2017 Herbicide Guide for Iowa Corn and Soybean Production

Industry Update for 2017 (and Beyond)

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Introduction

There have been no new herbicides with novel mechanisms of action introduced and, as previously stated numerous times, none are anticipated in the near future. Furthermore, weed management issues continue to escalate whether by new weed populations with evolved resistance(s) to herbicides or the introduction of a "new" weed such as Palmer amaranth, which was introduced via conservation plants or the use of "gin trash" as supplemental protein for cattle feeding enterprises and dairy operations. Weed management remains a major concern for Iowa agriculture and addressing these burgeoning problems will continue to be costly both in time and resources.

Anticipated new herbicide-resistant (HR) crops, while useful options for weed management when they become available, are still just chemical approaches and given the characteristics of the herbicides used on these HR crops bring new challenges. Another unknown for the immediate future is how the announced mergers of companies will impact agriculture and weed management specifically. Will the mergers better support herbicide discovery and development or will things remain status quo?

Regardless of pending changes in herbicides and crop traits, diversification of weed management approaches beyond herbicides must be considered in order to support the tools currently available to farmers. Despite recent pronouncements by some in the industry, agriculture will not be able to resolve weed management issues by simply spraying herbicides. What follows is a summary of changes in the industry for 2017; the information should not be considered all encompassing.

Selected Industry Updates

BASF

Engenia herbicide (HG4) is a new N,N-Bis (3- aminopropyl) methylamine [BAPMA] salt of dicamba that significantly reduces volatility of the active ingredient dicamba when compared to currently available formulations. *Engenia* treatments will not require additional additives to further reduce the potential for volatilization. *Engenia* is a 5 lb ai/gal formulation. It will be registered for over-the-top applications on dicamba-resistant soybean as well as preplant treatments without planting restrictions, but registration by the EPA is still pending.

Zidua Pro contains pyroxasulfone (HG15), imazethapyr (HG2), and saflufenacil (HG14). It is labeled for burndown and preemergence uses in soybean at rates of 4.5 to 6.0 fl oz/A. Optimum burndown of emerged weeds requires the use of MSO and a nitrogen source. No planting interval restriction is listed for *Zidua Pro* except when applications are made on coarse textured soils with < 2% organic matter where a 30-day interval between application and planting is required.

Preemergence applications were added to the *Armezon Pro* (HG 27 and 15) label for corn.

The *Zidua* (HR 15) postemergence application window in soybean has been expanded to allow treatment from emergence to 3rd trifoliate stage.

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BAYER CROP SCIENCE

DiFlexx Duo was registered for field, white, seed, and popcorn last spring. It is a combination of tembotrione (HG27), dicamba (HG4), and the safener cyprosulfamide. *DiFlexx Duo* is registered for preemergence and postemergence (up to V10 corn stage) applications. Use rates range from 24 to 40 oz/A. Adjuvants that are needed for POST *DiFlexx Duo* applications include HSOC, COC or MSO and a nitrogen source.

Balance GT soybean launch date is targeted for 2017 pending Japan and China approval of the trait.

DOW AGROSCIENCE

Resicore was approved in 2016 for application in field corn, seed corn, silage corn, and yellow popcorn for preemergence application and contains acetochlor (HG15), mesotrione (HG27), and clopyralid (HG4). *Resicore* may be applied postemergence to field corn, seed corn, and silage corn but not yellow popcorn. Postemergence applications must be made before the corn is 11 inches in height.

Enlist Duo (HG4 and 9) is registered and available for non-*Enlist* corn and soybean as preplant burndown and preemergence (corn) and preplant burndown (soybeans) but not available for postemergence use until the *Enlist* crops are approved by China. No adjuvants are described on the *Enlist Duo* label. It is anticipated that China may approve of the *Enlist* crops in 2017. *Enlist Duo* has less potential for volatilization than other HG4 formulations but care should be taken regardless to avoid conditions that may cause off-target movement of the herbicide. The *Enlist Duo* label describes appropriate nozzles for application, buffer requirements, and specific application techniques. Herbicide-resistant weed management requirements are also included in the *Enlist Duo* label.

DUPONT

Realm Q (HG2 and 27) is now registered for aerial application, and dicamba (HG 4) has been added as a tank mix partner. Aerial application of HG 27 and HG 4 herbicides represents a potentially serious risk for off-target herbicide movement.

Afforia can be applied either preplant or preemergence to any soybean at 2.5 oz/A. Preemergence applications must be made within three days after planting and prior to emergence. When used with *BOLT* soybean varieties, the *Afforia* rate can be increased to 2.5 to 3.75 oz/A for either preplant or preemergence applications. The *BOLT* technology provides enhanced tolerance to sulfonylurea herbicides (HG2).

MONSANTO

Soybean cultivars with dicamba (HG4) resistance are globally deregulated and recently the herbicide developed for the crop, XtendiMax with VaporGrip technology (HG4)was registered by the EPA. There are a number of application limitations, protection of sensitive area instructions and other restrictions that must be followed. No AMS is allowed in tank-mixture with XtendiMax. Proper spray system equipment cleanout is critically important to avoid injury to sensitive crops.

NUFARM

Cheetah contains glufosinate ammonium (HG10) and is registered for non-selective postemergence application in corn and soybean with the LibertyLink trait.

Panther SC is 4 lb ai/gal formulation of flumioxazin (HG14) and is registered for preplant burndown application in corn 3 to 30 days prior to planting. *Panther SC* can be applied prior to soybean planting or preemergence within three days after planting and prior to soybean emergence.

Scorch is a premixture of dicamba, 2,4-D and fluroxypyr, all HG4 herbicides that can be applied preplant, preemergence and postemergence in field corn. Fluroxypyr improves activity on kochia. Postemergence applications of *Scorch* can be applied broadcast to V5 or 8-inch corn and applications from V6 to 36-inch corn (or 15 days prior to tasseling) must be made with directed drop nozzles.

SYNGENTA

Acuron Flexi is a premixture of bicyclopyrone (HG27), mesotrione (HG27) and S-metolachlor (HG15) registered for preplant, preemergence and postemergence application in field corn, seed corn, and silage corn; sweet corn and yellow popcorn cannot be treated with *Acuron Flexi* postemergence.

There are numerous other modifications on the labels of existing Syngenta proprietary products (i.e., the addition of HRAC code and resistance management language in the *Bicep II Magnum* label). These changes pertinent for

Iowa can be found on the *Acuron, Bicep II Magnum, Callisto, Dual II Magnum, Dual Magnum, Evik DF, Flexstar GT 3.5, Fusilade DX, Gramoxone SL, Halex GT, Prefix,* and *Sequence* labels.

WINFIELD

Winfield and United Suppliers are merging and thus the herbicide product lines are somewhat in flux. Information about the Winfield product line can be found at http://www.winfield.com/Farmer/Products/ProductCategory/default.aspx?Cat=Herbicides&Seg=For%20Farmers while the United Suppliers product line can be found at http://www.unitedsuppliers.com/products/productlistings/tabid/269/default.aspx.

There do not appear to be significant changes in the proprietary products from **FMC** and **Valent** although **Valent** reports the development and pending registration of a liquid flumioxazin formulation (*Valor EZ*). **DuPont** and **Monsanto** have an agreement that will allow DuPont to sell *FeXapan plus VaporGrip* (HG4) when EPA registration is approved. This formulation of dicamba is suggested to reduce the potential for volatilization. The product, when registered will be available for weed management in the *Roundup Ready Xtend Crop System*. **Monsanto** and **Sumitoma** have signed an agreement to develop new PPO (HG14) technologies, presumably new HG14 herbicides and crops with resistance to HG14 herbicides. This agreement is unlikely to bring new tools for weed management within the next 10 years.

The path forward

The need for better weed management continues to be a critical concern for Iowa agriculture. However, despite the widespread occurrence of herbicide resistance in waterhemp, giant ragweed, and horseweed/marestail, most fields in Iowa are in a position to allow effective weed control if farmers will diversify the tactics. The thoughtful choice of herbicides with still-effective mechanisms of action is critically important. Adoption of cultural and mechanical tactics is also important and can deter the increasing problem of evolved herbicide-resistant weeds in specific fields and in specific areas of fields. There are no new herbicides in the developmental pipeline that will be commercialized within the next 10 years and possibly longer. Issues in weed management continue to be increasingly complex, and there are no simple and convenient answers despite what marketing might suggest.

Palmer amaranth: How big of threat is it?

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Palmer amaranth and waterhemp are two dioecious pigweed species native to North America. Waterhemp's original range was the western Corn Belt, including Iowa, whereas Palmer amaranth originally inhabited the southwestern United States. Palmer amaranth began to spread to the southeastern United States early in the 20th century but was not listed among the most troublesome weeds of the Southeast until the late 1980s. Interestingly, this is the same time frame that waterhemp emerged as a serious management issue in Iowa and surrounding states.

Palmer amaranth developed its reputation as a serious threat to agriculture in the southeast United States, particularly in cotton producing areas. Cotton farmers were nearly completely reliant on glyphosate for weed control. When glyphosate resistant Palmer amaranth evolved they failed to respond appropriately and many fields were completely overrun with the weed. Like waterhemp, Palmer amaranth is able to rapidly evolve resistance to herbicides that serve as the primary tool to manage the weed. However, Palmer amaranth is much more competitive than waterhemp, thus it will have a bigger impact on yields when a high level of control is not achieved. This paper will review the history of Palmer amaranth in Iowa, what to expect from the current introductions, and management considerations.

History in Iowa

The first report of Palmer amaranth in Iowa was in Harrison County in August 2013. The infested field had been in fallow for several years and used to spread sludge from a fermentation plant in Nebraska. It is believed the Palmer amaranth was introduced on vehicles used for sludge transport. Based on the heavy infestation in this area and adjacent areas, we concluded the Palmer amaranth must have been present at this location for at least two or three years prior to discovery.

The second report of Palmer amaranth was in September 2013 in Muscatine County. The weed was found on a farm near swine facilities and it is believed the Palmer amaranth may have been introduced in feed or transport of materials used in the swine operation. In October of 2013 Palmer amaranth was found in Page and Fremont counties. These sites were adjacent to commercial grain storage facilities. Palmer amaranth was found at two separate locations in Lee County in 2014, with one site involved in corn and soybean seed production and the other a dairy farm that imported cotton seed for feed.

We entered 2016 with Palmer amaranth infestations in the five counties described above, although we suspected it was present in additional counties. At the end of October 2016, Palmer amaranth had been confirmed in at least 46 counties, and again we believe it is present in many more counties (Fig. 1). We were surprised by both the dramatic increase in Palmer amaranth infestations in Iowa and the primary means of introduction. Six of the 2016 discoveries were associated with traditional agricultural practices. Several of the new infestations were located on dairy or cattle operations that imported feed or bedding from southern states, and one site was in an area where farming equipment, used in regions with known Palmer amaranth infestations, was stored. By far, the most important source of Palmer amaranth was the planting of native seed mixes used for conservation plantings, which were contaminated with Palmer amaranth seed.

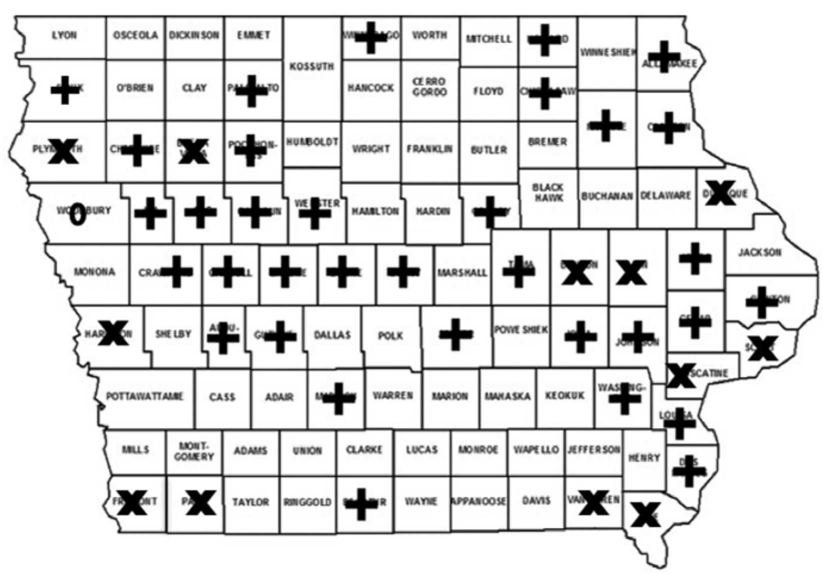

Figure 1. Counties with confirmed Palmer amaranth infestations, October 2016. 'X' indicates first detection via conventional agricultural practices, '+' indicates first detection via conservation planting. Several counties are known to have both means of introduction. Woodbury County infestation was found on a railroad siding.

Palmer amaranth in conservation plantings

In 2016, there was a tremendous increase in planting of native seed mixes across Iowa due to government programs like the Conservation Reserve Program (CRP). Pollinator habitat (CP 42) was one of the more popular programs due to cost share for establishment, signing incentives, and annual rental payments competitive with cash rent rates. Other programs such as wildlife food plots, native grass and forb plantings, and permanent wildlife habitat also encouraged planting of native seed mixes. In Iowa, over 200,000 acres were planted with native seeds in 2016, and many counties had between 100 and 200 fields entered into these programs.

In mid-July, we received the first two reports of Palmer amaranth discoveries in new conservation plantings. One of these sites was wildlife habitat (CP33) whereas the other was pollinator habitat. Due to the expertise of the two landowners and the random distribution of Palmer amaranth within the fields, we were confident the Palmer amaranth was not present in the fields prior to establishment of the new conservation planting in the spring of 2016. Since publicizing the concern over Palmer amaranth infesting conservation plantings, Palmer amaranth has been found in conservation plantings in 35 counties across Iowa.

TThe primary means of introduction of Palmer amaranth in conservation plantings has been use of native seed mixes contaminated with Palmer amaranth seed. We have obtained samples of several of the seed mixes used in fields with Palmer amaranth infestations, isolated *Amaranthus* spp. seed in the seed mix, and confirmed the seed as Palmer amaranth.

We have visited the largest Iowa producer of native seeds, inspected their production fields, and were unable to find Palmer amaranth. The huge increase in demand for seed of native prairie plants in 2016 resulted in local seed producers being unable to meet this demand. Most Iowa producers purchased seed of several species from outside vendors. The producers believe that these imported seed were the source of the Palmer amaranth.

Introduction of Palmer amaranth via contaminated native seed has occurred in other states as well. Ohio documented contaminated seed native seed mixes as a problem in 2014; the native seed contaminated with Palmer amaranth was imported from Texas. Both Illinois and Minnesota identified new conservation plantings this summer where Palmer amaranth was introduced, but the number of new introductions in those states appear to be a fraction of that in Iowa during 2016.

Threat to Iowa agriculture

The widespread introduction of Palmer amaranth during 2016 in conservation plantings was an unfortunate situation, and its long-term impact on the spread of Palmer amaranth in the state is uncertain. Palmer amaranth, like most annual weeds, is unlikely to persist in perennial plantings. However, during the initial years of establishment the Palmer amaranth in these fields will produce significant quantities of seed. Our concern is that some of these seed are likely to be transported outside of the conservation planting into nearby crop fields where the weed is better adapted for survival.

While the aggressive nature of Palmer amaranth is well documented, it is unlikely to overwhelm Iowa crop fields in a few years. When a weed species is introduced into a new region, the initial rate of spread typically is relatively slow for 20 to 30 years (lag phase), and then the weed spreads rapidly until it occupies nearly all suitable habitats. We feel it is safe to state that, for most Iowa farmers, waterhemp will be their number one pigweed foe for at least the next decade.

Several factors are likely to limit the rate that Palmer amaranth initially spreads across the Iowa landscape. First, nearly all crop acres are treated with a herbicide program targeting waterhemp. This will make it difficult for the few Palmer amaranth seed that are introduced into crop fields to survive and produce new seed. Waterhemp is able to overcome these management programs since most fields have millions of waterhemp seed in their seed bank.

The second is based on our belief that Palmer amaranth is not yet adapted to Iowa's climate and soils. While there is no doubt that Palmer amaranth can survive in Iowa, observations of the first Iowa infested fields suggest it is 'not ready for prime time' in the state. Several of the fields where Palmer amaranth was first found have atypical soils for Iowa crop fields (e.g. sand, silty clay). We have casually followed the infestations in Harrison, Page, and Fremont counties since 2013 by visiting the fields in early fall. While Palmer amaranth is still present in all fields, the populations in most fields have declined over time, and there is no evidence that it is spreading rapidly in the immediate area. We should state that there have not been any systematic scouting programs designed to detect the spread of Palmer amaranth in these areas.

The other observation that suggests it is not yet adapted to Iowa is the germination behavior of Palmer amaranth. One of the traits that makes waterhemp difficult to manage is a prolonged emergence pattern. Waterhemp typically begins emerging in early May and emergence continues until mid-July. Very few waterhemp seeds germinate after this time. When we have visited Palmer amaranth infested fields in September, there have always been significant numbers of newly emerged seedlings (assuming recent rains provided sufficient soil moisture). These seedlings are unlikely to complete their life cycle prior to the first frost, thus these very late emerging plants are depleting the seedbank rather than producing reproductive plants.

We are not suggesting agronomists be complacent about Palmer amaranth moving into Iowa. One trait of weeds is their ability to adapt, and Palmer amaranth is likely to acclimate to Iowa conditions over time. Rather than simply accepting the movement of Palmer amaranth into Iowa, we feel it is critical to take advantage of this 'grace period' and use every reasonable measure to prevent spreading the weed, and to eradicate new infestations before they establish a permanent seed bank.

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, a close relative of Palmer amaranth. The tactics used to control waterhemp are effective against Palmer amaranth. The primary differences when 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 much larger yield penalty.

Both Palmer amaranth and waterhemp are prone to evolving herbicide resistance when herbicides are used in a manner that results in significant selection pressure (Table 4). Both species also rapidly accumulate multiple resistances. 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 fence lines, roadsides and other crop areas. Combines are the most efficient seed disseminator ever developed; whenever possible harvest infested fields last to limit spread of seed.

   The Natural Resource Conservation Service (NRCS) and Farm Service Agency (FSA) are providing very little flexibility in managing Palmer amaranth in conservation plantings. Mowing and hand rogueing are the two options available, and experience with mowing in 2016 suggests it will not kill Palmer amaranth, but can

Table 4. Documented herbicide resistances in Palmer amaranth and waterhemp. International Survey of Herbicide Resistant Weeds. www.weedscience.com

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

reduce seed production. Taking steps to prevent seed movement from these fields is critical. Limit traffic in these fields, especially late in the season when seed is present on plants.

2) **Start clean.** Make sure all Palmer amaranth is killed before planting the crop.

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), 14 (PPO inhibitors), 15 (amides) and 27 (HPPD inhibitors) herbicides provide the crop a head start on Palmer amaranth. Full rates are important in order to extend control later in the season and reduce the potential for selecting resistant biotypes. This allows postemergence herbicides to be applied later in the season when the crop canopy may reduce weed establishment following the application.

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

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

Palmer amaranth is undoubtedly a permanent component of the Iowa flora. The key to minimizing the impact of this aggressive weed will be for everyone involved in production agriculture to learn how to differentiate Palmer amaranth from waterhemp and other pigweeds. Because of the ubiquitous presence of waterhemp across the Iowa landscape, it is easy to ‘tune out’ when encountering another *Amaranthus* infested field. Some Palmer amaranth plants are distinct enough in the reproductive stage to make long distance identification simple, but many plants require close up examination to confirm their identification.

New conservation plantings where Palmer amaranth was introduced during 2016 will serve as a source of Palmer amaranth seed production for several years. The time needed for the perennial vegetation to smother the Palmer amaranth will vary, depending primarily on the density and competiveness of the native plants. Care must be taken to minimize moving seed out of these fields into crop fields where Palmer amaranth is better adapted to long-term survival.

Palmer amaranth will adapt to Iowa conditions over time. When it does, its presence in fields will result in farmers needing to adopt more aggressive management tactics or accept greater yield losses than they have incurred with waterhemp. Early detection and eradication is the mantra for managing invasive species of natural areas, it is time that agronomists adopt this strategy in order to minimize the cost associated with the introduction of Palmer amaranth to Iowa.

Weed management for 2017 and beyond; considerations and perspectives

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Introduction

It has been approximately 30 years since the last new herbicide mechanism of action (MOA) was introduced and it is unlikely that a new MOA will be introduced in the near future. Furthermore, weed management issues continue to escalate, particularly the increasing number of herbicide-resistant weed populations and the increasing population densities in fields with herbicide-resistant weeds. For example, in Iowa, multiple resistance in waterhemp is the norm rather than the exception and the rate of spread is accelerating. The recent widespread introduction of Palmer amaranth in Iowa further contributes to future weed problems. Regardless, farmers in Iowa remain "techno-optimistic" that new herbicide solutions to the weed management problems will be soon introduced (Dentzman et al. 2016). This "techno-optimism" is contrasted by the "techno-skepticism" of farmers in the south. Interestingly, Iowa farmers also express concerns that new resistances in weeds are inevitable with the anticipated new herbicides but that the future new herbicides are essentially the only option for effective weed control. A number of current and future issues will be considered and perspectives provided in this paper.

Herbicide resistance

The three most common herbicide resistant weeds in Iowa are waterhemp, giant ragweed, and horseweed/marestail. We continue to evaluate populations of these weeds for herbicide resistance by treating with Group 2, 5, 9, 14, and 27 herbicides to characterize their resistance profiles. Herbicide resistance in waterhemp continues to be a major problem in Iowa and waterhemp populations with multiple resistances increasing. A population of giant ragweed was recently discovered that is resistant to both HG2 and HG9, and initial results support putative resistance to HG27.

The recent discovery of Palmer amaranth across Iowa brings in the possibility that this "new" weed problem will further contribute to the herbicide resistance issues. Considering that Palmer amaranth populations in Missouri, Illinois, Kansas, and Nebraska have evolved resistance to HG2, HG9 and HG27, it should come as no great surprise that the new Iowa populations will also have similar resistance profiles. Recently, Palmer amaranth populations in the mid-South have also evolved resistance to HG14. Efforts in Iowa are underway to understand the levels and types of herbicide resistances in the introduced Iowa Palmer amaranth populations. Importantly, efforts will be initiated at several levels to contain and eliminate the newly discovered Palmer amaranth populations.

New herbicide resistance traits and weed management

While the Roundup Ready2 Xtend (dicamba resistant) soybean cultivars have been deregulated and are approved by important international markets, and recently the Environmental Protection Agency (EPA) accepted the label for XtendiMax with VaporGrip. Enlist (2,4-D resistant) soybean is not widely available due to a decision by Dow AgroSciences to curtail availability until the crop is deregulated globally. However, the 2,4-D and glyphosate herbicide combination (Enlist Duo) specifically formulated and registered for the new trait is approved by EPA, albeit not widely applied by farmers at this time.

A primary concern for these new herbicide-resistant crops and the new HG4 herbicide formulations is the issue of off-target movement and injury. The three avenues for off-target injury include movement by herbicide volatilization, movement by the drift of the spray droplets during application, and the movement onto sensitive crops via the contamination of sprayers and support equipment.

Research conducted by Iowa State University characterized the impact of the two HG4 herbicides applied to susceptible soybean at the V3 stage of development with quantities of 1/10 to 1/5000 of the anticipated label rates that mimic the amount of the HG4 herbicides in a drift situation (Figs. 1 and 2)(McGregor and Owen 2014).

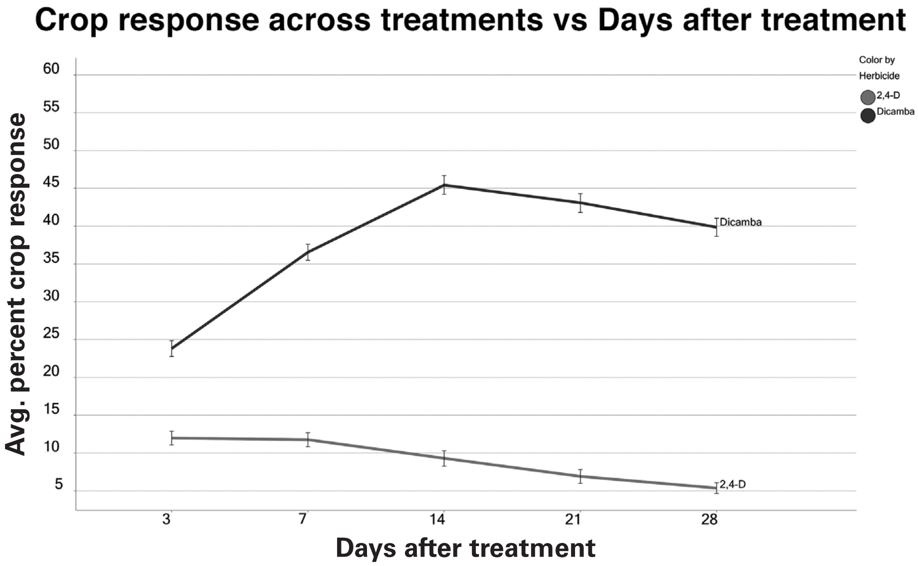

Figure 1. Soybean injury response to V3 applications of dicamba and 2,4-D. Data averaged for six experiments conducted in 2013 and 2014.

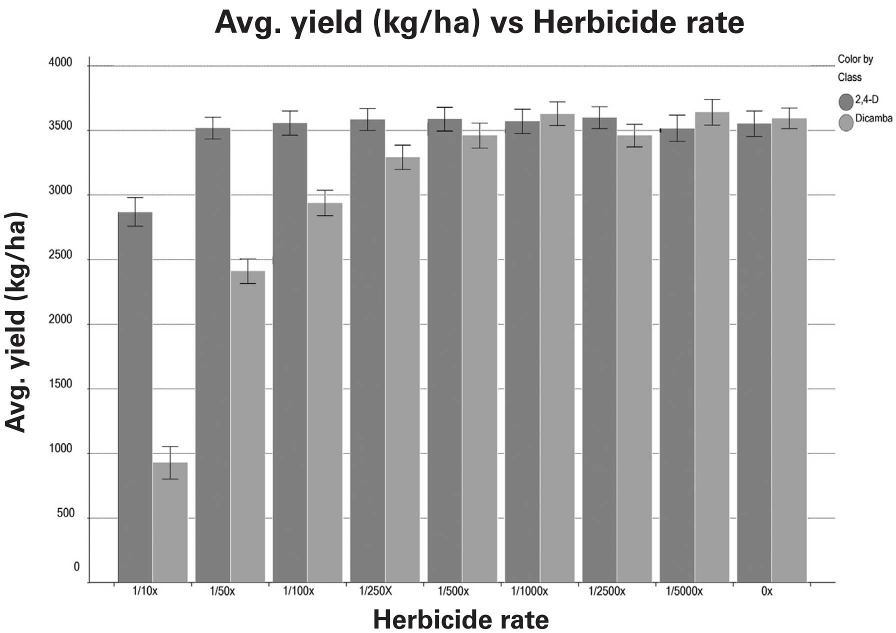

Figure 2. Effect of dicamba and 2,4-D applied to V3 soybeans. Data averaged for six experiments conducted in 2013 and 2014.

Clearly, non-dicamba soybeans are more sensitive to dicamba than 2,4-D. Dicamba caused greater yield reduction at lower relative rates than 2,4-D. Foliar injury was observed at herbicide rates that did not cause a reduction in yield. Importantly, the HG4 herbicides in these experiments were applied uniformly to the soybean and thus may not mimic the effects of herbicide drift whether from volatilization or physical drift. Also, drift that occurs during the reproductive development of sensitive soybeans has a greater negative impact on soybean yield (Bradley 2016). Given the issues that have developed during the past two years when the dicamba-resistant soybeans were available to farmers, the focus of the following discussion will be on dicamba. However, the basic concepts of off-target movement are also applicable to the 2,4-D formulations for the 2,4-D resistant soybeans.

Roundup Ready2 Xtend soybean have been widely planted despite the unavailability of the dicamba formulations labeled for application to the dicamba-resistant soybean cultivars. Unfortunately, decisions to use available, non-registered dicamba formulations for over-the-top applications has been common, particularly in the mid-south where more than 100,000 acres of non-dicamba resistant soybean and other crops were negatively impacted. The question is whether the use of the new dicamba products which were developed to reduce the potential for volatilization would have caused similar widespread problems.

There are three dicamba formulations that may be registered for use in Roundup Ready2 Xtend soybean. BASF has developed Engenia, a new salt of dicamba, which is described as having 70% lower relative volatility when compared to Clarity. Monsanto has developed Roundup Xtend (glyphosate + dicamba) and Xtendimax (dicamba) with VaporGrip; these formulations use the same salt of dicamba as Clarity, but include an additive (Vapor Grip) that reduces volatilization. DuPont will market its own brand of dicamba with Vapor Grip technology, FeXapan, through an arrangement with Monsanto.

The potential for volatilization for these new dicamba formulations was determined from laboratory and growth cabinet experiments as well as field evaluations. The question becomes whether the volatilization data derived from experiments that represent a relatively small area is valid when farmers adopt the technology and spray the new dicamba formulations over the landscape and under variable environmental conditions.

The companies have developed stewardship programs for farmers and applicators intended to minimize off-target movement of dicamba and 2,4-D. The goals of the programs are to increase awareness of application parameters and environmental conditions that contribute to particle and vapor drift. The labels for the new formulations take a different approach to off-target movement than seen previously. Only nozzle types specified on the label (manufacturer, type, and size) can be used to apply the new formulations. Only products that have been tested to determine their effects on spray droplet size can be tank-mixed with these herbicides. Non-treated buffer zones are specified when spraying adjacent to sensitive vegetation.

Given the widespread illegal use of dicamba on the dicamba-resistant soybean, it is suggested that the programs were less than successful at describing the needed stewardship concepts and gaining acceptance of the importance of these concepts. Again the question becomes how farmer adoption of the new dicamba formulations will fare when there is considerable more area treated across the landscape during widely variable environmental conditions. Will farmers and applicators use the appropriate spray tips and observe the environmental criteria described on the labels?

Lastly, the other potential problem for the new dicamba herbicides is sprayer and nurse tank contamination. Again, the herbicide labels describe the criteria to clean dicamba residues from tanks and sprayers. Research conducted at Iowa State University evaluating cleanout procedures demonstrates clearly that when specified procedures are followed, tank contamination can be significantly reduced and should minimize off-target issues (McGregor and Owen 2015). However, the studies did not assess the potential for contamination in spray lines, booms, and reservoirs where herbicide residues result in serious off-target problems if these are not appropriately cleaned (Bradley 2016). It will be crucial for farmers and applicators to observe the equipment cleanout processes.

Overall, the important considerations to reduce off-target movement of the new Group 4 herbicides are to follow the stewardship programs provided by the companies. Questions still exist with regard to the potential movement attributable to volatilization despite the new formulations, particularly when the area treated with the herbicides expands as anticipated. However, physical drift and injury attributable to sprayer and nurse tank contamination can be minimized by appropriate decisions by the applicator. These decisions and subsequent actions likely require time and procedures that are not simple or convenient. Importantly, these decisions and actions occur when there is limited time available for covering acres often contributing to poor decisions, especially during periods when unfavorable weather conditions limits time in the field. Furthermore, the expectations of the contributions that the new HG4 resistance soybeans will provide for the management of herbicide-resistant weeds need to be tempered by reality. While the HG4 herbicides can provide relatively good control of many important herbicide-resistant weeds, they do not represent the answer to this burgeoning problem. Unless these new tools are included in a more holistic approach to weed management, it is unlikely that the benefits they provide will offset the potential risks that exist.

Iowa Pest Resistance Management Plan

Iowa has experienced a rapid and widespread increase in evolved resistance in important pests. Weeds lead with most fields having infestations of waterhemp with evolved resistance to a number of herbicides (Owen 2013; Owen et al. 2015). More recently, populations of western corn rootworm evolved resistance to Bacillus thuringiensis (BT) and there are concerns about evolved resistance in soybean cyst nematode. National discussions and symposia on herbicide-resistant weeds and ISU faculty discussions about pest resistance in general resulted in an organized effort to determine what could be done to address the problems in Iowa. On January 30, 2015, a meeting was convened that included representatives from the Iowa State University College of Agriculture and Life Sciences, the Iowa Department of Agriculture and Land Stewardship, farmers, agriculture support groups, pesticide and biotechnology companies, ag retailers, land management firms, and commodity organizations. The meeting was convened in part because of growing concerns and the changing national regulatory framework to address pest resistance management that would impact Iowa agriculture. The meeting summary can be accessed at: http://www.ipm.iastate.edu/content/pesticide-resistance-workshop-2015.

The recommendations from the meeting included the need to develop a statewide voluntary pest resistance management plan to establish a consistent message about pest resistance action and to share outcomes of the meeting widely to all stakeholders. From that original meeting, a task force was charged to develop the conceptual framework for a state pest resistance management plan and to identify the roles that each stakeholder will play (Bradbury et al. 2016). The following stakeholders were identified as having important roles for the plan:

- Iowa agricultural organizations (i.e., Iowa Farm Bureau)
- Row-crop farmers, including land/farm owners and farm operators/renters
- Independent and certified crop advisers
- Seed, crop protection, technology/service, fertilizer providers, ag retailers
- Land owners, land managers
- Urban and rural community members
- EPA and USDA

Once the plan is accepted, the implementation of the ideas will be described. It will be critical that the plan is holistic and takes a long-term approach to pest resistance management. The economic impact of the plan must be addressed and the possibility of incentives considered. Individual approaches to pest management will be incorporated into the plan but community-based organizations to address the landscape implications of pest resistance will also be a factor of the plan. All of these considerations increase the complexity and difficulty in the successful implementation of the statewide plan. Monitoring results of the plan is critically important in the success as is developing an acceptable manner of governance of the voluntary plan. The Iowa pest resistance management plan will become public in the near future.

Conclusions

There are a number of changes in play for weed management in 2017 and beyond. While it is anticipated that the dicamba herbicides developed to provide weed control in dicamba-resistant soybean will be registered in the near future, it is not known whether the products will be available for use in 2017. Given the issues of illegal applications of dicamba in the mid-south, Iowa must not follow this path. New herbicide resistances in weeds are also a consideration for 2017 and more diverse plans should be established to manage these problems. Similarly, with Palmer amaranth populations being identified throughout Iowa, better weed management plans are needed. The Iowa Pest Resistance Management Plan will hopefully become the foundation of better weed management.

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Corn Herbicide Effectiveness Ratings

Weed response to selected herbicides E = excellent G = good F = fair P = poor	Herbicide Group Number	Crop tolerance	Grasses: Crabgrass	Fall panicum	Foxtail	Woolly cupgrass	Shattercane [2]	Broadleaves: Waterhemp [2, 4, 5, 6, 7, 8]	Black nightshade	Cocklebur [2]	Common ragweed	Giant ragweed [2, 4, 8]	Lambsquarter	Smartweed	Sunflower [2]	Velvetleaf	Perennials: Canada thistle	Quackgrass	Yellow nutsedge
Preplant/Preemergence																			
Atrazine	5	E	F	P	F	P	P	E	G	G	E	F-G	E	E	G	G	P	F	F
Balance Flexx	27	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, Harness, Surpass NXT, etc	15	E	E	E	E	F-G	F-G	G	G	P	P	P	P-F	P-F	P	P	P	P	G
Callisto	27	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	15	E	E	E	E	F	F	F-G	G	P	P	P	P	P	P	P	P	P	G
Hornet WDG	2, 4	G	P	P	P	P	P	G-E	F-G	G	G	G	G	G-E	G-E	G	P	P	P
Linex/Lorox	7	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	3	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	2	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)	14	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	2	G-E	P	G	G-E	G-E	E	G	P	F	P	P	P	G	P	F	F	G	F
Aim	14	G	P	P	P	P	P	F-G	G	P	P	F	G	P	P	E	P	P	P
Armezon, Impact	27	G-E	F-G	F	G	F	F	G-E	G-E	G-E	G	G	G	G	E	E	P	P	P
Atrazine	5	G	F	P	F	P	P	E	E	E	E	G	E	E	E	E	F*	F	G
Basagran	6	E	P	P	P	P	P	P	P	E	E	F	P	E	G	G-E	G*	P	G*
Basis, Basis Blend	2	F	F	F-G	G	F	G	G	P	F	F	P	G-E	G-E	G-E	G	P	G	P
Banvel, Clarity, DiFlexx, etc.	4	F-G	P	P	P	P	P	G-E	G	E	G-E	E	G	E	G	F-G	G*	P	P
Beacon	2	G	P	F-G	P-F	P	E	E	G	G	G	E	P	G	G	F-G	F-G*	G	F
Buctril	6	G	P	P	P	P	P	G	G-E	E	E	G	G-E	G-E	E	G	P	P	P
Callisto	27	G-E	P	P	P	P	P	E	E	G-E	F	G	G	E	G-E	E	P	P	P
Glyphosate (Roundup, etc.)[3]	9	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	2, 4	G	P	P	P	P	P	G-E	F	E	E	G-E	F	G-E	E	G-E	G	P	P
Liberty[3]	10	E	E	G	G-E	E	E	G	E	E	E	G	G	E	E	E	F-G	G	P
Laudis	27	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
Permit, Halomax, etc.	2	G	P	P	P	P	P	E	P	G-E	G-E	G	P	G-E	E	E	P	P	G
Resolve	2	F	F	F-G	G	F	G	G	P	F	F	P	G-E	G	P	F-G	F	G	F
Resource	14	G-E	P	P	P	P	P	G	P	F	F-G	P	F	P	P	E	P	P	P
Status	4, 19	F-G	P	F	F	P	F	G-E	G	E	G-E	G	G	E	G	G	G*	P	P

[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 waterhemp have been identified in Iowa. These biotypes may not be controlled by PPO inhibitor herbicides.
[6] HPPD-resistant biotypes of waterhemp have been identified in Iowa. These biotypes may not be controlled by HPPD herbicides.
[7] PSII-resistant biotypes of waterhemp have been identificed in Iowa. These biotypes may not be controlled by PSII herbicides.
[8] Biotypes of this weed with resistance to multiple sites of herbicide action have been identified in Iowa.
* 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.

Soybean Herbicide Effectiveness Ratings

Weed response to selected herbicides E = excellent G = good F = fair P = poor			Grasses					Broadleaves									Perennials		
	Herbicide Group Number	Crop tolerance	Crabgrass	Fall panicum	Foxtail	Woolly cupgrass	Shattercane [2]	Waterhemp [2,4,5,6,7,8]	Black nightshade	Cocklebur [2]	Common ragweed	Giant ragweed [2,4,8]	Lambsquarter	Smartweed	Sunflower [2]	Velvetleaf	Canada thistle	Quackgrass	Yellow nutsedge
Preplant/Preemergence																			
Authority/Spartan	14	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, Frontier, Warrant, Zidua, etc.	15	E	E	E	E	F	F	F-G	G	P	P	P	P	P	P	P	P	P	P
Command	13	E	G-E	G-E	E	F	F	P	F	F	G	P	G-E	G	F	E	P	P	P
FirstRate/Amplify	2	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	7	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	3	G-E	E	E	E	E	G-E	G	P	P	P	P	G	F	P	P	P	P	P
Pursuit	2	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	2	E	P	P	P	P	P	E	F	F	F	P	F-G	G-E	F	E	P	P	P
Metribuzin, Sencor, TriCor, etc	5	F-G	P	P	P-F	P	P	E	F	F	E	P	E	E	F-G	G-E	P	P	P-F
Sharpen	14	G	P	P	P	P	P	F	F	F	F	F	F	F	F	F	P	P	P
Valor SX, Rowel	14	F-G	P	P	P	P	P	G-E	E	P	G	F	G-E	F	P	F	P	P	P
Postemergence																			
Assure II, Fusilade DX, Fusion, Poast Plus, Select, etc.	1	E	E	E	E	E	E	P	P	P	P	P	P	P	P	P	P	G-E*	P
Basagran	6	E	P	P	P	P	P	P-F	P-F	E	E	F	P	E	G	G-E	G*	P	G*
Blazer	14	F-G	P	P	F	P	F	E	G	F	G	F	F	E	F	F	F	P	P
Classic	2	G	P	P	P	P	P	E	P	E	G-E	F	P	G-E	E	G-E	F	P	G-E
Cobra/Phoenix	14	F-G	F	P	P	P	P	E	G	G-E	E	F-G	F	G	G	F	F	P	P
FirstRate/Amplify	2	G	P	P	P	P	P	P	P	G-E	E	E	P	G	E	G	P	P	P
Glyphosate (Roundup, etc.)[3]	9	E	E	G-E	E	E	E	G-E	F-G	E	E	G-E	G	E	E	G	G	G-E	F
Harmony	2	F	P	P	P	P	P	E	P	F	F	P	G-E	G-E	G-E	G	P	P	P
Liberty[3]	10	E	E	G	G-E	E	E	G	E	E	E	G	G	E	E	E	F-G	G	F
Pursuit	2	G	G	G	F-G	F	E	F-G	E	G-E	G	F	P-F	E	G	G-E	F	P	P
Raptor	2	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, Dawn, Rhythm	14	F-G	P	P	P	P	P	E	F-G	F	G	G	F	G-E	F	F	P-F	P	P
Resource	14	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.

[3] Use only on appropriate resistant varieties.

[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.

[7] PSII-resistant biotypes of these weeds have been identifed in Iowa. These biotypes may not be controlled by PSII inhibitor herbicides.

[8] Biotypes of this weed with resistance to multiple sites of herbicide action have been identified in Iowa.

* 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
2, 4-D	2, 4-D	1.5 to 2.0 lb ae		7 days			7 days
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

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)
Acuron	15	2.14 lb S-metolachlor	3 qt	1.6 lb S-metolachlor	27 oz Dual II Magnum
	5	1.0 lb atrazine		0.75 lb atrazine	1.5 pt atrazine 4L
	27	0.24 mesotrione		0.18 lb mesotrione	5.8 oz Callisto
	27	0.06 lb bicyclopyrone		0.045 lb bicyclopyrone	N/A
Acuron Flexi	27	0.08 lb bycylopyrone	2.25 qt	0.045 lb bicyclopyrone	N/A
	27	0.32 lb mesotrione		0.18 lb mesotrione	5.8 oz Callisto
	15	2.86 lb S-metolachlor		1.61 ls S-metolachlor	27 oz Dual II Magnum
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 pyroxaslufone	10 oz	0.16 lb pyroxasulfone	3.0 oz Zidua
	14	0.063 lb fluthiacet-methyl		0.005 lb fluthiacet-methyl	0.7 oz Cadet
Anthem Maxx	15	4.174 lb pyroxasulfone	5 oz	0.16 oz pyroxasulfone	3.0 oz Zidua
	14	0.126 lb fluthiacet-methyl		0.005 lb 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
Armezon Pro	15	5.25 lb dimethenamid-P	20 oz	0.82 lb dimethenamid-P	17.5 oz Outlook
	27	0.1 lb topramezone		0.016 lb topramezone	0.73 oz Armezon
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, Medal II AT, Charger Max 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, Cinch ATZ Lite, Charger Max ATZ Lite	15	3.33 lb S-metolachlor	1.5 qt	1.25 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
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

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)
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
DiFlexx Duo	27	0.27 lb tembotrione	32 oz	0.067 lb tembotrione	2.5 oz Laudis
	4	1.86 lb dicamba		0.31 lb dicamba	10 oz DiFlexx
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	24.4% 2,4-D choline salt	4.75 pt	0.95 lb ae 2,4-D	30.4 oz 2,4-D 4A
	9	22.1% glyphosate DMA		1.0 lb ae glyphosate	32 oz Durango DMA
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, Confidence Xtra	15	4.3 lb acetochlor	2.3 qt	2.5 lb acetochlor	2.9 pt Harness 7E
Keystone LA NXT	5	1.7 lb atrazine		0.98 lb atrazine	1 qt atrazine 4L
Harness Xtra 5.6L, Confidence Xtra 5.6	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 oz	0.924 oz flumetsulam	1.15 oz Python WDG
	4	60% clopyralid		0.195 lb clopyralid	6.68 oz Stinger 3S

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)
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
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
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
Resicore	15	2.8 lb acetochlor	2.5 qt	1.75 lb acetochlor	2.0 pt Surpass NXT
	27	0.3 lb mesotrione		0.188 lb mesotrione	6.0 oz Callisto
	4	0.19 lb clopyralid		0.119 lb clopyralid	5.0 oz Stinger
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 Q
Scorch	4	1 lb gal dicamba	1.5 pt	0.187 lb dicamba	0.37 pt Clarity
	4	3.02 lb 2,4-D		0.57 lb 2,4-D	1.1 pt 2,4-D LVE 4
	4	0.75 lb fluroxypyr		0.14 lb fluroxypyr	0.4 pt Starane Ultra

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)
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 lb diflufenzopyr	0.05 lb diflufenzopyr
	4	44% dicamba		0.125 lb 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, Trisidual	15	3.75 lb acetochlor	2.0 pt	0.94 lb acetochlor	1.2 pt Surpass 6.4E
	4	0.38 lb clopyralid		1.5 oz clopyralid	4.1 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
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)
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
Anthem Maxx	15	4.174 lb pyroxasulfone	5 oz	0.16 oz pyroxasulfone	3 oz Zidua
	14	0.126 lb fluthiacet methyl		0.005 lb fluthiacet	0.7 oz Cadet

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 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, BroadAxe XC	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	62.1% 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, Presidual	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
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

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)
	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	24.57% flumioxazin	4 oz	1.0 oz flumioxazin	2 oz Valor
	15	31.17% pyroxasulfone		1.28 oz pyroxasulfone	1.5 oz Zidua
	2	6.67% 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
Harrow	2	50% rimsulfuron	0.5 oz	0.25 oz rimsulfuron	1 oz Matrix SG
	2	25% thifensulfuron		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		0.75 oz imazethapyr	3 oz Pursuit
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
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
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
Rowel FX	2	10.3% chlorimuron ethyl	5 oz	0.52 oz chlorimuron ethyl	0.21 oz Classic

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)
	14	30% flumioxazin		1.5 oz flumioxazin	2.94 oz Valor
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
Surveil	14	51% flumioxazin	3.6 oz	1.5 oz flumioxazin	3.0 oz Valor
	2	84% chloransulam		0.5 oz cloransulam	0.6 ox FirstRate
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
Varisto	6	4.0 lb bentazon	27 oz	0.84 lb bentazon	0.84 qt Basagran
	2	0.187 lb imazamox		0.04 lb imazamox	5.1 oz Raptor
Warrant Ultra	15	2.82 lb acetochlor	50 oz	1.1 lb acetochlor	3 pt Warrant
	14	0.63 lb fomesafen		0.25 lb fomesafen	1 pt Reflex
Zidua Pro	14	0.48 lbs saflufenacil	4.5 oz	0.016 lb saflufenacil	0.73 oz Sharpen
	2	1.33 lbs imazethapyr		0.047 lb imazethapyr	3 oz Pursuit
	15	2.28 lbs pyroxasulfone		0.08 lb pyroxasulfone	1.5 oz Zidua

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.

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)
7	D1 protein (Photosystem II inhibition)
9	EPSPS (shikimic acid pathway inhibition)

Group No.	Site of Action (mode of action)
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	Herbicide Group No.	Active Ingredient
2,4-D and others	4	2,4-D
Accent Q	2	nicosulfuron
Aim	14	carfentrazone
Assure II	1	quizalofop
atrazine	5	atrazine
Autumn	2	iodosulfuron
Balance Flexx	27	isoxaflutole
Banvel/Clarity/DiFlexx and others	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/Cinch	15	S-metolachlor
Express	2	tribenuron
FirstRate	2	cloransulam
FlexStar/Reflex	14	fomasafen
Fusilade DX	1	fluazifop
Gramoxone SL	22	paraquat
Harmony	2	thifensulfuron
Harness/Surpass/Breakfree/ Warrant	15	acetochlor
Impact/Armezon	27	topramezone
Laudis	27	tembotrione
Liberty	10	glufosinate

Trade name	Herbicide Group No.	Active Ingredient
Lorox/Linex	7	linuron
Metribuzin/TriCor/Sencor	5	metribuzin
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/Bestow	2	rimsulfuron
Resource	14	flumiclorac
Roundup/Touchdown	9	glyphosate
Scepter	2	imazaquin
Select	1	clethodim
Sharpen	14	saflufenacil
Sonalan	3	ethalfluralin
Spartan/Authority	14	sulfentrazone
Stinger	4	clopyralid
Treflan, Thrust	3	trifluralin
UltraBlazer	14	acifluorfen
Valor/Rowel	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	Herbicide Group No.	Active Ingredients
Acuron	5, 15, 27, 27	atrazine, S-metolachlor, mesotrione, bicyclopyrone
Acuron Flexi	15, 27, 27	S-metolachlor, mesotrione, bicyclopyrone
Afforia	2, 2, 14	thifensulfuron, tribenuron, flumioxazin
Alluvex	2, 2	rimsulfuron, thifensulfuron
Anthem	14, 15	fluthiacet, pyroxasulfone
Anthem ATZ	5, 14, 15	atrazine, fluthiacet, pyroxasulfone
Anthem Maxx	14, 15	fluthiacet, pyroxasulfone
Armezon Pro	15, 27	dimethenamid-P, topramezone
Authority Assist	2, 14	imazethapyr, sulfentrazone
Authority Elite	14, 15	sulfentrazone, S-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, S-metolachlor
Breakfree NXT ATZ, Breakfree NXT Lite	5, 15	atrazine, acetochlor
BroadAxe	14, 15	sulfentrazone, S-metolachlor
Callisto GT	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
Charger Max ATZ	5, 15	atrazine, S-metolachlor
Cheetah Max	10, 14	glufosinate, fomesafen
Cinch ATZ	5, 15	S-metolachlor, atrazine
Confidence Xtra	5, 25	atrazine, acetochlor
Corvus	2, 27	thiencarbazone, isoxaflutole
Crusher	2, 2	Rimsulfuron, thifensulfuron
Degree Xtra	5, 15	atrazine, acetochlor
DiFlexx	4, 27	dicamba, isoxaflutole
Diflexx Duo	4, 27	dicamba, tembotrione
Enlist Duo	4, 9	2,4-D, glyphosate
Enlite	2, 2, 14	chlorimuron, thifensulfuron, flumioxazin
Envive	2, 2, 14	chloriuron, thifensulfuron, flumioxazin
Expert	5, 9, 15	atrazine, glyphosate, S-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
Halex GT	9, 15, 27	glyphosate, S-metolachlor, mesotrione
Harness Xtra	5, 15	atrazine, acetochlor
Harrow	2, 2	rimsulfuron, thifensulfuron
Instigate	2, 27	rimsulfuron, mesotrione
Keystone NXT, Keystone LA NXT	5, 15	atrazine, acetochlor
Latir	2, 14	imazethapyr, flumioxazin
Lexar EZ	5, 15, 27	atrazine, S-metolachlor, mesotrione
Lumax EZ	5, 15, 27	atrazine, S-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
Prefix	14, 15	fomesafen, S-metolachlor
Presidual	5, 15	metribuzin, S-metolachlor
Prequel	2, 27	rimsulfuron, isoxaflutole
Priority	2, 14	halosulfuron, carfentrazone
Pummel	2, 15	Imazethapyr, metolachlor
Pursuit Plus	2, 3	imazethapyr, pendimethalin

Tradename	Herbicide Group No.	Active Ingredients
Realm Q	2, 27	rimsulfuron, mesotrione
Require Q	2, 4	rimsulfuron, dicamba
Resicore	4, 15, 27	clopyralid, acetochlor, mesotrione
Resolve Q	2, 2	rimsulfuron, thifensulfuron
Revulin Q	2, 27	nicosulfuron, mesotrione
Rowel FX	2, 14	chlorimuron ethyl, flumioxazin
Scorch	4, 4, 4	2,4-D, dicamba, fluroxypyr
Sequence	9, 15	glyphosate, S-metolachlor
Solstice	14, 27	fluthiacet, mesotrione
Sonic	2, 14	cloransulam, sulfentrazone
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
Surveil	2,14	cloransulam, flumioxazin
Synchrony	2, 2	chlorimuron, thifensulfuron
Tailwind	5, 15	metribuzin, metolachlor
Torment	2, 14	Imazethapyr, formesafen
TripleFLEX II	2, 4, 15	flumetsulam, clopyralid, acetochlor
Trisidual	2, 4, 15	flumetsulam, clopyralid, acetochlor
Trivence	2, 5, 14	chlorimuron, metribuzin, flumioxazin
Valor XLT	2, 14	chlorimuron, flumioxazin
Varisto	2, 6	imazamox, bentazon
Verdict	14, 15	saflufenacil, dimethenamid
Warrant Ultra	14, 15	formesafen, acetochlor
Weedmaster	4, 4	2,4-D, dicamba
Yukon	2, 4	halosulfuron, dicamba
Zemax	15, 27	S-metolachlor, mesotrione
Zidua Pro	2, 14, 15	imazethapyr, saflufenacil, pyroxasulfone

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 synthase (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 (brown, dead tissue), and are evident 1 to 4 weeks after herbicide application, depending upon the herbicide 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. Some weed species have both target-site and metabolic resistances.

Microtubule Inhibitors – 3

Dinitroaniline (DNA) herbicides inhibit cell division by interfering with the formation of microtubules by inhibiting 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 (brown, dead) 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. There are several herbicide families that are classified as PPO inhibitors. Postemergence applied diphenyl ether herbicides (e.g., acliflurofen, 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. Clomazone (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, horseweed/marestail 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	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 HG 2	
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 HG 3	
dinitroanilines	
Balan	benefin
Prowl H_20, Pendimax, Framework, Satellite, others	pendimethalin
Sonalan	ethalfluralin
Surflan	oryzalin
Treflan, Trust, others	trifluralin

Synthetic auxin HG 4	
benzoic	
Banvel, Clarity, DiFlexx, 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, atrazine, others	atrazine
Evik	ametryn
Metribuzin, Tricor	metribuzin
Princep	simazine
ureas	
Karmex	diuron
LInex, Lorox	linuron

Photosystem I inhibitors HG 22	
Diquat, Reward	diquat
Gramoxone Max	paraquat

Protoporphyrinogen Oxidase (PPO) inhibitors HG 14	
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, Rowel	flumioxazin
pyrimidinedione	
Sharpen (Kixor)	saflufenacil
other	
Cadet	fluthiacet

Enolpyruvyl shikimate phosphate synthase (EPSPS) inhibitors HG 9	
Roundup, Touchdown, others	glyphosate

Glutamine synthetase inhibitors HG 10	
Liberty, Cheetah	glufosinate

Hydroxyphenyl pyruvate dioxygenase (HPPD) inhibitors HG 27	
Balance Flexx	isoxaflutole
Callisto	mesotrione
Armezon/Impact	topramezone
Laudis	tembotrione
bicyclopyrone	bicyclopyrone

Diterpene inhibitors HG 13	
Command	clomazone

Auxin transport inhibitors HG 19	
Distinct, Status	diflufenzopyr

Lipid synthesis inhibitors HG 15	
Harness, Surpass, Warrant	acetochlor
Dual II MAGNUM, Cinch, Medal, Charger Max, others	S-metolachlor, metolachlor
Frontier, Outlook, Commit, others	dimethenamid-P
Zidua	pyroxasulfone

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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