2011 Herbicide Guide for Iowa Corn and Soybean Production

New options for weed management in 2011

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Introduction

Weeds have a major impact on global agricultural profitability and represent the most important pest complex to the well-being of mankind. In 2004, the ubiquitous nature of weeds impacted U.S. agriculture representing a $20 billion cost to the growers (Basu et al., 2004; Bridges, 1994). Weeds are the most important and consistent pest complex that affects the economic profitability of Iowa agriculture. Killing weeds, as opposed to managing weeds has become the norm with the glyphosate-based crop systems and has resulted in weeds that no longer respond to glyphosate as well as uncalculated losses of profit due to early season interference of the weeds on the crops. Furthermore, the industry has not been able to provide the historic "solutions" to the ever-evolving weed issues. This paper will address the changes in the agricultural chemical industry and provide perspectives and suggestions to resolve weed management problems.

What is new for Iowa weed management?

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BASF

BASF has expanded the Integrity herbicide label to include soybeans and changed the name to Verdict powered by Kixor herbicide. Verdict is a combination of saflufenacil and dimethenamid-P and should be applied prior to crop emergence. The saflufenacil component of Verdict is a PPO inhibitor herbicide and has excellent burndown activity on sensitive weeds. Saflufenacil has demonstrated inconsistent control of PPO resistant common waterhemp. If crops have emerged prior to Verdict application, do not apply as the likelihood of crop injury is high. In corn, Verdict can be applied preplant surface, preplant incorporated or preemergence. Field corn (grain and silage) and popcorn are described on the Verdict label. In soybeans, Verdict may be applied in the fall or in the spring early preplant through preemergence. A minimum preplant interval of 30 days is required on coarse (sand, loamy sand and sandy loam) soils with < 2% organic matter. No preplant interval is required on coarse soils with > 2% organic matter and all medium and fine textured soils.

Bayer Crop Science

Bayer Crop Science has initiated an important effort to provide growers with a better understanding of the implications of evolved resistance to herbicides, particularly glyphosate. These efforts include, but are not limited to hosting an international conference (Pan-American Weed Resistance Conference) in January, 2010 and field meetings in the Mississippi Delta regions in the summer and fall, 2010. They are promoting stewardship for weed management in order to minimize the evolution of glyphosate-resistant weeds. Interestingly, the first weed with resistance to glufosinate (Ignite) was recently reported.

Capreno will be widely available in 2011. The herbicide premixture contains an ALS inhibiting herbicide (thiencarbazone-methyl), an HPPD inhibiting herbicide (tembotrione) and a safener (isoxadifen). Other products such as Balance Pro and Option will not be available in 2011. Balance Pro has been replaced with Balance Flexx which includes isoxaflutole and a safener (cyprosulfamide) thus allowing early postemergence application through V2 stage of corn development. However, ISU recommends that Balance Flexx is best used as an early preplant or preemergence application.

Bayer Crop Science is also developing HPPD-resistant genetically-engineered crops. Given the current political situation and the impact it may have on registration of new technologies, it is unclear what the results of the research will be.

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Dow AgroSciences

Dow AgroSciences has launched an aggressive stewardship campaign describing the evolution of glyphosate-resistant weeds, the perspectives offered by growers and the benefits growers describe for glyphosate and genetically-engineered crops. These efforts included surveys and informational reports in the popular agricultural press. Not surprisingly, the most important benefit for the glyphosate-based crop systems described by growers from the surveys was the simplicity for managing weeds provided by the glyphosate-based systems. Also concerning was the report from a survey conducted in June 2010 that only 38% of growers reported that glyphosate-resistant weeds were a significant or very significant threat. These informational reports provided insights about why glyphosate-resistant weeds are important considerations and why growers should provide stewardship to preserve the viability of the glyphosate-based crop systems. Interestingly, 79% of the growers surveyed suggested that glyphosate-based crop systems would not be effective in ten or fewer years. The bottom-line message was that growers need to act now in order to protect the technology.

DuPont/Pioneer

DuPont has made a number of changes to the Resolve Q label. Resolve Q is a mixture of rimsulfuron and thifensulfuron-methyl, both of which are ALS inhibiting herbicides. The changes include increasing the amount of rimsulfuron that can be used in a growing season from 0.5 to 1.0 oz A.I. per acre and the use of Resolve Q as a burndown treatment for weeds. The latter is the same as described on the Basis (rimsulfuron) label. The Resolve Q label now describes the use of Prequel (rimsulfuron and isoxaflutole) and Breakfree (acetochlor) as tank mixture companions. Lastly, the re-crop restrictions for Resolve Q now are the same as those described on the Basis label.

Realm Q is a DuPont premixture of rimsulfuron and mesotrione that is available for contact plus residual weed control with or without glyphosate in corn. Realm Q also includes isoxadifen, a safener which minimizes the potential for corn injury. Realm Q can be applied to corn after emergence but prior to corn exhibiting seven leaf collars or being 20 inches tall.

DuPont/Pioneer continues to develop Optimum GAT corn and soybeans. The development of Optimum GAT soybean continues on the same timeline as previously reported; availability is anticipated in 2013-2014 pending field testing and regulatory approvals. Optimum GAT corn hybrids are anticipated later in the decade.

FMC Corporation

FMC Corporation has introduced Authority XL herbicide for use in soybeans to control a number of difficult weeds such as common waterhemp, giant ragweed and horseweed (marestail). Authority XL herbicide is a 70 DF formulation prepackage mixture of sulfentrazone (sulf) (62.2%) and chlorimuron-ethyl (CE)(7.78%) which represents a ratio of 8:1 sulf:CE; the ratio is 5:1 in Authority BL and Canopy XL. Authority XL herbicide provides two mechanisms of herbicide action: PPO inhibition and ALS inhibition. These products may not provide effective control of weeds that have multiple resistances to PPO and ALS inhibiting herbicides such as common waterhemp biotypes. Results of the soil-applied PPO inhibitor herbicides controlling PPO-resistant common waterhemp have been inconsistent in some instances. However the higher rates of PPO inhibitor herbicides used with preemergence applications may result in acceptable control of some common waterhemp biotypes that have been shown resistance to postemergence rates of PPO inhibitor herbicides.

Monsanto

Monsanto Company has a number of "new" products including TripleFLEX and Warrant herbicides. TripleFLEX is a prepackage mixture of acetochlor, flumetsulam and clopyralid and also contains dichlormid, a safener. TripleFLEX will be positioned for use on herbicide-tolerant corn (field and silage) including cultivars resistant to glyphosate and/or glufosinate. The three different herbicide mechanisms of action will provide a broad spectrum of weed control including some herbicide-resistant weed biotypes. Warrant is an encapsulated formulation of acetochlor that is specifically labeled for postemergence application in soybeans but timed to be preemergence to weeds. Encapsulation provides a safer formulation for the postemergence application timing. Application should be made before soybeans are R2. Optimum application timing, according to the Warrant label, is V2-V3. A second directed application can be made at V5-V6 stage of soybean development. The emphasis for Warrant will be the residual control of difficult small-seeded broadleaf weeds (i.e. common waterhemp) and annual grasses. Warrant does not provide control of emerged weeds.

Monsanto has also established partnerships with several companies in order to better manage glyphosate-resistant weed biotypes and provide stewardship for the Roundup Ready technologies. Specifically, Monsanto has agreements with Sumitomo Chemical Company, Ltd. and Valent U.S.A. Corporation for the use of flumioxazin (Valor) including Valor SX (flumioxazin), Valor XLT (flumioxazin and chlorimuron-ethyl) and Gangster multipack (flumioxazin and cloransulam-methyl). The arrangement also includes Select (clethodim).

Monsanto has also has an agreement with FMC Corporation for products including Authority First DF (sulfentrazone and cloransulam-methyl), Authority MTZ (sulfentrazone and metribuzin), Authority XL (sulfentrazone and chlorimuron-ethyl) and Authority Assist (sulfentrazone and imazethapyr).

Monsanto continues to develop the dicamba-resistant genetically-engineered soybean cultivars. However, this technology was the focus of the recent discussion at the House Oversight Committee Hearings on Domestic Policy. The discussions were not positive and there were mixed perspectives about the benefits and risks of the technology from a number of witnesses who testified at the hearings.

Syngenta

Syngenta has reported a number of "new" products including Callisto Xtra (mesotrione and atrazine), Flexstar GT (fomesafen and glyphosate) and Peak (prosulfuron). Callisto Xtra is labeled for postemergence application in field corn, seed corn, sweet corn, silage corn and yellow popcorn. Flexstar GT is specifically registered for glyphosate-resistant soybean and has provided control of some glyphosate-resistant weed biotypes. Peak is now registered for weed management in corn. There are a number of restrictions and precautions on the supplemental label that describes corn including concerns for applications to stressed corn, interactions with organophosphate insecticides and potential interactions with other herbicides. Peak has demonstrated good activity on burcucumber.

There are also a number of label updates for Fusilade DX (fluazifop-P-butyl), Flexstar (fomesafen), and Prefix (S-metolachlor and fomesafen). Fusilade DX can now be applied post-bloom to soybeans and has a 60 day post harvest interval. Flexstar has numerous updates described on the label such as changes for application timing, adjuvants and rain-fastness. Prefix has several additions to the label including the application of Ignite following Prefix applications the removal of restrictions of S-metolachlor prior to postemergence application of Prefix. Bicep II MAGNUM (S-metolachlor and atrazine) can now be applied postemergence to corn 5-12 inches tall. Callisto, Callisto Xtra, and Halex GT labels now include language about HPPD-resistant weeds.

Valent U.S.A. Corporation

Valent U.S.A. Corporation has a registration pending for Fierce herbicide. Fierce is a prepackage mixture of flumioxazin and pyrosulfone and will be registered as a preemergence herbicide in soybean, no-tillage and reduced tillage corn production and as a fall burndown treatment. Pyroxasulfone has been studied for a number of years as the Kumiai Chemical Industry Co., LTD product KIH-485 and has a described mechanism of action as a shoot growth inhibitor and attacks the enzyme responsible for long chain fatty acid elongation. Flumioxazin is a PPO inhibitor herbicide. Fierce has demonstrated good control of many annual grasses and small-seeded annual broadleaf weeds and has good residual properties.

Management of weeds: The implications of herbicide use and other tactics

The recurrent use of any herbicide or herbicide mechanism of action imparts selection pressures on a weed population and thus creates an ecological advantage to those rare individual weeds within the population that have a heritable mutation conferring the ability for these weeds to survive the herbicide, particularly if no other alternative management tactics are included (Llewellyn et al., 2001; Owen and Zelaya, 2005). Similarly, the recurrent use of any weed management tactic or crop production strategy will also select for weed biotypes or species that are ecologically adapted ("fit") and thus provide them with an ecological opportunity to become dominant within the weed community (Owen, 2008b).

The most important agricultural manipulation, or selective forces, that affect changes in weeds are tillage (disturbance) and herbicide use which will cause the composition of the weed communities to change to species that no longer are affected by these practices (Owen, 2008b). Herbicides tend to impart greater and more consistent selective force on a weed community resulting in relatively faster changes or shifts in species composition than tillage, although both are ultimately important (Heard et al., 2003; Heard, 2003).

The current weed management strategies reflect the wide-spread utilization of the glyphosate-resistant crop cultivars and the use, often exclusively, of glyphosate. The primary benefits of the genetically-engineered crops, as stated by growers, is the convenience and simplicity of weed control (Bonny, 2007; Owen, 2008a). This has contributed to the dramatic decline in alternative tactics used to manage weeds and thus loss of integrated weed management (IWM) in the in Iowa.

While the lack of diversity for weed management tactics and subsequent changes in weed communities may not eliminate the use of glyphosate, it does provide a strong impetus for the development of improved weed management strategies and the adoption of more diverse IWM tactics (Table 1) (Green, 2007; Swanton and Weise, 1991).

Conclusions

Weeds represent the most economically important pest complex to global food production and also significantly impact mankind at all levels, from health perspectives to the pursuit of recreation (Bridges, 1994). Interestingly, the better weed management becomes, the more difficult it becomes to manage weeds. This conundrum reflects the diversity of weed genomes facilitating their continued adaptation to all forms of selective practices (control) necessary for effective crop production (Barrett, 1983; De Wett and Harlan, 1975; Gould, 1991). Recent efforts to manage weeds have taken a slightly different path and focus on the use of herbicides that are selective to crops due to genetic-engineering (Duke and Powles, 2008). Glyphosate in genetically-engineered crops has provided exceptional control of many weeds.

Models clearly demonstrate that the adoption of a diverse management approach to controlling weeds can prolong the utility of the genetically-engineered cultivars and glyphosate (Werth et al., 2008). Proactive management of glyphosate-resistant weeds is economically sustaining and provides stewardship for the genetically-engineered traits (Mueller et al., 2005).

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Table 1. Assessment of cultural, mechanical and herbicidal tactics used for an Integrated Weed Management (IWM) program. Adapted from Green and Owen (2010) and Owen (2001) (Green and Owen, 2010; Owen, 2001)

Tactics	Benefits	Risks	Potential adoption and impact
Herbicide MOA rotation	Reduced selection pressure, possible control of HR weeds	Lack of available different MOAs, phytotoxicity, cost, weed spectrum not controlled by available alternatives	Excellent
Herbicide tank mixes	Reduced selection pressure, improved control on a broader weed spectrum	Poor activity on HR weed species, increased cost; potential phytotoxicity	Excellent
Variable herbicide application timing	Better control of HR species, more efficient use of herbicide(s)	Lack of herbicide residual activity, postemergence applications may be too late to protect yield potential, more application trips	Good to excellent
Adjusted herbicide rates	Better control of target species	Increased selection pressure (higher rates), selection for non-target site, polygenic resistance (lower rates)	Poor to fair
Herbicide banding	Reduced cost, reduced selection pressure, less herbicide used	Need for mechanical inter-row control tactics, specialized equipment, increased application time required	Poor
Precision herbicide application	Decreased herbicide use, reduced selection pressure	Increased cost of application, unavailability of consistent weed population maps; poor understanding of weed seedbank dynamics; increased variability of control	Poor
Herbicide synergists alternative products	Improved efficacy; reduced herbicide amount, possible new MOA	No research base; inconsistent efficacy, lack of available products	Poor
Herbicide resistant crops	No phytotoxicity, possible different MOA, possible reduced herbicide amount; application timing variable	Increased cost of traited seed; need for more applications per season; increased selection pressure from the MOA used, possible movement of HR trait into near-relative weeds, volunteer HR crops as weeds	Excellent
Primary tillage	Decreased selection pressure, excellent and consistent efficacy; depletion of weed seedbank	Increased time requirement, increases soil erosion, increased costs, requires additional tactics,	Good to excellent
Mechanical weed control strategies	Decreases selection pressure; consistent efficacy, relatively inexpensive	Increase time requirement, high level of management skill needed, requires additional tactics, potential for crop injury	Poor to fair
Crop rotation	Changes agro-ecosystem, allows different herbicide tactics (MOA, etc.), may facilitate other alternative strategies	Economic risk of alternative rotation crop, lack of adapted rotation crop, rotation crop not dissimilar and thus minimal impact on the weed community, requirement for herbicides	Fair to good
Adjusted time of planting	Potential improved efficacy on target weeds, reduction of selection pressure	Requires alternative strategies (primary tillage or herbicide application), potential for yield loss, need for increased rotation diversity	Poor to fair
Adjusted seeding rate	Reduced selection pressure, improved competitive ability for the crop	Increased seed cost, potentially increased pest problems, increased intraspecific competition, reduced potential yields	Fair
Alternative planting configuration	Improved competitive ability for the crop, reduced selection pressure	Unavailability of mechanical strategies, emphasis on herbicides, equipment limitations	Good
Selection of crop cultivars	Improved competitive ability for the crop, reduced selection pressure	Lack of research base, inconsistent impact on HR weed populations	Fair
Cover crops, mulches, intercrop systems	Improved competitive ability, reduced selection pressure, improved systems diversity, allelopathy	Inconsistent effect on HR weed populations, lack of understanding about the systems, limited research base, potential crop yield loss, need for herbicide to manage the cover crop, lack of good cover crop species	Poor
Seedbank management	Reduced HR weed pressure, reduced selection pressure	Lack of understanding about weed seedbank dynamics, requires aggressive tillage, emphasis on late herbicide applications, requires high level of management skills	Fair to good
Adjustment of nutrient use	Improved competitive ability for the crop, efficient use of nutrients, reduced selection pressure	Lack of research base, inconsistent results, potential for crop yield loss	Poor

Herbicide-resistant weeds and management tactics

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Introduction

Currently, herbicide-resistant weeds likely represent an economic threat to U.S. agriculture, particularly corn and soybean. Herbicide resistance is not a concern attributable to the adoption of genetically-engineered crops however how this technology has been implemented significantly impacted the evolution of herbicide-resistant weeds. Currently, there are over 340 herbicide-resistant weed biotypes in more than 190 different plant species (Figure 1) (Heap, 2010). Recently, herbicide-resistant weeds have gained much attention nationally, despite the fact that herbicide-resistant weeds have been an economic issue to agriculture for more than three decades. Furthermore, regulators now have intentions of developing more restrictive rules how the technologies can be used with a stated goal to "manage" herbicide-resistant weeds. Thus, it is clear that herbicide-resistant weeds will continue to have a major role in the future of Iowa agriculture. The issues reflect, in part, an inability or unwillingness on the part of growers and agricultural chemical and seed companies to fully embrace the problem and change weed management programs. This paper will address the current situation with regard to herbicide-resistant weeds and provide perspectives and suggestions to resolve weed management problems.

Current state of herbicide-resistant weeds

The current status of herbicide-resistant weeds from a global perspective strongly supports the premise that new herbicide-resistant weed populations continue to evolve at an increasing rate. Weeds have evolved resistance to 20 different herbicide mechanisms of action (Heap, 2010). Most recently, HPPD inhibitor herbicide-resistant common waterhemp (Amaranthus tuberculatus syn. rudis) was reported in Iowa and Illinois. Currently there are 20 weeds confirmed to have evolved resistance to glyphosate and 11 in the U.S. (Table 1 and Figure 2) (Heap, 2010). Iowa has glyphosate-resistant populations of giant ragweed (Ambrosia trifida), horseweed (Conyza canadensis) and common waterhemp distributed widely across the state. Resistance to triazine herbicides, ALS inhibitor herbicides and PPO inhibitor herbicides is common in Iowa. In fact, all common waterhemp populations in Iowa should be considered cross-resistant to the ALS inhibitor herbicides and in many instances, the common waterhemp populations also demonstrate multiple resistances to several herbicide mechanisms of action. For a complete list of herbicide resistant weeds validated in Iowa, refer to the International Survey of Herbicide Resistant Weeds (www.weedscience.org) (Heap, 2010).

Management of weeds resistant to glyphosate and other herbicides

As a result of ill-advised use of herbicides, weeds have inevitably evolved genetically-heritable resistance to herbicides (Owen, 1997). This exhibition of "Darwinian evolution in fast forward" is a consequence of the effectiveness and consistency of herbicides in managing weed complexes. Importantly, the concern for and management of weeds that no longer respond to glyphosate has taken on a particularly important perspective in Iowa agriculture. It is unfortunate that surveys, while somewhat dated, indicated that generally growers are not overly concerned about glyphosate-resistant weeds (Johnson et al., 2009).

The management of glyphosate- and herbicide-resistant weeds must include as many tactics as possible. However, given the current crop production systems, these solutions will focus on herbicides almost to the exclusion of other tactics. Importantly, there are short-term gains than can be realized with tactics such as herbicide rotation, herbicide tank mixtures and other genetically-engineered traits (i.e. glufosinate). Importantly, growers must recognize that tactics they can and will adopt to mitigate glyphosate-resistant weed problems have different "returns"; herbicide rotation tends to provide only one year of benefit for each year of adoption while the use of herbicide mixtures is a much more effective strategy (Beckie, 2006; Maxwell and Jasieniuk, 2000).

Studies conducted in grower fields in Iowa during 2009 and 2010 demonstrated conclusively that herbicide-resistant weeds can be effectively managed with the correct selection of herbicides. These studies validated the existence of glyphosate-resistant populations of giant ragweed and common waterhemp as well as populations of common waterhemp with resistance to PPO inhibitor herbicides. These herbicide-resistant weed populations were managed with the alternative herbicides included in the experiments. Interestingly, these experiments also confirmed the existence of multiple resistances in these weed populations; at each location, the weed population was not only resistant to the target herbicide but also resistant to imazethapyr (i.e. Pursuit). Research conducted in grower fields has confirmed that common waterhemp populations in Iowa are resistant to ALS inhibitor herbicides and demonstrated the existence of cross resistance to ALS inhibitor herbicides in common waterhemp populations (Hinz and Owen, 1997). Suggestions of herbicides alternatives to glyphosate or to be used in combination with glyphosate (in sequence or as a tank mixture) and the relative efficacies on giant ragweed, common waterhemp and common lambsquarters are reported in Tables 2 and 3.

Conclusions

Weeds represent the most economically important pest complex to global food production and also significantly impact mankind at all levels, from health perspectives to the pursuit of recreation (Bridges, 1994). During the last five decades, herbicides have been an important component for effectively managing weeds. As a result, biochemical adaptation or "mimicry" has become an important problem (Gould, 1991). Weed management in corn and soybean over the last decade has focused almost exclusively in many situations, on the use of glyphosate with crop selectivity due to genetic-engineering (Duke and Powles, 2008). There can be no question that glyphosate in genetically-engineered crops has provided exceptional control of many weeds and also many other environmental and economic benefits to growers and society. Growers deem weed management with the glyphosate-based systems as simple and convenient and have used this non-diverse system despite the inevitability that weed populations would again rise to the genetic challenge and resistance to glyphosate would evolve despite suggestions otherwise (Bradshaw et al., 1997; Neve, 2007). Furthermore, short-sighted recommendations from the industry contributed to the problems (Sammons et al., 2007).

The ability to effectively manage herbicide-resistant weeds including those resistant to glyphosate is well-studied and tactics readily available to growers (Beckie, 2006). Models clearly demonstrate that the adoption of a diverse management approach to controlling weeds can prolong the utility of the genetically-engineered cultivars and glyphosate (Werth et al., 2008). Proactive management of glyphosate-resistant weeds is economically sustaining and provides stewardship for the genetically-engineered traits (Mueller et al., 2005). It is imperative that Iowa agricultural practices change immediately in order to maintain the viability of genetically-engineered crops and glyphosate and to improve economic returns on crop production.

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Table 1. Weeds with evolved resistance to glyphosate in the United States of America[1]

Weed (common name)	State	Year of first report
Amaranthus palmeri (Palmer amaranth)	GA, NC, AR, TN, NM, AL, MS[2], MO	2005
Amaranthus tuberculatus (syn. rudis) (common waterhemp)	MO[2], IL[2], KS, MN, IA, MS	2005
Ambrosia artemisiifolia (common ragweed)	AR, MO, OH[2], KS	2004
Ambrosia trifida (giant ragweed)	OH[2], AR, IN, KS, MN, TN, IA, MO	2004
Conyza bonariensis (hairy fleabane)	CA[2]	2007
Conyza canadensis (horseweed)	DE, KY, TN, IN, MD, MO, NJ, OH[2], AR, MS, NC, PA, CA, IL, KS, MI, IA	2000
Kochia scoparia (kochia)	KS	2007
Lolium multiflorum (Italian ryegrass)	OR, MS, AR	2004
Lolium rigidum (rigid ryegrass)	CA	1998
Poa annua (annual bluegrass)	MO	2010
Sorghum halepense (johnsongrass)	AR, MS	2007

[1]Adapted from the International Survey of Herbicide Resistant Weeds (www.weedscience.org) (Heap, 2010)
[2]Biotypes demonstrating resistance to multiple herbicide mechanisms of action

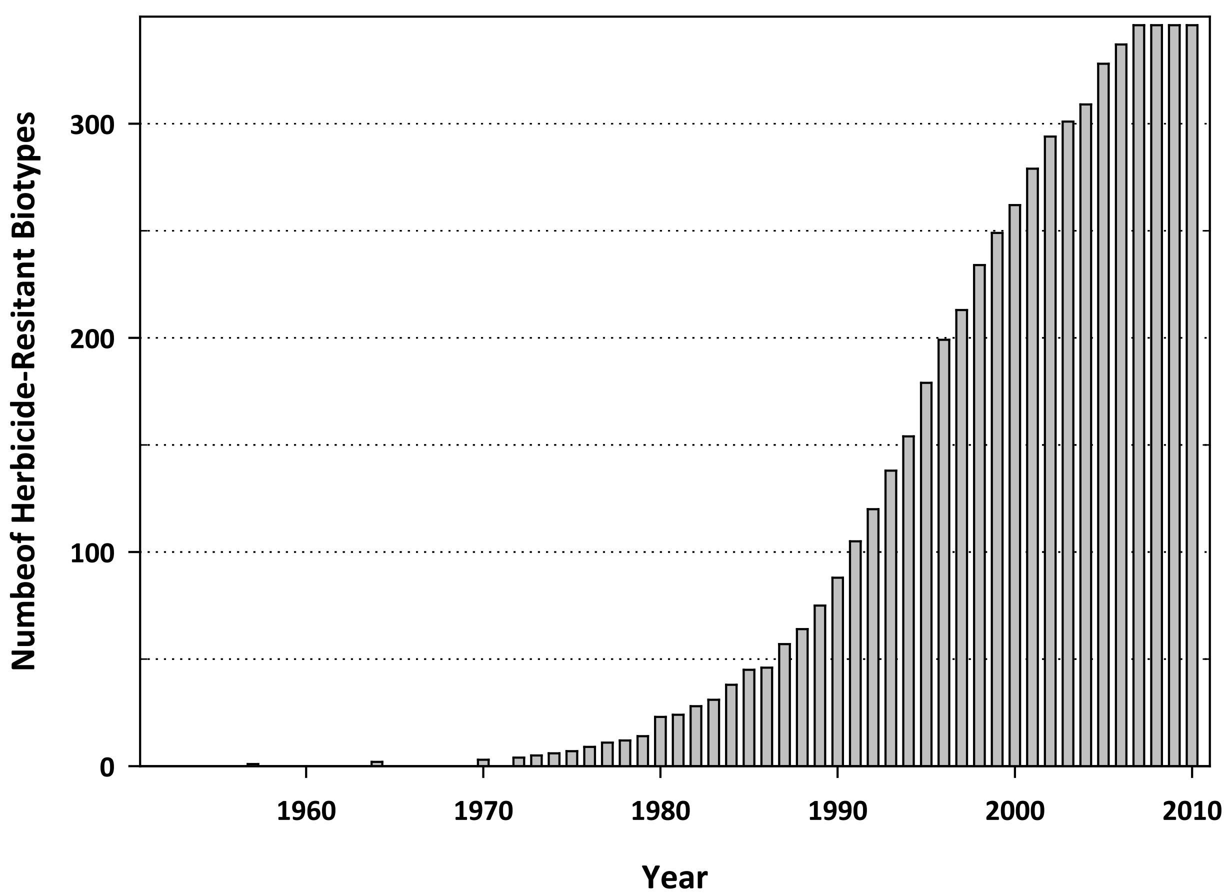

Figure 1. Cumulative global total of herbicide-resistant weed biotypes 1952-2010. Adapted from the International Survey of Herbicide Resistant Weeds (www.weedscience.org) (Heap, 2010)

Table 2. Herbicides used in combination with glyphosate for control of giant ragweed, common lambsquarters and common waterhemp in corn (adapted from NDSU/UMN Extension publication). (P, F, G, E are poor, fair, good and excellent, respectively)

	Giant ragweed[1,2]	Common waterhemp[1,2,3]	Common lambsquarters
PRE in sequence with glyphosate			
Atrazine (0.5 to 1.0 lb ai/A)	F/G	G/E	G/E
Balance Flex	F	G/E	G
Banvel/Clarity	F	G	G
Callisto	F	G/E	E
Camix	G	G/E	E
Harness/Surpass/Dual/Outlook	P	G/E	F/G
Hornet	F/G	P/F	G
Integrity	G	G/E	G/E
Lumax	G	E	G/E
Prequel	F/G	E	G
Prowl	P	G	G/E
SureStart	F/G	G/E	E
POST as part of a tank mixture with glyphosate			
Aim	F	F/G	G
Atrazine (0.38 to 1.0 lb ai/A)	G	E	E
Banvel/Clarity	E	G	G/E
Basis	P	P	G/E
Buctril	G	G/E	G
Cadet	P	F	F
Callisto	G	E	G/E
Capreno	G	G/E	G/E
Hornet	G/E	P/F	P/F
Impact	G	G/E	G
Laudis	G	G/E	G/E
Option	P	P	P
Permit	P/F	P	P
Resolve Q	P	P	F
Resource	P	F	F
Status/Distinct	G/E	G/E	G/E
Alternative Technology			
Ignite in Liberty Link corn hybrids	G/E	G	F

[1]ALS inhibitor herbicide resistant biotypes have been confirmed in Iowa
[2]Glyphosate resistant biotypes have been confirmed in Iowa
[3]PPO inhibitor herbicide resistant biotypes have been confirmed in Iowa

Table 3. Herbicides used in combination with glyphosate for control of giant ragweed, common lambsquarters and common waterhemp in soybean (adapted from NDSU/UMN Extension publication). (P, F, G, E are poor, fair, good and excellent, respectively)

	Giant ragweed[1,2]	Common waterhemp[1,2,3]	Common lambsquarters
PRE in sequence with glyphosate			
IntRRo (alachlor)	P	F/G	P/F
Dual/Outlook	P	F/G	P/F
Authority Assist	P	G/E	E
Authority First/Sonic	G	G/E	G/E
Authority MTZ	P/F	G/E	G
Boundary	P/F	G/E	G
Enlite	F	FG/E	F
FirstRate	G/E	P	G
Gangster	F/G	G	G/E
OptiIl	F/G	G	G/E
Prefix	F	G	G
Prowl	P	G	G
Sencor	P	E	E
Sharpen (1 oz/A)	F	G	G/E
Spartan	F	E	G/E
Treflan	P	G	G
Valor	F	G/E	E
POST as part of a tank mixture with glyphosate			
Cadet	P	F	F
Classic	F	P	P
Cobra/Phoenix	F/G	E	F
FirstRate	E	P	P
Flexstar	G	E	F
Harmony GT	P	P	G/E
Pursuit	F	P	P/F
Raptor	G	P	G
Resource	P	G	F
Synchrony	F/G	P	G/E
Ultra Blazer	F	E	F
Alternative Technology			
Ignite in Liberty Link soybean hybrids	G/E	G	G

[1]ALS inhibitor herbicide resistant biotypes have been confirmed in Iowa
[2]Glyphosate resistant biotypes have been confirmed in Iowa
[3]PPO inhibitor herbicide resistant biotypes have been confirmed in Iowa

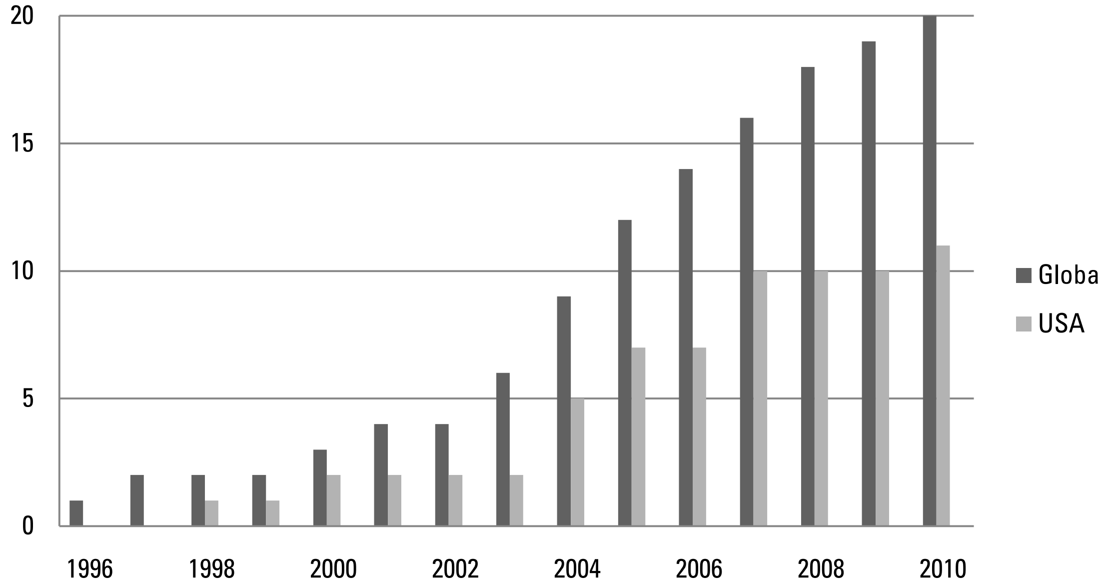

Figure 2. Occurrence of weeds with evolved resistance glyphosate. Adapted from the International Survey of Herbicide Resistant Weeds (www.weedscience.org) (Heap, 2010)

Glyphosate interactions with micronutrients and plant diseases

Bob Hartzler, professor and extension weed specialist, Agronomy, Iowa State University

Glyphosate is the most widely used pesticide in the world. As has happened with other pesticides that attained widespread use, concerns over unintended consequences resulting from glyphosate use have arisen. In addition to articles appearing in trade journals and the popular press, an entire issue of a scientific journal (Journal of European Agronomy) was devoted to this topic: Glyphosate interactions with physiology, nutrition, and diseases of plants: Threat to agricultural sustainability? This paper will provide an overview of the controversy regarding negative impacts of glyphosate on crop production

Interactions with micronutrients

Shortly after the introduction of glyphosate resistant (GR) soybean, questions arose whether these varieties or glyphosate applications to them altered manganese (Mn) relations compared to conventional soybean varieties. It is well documented that certain cations, including Mn, can reduce the performance of glyphosate when they are present in water used as a carrier for the herbicide application. The complexes formed between glyphosate and metal cations are not absorbed as efficiently as free glyphosate, resulting in reduced weed control. Although the majority of research investigating the effect of glyphosate on mineral nutrition has focused on Mn, glyphosate would interact similarly with other metal cations (e.g. calcium, iron, magnesium).

Mn efficiency of soybeans with glyphosate resistant trait

Some of the first reports of Mn-related problems with GR soybean were reported by researchers at Purdue University in 2001. After the initial reports of Mn deficiency in GR soybean, other researchers in other regions of the U.S. and South America studied this relationship. When experiments included more than one GR variety, it was found that not all GR varieties were inefficient at Mn absorption or utilization. Since not all GR varieties are less efficient at Mn utilization that conventional varieties, it is unlikely that the GR trait itself is responsible for differences in Mn nutrition in those varieties that exhibited Mn deficiency. The efficiency of soybean at utilizing Mn is determined by the base genetics of the variety, rather than the GR trait.

Interactions of glyphosate and Mn within soybean

A second issue with glyphosate and Mn is related to interactions between the two compounds in the plant, rather than the characteristics of GR varieties. An injury response often seen following glyphosate application to GR soybean is chlorosis in newly emerged leaves. These symptoms are similar to Mn deficiency symtoms, so it has been implied that glyphosate may interfere with Mn relations within the plant.

Although a few studies have shown interactions between glyphosate applications and Mn utilization in GR soybean, the majority of research has not identified differences in Mn absorption, accumulation and availability between glyphosate-treated and non-treated GR soybean. If glyphosate was immobilizing Mn within soybean, it would seem that the chlorosis observed following glyphosate applications could be eliminated by foliar applications of Mn, but this has not been the case. In addition, it has been documented that glyphosate is metabolized by GR soybean to a compound (AMPA) that is responsible for the chlorosis in new growth following glyphosate applications.

Interactions of glyphosate with Mn in the soil

It also has been speculated that glyphosate may interfere with Mn relations by reducing its availability in the soil via chelation (complexes formed between a metal ion and an organic compound, similar to what happens when hard water is used as a carrier for glyphosate applications), or that glyphosate alters the activity of microorganisms that control the solubility of Mn within the soil.

Glyphosate is a strong chelater of divalent metals (Mn, Ca, Mg), thus it could temporarily tie up these nutrients. However, glyphosate would not specifically target Mn, but rather would interact with the most prevalent cations in the vicinity of the roots. In Iowa soils, the majority of glyphosate would likely interact with the highly abundant Ca and Mg rather than Mn, and also with organic matter.

Manganese is absorbed by plants in the reduced state (Mn^{2+}). High soil pH limits Mn availability by oxidizing it to the Mn^{4+} state. While the specific physiological mechanisms are poorly understood, many plants are able to absorb Mn from soils with limited Mn availability. This is accomplished either via associations between the plant and Mn-reducing bacteria, or alteration of the pH of the rhizosphere via root exudates.

Glyphosate is similar to most herbicides in that when it enters the soil it differentially affects soil microorganisms. Glyphosate applications to GR soybean were reported to alter the balance of Mn reducing and oxidizing bacteria associated with soybean roots in a manner that suggested that Mn was immobilized in the soil. However, published data documenting reduced soil availability of Mn due to the activity of glyphosate on soil microorganisms is lacking. Furthermore, there have been no documented reports of Mn crop deficiency symptoms in Iowa. Mn deficiency symptoms occur in some regions of the Cornbelt, and these areas are where interactions between glyphosate and Mn nutrition have been reported.

Interactions with plant diseases

Interactions between herbicides and plant diseases are well documented, with both positive and negative responses. Glyphosate predisposes many plants to pathogens due to its inhibition of the shikimic acid pathway. Phytoalexins, which are compounds produced by plants to defend against pathogens, are products of this pathway. GR crops gain their resistance to glyphosate by insertion of a gene for an insensitive target site (EPSPS). Since glyphosate does not bind to the transgenic enzyme, the shikimic acid pathway functions normally and the effects of glyphosate on phytoalexin accumulation in plants should be minimal in GR crops.

Other mechanisms for glyphosate affecting disease development have been proposed, including increasing soil pathogen populations or immobilizing micronutrients involved in disease resistance. Glyphosate applications to GR crops alter the types and quantity of compounds released from crops roots into the rhizosphere, including the exudation of glyphosate. These changes in exudates can have a dramatic impact on the microbes found in the root zone.

An increase in colonization of GR soybean roots by Fusarium following treatment with glyphosate has been documented in greenhouse studies. However, based on field research it was concluded that SDS development was influenced by cultivar susceptibility independent of the GR trait or glyphosate use.

Mn plays an important role in plants' disease defense mechanisms. It has been proposed that glyphosate interferes with absorption and utilization of Mn, thus increasing a plant's susceptibility to disease. However, as discussed previously, the majority of research has not found reductions in Mn concentrations within plants following glyphosate applications.

Powell and Swanton reviewed research that has evaluated interactions between glyphosate and diseases caused by Fusarium. Their conclusion was that field research has not documented a causative link between glyphosate and an increase in diseases caused by Fusarium spp. However, they also stated that it is impossible to rule out the link between the two.

Summary

Glyphosate has been described as 'The Herbicide of the Century' due to its high level of effectiveness. Three factors contribute to its efficacy: 1) interference with an important metabolic pathway; 2) highly efficient translocation within plants, and 3) slow metabolism by plants. These factors, combined with the large margin of crop safety provided by the GR trait, have resulted in unparalleled use of glyphosate in Iowa and other areas with similar cropping systems.

Much of the concern regarding glyphosate is related to its effects within the rhizosphere. The persistence of glyphosate is dependent upon soil characteristics and environmental conditions, with half-lives reported from 14 to 60 days. It is well documented that the presence of glyphosate in soil can significantly impact microbial populations. Due to the complexity of the processes that occur within the root zone, it is impossible to completely rule out negative effects of glyphosate on mineral nutrition or disease development in GR crops. However, results from field research and our widespread experience with glyphosate on GR crops for over a decade do not indicate widespread negative impacts of glyphosate on these factors.

A similar article with citations is available online: http://www.weeds.iastate.edu/mgmt/2010/glyMndisease.pdf

Corn Herbicide Effectiveness Ratings[1]

Weed response to selected herbicides

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

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

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

Weed response to selected herbicides

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

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

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

Grazing and haying restrictions for herbicides used in grass pastures

			Beef and Non-Lactating Animals			Lactating Dairy Animals	
Herbicide	A.I.	Rate/A	Grazing	Hay harvest	Removal before slaughter	Grazing	Hay harvest
Ally		0.1 - 0.3 oz	0	0	0	0	0
Clarity and many others	dicamba	Up to 1 pt	0	0	30 days	7 days	37 days
		1-2 pt	0	0	30 days	21 days	51 days
		2- 4 pt	0	0	30 days	40 days	70 days
		4 - 16 pt	0	0	30 days	60 days	90 days
Cimarron Max (co-pack)	metsulfuron methyl + dicamba + 2,4-D	0.25-1 oz A + 1-4 pt B	0	0	30 days	7 days	37 days
Cimarron X-Tra	metsulfuron methyl + chlorsulfuron	0.1 - 1.0 oz	0	0	0	0	0
Crossbow	triclopyr + 2,4-D	1 - 6 qt	0	14 days	3 days	Growing season	Growing season
Escort XP	metsulfuron methyl	Up to 1.7 oz	0	0	0	0	0
		1.7- 3.3 oz	NA	3 days	NA	NA	3 days
ForeFront R&P	aminopyralid + 2,4-D	1.5 - 2.6 pt	0	7 days	0	0	7 days
Grazon P&D	picloram + 2,4-D	3 - 4 pt	0	0	0	7 days	30 days
Milestone	aminopyralid	3 - 7 pt	0	0	0	0	0
Overdrive	dicamba + diflufenzopyr	4 - 8 oz	0	0	0	0	0
Pasturegard	triclopyr + fluroxypyr	1.5 - 2 pt	0	14 days	3 days	1 year	1 year
Rave	dicamba + triasulfuron	2 - 5 oz	0	37 days	30 days	7 days	37 days
Redeem R&P	triclopyr + clopyralid	1.5 - 4 pt	0	14 days	3 days	Growing season	Growing season
Remedy Ultra	triclopyr	1 - 2 qt	0	14 days	3 days	Growing season	Growing season
Surmount	picloram + fluroxypyr	1.5-6 pts	0	7	3	14	7
Tordon 22K	picloram	< 2 pts	0	0	3	14	14
		> 2 pts	0	14	3	14	14
Weedmaster	dicamba + 2,4-D	1-4 pts	0	37 days	30 days	7 days	37 days
2,4-D (many tradenames) Uses may vary among products	2,4-D	2-4 pt 4 lb/G	0	30 days	3 days	7 days	30 days

Herbicide Package Mixes

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

Corn Herbicide Premixes or Co-packs and Equivalents

Herbicide	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Basis 75DF	50% rimsulfuron	0.33 oz	0.167 oz rimsulfuron	0.167 oz rimsulfuron
	25% thifensulfuron		0.083 oz thifensulfuron	0.33 oz Pinnacle 25DF
Bicep II MAG. 5.5L, Cinch ATZ	2.4 lb S-metolachlor	2.1 qt	1.26 lb S-metolachlor	21 oz Dual II MAGNUM
	3.1 lb atrazine		1.63 lb atrazine	52 oz atrazine 4L
Bicep Lite II MAG, Cinch ATZ Lite	3.33 lb S-metolachlor	1.5 qt	1.24 lb S-metolachlor	21 oz Dual II MAGNUM
	2.67 lb atrazine		1.00 lb atrazine	32 oz atrazine 4L
Breakfree ATZ 5.25L	3.0 lb acetochlor	2.7 qt	2.0 lb acetochlor	2.5 pt Breakfree 6.4E
	2.25 lb atrazine		1.5 lb atrazine	3.0 pt atrazine 4L
Breakfree ATZ Lite 5.5L	4.0 lb acetochlor	2.0 qt	2.0 lb acetochlor	2.5 pt Breakfree 6.4E
	1.5 lb atrazine		0.75 lb atrazine	1.5 pt atrazine 4L
Buctril + Atrazine	1.0 lb bromoxynil	2.0 pt	0.25 lb bromoxynil	1 pt bromoxynil 2E
	2.0 lb atrazine		0.50 lb atrazine	1 pt atrazine 4L
Bullet 4ME	2.5 lb alachlor	4.0 qt	2.5 lb alachlor	2.5 qt Micro-Tech 4ME
	1.5 lb atrazine		1.5 lb atrazine	1.5 qt atrazine 4L
Callisto Xtra	0.5 lb mesotrione	24 fl oz	0.09 lb mesotrione	3.0 oz Callisto
	3.2 lb atrazine		0.6 lb atrazine	1.2 pt atrazine 4L
Capreno	0.57 thiencarbazone methyl	3.0 oz	0.01 lb thiencarbazone methyl	-
	2.88 lb tembotrione		0.068 lb tembotrione	-
Cinch ATZ	2.4 lb S-metolachlor	2.1 qt	1.26 lb S-metolachlor	21 oz Dual II Magnum
	2.67 lb atrazine		1.63 lb atrazine	3.25 pt atrazine 4L
	1.88 isoxaflutole		0.083 lb isoxaflutole	2.6 oz Balance
Degree Xtra	2.7 lb acetochlor	3 qt	2 lb acetochlor	36.6 oz Harness 7E
	1.34 lb atrazine		1 lb atrazine	1 qt atrazine 4L
Distinct 70WDG	21.4 % diflufenzopyr	6 oz	1.3 oz diflufenzopyr	1.3 oz diflufenzopyr
	55.0% dicamba		3.3 oz dicamba	6 oz Banvel
Epic 58DF	48% flufenacet	12 oz	0.36 lb flufenacet	9.6 oz Define
	10% isoxaflutole		0.075 lb isoxaflutole	1.6 oz Balance

Corn Herbicide Package Mixes (continued)

Herbicide	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Exceed 57WG	28.5% prosulfuron	1 oz	0.018 lb prosulfuron	0.5 oz Peak 57WG
	28.5% primisulfuron		0.018 lb primisulfuron	0.38 oz Beacon 75SG
Expert 4.9SC	1.74 lb S-metolachlor	3 qt	1.3 lb S-metolachlor	1.4 lb Dual II Mag.
	2.14 lb atrazine		1.61 lb atrazine	1.6 qt Aatrex 4L
	0.74 lb ae glyphosate		0.55 lb ae glyphosate	1.5 pt Glyphosate 3L
FieldMaster	2.0 lb acetochlor	4.0 qt	2.0 lb acetochlor	2.3 pt Harness
	0.75 lb glyphosate		0.75 lb glyphosate	24 oz Roundup Ultra
	1.5 lb atrazine		1.5 lb atrazine	1.5 qt atrazine 4L
Freestyle	12.5% chlorimuron	0.66 oz	0.083 oz chlorimuron	-
	18.75% thifensulfuron		0.125 oz thifensulfuron	-
	18.75% tribenuron		0.125 oz tribenuron	-
FulTime 4CS	2.4 lb acetochlor	4 qt	2.4 lb acetochlor	3 pt Surpass 6.4EC
	1.6 lb atrazine		1.6 lb atrazine	3.2 pt atrazine 4L
G-Max Lite 5L	2.25 lb dimethenamid	3.0 pt	0.84 lb dimethenamid-P	18 oz Outlook
	2.75 lb atrazine		1.0 lb atrazine	2 pt Aatrex 4L
Guardsman Max 5L	1.7 lb dimethenamid-P	3.4 pt	0.7 lb dimethamid-P	15 oz Outlook
	3.3 lb atrazine		1.4 lb atrazine	1.4 lb atrazine 4L
Halex GT	2.09 lb *S*-metolachlor	3.6 pt	0.94 lb *S*-metolachlor	1.0 pt Dual II Magnum
	0.209 lb mesotrione		0.09 lb mesotrione	3.0 oz Callisto
	2.09 lb glyphosate		0.94 lb glyphosate ae	24 oz Touchdown HiTech
Harness Xtra	4.3 lb acetochlor	2.3 qt	2.5 lb acetochlor	46 oz Harness 7E
	1.7 lb atrazine		0.98 lb atrazine	1 qt atrazine 4L
Harness Xtra 5.6L	3.1 lb acetochlor	3 qt	2.325 lb acetochlor	42.5 oz Harness 7E
	2.5 lb atrazine		1.875 lb atrazine	1.9 qt atrazine 4L
Hornet WDG	18.5% flumetsulam	5 oz	0.924 oz flumetsulam	1.15 oz Python WDG
	60% clopyralid		0.195 lb clopyralid	6.68 oz Stinger 3S
Integrity	6.24% saflufenacil	13 oz	0.058 lb saflufenacil	2.6 oz Sharpen
	55.04% dimethenamid		0.5 lb dimethenamid	10.9 oz Outlook
Instigate	4.7% chlorimuron ethyl	6.9 oz	0.325 oz chlorimuron	
	4.7% rimsulfuron		0.325 oz rimsulfuron	
	31.2% mesotrione		2.15 oz mesotrione	
Keystone 5.25L	3.0 lb acetochlor	2.7 qt	2.0 lb acetochlor	2.5 pt Surpass 6.4E
	2.25 lb atrazine		1.5 lb atrazine	3.0 pt Aatrex 4L

Corn Herbicide Package Mixes (continued)

Herbicide	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Keystone LA 5.5L	4.0 lb acetochlor 1.5 lb atrazine	2.0 qt	2.0 lb acetochlor 0.75 lb atrazine	2.5 pt Surpass 6.4E 1.5 pt Aatrex 4L
Laddok S-12 5L	2.5 lb bentazon 2.5 lb atrazine	1.67 pt	0.52 lb bentazon 0.52 lb atrazine	1.0 pt Basagran 4S 1.0 pt atrazine 4L
Lariat 4L	2.5 lb alachlor 1.5 lb atrazine	4 qt	2.5 lb alachlor 1.5 lb atrazine	2.5 qt Lasso 4E 1.5 qt atrazine 4L
Lexar 3.7L	1.74 lb S-metolachlor 1.74 lb atrazine 0.224 lb mesotrione	3.5 qt	1.52 lb S-metolachlor 1.52 lb atrazine 0.196 lb mesotrione	1.6 pt Dual II Mag. 3 pt Aatrex 4L 6.27 oz Callisto
Liberty ATZ	1.0 lb glufosinate 3.3 lb atrazine	32 oz	0.25 lb glufosinate 0.825 lb atrazine	20 oz Liberty 0.825 qt atrazine 4L
Lightning 70DF	52.5% imazethapyr 17.5% imazapyr	1.28 oz	0.672 oz imazethapyr 0.224 oz imazapyr	0.96 oz Pursuit 70DG 0.78 oz Arsenal 28.7DF
Lumax	0.268 lb mesotrione 2.68 lb S-metolachlor 1.0 lb atrazine	3 qts	0.2 lb mesotrione 2.0 lb S-metolachlor 0.75 lb atrazine	6.4 oz Callisto 2 pt Dual II MAGNUM 0.75 qt Aatrex 4L
NorthStar	7.5% primisulfuron 43.9% dicamba	5.0 oz	0.375 oz primisulfuron 2.20 oz dicamba	0.5 oz Beacon 75SG 4.0 oz Banvel 4L
Optill	17.8% saflufenacil 50.2% imazethapyr	2.0 oz	0.35 oz saflufenacil 1 oz imazethapyr	1 oz Sharpen 4 oz Pursuit AS
Prequil 45% DF	15% rimsulfuron 30% isoxaflutole	2 oz	0.3 oz rimsulfuron 0.59 oz isoxaflutole	0.3 rimsulfuron 1.2 oz Balance Pro
Priority	12.3% carfentrazone 50% halosulfuron	1.0 oz	0.008 lb carfentrazone 0.032 lb halosulfuron	0.5 oz Aim 0.68 oz Permit
Radius	3.57 lbs flufenacet 0.43 lbs isoxaflutole	16 oz	0.47 lb flufenacet 0.05 lb isoxaflutole	15 oz Defince 4SC 1.7 oz Balance Pro
ReadyMaster ATZ,	2 lb glyphosate 2 lb atrazine	2 qt	1 lb glyphosate 1 lb atrazine	1 qt Roundup Ultra 1 qt atrazine 4L
Require Q	0.062 lb rimsulfuron 0.481 lb dicamba	4 oz	0.016 lb rimsulfuron 0.12 lb dicamba	1.0 Resolve 3.9 Clarity/Banvel
Resolve Q	0.184 lb rimsulfuron 0.04 lb thifensulfuron	1.25 oz	0.0143 lb rimsulfuron 0.0031 lb thifensulfuron	0.9 oz Resolve 0.067 oz Harmony GT

Corn Herbicide Package Mixes (continued)

Herbicide	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Shotgun 3.25L	2.25 lb atrazine	2 pt	0.56 lb atrazine	1.12 pt atrazine 4L
	1 lb 2,4-D		0.25 lb a.e. 2,4-D	0.53 pt Esteron 99 3.8E
Spirit 57WG	14.25% prosulfuron	1 oz	0.1425 oz prosulfuron	0.25 oz Peak 57WG
	42.75% primisulfuron		0.4275 oz primisulfuron	0.57 oz Beacon 75SG
Steadfast Q	25.2% nicosulfuron	1.5 oz	0.37 oz nicosulfuron	0.68 oz Accent Q
	12.5% rimsulfuron		0.19 oz rimsulfuron	0.19 oz rimsulfuron
SureStart SE/Tripleflex	3.75 lb acetochlor	2.0 pt	0.94 lb acetochlor	1.2 pt Surpass 6.4E
	0.29 lb clopyralid		1.2 oz clopyralid	3.2 oz Stinger 3S
	0.12 lb flumetsulam		0.48 oz flumetsulam	0.6 oz Python WDG
Surpass 100 5L	3 lb acetochlor	2.5 qt	1.88 lb acetochlor	1.18 qt Surpass 6.4E
	2 lb atrazine		1.25 lb atrazine	1.25 qt atrazine 4L
Traverse	12.5% chlorimuron ethyl	2.6 oz	0.325 oz chlorimuron	-
	12.5% rimsulfuron		0.325 oz rimsulfuron	-
Trigate	6.7% rimsulfuron	3.75 oz	0.25 oz rimsulfuron	-
	5.0% tribenuron		0.187 oz tribenuron	-
	33.3% mesotrione		1.25 oz mesotrione	-
Verdict	6.24% saflufenacil	14 oz	0.992 oz saflufenacil	2.8 oz Sharpen
	55.04% dimethenamid-P		0.547 lb dimethenamid-P	11.7 oz Outlook
WideMatch 1.5EC	0.75 lb fluroxypyr	1.3 pt	0.125 lb fluroxypyr	10.6 oz Starane 1.5E
	0.75 lb clopyralid		0.125 lb clopyralid	5.3 oz Stinger 3S
Yukon	12.5% halosulfuron	4 oz	0.031 lb halosulfuron	0.66 oz Permit
	55% dicamba		0.125 lb dicamba	4.0 oz Banvel

Soybean Herbicide Package Mixes or Co-packs and Equivalents

Herbicide	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	33.3% sulfentrazone 6.67% imazethapyr	10 oz	3.3 oz sulfentrazone 0.67 oz imazethapyr	4.4 oz Authority 75DF 2.7 oz Pursuit AS
Authority First/Sonic	6.21% sulfentrazone 7.96% cloransulam-methyl	8.0 oz	0.31 lb sufentrazone 0.04 lb cloransulam-methyl	6.6 oz Authority 75DF 0.76 oz FirstRate
Authority MTZ	18% sulfentrazone 27% metribuzin	16 oz	0.18 lb sulfentrazone 0.27 metribuzin	3.8 oz Authority 75DF 1.0 pt Sencor 4L
Authority XL	62.2% sulfentrazone 7.8% chlorimuron	8 oz	5.0 oz sulfentrazone 0.6 oz chlorimuron	6.6 oz Authority 75DF 2.4 oz Classic
Boundary 7.8EC	5.2 lbs s-metolachlor 1.25 lbs metribuzin	2.1 pt	1.4 lb s-metolachlor 0.3 lb metribuzin	1.5 pt Dual II MAG. 6.4 oz Sencor 75DF
Canopy 75DF	10.7% chlorimuron ethyl 64.3% metribuzin	6 oz 0.24 lb	0.64 lb chlorimuron metribuzin	2.57 oz Classic 25DF 5.14 oz metribuzin 75DF
Canopy EX	22.7% chlorimuron 6.8% tribenuron	1.5 oz	0.34 oz chlorimuron 0.10 oz tribenuron	1.36 oz Classic 0.10 tribenuron
Commence 5.25E	2.25 lb clomazone 3.00 lb trifluralin	2.5 pt	0.70 lb clomazone 0.94 lb trifluralin	1.4 pt Command 4E 1.9 pt Treflan 4E
Enlite 47.9DG	36.2% flumioxazin 8.8% thifensulfuron 2.8% chlorimuron ethyl	2.8 oz	1.0 oz flumioxazin 0.25 oz thifensulfuron 0.08 chlorimuron ethyl	2.0 oz Valor 0.33 oz Harmony GT 0.32 oz Classic
Envive 41.3DG	29.2% flumioxazin 2.9% thifensulfuron 9.2% chlorimuron ethyl	5.3 oz	1.5 oz flumioxazin 0.15 oz thifensulfuron 0.49 oz chlorimuron ethyl	3.0 oz Valor 0.20 oz Harmony GT 1.9 oz Classic
Extreme	1.8% imazethapyr 22% glyphosate	3 pt	0.064 lb imazethapyr 0.75 lb glyphosate	1.44 oz Pursuit DG 24 oz Roundup
Flexstar GT	0.66 lb fomesafen 2.63 lb glyphosate	3.75 pt	0.3 fomesafen 1.2 lb glyphosate	1.2 pt Flexstar 31 oz Touchdown or HiTech
Freestyle	12.5% chlorimuron 18.75% thifensulfuron 18.75% tribenuron	0.66 oz	0.083 oz chlorimuron 0.125 oz thifensulfuron 0.125 oz tribenuron	- - -
FrontRow	flumetsulam chloransulam	5 acres/pkg	0.15 oz flumetsulam 0.25 oz chloransulam	0.12 oz Python 80WDG 0.3 oz FirstRate 84WDG
Fusion 2.67E	2 lb fluazifop 0.67 lb fenoxaprop	8 fl oz	0.125 lb fluazifop 0.042 lb fenoxaprop	8 fl oz Fusilade DX 2E 8 fl oz Option II 0.67E

Soybean Herbicide Package Mixes (continued)

Herbicide	Components (a.i./gal or % a.i.)	If you apply (per acre)	You have applied (a.i.)	An equivalent tank mix of (product)
Galaxy 3.67S	3 lb bentazon	2 pt	0.75 lb bentazon	1.5 pt Basagran 4S
	0.67 lb acifluorfen		0.17 lb actfluorfen	0.67 pt Blazer 2S
Gangster (co-pack)	51% flumioxazin	3.6 oz	1.5 oz flumioxazin	3.0 oz Valor
	84% chloransulam		0.5 oz chloransulam	0.6 oz FirstRate
OpTill	17.8% saflufenacil	2 oz	0.35 oz saflufenacil	1 oz Sharpen
	50.2% imazethapyr		1.0 oz imazethapyr	4 oz Pursuit AS
Prefix	46.4% S-metolachlor	2 pt	1.09 lb S-metolachlor	1.14 pt Dual Magnum
	10.2% fomesafen		0.238 lb fomesafen	0.95 pt Reflex
Pursuit Plus 2.9E	0.2 lb imazethapyr	2.5 pt	0.063 lb imazethapyr	4.0 oz Pursuit 2S
	2.7 lb pendimethalin		0.84 lb pendimethalin	2.00 pt Prowl 3.3E
Sequence 5.25L	3.0 lb S-metolachlor	3 pt	1.13 lb S-metolachlor	1.2 pt Dual Magnum
	2.25 lb glyphosate		0.84 lb ae glyphosate	26 oz Touchdown Total
Sonic	6.21% sulfentrazone	8.0 oz	0.361 lb sulfentrazone	6.6 oz Authority 75DF
	7.96% cloransulam-methyl		0.04 lb cloransulam-methyl	0.76 oz FirstRate
Stellar 3.1E	2.4 lb lactofen	5 fl oz	0.094 lb lactofen	6 fl oz Cobra 2E
	0.7 lb flumiclorac		0.027 lb flumiclorac	4 fl oz Resource 0.86E
Storm 4S	2.67 lb bentazon	1.5 pt	0.50 lb bentazon	1 pt Basagran 4S
	1.33 lb acifluorfen		0.25 lb acifluorfen	1 pt Blazer 2S
Synchrony STS DF	31.8% chlorimuron	0.5 oz	0.159 oz chlorimuron	0.64 oz Classic 25DF
	10.2% thifensulfuron		0.051 oz thifensulfuron	0.068 oz Harmony GT
Traverse	12.5% chlorimuron ethyl	2.6 oz	0.325 oz chlorimuron	-
	12.5% rimsulfuron		0.325 oz rimsulfuron	-
Valor XLT	30.3% flumioxazin	3 oz	0.056 lb flumioxazin	1.76 oz Valor
	10.3% chlorimuron ethyl		0.019 lb chlorimuron	1.24 oz Classic

Herbicide Site of Action and Injury Symptoms

Herbicides kill plants by disrupting an essential physiological process. 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 family generally have the same site of action, although the specific amino acid base pair on the protein where the herbicide "attaches" may be different for different herbicides in the same family. The mechanism by which a herbicide kills a plant is known as its "**mechanism 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 and 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 site of action. Certain sites of action (e.g. photosystem II inhibitors) have multiple numbers since different herbicides may bind at different locations on the enzyme (e.g. photosystem II inhibitors) or different enzymes in the pathway may be targeted (e.g. carotenois synthesis). The number following the herbicide site of action heading is the WSSA classification. Some manufacturers are including these numbers on herbicide labels to aid development of herbicide resistance management strategies.

ACCase Inhibitors – 1

The ACCase enzyme is involved in the synthesis of fatty acids. Two herbicide families attack this enzyme. 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 is responsible for the resistance.

ALS Inhibitors – 2

Several chemical families interfere with acetolactate synthase (ALS), an enzyme involved in the synthesis of the essential branched chain amino acids (valine, leucine, and isoleucine). This enzyme is also called acetohydroxy acid synthaes (AHAS). These amino acids are necessary for protein synthesis and plant growth. Generally, these herbicides are absorbed in plant roots and foliage and are readily translocated in the xylem and phloem. The herbicides accumulate in meristematic regions of the plant and the herbicidal effects are first observed there. Symptoms include plant stunting, chlorosis (yellowing), and tissue necrosis (death), and are evident 1 to 4 weeks after herbicide application, depending upon the plant species and environmental conditions. Soybeans and other sensitive broad-leaf plants often develop reddish veins on the undersides of leaves. Symptoms in corn include reduced secondary root formation, stunted roots, shortened internodes, leaf malformations (chlorosis, window-paning) and nutrient deficiencies. However, symptoms typically are not distinct or consistent. Factors such as soil moisture, temperature, and soil compaction can enhance the occurrence of injury or may 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.

Microtubule Inhibitors – 3

Dinitroaniline (DNA) herbicides inhibit cell division by interfering with the formation of microtubules. 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 thick and short. Hypocotyl swelling also occurs. 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. 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 areas of high growth. Corn injury may occur in the form of onion leafing, proliferation of roots, or abnormal brace root formation. Corn stalks may become brittle following application; this response usually lasts for 7 to 10 days following application. The potential for injury increases when applications are made to corn larger than 10 to 12 inches in height. Soybean injury from synthetic auxin herbicides is characterized by cupping and crinkling of leaves. Soybeans are extremely sensitive to dicamba; however, early season injury resulting only in leaf malformation usually does not affect yield potential. Soybeans occasionally develop symptoms characteristic of auxin herbicides in the absence of this herbicide. This response is poorly understood, but usually develops during periods of rapid growth, low temperatures or following stress from other postemergence herbicide applications. Dicamba has 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 interveinal chlorosis of plant leaves followed by necrosis of leaf tissue. Other secondary substances resulting from photosynthesis inhibition may be responsible for 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 occurs 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 most affected, and new leaves may be unaffected. Triazine (5) and urea (7) herbicides generally are absorbed both by roots and foliage, whereas benzothiadiazole (6) and nitrile (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.

Photosystem I Inhibitors - 22

Herbicides in the bipyridilium family rapidly disrupt cell membranes, resulting in wilting 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

The specific site of action is an enzyme involved in synthesis of a precursor of chlorophyll; the enzyme is referred to as PPO. Postemergence applied diphenyl ether herbicides (e.g., aciflurofen) kill weed seedlings through contact action, membrane destruction, and ultimately photosynthesis inhibition. 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 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 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. Several different enzymes in the synthesis of carotenoids are targeted by herbicides. Clomozone (Command) inhibits DOXP (13), whereas the other bleaching herbicides used in corn (Callisto, Balance Flexx, Laudis, Impact) inhibit HPPD (27). Carotenes are pigments with a primary function of dissipating the oxidative energy of compounds (singlet oxygen) produced during photosynthesis. In the absence of carotenes, chlorophyll and membranes are destroyed. The loss of chlorophyll results in bleaching of affected tissues. These herbicides are xylem mobile and absorbed by both roots and leaves.

Enolpyruvyl Shikimate Phosphate Synthase (EPSPS) Inhibitors – 9

Glyphosate is a substituted amino acid that interferes with amino acid synthesis by inhibiting the EPSPS enzyme. This enzyme is involved in the synthesis of several essential amino acids. Glyphosate is nonselective and is very tightly bound in soil, so no root uptake occurs. 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.

Glutamine Synthetase Inhibitors – 10

Glufosinate (Liberty, Ignite) inhibits the enzyme glutamine synthetase, causing a buildup of ammonia in the plant which becomes phytotoxic. 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. The herbicide has no soil activity. Ignite is nonselective except to crops that carry the Liberty Link gene.

Fatty acid and lipid synthesis inhibitors – 8

The specific site of action for the thiocarbamate herbicides (EPTC, butylate) is unknown, but it is believed they may conjugate with acetyl coenzyme A and other molecules with a sulfhydryl component. Interference with these molecules results in the disruption of fatty acid and lipid synthesis, along with other 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 and tetrazolinone) are thought to inhibit synthesis of very long chain fatty acids. VLCFA are believed to play important roles in maintaining membrane structure. These herbicides affect susceptible weeds before emergence and have little effect on emerged plants. They are most effective on annual grasses, but have activity on certain small-seeded 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 (Distinct) has a unique mode of action in that it inhibits the transport of auxin, a naturally occurring plant-growth regulator. It is sold only in combination with dicamba. Diflufenzopyr 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 through the soil for some residual activity. Injury symptoms are similar to growth regulator herbicides. Status (dicamba + diflufenzopyr) includes a safener to improve crop safety.

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

ALS inhibitors	
imidazolinones	
Authority Assist	imazethapyr + sulfentrazone
Lightning	imazethapyr + imazapyr
OpTill	imazethapyr + saflufenacil
Pursuit	imazethapyr
Pursuit Plus	imazethapyr + pendimethalin
Raptor	imazamox
Scepter	imazaquin
Squadron	imazaquin + pendimethalin
sulfonanilides	
FirstRate, Amplify	chloransulam
Hornet WDG	flumetsulam + clopyralid
Python	flumetsulam
SureStart/TripleFlex	flumetsulam + clopyralid + acetochlor
sulfonylureas	
Accent	nicosulfuron
Accent Q	nicosulfuron +safener
Ally, Cimarron	metsulfuron
Authority XL	chlorimuron + sulfentrazone
Basis	rimsulfuron + thifensulfuron
Beacon	primisulfuron
Canopy	chlorimuron + metribuzin
Canopy EX	chlorimuron + tribenuron
Classic	chlorimuron
Envive	flumioxazin + thifensulfuron + chlorimuron
Enlite	flumioxazin + thifensulfuron + chlorimuron
Equip	foramsulfuron + iodosulfuron + safener
Exceed, Spirit	prosulfuron + primisulfuron
Express	tribenuron
Freestyle	chlorimuron + thifensulfuron + tribenuron
Harmony GT	thifensulfuron
Instigate	chlorimuron + rimsulfuron + mesotrione
NorthStar	primisulfuron + dicamba
Option	foramsulfuron + safener
Permit, Halofax	halosulfuron
Prequel	rimsulfuron + isoxaflutole
Require Q	rimsulfuron + dicamba
Resolve Q	rimsulfuron + thifensulfuron + safener
Steadfast Q	nicosulfuron + rimsulfuron + safener
Synchrony STS	chlorimuron + thifensulfuron
Traverse	chlorimuron + rimsulfuron
Trigate	rimsulfuron + tribenuron methyl + mesotrione
Valor XLT	flumioxazin + chlorimuron
Yukon	halosulfuron + dicamba
Other	
Corvus	thiencarbazone-methyl + isoxaflutole safener

Microtubule inhibitor	
dinitroanilines	
Balan	benefin
Commence	trifluralin + clomazone
Prowl H_2O, Pentagon, Pendimax, others	pendimethalin
Sonalan	ethalfluralin
Surflan	oryzalin
Treflan, others	trifluralin

Synthetic auxin	
benzoic	
Banvel, Clarity, others	dicamba
Distinct, Status	dicamba + diflufenzopyr
NorthStar	dicamba + primisulfuron
Require Q	rimsulfuron + dicamba
Yukon	dicamba + halosulfuron
phenoxy	
many	MPCA
many	2,4-D
Butyrac, Butoxone	2,4-DB
pyridines	
Crossbow	triclopyr + 2,4-D
Grazon P&D	picloram + 2,4-D
GrazonNext, ForeFront R&P	aminopyralid + 2,4-D
Hornet WDG	clopyralid + flumetsulam
PastureGard	triclopyr + fluroxypyr
Redeem	triclopyr + clopyralid
Remedy Ultra, Pathfinder II, many others	triclopyr

Milestone	aminopyralid
Stinger, Transline	clopyralid
SureStart/TripleFlex	clopyralid + acetochlor + flumetsulam
Tordon	picloram

Photosystem II inhibitors

benzothiadiazole	
Basagran	bentazon
Galaxy, Storm	bentazon + acifluorfen
Laddok	bentazon + atrazine
nitriles	
Buctril, others	bromoxynil
Buctril + atrazine	bromoxynil + atrazine
triazines	
AAtrex, others	atrazine
Evik	ametryne
Princep	simazine
Sencor	metribuzin
ureas	
Karmex	diuron
Lorox	linuron

Photosystem I inhibitors

Diquat, Reward	diquat
Gramoxone Max	paraquat

Protoporphyrinogen Oxidase (PPO) inhibitors

aryl triazolinones	
Aim	carfentrazone
Authority, Spartan	sulfentrazone
Authority First, Sonic	sulfentrazone + cloransulam
AuthorityAssist	sulfentrazone + imazethapyr
Authority XL	sulfentrazone + chlorimuron
diphenyl ethers	
Blazer, UltraBlazer	acifluorfen
Cobra, Phoenix	lactofen
ET, Vida	pyraflufen
Flexstar, Reflex	fomesafen
Goal	oxyfluorfen
phenylphthalimides	
Envive	flumioxazin + thifensulfuron + chlorimuron
Enlite	flumioxazin + thifensulfuron + chlorimuron
Gangster	flumioxazin + cloransulam
Resource	flumiclorac
Valor	flumioxazin
Valor XLT	flumioxazin + chlorimuron
pyrimidinedione	
Sharpen (Kixor)	saflufenacil
Integrity	saflufenacil + dimethenamid P
Optill	saflufenacil + imazethapyr
Verdict	saflufenacil + dimethenamid-P
other	
Cadet	fluthiacet

Enolpyruvyl shikimate phosphate synthase (EPSPS) inhibitors

Roundup, Touchdown, others	glyphosate
ReadyMaster ATZ	glyphosate + atrazine
Extreme	glyphosate + imazethapyr
Sequence	glyphosate + s-metolachlor

Glutamine synthetase inhibitors

Liberty, Ignite	glufosinate
Liberty ATZ	glufosinate + atrazine

Hydroxyphenyl pyruvate dioxygenase (HPPD) inhibitors

Balance Flexx	isoxaflutole + safener
Epic, Radius	isoxaflutole + flufenacet
Callisto	mesotrione
Callisto Xtra	mesotrione + atrazine
Impact	topramezone
Lexar, Lumax	mesotrione + atrazine + s-metolachlor
Corvus	isoxaflutole + theincarbazone-methyl + safener

Diterpene inhibitors

Command	clomazone
Command Xtra	clomazone + sulfentrazone

Auxin transport inhibitors

Distinct, Status	diflufenzopyr + dicamba

Lipid synthesis inhibitors

amides or acetanilides	
Bicep II MAGNUM, Bicep Lite II MAGNUM, Cinch ATZ, others	s-metolachlor + atrazine + safener
Boundary	metolachlor + metribuzin
Bullet	alachlor + atrazine
Degree, Harness, Surpass, TopNotch, others	acetochlor + safener
Dual II MAGNUM, Cinch, others	s-metolachlor + safener
Radius	flufenacet + isoxaflutole
FieldMaster	acetochlor + atrazine + glyphosate + safener
Frontier, Outlook, others	dimethenamid
FulTime, Surpass 100	acetochlor + atrazine + safener
Guardsman Max	dimethenamid + atrazine
Lariat	alachlor + atrazine
Lasso, Intrro, MicroTech	alachlor

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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