapyr	3 oz Pursuit
N		4.00/ (1.1.)	-		
iviarvel	14	1.2% fluthlacet	5 OZ	U.U/5 OZ fluthiacet	U.bb oz Cadet
	14	JU.UX% TOMESATEN		ı.8 oz tomesaten	u.5 pt Flexstar
Matador	15	4 lb metolachlor	2 pt	1 lb metolachlor	1 pt Stalwart
	5	0.56 lb metribuzin		2.25 oz metribuzin	3 oz Metribuzin 75DG
	2	0.13 lb imazethapyr		2 oz imazethapyr	2 oz Pursuit 2AS

# Soybean Herbicide Package Mixes (continued)

Herbicide	Group	Components (a.i./gal or % a.i.)	lf you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
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
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	1.2 pt Stalwart
	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
Statement	15	4.22 lb metolachlor	2 pt	1.1 lb metolachlor	1.1 pt Stalwart
	14	0.91 lb fomesafen		0.23 lb fomesafen	15.3 oz Rhythm
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	1.3 pt Stalwart 8E
	5	1.25 lb metribuzin		0.31 lb metribuzin	0.4 lb Metribuzin 75DF
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	6 oz	0.23 oz chlorimuron	1.0 oz Classic 25DF
	14	12.8% flumioxazin		0.77 oz flumioxazin	1.5 oz Valor
	5	44.6% metribuzin		2.68 oz metribuzin	0.22 lb Metribuzin 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

# Soybean Herbicide Package Mixes (continued)

# **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 herbicide sites 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.

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

## Table 1. Herbicide classification by group number and site of action

## Table 2. Active ingredients and group numbers of single ingredient products.

Trade name	Group No.	Active Ingredient	Trade name	Group No.	Active Ingredient
2,4-D	4	2,4-D	Lorox	7	linuron
Accent Q	2	nicosulfuron	Metribuzin/TriCor/Sencor	5	metribuzin
Aim	14	carfentrazone	Option	2	foramsulfuron
Assure II	1	quizalofop	Outlook	15	dimethenamid
atrazine	5	atrazine	Peak	2	prosulfuron
Autumn	2	iodosulfuron	Permit	2	halosulfuron
Balance Flexx	27	isoxaflutole	Poast	1	sethoxydim
Banvel/Clarity	4	dicamba	Prowl	3	pendimethalin
Basagran	6	bentazon	Pursuit	2	imazethapyr
Beacon	2	primisulfuron	Python	2	flumetsulam
Buctril	6	bromoxynil	Raptor	2	imazamox
Cadet	14	fluthiacet-ethyl	Resolve/Bestow	2	rimsulfuron
Callisto	27	mesotrione	Resource	14	flumiclorac
Classic	2	chorimuron	Roundup	9	glyphosate
Cobra	14	lactofen	Scepter	2	imazaquin
Command	13	clomazone	Select	1	clethodim
Dual/Cinch	15	metolachlor	Sharpen	14	saflufenacil
Express	2	tribenuron	Sonalan	3	ethalfluralin
FirstRate	2	cloransulam	Spartan/Authority	14	sulfentrazone
FlexStar/Reflex	14	fomasafen	Stinger	4	clopyralid
Fusilade DX	1	fluazifop	Treflan	3	trifluralin
Gramoxone SL	22	paraquat	UltraBlazer	14	acifluorfen
Harmony	2	thifensulfuron	Valor	14	flumioxazin
Harness/Surpass/Breakfree	15	acetochlor	Warrant	15	acetochlor
Impact/Armezon	27	topramezone	Zidua	15	pyroxasulfone
IntRRo	15	alachlor	Only sold in premix	2	thiencarbazone
Laudis	27	tembotrione	Only sold in premix	19	diflufenzopyr
Liberty/Ignite	10	glufosinate	Only sold in premix	1	fenoxaprop

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

Tradename	Group No.	Active Ingredients	Tradename	Group No.	Active Ingredients
Afforia	2, 2, 14	thifensulfuron, tribenuron, flumioxazin	Fierce XLT	2, 14, 15	chlorimuron, flumioxazin, pyroxachlor
Alluvex	2, 2	rimsulfuron, thifensulfuron	Flexstar GT	9, 14	glyphosate, fomesafen
Anthem	14, 15	fluthiacet, pyroxasulfone	FulTime NXT	5, 15	atrazine, acetochlor
Anthem ATZ	5, 14, 15	atrazine, fluthiacet,	Fusion	1, 1	fenoxaprop, fluazifop
Authority Assist	2 14	imazothanyr sulfontrazono	Gangster	2, 14	cloransulam, flumioxazin
Authority Flite	14 15	sulfentrazone metolachlor	Halex GT	9, 15, 27	glyphosate, metolachlor, mesotrione
Authority MTZ	5 1/	metrihuzin sulfentrazone	Harness Xtra	5 15	atrazine acetochlor
	3, 14 2 1/	chlorimuron, sulfontrazono	Harrow	3, 13	rimsulfuron thifonsulfuron
	2, 14	iodosulfuron, suitentrazone	Instigato	2,2	rimsulfuron, mensulfuron
Autumn Super	2, 2	rimeulfuron, thifoneulfuron	Kovotopo NVT	5 15	
Dasis Diellu Dieen	Z, Z		Keystone LA NXT	5, 15	atrazine, acelociilor
Dicep	5,15		Latir	2, 14	imazethapyr, flumioxazin
ATZ, Breakfree NXT Lite	5, 15	atrazine, acetochior	Lexar EZ	5, 15, 27	atrazine, metolachlor, mesotrione
Callisto GT	9, 27	Glyphosate, mesotrione	Lumax EZ	5, 15, 27	atrazine, metolachlor,
Callisto Xtra	5, 27	atrazine, mesotrione			mesotrione
Canopy	2, 5	chloriuron, metrbuzin	Marksman	4, 5	dicamba, atrazine
Canopy EX	2, 5	chlorimuron, tribenuron	Marvel	14,14	Fluthiacet, fomesafen
Capreno	2, 27	thiencarbazone, tembotrione	Northstar	2, 4	primisulfuron, dicamba
Cheetah Max	10, 14	glufosinate, fomesafen	Optill	2, 14	imazethapyr, saflufenacil
Cinch ATZ	5, 15	acetochlor, atrazine	Panoflex	2, 2	Tribenuron, thifensulfuron
Corvus	2, 27	thiencarbazone, isoxaflutole	Permit Plus	2, 2	halosulfuron, thifensulfuron
Crusher	2, 2	Rimsulfuron, thifensulfuron	Prefix	14, 15	fomesafen, metolachlor
Degree Xtra	5, 15	atrazine, acetochlor	Prequel	2, 27	rimsulfuron, isoxaflutole
DiFlexx	4, 27	dicamba, isoxaflutole	Priority	2, 14	halosulfuron, carfentrazone
Enlist Duo	4, 9	2,4-D, glyphosate	Pummel	2, 15	lmazethapyr, metolachlor
Enlite	2, 2, 14	chlorimuron, thifensulfuron,	Pummel	2, 15	imazethapyr, metolachlor
		flumioxazin	Pursuit Plus	2, 3	imazethapyr, pendimethalin
Envive	2, 2, 14	chloriuron, thifensulfuron,	Realm Q	2, 27	rimsulfuron, mesotrione
-		flumioxazin	Require Q	2, 4	rimsulfuron, dicamba
Expert	5, 9, 15	atrazıne, glyphosate, metolachlor	Resolve Q	2, 2	rimsulfuron, thifensulfuron
Fxtreme	29	imazethanyr glynhosate	Revulin Q	2, 27	nicosulfuron, mesotrione
Fierce	14, 15	flumioxazin, pyroxasulfone	Sequence	9, 15	glyphosate, metolachlor
Fierce XIT	2, 14, 15	chlorimuron, flumioxazin	Solstice	14, 27	fluthiacet, mesotrione
	_,, .0	pyroxasulfone	Sonic	2, 14	cloransulam, sulfentrazone

Tradename	Group No.	Active Ingredients
Spirit	2, 2	primisulfuron, prosulfuron
Spitfire	4, 4	2,4-D, dicamba
Statement	14, 15	metolachlor, fomesafen
Status	4, 19	dicamba, diflufenzopyr
Steadfast Q	2, 2	nicosulfuron, rimsulfuron
Suprass NXT	5, 25	atrazine, acetochlor
Surestart	2, 4, 15	flumetsulam, clopyralid, acetochlor
Synchrony	2, 2	chlorimuron, thifensulfuron
Tailwind	5, 15	Metribuzin, metolachlor
Torment	2, 14	lmazethapyr, formesafen
Torment	2, 14	imazethapyr, fomesafen
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 offtarget herbicide injury problems, whereas knowledge of the site of action is needed for designing weed management programs with a low risk of selecting for herbicideresistant 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 (vellowing), 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, "bottlebrush" 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 (interveinal 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 triazineresistant 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, Armezon, 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 HG 1** aryloxyphenoxy-propanoate

Assure II, others Fusilade DX Fusion Hoelon cyclohexanediones Poast, Poast Plus Select, Section, Arrow,

others

quizalofop-p-ethyl fluazifop-p-butyl fenoxaprop diclofop sethoxydim

# ALS inhibitors HG 2

imidazolinones Pursuit Raptor Scepter sulfonanilides FirstRate, Amplify Python sulfonylureas Accent Ally, Cimarron Beacon Classic Express

Harmony GT

Permit, Halofax

fluazifop-p-butyl + clethodim

# imazethapyr imazamox imazaguin

chloransulam flumetsulam

nicosulfuron metsulfuron primisulfuron chlorimuron tribenuron thifensulfuron halosulfuron

# **Microtubule inhibitor HG 3**

dinitroanilines	
Balan	benefin
Prowl H <sub>2</sub> 0, Pendimax, Framework, Satellite, others	pendimethalin
Sonalan	ethalfluralin
Surflan	oryzalin
Treflan Trust others	trifluralin

### Synthetic auxin HG 4

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
Streamline	Aminocyclopyrachlor
Tordon	picloram

### Photosystem II inhibitors HG 5, 6, 7

benzothiadiazole	
Basagran, Broadlawn	bentazon
nitriles	
Buctril, others	bromoxynil
triazines	
AAtrex, others	atrazine
Evik	ametryn
Metribuzin, Tricor	metribuzin
Princep	simazine
ureas	
Karmex	diuron
Inex, Lorox	linuron

### Photosystem I inhibitors HG 22 Diguat, Reward diquat Gramoxone Max

paraquat

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Protoporphyrinog inhibitors HG 14	jen Oxidase (PPO)
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 shik synthase (EPSPS	timate phosphate 5) inhibitors HG 9
Roundup, Touchdown, others	glyphosate
Glutamine synth HG 10	etase inhibitors
Liberty, Cheetah	glufosinate
Hydroxyphenyl p dioxygenase (HP HG 27	yruvate PD) inhibitors
Balance Flexx	isoxaflutole
Callisto	mesotrione
Armezon/Impact	topramezone

tembotrione

Laudis

<b>Diterpene inhibito</b>	rs HG 13
Command	clomazone
Auvin transport in	hibitors HG 19
Distinct, Status	diflufenzopyr + dicamba
Lipid synthesis inh	nibitors HG 15
Degree, Harness, Surpass, Warrant	acetochlor
Dual II MAGNUM, Cinch, Medal, Charger Max, others	S-metolachlor, metolachlor
Frontier, Outlook, Commit, others	dimethenamid

alachlor

pyroxasulfone

Lasso, Intrro, MicroTech

Zidua

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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<sup>...</sup> and justice for all

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