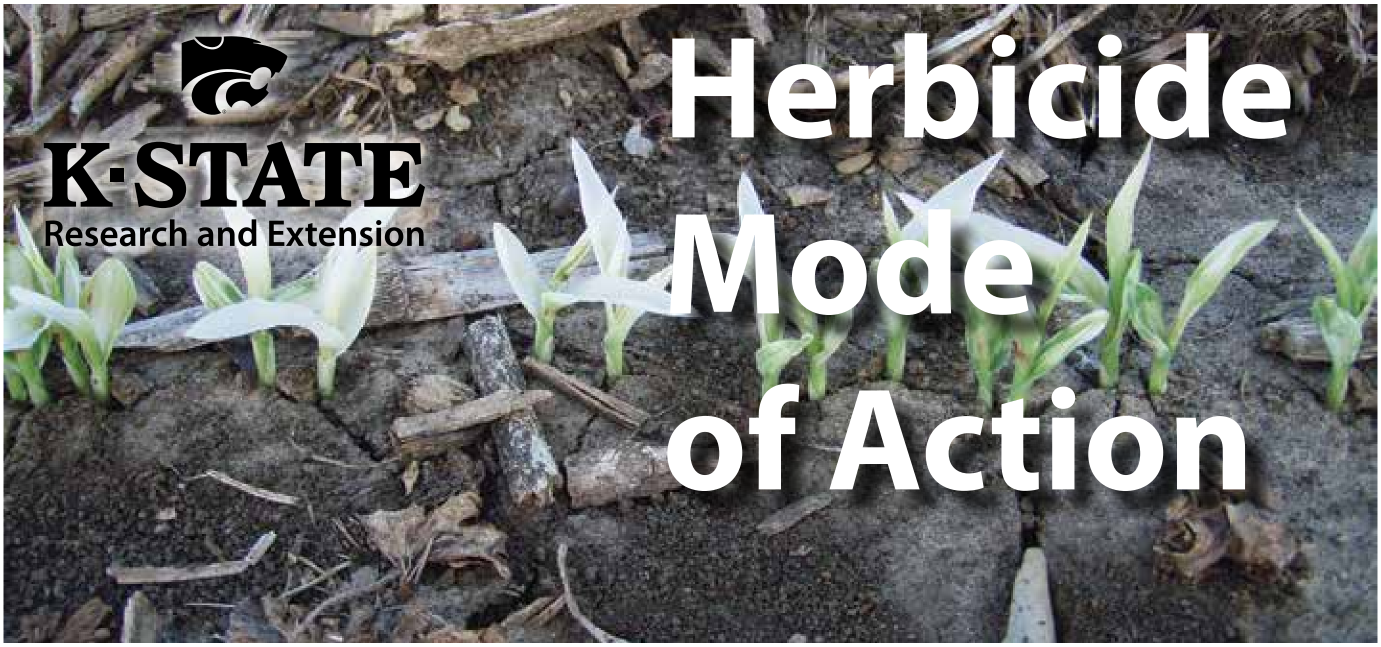

K-STATE
Research and Extension

Herbicide Mode of Action

Herbicides are chemicals that inhibit or interrupt normal plant growth and development. They are widely used in agriculture, industry, and noncrop areas for weed management. Herbicides can provide cost-effective weed control while minimizing labor. However, improper herbicide use may result in crop injury, poor weed control, evolution of herbicide resistant weeds, environmental contamination, or health risks. Herbicide mode of action refers to how herbicides work. Understanding how herbicides work provides insight into how to use the chemicals and helps diagnose performance problems and related injury symptoms.

The best source of information for herbicide use is the herbicide label. Always apply herbicides according to label directions. Publications such as the K-State Research and Extension Report of Progress, *Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland*, also provide information on available herbicide options and application guidelines. The herbicide label, however, is a legal document, and an applicator is responsible for applying the herbicide according to label directions.

Herbicides kill plants in different ways. A herbicide must meet several requirements to be effective. It must come in contact with the target weed, be absorbed by the weed, move to the site of action in the weed, and accumulate sufficient levels at the site of action to kill or suppress the growth of the target plant. Weed control is unsatisfactory unless these requirements are met.

All herbicide interactions with a plant, from application to final effect, are considered the mode of action. The herbicide mode of action involves absorption into the plant, translocation or movement in the plant, metabolism of the herbicide, and the physiological plant response. Herbicide site of action refers to the specific biochemical or biophysical process in the plant that the herbicide disrupts to interfere with plant growth and development. The term "herbicide mode of action" is sometimes used interchangeably with "herbicide site of action" or "herbicide mechanism of action."

Herbicides may be classified according to selectivity (nonselective, grass control, broadleaf control, etc.), time of application (preplant incorporated, preemergence, or postemergence), translocation in the plant (contact or systemic), persistence, or site of action.

Herbicide Selectivity

The potential for a herbicide to kill certain plants without injuring others is called selectivity. Herbicides that kill or suppress the growth of most plant species are relatively nonselective. Nonselective herbicide use is limited to situations where control of all plant species is desired, or the herbicide is directed on the target weed and away from desirable plants. Glyphosate and paraquat historically have been considered nonselective herbicides. However, glyphosate is a highly selective herbicide when used in conjunction with crops that have been genetically engineered with resistance to glyphosate.

Most herbicides used in crop production are selective. Herbicide selectivity is relative and depends on several factors, including plant biology, environment, herbicide application rate, application timing, and application technique. Even a tolerant plant species may be susceptible to a herbicide if the application rate is high enough. Herbicide selectivity may be based on herbicide placement, differential spray retention, absorption, translocation, metabolism, or an insensitive site of action.

Herbicide Resistance

Herbicide resistance is defined by the Weed Science Society of America as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis." Plant species that are not controlled by a herbicide before any selection pressure or genetic manipulation would be considered naturally tolerant, but not herbicide resistant.

Herbicide resistant weed populations are generally selected from the native population in field situations through repeated treatment over time with a given herbicide or herbicides having the same site of action. A small percentage of the original weed population is genetically different and contains the resistant trait. Repeated use of the herbicide or herbicides with the same site of action results in removal of susceptible biotypes, while resistant biotypes increase until the weed population is no longer controlled effectively with that group of herbicides.

Herbicide resistance may be based on differential absorption, translocation, metabolism, an altered site of action, sequestration of the herbicides, or over-expression of the target protein. Herbicide resistance can result from a single gene mutation or from a combination of multiple gene changes. Single gene mutation resistance generally confers a relatively high level of resistance and population shifts can occur in just a few years.

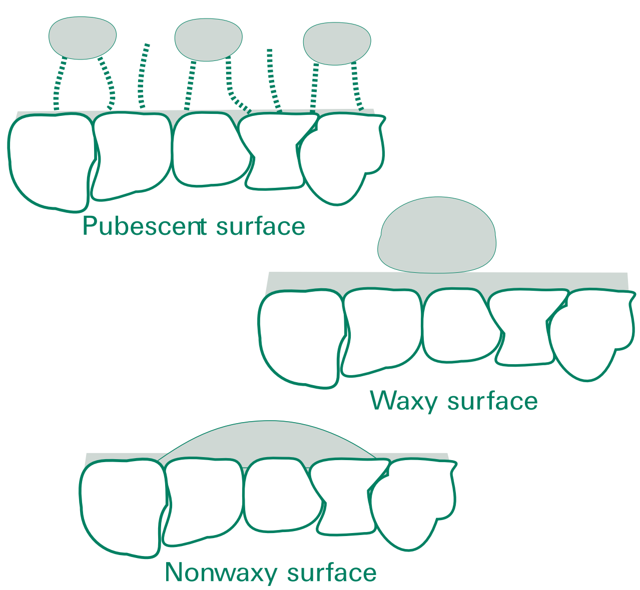

Figure 1. *Spray droplet spread on a leaf surface as influenced by leaf pubescence and waxiness.*

Multi-gene resistance is often a lower level resistance that gradually increases over time and is more difficult to confirm.

Herbicide Placement

Herbicide placement can be critical to effectiveness and selectivity. Most small weed seeds germinate and emerge from the top ½ inch of soil. Herbicides applied and positioned near the soil surface will be most available for absorption by shallow-germinating weed seeds. However, larger seeded weeds that emerge from deeper in the soil may not be controlled very well by a preemergence herbicide unless it is incorporated or moved deep enough into the soil by water movement. Selectivity may be achieved by seeding the crop below the herbicide-treated zone, especially if the herbicide is root absorbed and relatively immobile in the soil.

Spray Retention

Greater spray retention by a plant is likely to result in more herbicide absorption. Spray retention depends on the properties of the spray solution and the target plant. Leaf waxiness, pubescence (hairiness), and orientation are among the characteristics that affect spray retention. Waxy leaf surfaces repel water-based spray solutions, allowing spray droplets to run off more easily than on less waxy leaves. Sparse leaf pubescence or hairs may help retain spray droplets, but dense pubescence can hold spray droplets above the leaf surface and reduce spray contact with the leaf (Figure 1).

Growth Habit

Grass plants tend to be more difficult to wet than broadleaf plants because grasses often have narrow, waxy leaves with upright orientation. Thus, grass leaves present a small, vertical target, resulting in a good chance the spray droplet will roll off the leaves on contact. Broadleaf plants may be easier to wet because they present a large target with some pubescence and horizontal orientation (Figure 2). Some weed species, like velvetleaf, change leaf orientation based on time of day, with their leaves folding down and becoming more

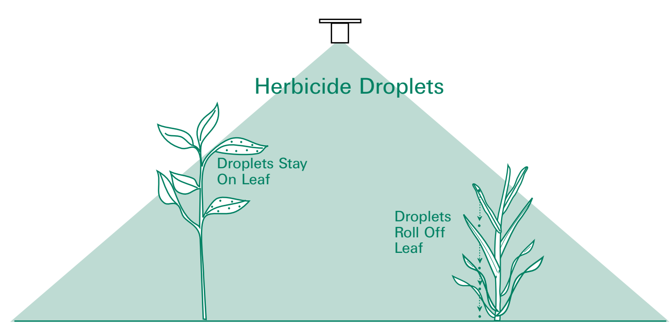

Figure 2. *Spray droplet retention on grass and broadleaf leaves due to leaf orientation.*

Table 1. *Scepter selectivity due to differential metabolism in different plant species (Shaner and Robson, 1985, Weed Science 33:469–471).*

Plant species	Scepter remaining in plants after 3 days	Scepter half-life in plants (days)	Plant response
Common cocklebur	99%	30	Very Susceptible
Soybean	38%	3	Tolerant
Velvetleaf	89%	12	Susceptible

vertical at night resulting in less herbicide interception and reduced control when treated too early or too late in the day.

Herbicide Metabolism

Metabolism is one of the most important ways a plant can escape the toxic effects of a herbicide. Herbicide-tolerant plants often have the ability to metabolize or break down the chemical to nonactive compounds before it can build up to toxic levels at the site of action. Susceptible plants are unable to detoxify herbicides. Selectivity of many herbicides is based on differing rates of metabolism. Table 1 illustrates differential metabolism and tolerance of Scepter among soybeans, velvetleaf, and common cocklebur. Enhanced herbicide metabolism within a plant species could be a potential mechanism of herbicide resistance. Metabolism can be reduced in certain environmental conditions such as cold weather. Reduced metabolism of an herbicide in tolerant crops may result in crop injury.

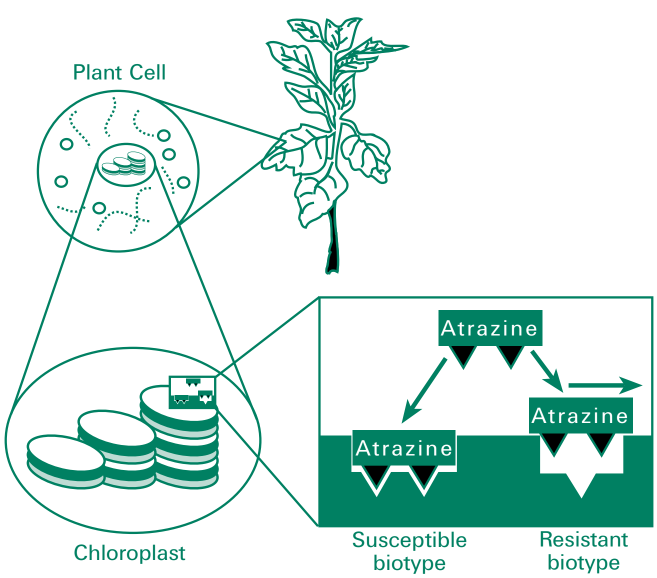

Figure 3. *Site exclusion type of herbicide resistance. Atrazine is ineffective on resistant biotype because a conformational change in the chloroplast prevents it from binding at the site of action (adapted from Gunsolus).*

Altered Site of Action

An altered site of action can result in dramatic resistance to a herbicide. An altered site of action refers to genetically different plant biotypes that have a structurally altered site of action that prevents herbicide binding and activity. An altered site of action can be visualized using the lock-and-key concept illustrated in Figure 3. Altered site of action has been the basis for many herbicide-resistant weed problems and usually results in a high degree of resistance. Kochia resistance to atrazine or Glean is an example of herbicide resistance due to an altered site of action. Weeds that are resistant to a specific herbicide due to an altered site of action often are also resistant to other herbicides with the same site of action.

Herbicide Translocation in Plants

Systemic herbicides are translocated in plants, while contact herbicides are not translocated. Most foliar-applied contact herbicides work by disrupting cell membranes. Thorough spray coverage of a plant is essential with foliar-applied contact herbicides to kill the entire plant.

Contact herbicides generally are ineffective for long-term perennial weed control. Contact herbicides damage the plant parts that the spray solution comes in contact with, but the underground portion of perennial plants remains unaffected and can rapidly initiate new growth.

Contact herbicides often are more effective on broadleaves than on grasses. The growing point of young grasses is located in the crown region of the plant, which is at or below the soil surface, and thus, difficult to contact with the spray. In contrast, the growing point on young broadleaf plants is exposed to the spray treatment. Thus, paraquat may not kill all the growing points of a tillered grass plant, and regrowth can occur.

Systemic herbicides can be translocated to other parts of the plant either in the xylem or the phloem (Figure 4). The xylem is nonliving tissue through which water and nutrients move from the roots to the shoots and leaves of plants. Translocation in the xylem is only upward and outward in plants from the roots to the leaves and leaf margins. Phloem is a living, conducting system in which materials can move both upward and

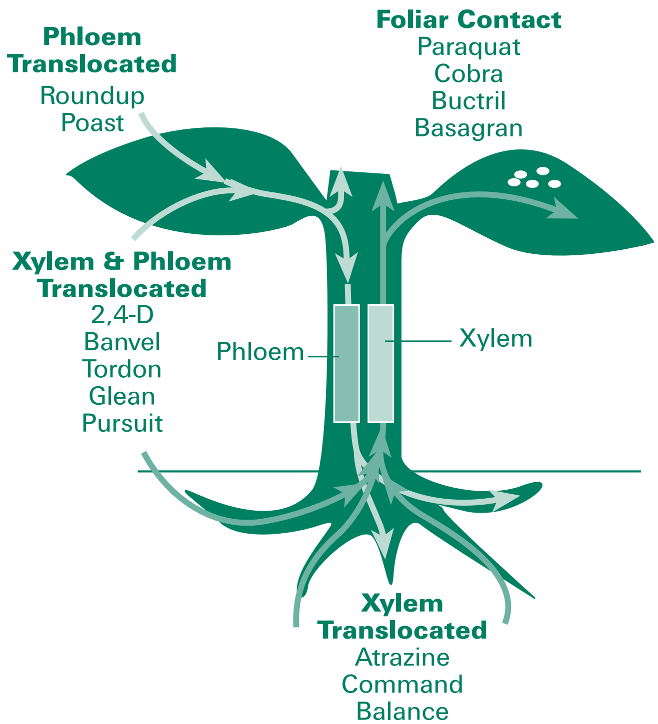

Figure 4. *Herbicide translocation in plants.*

downward. The phloem transports the food that is produced in the leaves to the roots and to areas of new growth (Figure 4).

Herbicides can be translocated in the xylem, the phloem, or both. Translocation depends on the chemical and the plant species. Herbicides translocated only in the xylem are most effective as soil-applied or early postemergence treatments because translocation occurs only upward. Atrazine is a good example of a herbicide that is translocated only in the xylem. Phloem translocated herbicides that move downward and disrupt root and rhizome growth, as well as top growth, provide the best perennial weed control. Tordon, 2,4-D, Banvel, and Roundup are examples of systemic herbicides that will translocate in the phloem and provide good, long-term control of certain perennial weeds.

Reduced herbicide translocation within a plant species could be the basis for herbicide resistance, but probably would result in only a marginal decrease in plant susceptibility.

Factors Affecting Herbicide Activity

Factors influencing herbicide activity include application rate, application technique, plant maturity, and environmental conditions. In addition, soil characteristics can affect soil-active herbicides.

Moisture and temperature are environmental factors that influence activity of soil-applied herbicides. Precipitation is essential to move surface-applied or preemergence herbicides into the soil and activate them. Mechanically incorporated herbicides tend to provide more consistent weed control than surface-applied herbicides because the herbicide is in place, and adequate moisture usually is present in the soil to activate the chemical. However, incorporation too deep into the soil may dilute the herbicide resulting in poor weed control. Improperly adjusted equipment, or incorporation when soils are too wet, may result in streaking and poor weed control.

Soil moisture is important because it influences herbicide adsorption to soils. Therefore, the herbicide is unavailable for plant uptake in dry soils. Adsorption occurs when herbicide molecules adhere to soil particles and organic matter. While adsorbed, herbicide molecules are unavailable for absorption by plants. Water molecules compete with herbicide molecules for adsorption sites on soil particles and organic matter. Therefore, herbicide adsorption is highest under dry soil conditions, and lowest in moist soils. Consequently, weed control is generally best with moist soil conditions because more herbicide is in the soil solution or gaseous phase and available for plant uptake.

Temperature affects the activity of soil-applied herbicides primarily because of its influence on the rate of seed germination, emergence, and growth. Young seedling plants tend to be more susceptible to soil-applied herbicides under cool conditions than under warm temperatures because plant emergence is delayed and metabolism is slowed. On the other hand, extremely high temperatures sometimes increase crop injury simply by placing the plant under multiple stresses.

Soil characteristics affecting herbicide activity are texture, organic matter, and pH. Herbicide adsorption is greater in fine-textured soils high in organic matter than in coarse-textured soils low in organic matter. Thus, a lower proportion of herbicide is available for plant uptake in the fine-textured soils, so a higher herbicide application rate is required to provide the same level of weed control as in a coarse-textured soil. At the same time, the chance of crop injury is greater on coarse-textured soils low in organic matter because a higher proportion of the applied herbicide is available for plant uptake. Soil-applied herbicide rates may need to be adjusted according to soil texture and organic matter content.

Soil pH influences the availability and persistence of certain herbicides in the soil. Soil pH can alter the ionic nature of the herbicide molecule, which influences adsorption, solubility, and rate of herbicide breakdown. The triazine herbicides (atrazine, metribuzin, and simazine) and some of the sulfonylurea herbicides (Amber, Finesse, Peak, Maverick, Oust, and Classic) are more active and more persistent in high pH soils (> 7.0) than in low pH soils. A few herbicides such as Scepter and Python may be somewhat more persistent in low than in high pH soils, but that response is less common and generally less dramatic than for the opposite reaction.

Environmental conditions can have a two-fold effect on the performance of postemergence herbicides. Higher humidity and favorable temperatures generally result in greater herbicide absorption and activity in plants.

Environment also influences herbicide efficacy by affecting plant growth. Plants are generally most susceptible to postemergence herbicides when actively growing. Extreme environmental conditions that slow plant growth and thicken leaf cuticles often increase plant tolerance to a herbicide. Crop injury from a herbicide, however, can increase during poor growing conditions because of slower metabolism and detoxification of the herbicide. Thus, if crop tolerance is based on the ability of the crop to rapidly metabolize the herbicide, the potential for crop injury may increase and weed control decrease if a herbicide is applied when plants are not actively growing. For this reason, most herbicide labels caution against application during extreme environmental conditions.

Annual plants are usually more susceptible to herbicides when they are small than when they are mature. As they mature, plants develop thicker wax layers on leaf surfaces, reducing herbicide absorption. In addition, it is harder to achieve thorough spray coverage, making it more difficult to kill all growing points on large plants compared to that of small plants.

Established perennial weeds tend to be more susceptible to herbicides if applied during the early flowering stage of growth or to actively growing plants in the fall, probably because application at these times results in the greatest translocation of the herbicide to the roots. However, true seedlings respond like annuals and are much easier to control than established perennial weeds.

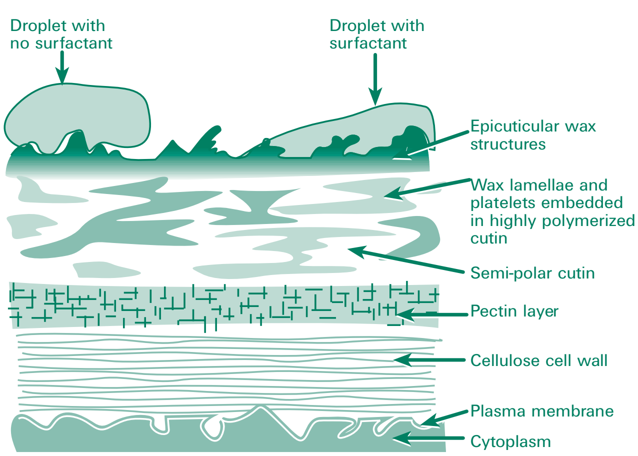

Figure 5. *Leaf surface composition and the influence of surfactants on droplet spread over the leaf surface (adapted from Hull, Davis, and Stolzenberg).*

Spray Adjuvants

Spray adjuvants or additives often improve spray retention and absorption by plant foliage by reducing the surface tension of the spray solution, allowing the spray droplet to spread more evenly over the leaf surface (Figure 5). Herbicide absorption may be further enhanced by interacting with the waxy cuticular layer on the leaf surface.

Many different types of spray adjuvants are available that have different functions. It is important to use the proper type and rate of adjuvant according to herbicide label guidelines to optimize product performance. Spray adjuvants can increase weed control, but potentially can reduce selectivity by increasing the spray retention and herbicide absorption by the crop more than by the weed. Thus, spray adjuvants should be used only if recommended on the herbicide label.

Herbicide Sites of Action

Herbicides can work at various sites in plants. They generally interfere with a process essential for normal plant growth and development. Herbicides can be classified by site of action based on how they work and the injury symptoms they cause. The Weed Science Society of America (WSSA) has developed a numbered classification system based on the herbicide site of action. Knowledge of herbicide sites of action allows proper selection and rotation of herbicides to reduce the risk of developing herbicide-resistant weeds. Classification of herbicides by site of action and the WSSA classification number (in parenthesis) are described in the following sections.

Growth Regulators

Synthetic Auxins (4)	
Phenoxy	2,4-D, 2,4-DB (Butyrac), 2,4-DP, MCPA, MCPP
Benzoic acid	dicamba (Banvel, Diablo, Oracle, Rifle, Clarity, Distinct, Status, Vanquish)
Pyridinecarboxylic Acid	picloram (Tordon, Trooper) clopyralid (Stinger, Garrison) fluroxypyr (Starane, Comet, Vista) triclopyr (Garlon, Remedy, Renovate, Relegate) aminopyralid (Milestone) aminocyclopyrachlor (component of Perspective, Viewpoint, and Streamline)
Arylpicolonate	halauxifen (component of Quelex)
Quinoline	quinclorac (Facet)

Auxin Transport Inhibitors (19)	
Semicarbazone	Diflufenzopyr (component of Distinct and Status)

Photos 1 and 2. *Growth regulator herbicides often cause abnormal leaf growth and development, such as the cupping symptom on soybean leaves from dicamba injury (top) and the puckering and parallel venation in the soybeans from 2,4-D (bottom).*

Photo 3. *Grasses treated with growth regulator herbicides sometimes exhibit leaf rolling or "onion-leafing" similar in appearance to drought stress. Injury can be exaggerated by tank mixes with other herbicides or the addition of adjuvants.*

Growth regulator herbicides consist of the synthetic auxin and auxin transport inhibitor compounds, which are used primarily for controlling broadleaf weeds in grass crops and pastures and include some of the more effective chemicals for perennial broadleaf weed and brush control. Most growth regulator herbicides are readily absorbed through both roots and foliage and are translocated in both the xylem and phloem (Figure 4). Translocation of foliar-applied treatments, however, is more restricted in grasses than in susceptible broadleaves.

These herbicides are called growth regulators because they mimic natural plant growth hormones, and thus, upset the natural hormone balance in plants. Growth hormones regulate cell elongation, protein synthesis, and cell division. The killing action of growth-regulating chemicals is not caused by any single factor, but rather by the disruption of several growth processes in susceptible plants.

Injury symptoms on susceptible plants treated with growth regulator herbicides include growth and reproduction abnormalities, especially on new growth. Broadleaf species exhibit stem and petiole twisting (epinasty), leaf malformations (parallel venation, crinkling, leaf strapping, and cupping), (Photos 1 and 2) stem callus formation, and stunted root growth. Grass plants exhibit rolled leaves (onion leafing) (Photo 3), fused brace roots (Photo 4), leaning stems (Photo 5), and stalk brittleness (Photo 6). Growth regulator herbicides may affect reproduction, resulting in sterile or multiple florets (Photos 7 and 8), and nonviable seed production.

Auxin transport inhibitors such as diflufenzopyr inhibit the movement of auxinic compounds out of cells. Consequently, when combined with a synthetic auxin herbicide such as dicamba, the dicamba can move into the cells, but cannot move back out of the cell, thus maintaining a greater concentration of the auxinic herbicide within the cell. Diflufenzopyr has minor herbicide activity when applied alone, but enhances the activity of auxinic herbicides.

Environmental and use considerations. Growth regulator herbicides can cause serious drift injury to susceptible plants (i.e. tomatoes, grapes, cotton, sunflowers, soybeans, cucumbers). The phenoxy herbicides may be formulated as esters or amines. The esters are volatile and are susceptible to both physical spray drift as well as vapor drift damage. Amine and salt formulations are relatively nonvolatile and therefore less susceptible to vapor drift, but still susceptible to physical spray drift. Banvel, Clarity, Distinct, and Status also are subject to vapor drift. Vapor drift increases as temperatures increase, and may occur for several hours or even days after application.

Photo 4. *Growth regulator herbicides can interfere with normal root growth as exhibited by the brace roots on this corn plant that was treated with 2,4-D.*

Photo 7. *Misapplied growth regulator herbicides can cause sterility, twisted awns, and head trapping in small grains, as pictured on the right.*

Photos 5 and 6. *Growth regulator herbicides such as 2,4-D and dicamba can cause the stems of grasses to lean over and become weakened after application (top), after which the stems may exhibit "goosenecking" as plants try to grow upright (bottom). May also cause complete stem breakage, called "green snap," from which plants do not recover.*

Photo 8. *Late applications of plant growth regulator herbicides such as dicamba and 2,4-D can interfere with pollination and seed production, sometimes called headblasting in sorghum. Cold night temperatures during pollination can also cause poor grain fill.*

The phenoxies are relatively short-lived in the environment and have small pollution potential. Tordon is water soluble and persistent in the soil. Consequently, Tordon has a high leaching potential and should not be used on coarse-textured soils with a shallow water table, where groundwater contamination is most likely to occur.

Seedling Growth Inhibitors

The seedling growth inhibitors work during germination and emergence and include three groups: 1) the lipid synthesis inhibitors (thiocarbamates), 2) the very long chain fatty acid (acetamides), and 3) the microtubule assembly inhibitors (dinitroanilines).

Lipid Synthesis Inhibitors – non-ACCase (8):	
Thiocarbamates	EPTC (Eradicane, Eptam) triallate (Far-Go)

Thiocarbamate herbicides are soil-incorporated for control of annual grasses and some broadleaf weeds. All are volatile and need to be incorporated immediately after application to avoid excessive vapor loss. Vapor loss of the thiocarbamate herbicides is less when applied to dry soils than when applied to moist soils. The thiocarbamates are absorbed from the soil solution or vapor phase through both roots and emerging shoots, but are translocated only in the xylem. The primary site of absorption and action is the emerging shoot and growing point. The mechanism of action of these herbicides is not well understood, but they seem to interfere with fatty acid and lipid biosynthesis in the newly developing shoot.

Corn tolerance to the thiocarbamate herbicides increases with use of dichlormid safener (formulated in Eradicane), which increases metabolism of the chemicals to nontoxic substances. Dichlormid is unique because it can be applied with the spray formulation at low rates and selectively protects only corn against herbicide injury.

Repeated use of the thiocarbamate herbicides on the same field results in a buildup of microbes that break down the herbicides, decreasing their residual life and period of weed control. This phenomenon is known as "enhanced degradation" or soil conditioning. Repeated use of one thiocarbamate herbicide also conditions the soil for enhanced degradation of the other thiocarbamates. The best way to avoid enhanced degradation of herbicides is to rotate to a different class of herbicides and avoid application of thiocarbamates in successive years.

Injury symptoms on grass plants include failure of the shoot to emerge from the coleoptile or whorl of the plant, giving the plant a buggy-whip appearance. Susceptible grass seedlings often fail to emerge from the soil. Injury symptoms on broadleaf plants include enlarged cotyledons, restricted growth of the true leaves, and a dark green color, a symptom sometimes referred to as bud seal. The roots become short, thick, brittle, and club-shaped.

Very Long Chain Fatty Acid (VLCFA) Inhibitors (15):

Acetamide	*S*-metolachlor (Dual MAGNUM, Brawl, Cinch, Charger) metoloachlor (Me-Too-Lachlor, Parallel) acetochlor (Surpass, Harness, Degree, Volley, Confidence, Breakfree, Cadence, Overtime, Warrant) flufenacet (Define) dimethenamid-P (Outlook, Propel, Establish)
Pyrazole	pyroxasulfone (Zidua)

VLCFA herbicides are used preemergence or with shallow soil incorporation to control annual grasses and some small-seeded broadleaf weeds in a variety of crops. The VLCFAs do not control emerged plants. The primary site of absorption and action of these herbicides on broadleaf species is the roots, while the primary site of absorption and action on grass species is the emerging shoot. The VLCFAs are not readily translocated in the plant, so herbicide placement and availability are important. As with the thiocarbamates, the mechanism of action of the VLCFAs has not been well defined, but appear to interfere with normal cellular development in seedling plants. Dual MAGNUM, Degree Xtra, FulTime NXT, Warrant, and Outlook may be used in sorghum if the seed is treated with Concep seed protectant. The seed protectant increases sorghum tolerance to the acetamide herbicides by increasing metabolism of the herbicide to inactive compounds.

Photo 9. *VLCFA herbicides can cause emergence problems and distorted shoots of grasses, such as this unsafened sorghum that was treated with Dual. Only Concep treated sorghum seed should be planted if VLCFA herbicides will be used.*

Photo 10. *VLCFA herbicides sometimes cause minor stunting and distorted leaves such as the heart-shaped leaf on this soybean plant, which resulted from acetochlor injury following cold, wet weather during emergence.*

Photo 11. *Preemergence pendimethalin can cause callus formation and brittle stems on soybeans, resulting in breakage and lodging.*

Photo 12. *DNA herbicides like Treflan and Prowl can cause poor root development and short, stubby roots, especially if misapplied.*

Injury symptoms caused by the VLCFAs are similar to those caused by the thiocarbamates. The new shoots fail to emerge from the coleoptile and whorl of the shoot of grass species (Photo 9). Susceptible germinating grasses often fail to emerge from the soil. Injury symptoms on broadleaf species include general stunting and a drawstring effect around the margins of the true leaves (Photo 10).

Microtubule Assembly Inhibitors (3):

Dinitroaniline	trifluralin (Treflan, Trust, Trilin) pendimethalin (Prowl,Pendant, Acumen, Stealth, Framework) ethalfluralin (Sonalan) benefin (Balan)

Dinitroaniline herbicides are generally applied preemergence to control annual grasses and some broadleaf weeds in many crops. Trifluralin, ethalfluralin, and benefin need to be incorporated to avoid photodecomposition and volatility losses. Pendimethalin is less volatile than the other dinitroaniline herbicides and can be applied preemergence, but generally provides better weed control when soil-incorporated. The dinitroaniline herbicides are absorbed by both roots and shoots of emerging seedlings, but are not readily translocated (Figure 4). The emerging shoot is the primary site of absorption and action on grass species. These herbicides are mitotic poisons that inhibit cell division. Thus, the meristematic regions, such as the growing points of stems and roots, are most affected. Selectivity may be based on metabolism, as well as herbicide placement and type of emergence of the grass species.

Injury symptoms on grass species include short, swollen coleoptiles. Injured broadleaf plants often have swollen hypocotyls. Preemergence application of pendimethalin sometimes causes callus formation and brittle stems near the soil surface, which may break over during the growing season (Photo 11). Both grasses and broadleaves may have short, stubby secondary roots (Photo 12). Consequently, the plants may be stunted and exhibit nutrient deficiency or drought symptoms because of the poorly developed root system.

Environmental and use considerations. The thiocarbamates and dinitroanilines are characterized by low solubility in water and high adsorption to soils. Thus, they are not readily leached or moved in water. The VLCFAs are more soluble and less adsorptive, but less persistent in the soil.

Photosynthetic Inhibitors

Photosystem II, Site A (5):

Triazine	atrazine (multiple) simazine (Princep) ametryn (Evik) prometon (Pramitol)
Triazinone	metribuzin (Sencor, Dimetric, Tricor, Metri) hexazinone (Velpar)
Uracil	terbacil (Sinbar) bromacil (Hyvar)

Photosystem II, Site B (7):

Phenylurea	linuron (Lorox, Linex) diuron (Karmex, Diurex) tebuthiuron (Spike)

Photosystem II, Site C (6):

Benzothiadiazole	bentazon (Basagran)
Nitrile	bromoxynil (Buctril, Moxy)

Photosynthetic inhibitor herbicides control many broadleaf and some grass weeds. These herbicides work by disrupting photosynthesis, but there are three different binding sites. Binding site A includes the triazines, triazinones, and uracils, binding site B includes the phenylureas, and binding site C includes bentazon and bromoxynil.

Photo 13. *Photosynthetic inhibitors can cause chlorosis and necrosis around the margins of the oldest leaves of susceptible broadleaves. This injury could be from atrazine carryover, metribuzin damage, or a combination of the two.*

Photos 14 and 15. *Atrazine can carry over and cause damage to susceptible crops. Carryover injury is most likely on high pH soils or in areas with higher application rates such as turn row overlaps (top). Susceptible plants will emerge, followed by leaf yellowing and dieback beginning at the tips (bottom).*

The triazines, triazinones, uracils, and phenylureas are soil-applied or early postemergence herbicides in crops and noncropland sites. These herbicides are absorbed by both shoots and roots, but are translocated only in the xylem (Figure 4).

Bentazon and bromoxynil are used primarily as early postemergence treatments. They are contact herbicides that are not translocated in the plant (Figure 4). Thorough spray coverage of the foliage is essential for good weed control with these herbicides.

These herbicides block photosynthesis, the food production process in plants. Plants are not affected by the herbicide until after they emerge and begin photosynthesis. Even though photosynthesis is inhibited, susceptible plants do not die simply from starvation. Herbicide injury symptoms appear too quickly and are not typical of starvation. Instead, susceptible plants treated with a photosynthetic inhibitor die from a buildup of highly reactive molecules that destroy cell membranes.

The selective action of triazine herbicides is primarily determined by differential metabolism. Plant species such as corn and sorghum possess the glutathione-S-transferase enzyme and can selectively metabolize atrazine into nontoxic substances. Crop and weed selectivity to urea herbicides, such as Linuron, is due primarily to herbicide placement rather than metabolism or differential physiological tolerance of plant species.

Injury symptoms from soil-applied treatments will not appear until after photosynthesis begins. Susceptible broadleaf plants will exhibit interveinal chlorosis and necrosis beginning around the leaf margins and progressing toward the center of the leaves (Photo 13). Susceptible grasses will become chlorotic and necrotic beginning at the leaf tips and progressing toward the base of the leaves (Photos 14 and 15). Injury symptoms from foliar applications will appear as leaf burn as cell membranes are destroyed. Leaf burn symptoms generally occur most rapidly with hot, humid conditions.

Environmental and use considerations. Bentazon and bromoxynil are foliar-applied and relatively short-lived in the environment. They do not pose a serious environmental threat. The other photosynthetic inhibitor herbicides are primarily soil-applied and have fairly long persistence in the soil. These herbicides may contaminate surface water in regions with fine-textured soils and groundwater in regions with coarse-textured soils and shallow water tables.

Amino Acid Synthesis Inhibitors

Acetolactate Synthase (ALS) inhibitors (2):

Sulfonylurea	chlorsulfuron (Glean, Telar, Report, Corsair) metsulfuron (Ally, Escort, Cimarron, Manor, Metgard, Valuron, Patriot, Purestand, Plotter) tribenuron (Express, Victory, Nuance) triasulfuron (Amber) chlorimuron (Classic) thifensulfuron (Harmony, Unity, Harass, Treaty) sulfometuron (Oust) iodosulfuron (component of Autumn Super) primisulfuron (Beacon) nicosulfuron (Accent, Nic-It, Primero) halosulfuron (Permit) mesosulfuron (Osprey) prosulfuron (Peak) rimsulfuron (Resolve, Solida) sulfosulfuron (Maverick, Outrider) pyrithiobac (Staple)
Imidazolinone	imazaquin (Scepter) imazethapyr (Pursuit) imazapic (Plateau, Panoramic) imazapyr (Contain, Arsenal, Habitat, Chopper, Rotary) imazamox (Raptor, Beyond)
Sulfonamide	flumetsulam (Python) cloransulam (FirstRate) florasulam (component of Orion and Quelex)
Sulfonylaminocarbonyl-triazolinone	flucarbazone (Everest, PrePare, Sierra) propoxycarbazone (Olympus) thiencarbazone (component of Corvus and Capreno, and Autumn Super)

Photo 16. *ALS herbicide injury generally appears as chlorosis and general stunting of the growing point, followed by gradual death of the plants. The tansy mustard in this wheat was treated with Glean.*

The acetolactate synthase (ALS) inhibiting herbicides have a broad spectrum of selectivity and are used at low rates as soil-applied or postemergence treatments in a variety of crops. These herbicides inhibit the activity of the ALS enzyme, which is involved in the synthesis of the branched chain amino acids (leucine, isoleucine, and valine). Amino acids are essential building blocks of proteins and are required for production of new cells. ALS herbicides are readily absorbed by both roots and foliage and translocated in both the xylem and phloem to the site of action at the growing points (Figure 4). Selectivity is based on differential metabolism and or an altered site of action exclusion. Kochia, Russian thistle, cocklebur, sunflower, shattercane, waterhemp, Palmer amaranth, cheat, bushy wallflower, and flixweed populations resistant to ALS herbicides have developed in some areas of Kansas where these herbicides have been used frequently.

Photos 17 and 18. *Some ALS herbicides can carry over and damage the following crop. These soybeans were damaged by Peak carryover, resulting in yellow, stunted plants (top). Planting ALS resistant or tolerant crops can help alleviate the potential for carryover, as with the STS soybeans (sulfonylurea tolerant) planted in the background of this picture (bottom).*

Photo 19. *ALS herbicides such as Basis, Resolve, Spirit, Accent, and Beacon can sometimes cause a chlorotic band, crinkled leaves, and bending of new corn leaves coming out of the whorl, especially with cold conditions following application or when applied in conjunction with certain insecticides.*

Photo 20. *ALS herbicides sometimes cause a purple or red venation of leaves as evident on the underside of this soybean leaf that was treated with Classic herbicide.*

Photo 21. *ALS herbicide carryover can cause a proliferation of secondary roots or "bottle brushing" on susceptible crops. The roots do not function normally and shoots may be stunted and show nutrient deficiency symptoms.*

Injury symptoms caused by ALS inhibiting herbicides are not apparent until several days after treatment, although susceptible plants stop growing almost immediately. Affected plants can exhibit stunting, interveinal chlorosis (Photos 16, 17, and 18), chlorotic banding on grass leaves (Photo 19), red leaf venation (Photo 20), purpling, root pruning (Photo 21), and gradual death. The risk of crop injury from the sulfonylurea and sulfonamide herbicides is more likely on high than low pH soils (Photo 22).

Environmental and use considerations. These herbicides have exceptionally low mammalian toxicity and have minimal environmental concerns because of the low use rates. Herbicide drift and spray contamination, however, are a concern because susceptible crops are very sensitive to these chemicals. Many of the ALS inhibiting herbicides can carry over in the soil and injure subsequent crops. Carryover of the sulfonylurea herbicides is much greater in high pH soils than low pH soils, while carryover of the imidazolinone and sulfonamide herbicides tends to be more likely in soils with low pH. The widespread development of ALS-resistant weed populations has decreased the utility of this class of herbicides over time.

Enolpyruvyl-shikimate-phosphate (EPSPS) Synthase inhibitors (9):

Amino acid derivative	glyphosate (Roundup, Touchdown, and many others)

The EPSPS inhibitor herbicides are readily absorbed through plant foliage and translocated in the phloem to the growing points (Figure 4). These herbicides inhibit the EPSPS enzyme, which is involved in the synthesis of the aromatic amino acids (tyrosine, tryptophan, and phenylalanine). Glyphosate is a relatively nonselective postemergence herbicide that is inactive in the

Photo 22. *ALS herbicide injury is sometimes confounded by iron deficiencies on high pH soils resulting in interveinal chlorosis as evident on this grain sorghum that was treated preemergence with Peak herbicide.*

Photo 23. *The EPSP inhibitors, such as glyphosate, are systemic herbicides that affect the growing points and cause a gradual discoloration and death of plants. The glyphosate drift to sorghum plants in this picture is causing different degrees of injury, including chlorotic banding of the leaves in the whorl on the center plant and purple and brown plants on either side.*

Photo 24. *Glyphosate drift to wheat plants at the heading stage of growth can result in white heads and stems above the flag leaf, while the rest of the plant remains green. Wheat heads of some tillers may turn white while others remain green depending on the stage of development at exposure.*

soil because of adsorption. Glyphosate resistant crops with an alternative EPSP enzyme have been developed through genetic engineering. Several weed species have developed resistance to glyphosate in Kansas, including marestail, waterhemp, giant and common ragweed, and kochia. Glyphosate resistance in weeds appears to be due to an altered EPSPS gene or overproduction of the EPSPS protein and may have varying degrees of resistance.

Injury symptoms are not apparent until 3 to 5 days after treatment and include stunting, foliage discoloration, and slow plant death (Photo 23). Grasses exposed

Photo 25. *Late applications of glyphosate on glyphosate resistant soybeans can result in chlorosis or yellow flashing of the new growth, especially with hot humid conditions.*

Photo 26. *Glyphosate applied to Roundup Ready corn hybrids later than label specifications, may result in malformation of ears and poor seed set.*

to a sublethal dose of ESPSP inhibitors may exhibit a chlorotic band across the leaves in the whorl of the plant. Glyphosate drift to wheat plants at the heading stage of growth can result in white heads and stems above the flag leaf, while the rest of the plant remains green. Some tillers may turn white while others remain green due to minor differences in developmental stage at the time of exposure (Photo 24). Glyphosate resistant crops also can be injured by glyphosate, especially if misapplied or with extreme environmental conditions. Late applications of glyphosate on glyphosate resistant soybeans often results in chlorosis of the new growth (Photo 25). Symptoms generally dissipate with time. Late applications of glyphosate on glyphosate resistant corn can result in abnormal ears and arrested ear development (Photo 26). Abnormal ear development may also occur with application of other agrichemicals, and may be worse when multiple products are applied together.

Environmental and use considerations. The EPSPS inhibitor herbicides have exceptionally low mammalian toxicity and have minimal pollution concerns because of high adsorption to soil colloids. Herbicide drift and spray contamination, however, are a concern because of the sensitivity of susceptible crops to these chemicals. Continued reliance on glyphosate for weed control will likely lead to more occurrence of glyphosate resistance over time. Integration of other herbicide modes of action and control methods may be necessary to manage glyphosate resistance and maintain effectiveness. Refer to K-State Research and Extension publication *Glyphosate Stewardship*, MF2767, for additional information regarding glyphosate resistance and optimizing performance.

Nitrogen Metabolism Inhibitors

Glutamine Synthetase Inhibitors (10):

Phosphorylated amino acid	glufosinate (Liberty, Ignite)

Liberty is a broad-spectrum postemergence herbicide that has no soil activity. Liberty inhibits the activity of the glutamine synthetase enzyme that is necessary for the plant to convert ammonia into other nitrogen compounds. Consequently, ammonia accumulates and glutamine levels decrease. Plant damage probably occurs due to the combined effects of ammonia toxicity and deficiency of amino acids required for other metabolic processes. Liberty has limited translocation, so thorough spray coverage of small weeds generally provides the best performance. Glufosinate resistant (Liberty Link) crops with an alternative glutamine synthetase enzyme have been developed through genetic engineering. Injury symptoms appear as foliar burn within several hours following application. Large weeds will often initiate regrowth from axillary buds.

Environmental and use considerations. Liberty has low mammalian toxicity and minimal pollution concerns because of high adsorption to soil colloids.

Lipid Synthesis Inhibitors

Acetyl-CoA Carboxylase (ACCase) Inhibitors: (1)

Aryloxyphenoxypropionate	diclofop (Hoelon) fluazifop (Fusilade) quizalofop (Assure II, Targa)
Cyclohexanedione	sethoxydim (Poast, Poast Plus, Rezult G) clethodim (Select, Select Max, Arrow, Volunteer, Section, Trigger, Intensity)

ACCase inhibitor herbicides primarily are used postemergence for grass control in broadleaf crops. They have a high degree of selectivity with little or no broadleaf activity. These herbicides are absorbed through the foliage and translocated in the phloem to

Photo 27. *ACCase inhibitors such as Select, Poast, Fusion, and Assure are systemic herbicides that interfere with the production of new cells at the base of grass leaves. Consequently, about 1 week after treatment the new leaves can be pulled out of the whorl and the leaf tissue at the base of the leaves appears rotten.*

Photo 28. *Sublethal doses of ACCase inhibitor herbicides can cause a chlorotic band across the leaves of grasses as they emerge from the whorl of the plant.*

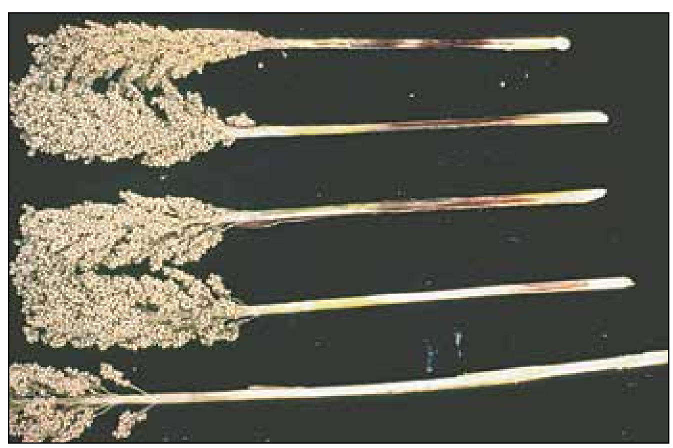

Photo 29. *Drift of ACCase inhibitors to susceptible grass crops such as grain sorghum, can partially damage and weaken the stem without completely destroying the tissue, as shown on these sorghum stems.*

the meristematic regions (Figure 4). The postemergence grass control herbicides halt meristematic activity by inhibiting the acetyl-CoA carboxylase (ACCase) enzyme that is involved in the synthesis of lipids and fatty acids. Lipids are essential components of cell membranes, and without them, new cells cannot be produced.

Application of the postemergence grass herbicides tank-mixed with a broadleaf herbicide often results in reduced grass control, a response called antagonism. The antagonism can be overcome by applying the separate herbicides several days apart, or by increasing the rate of the grass control herbicide in a tank mix.

Injury symptoms caused by the lipid synthesis inhibitors are not evident until several days after treatment, although the plants cease growing soon after herbicide application. Fully developed leaves of treated grass plants may still look healthy for several days after treatment, but new leaves in the whorl of the plant will pull out easily, exposing decayed tissue at the base of the leaves (Photo 27). The plants will gradually turn purple, brown, and die, but older leaves may stay green for a long time. Drift of sublethal rates of lipid synthesis inhibitors to susceptible grasses can cause a chlorotic band across the leaves in the whorl, damage the stems, or kill the main shoots, depending on the dosage and stage of growth of the plant (Photos 28 and 29).

Environmental and use considerations. The selective postemergence grass control herbicides are foliar applied, short-lived in the soil, have a low water solubility, and are used at relatively low rates. Thus, they have a low leaching potential and do not pose a serious threat to the environment.

Cell Membrane Disrupters

Protoporphyrinogen Oxidase (PPO) inhibitors (14):

Diphenylether	aciflourfen (Ultra Blazer) lactofen (Cobra, Phoenix) fomesafen (Reflex, Flexstar, Dawn, Rhythm) pyraflufen (ET, Vida)
Aryl triazolinone	sulfentrazone (Authority, Spartan) carfentrazone (Aim)
N-Phenylphthalimide	flumiclorac (Resource) flumioxazin (Valor, Encompass, Chateau, Rowel)
Imine	fluthiacet (Cadet)
Pyrimidinedione	saflufenacil (Kixor, Sharpen)

Photosystem I Electron Diverters (22):

Bipyridilium	paraquat (Gramoxone) diquat (Reglone)

The cell membrane disrupters are primarily nontranslocated herbicides that are light activated.

Photo 30. *Cell membrane disruptors cause foliar burn type symptoms, as exhibited by this soybean leaf treated with Cobra herbicide.*

Photo 31. *Aim and Resource herbicides frequently cause foliar burn on corn, especially when conditions are hot and humid following application.*

Paraquat and diquat are relatively nonselective chemicals used to control all existing vegetation and as preharvest desiccants. The PPO inhibitor herbicides provide selective broadleaf weed control in various crops. These herbicides quickly form highly reactive compounds in the plants that rupture cell membranes, causing the fluids to leak out. Thorough spray coverage is essential for good postemergence weed control. Because they are not translocated to the roots, these herbicides are ineffective for long-term perennial weed control.

Injury symptoms can occur within 1 to 2 hours after application, appearing first as water-soaked foliage, which is followed by browning (necrosis) of the tissue wherever the spray contacts the foliage (Photos 30, 31, and 32). Symptoms will appear most quickly with bright, sunny conditions at application. Drift injury will appear as speckling on leaf tissue (Photo 33). Injury from soil applications or residues appears as a mottled chlorosis and necrosis (Photo 34).

Environmental and use considerations. The bipryidiliums are irreversibly adsorbed upon contact with the

Photo 32. *Sorghum injury from a late application of Aim + NIS is frequently observed when conditions are hot and humid or a light dew is present at application.*

Photo 33. *Paraquat drift will cause necrotic burn spots wherever the spray droplets come in contact with plant foliage, as with this wheat that was next to a treated field.*

Photo 34. *Preemergence sulfentrazone treatments may cause a mottled chlorosis of foliage, especially with wet conditions on coarse-textured soils having high pH and low organic matter, as with these sunflowers treated with Spartan.*

Photos 35 and 36. *Pigment inhibitor herbicides cause a bleaching symptom when the chlorophyll in the leaves is destroyed (top). Command herbicide can carry over and damage small grains, especially in areas with higher application rates (bottom).*

soil and have no soil activity. They are persistent in the soil, however, and could potentially move with the soil. Bipyridiliums are respiratory inhibitors and can be a significant risk to humans if inhaled or ingested.

Pigment Inhibitors

Deoxy-xylulose Phosphate Synthase (DOXP) inhibitors (13):	
Isoxazolidinone	clomazone (Command)
Hydroxyphenylpyruvate dioxygenase (HPPD) synthesis inhibitors (27):	
Isoxazole	isoxaflutole (Balance Flexx, Scoparia) pyrasulfotole (component of Huskie)
Triketone	mesotrione (Callisto) tembotrione (Laudis) bicyclopyrone (component of Acuron)
Pyrazolone	topramezone (Impact, Armezon)
Phytoene desaturase (PDS) synthesis inhibitors (12):	
Pyridazinone	norflurazone (Zorial)

The pigment inhibitor herbicides interfere with pigment production and protection of chlorophyll.

Ultimately, chlorophyll production is inhibited, and plant foliage turns white and appears bleached. Although injury symptoms are similar with these herbicides, the specific site of action is different. Injury symptoms from the pigment inhibitor herbicides are expressed as white to translucent foliage (Photos 35, 36, 37, 38, 39, and 40).

Environmental and use considerations. Drift to nontarget plants will cause foliage to turn white. Balance herbicide is quickly converted to a fairly soluble and persistent herbicidally active metabolite in the soil. Balance use is restricted on coarse textured soils with a shallow water table.

Nonherbicide Stresses

Occasionally, physiological crop responses to diseases, insects, or nutrient deficiencies resemble certain herbicide symptoms and may be mistaken for herbicide injury (Photo 41).

Photo 37. *Susceptible species to pigment inhibitors will have white or bleached foliage following emergence, as shown by this crabgrass emerging from soil treated with Balance herbicide.*

Photo 38. *Corn injury from Balance can result following cool, wet conditions on low organic matter, high pH soils.*

Photo 39. *Corn injury from a misapplication of Callisto + methylated seed oil applied postemergence. Typical HPPD injury symptoms. Callisto should not be applied with methylated seed oil.*

Photo 40. *Sorghum injury from preemergence applied Lumax or Lexar can result from excess rainfall following herbicide application and prior to sorghum emergence or when applied on sandy soil types. Do not use Lumax on sorghum planted in sandy soils.*

Photo 41. *This picture shows symptoms from a disease, downy mildew, which can often be mistaken for Lumax and Lexar injury.*

Herbicides, active ingredients, WSSA site of action classification, and labeled crops.

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
2,4-D	2,4-D	4 GR	corn, sorghum, small grains, pasture
Accurate Extra	thifensulfuron tribenuron metsulfuron	2 ALS 2 ALS 2 ALS	small grains
Acuron	atrazine bicyclopyrone mesatrione s-metolachlor	5 PSII(A) 27 HPPD 27 HPPD 15 VLCFA	corn
Affinity BroadSpec	thifensulfuron tribenuron	2 ALS 2 ALS	small grains
Affinity TankMix	thifensulfuron tribenuron	2 ALS 2 ALS	small grains
Afforia	flumioxazin thifensulfuron tribenuron	14 PPO 2 ALS 2 ALS	soybeans
Agility SG	thifensulfuron tribenuron metsulfuron dicamba	2 ALS 2 ALS 2 ALS 4 GR	small grains
Aim	carfentrazone	14 PPO	corn, sorghum, wheat
Ally	metsulfuron	2 ALS	small grains, pasture, CRP
Ally Extra	thifensulfuron tribenuron metsulfuron	2 ALS 2 ALS 2 ALS	small grains
Amber	triasulfuron	2 ALS	small grains, pasture
Anthem (Maxx)	pyroxasulfone fluthaicet	15 VLCFA 14 PPO	corn, soybeans
Anthem ATZ	pyroxasulfone fluthaicet atrazine	15 VLCFA 14 PPO 5 PSII(A)	corn
Anthem Flex	pyroxasulfone carfentrazone	15 VLCFA 14 PPO	wheat
Armezon	topramezone	27 HPPD	corn
Assure II	quizalofop	1 ACCase	soybeans, cotton
Atrazine	atrazine	5 PSII(A)	corn, sorghum, fallow
Authority Assist	sulfentrazone imazethapyr	14 PPO 2 ALS	soybeans
Authority Elite	sulfentrazone s-metolachlor	14 PPO 15 VLCFA	soybeans
Authority First	sulfentrazone cloransulam	14 PPO 2 ALS	soybeans
Authority Maxx	sulfentrazone chlorimuron	14 PPO 2 ALS	soybeans
Authority MTZ	sulfentrazone metribuzin	14 PPO 5 PSII(A)	soybeans
Authority XL	sulfentrazone chlorimuron	14 PPO 2 ALS	soybeans
Autumn Super	iodosulfuron thiencarbazone	2 ALS 2 ALS	corn, soybeans
Axial XL	pinoxaden	1 ACCase	small grains

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Balan	benefin	3 MT	alfalfa
Balance Flexx	isoxaflutole	27 HPPD	corn
Banvel	dicamba	4 GR	corn, sorghum, small grains, fallow, pasture
Banvel+Atrazine	dicamba atrazine	4 GR 5 PSII(A)	corn, sorghum
Basagran	bentazon	6 PSII(C)	soybeans, corn, sorghum
Basis Blend	rimsulfuron thifensulfuron	2 ALS 2 ALS	corn
Beacon	primisulfuron	2 ALS	corn
Beyond	imazamox	2 ALS	Clearfield wheat and sunflower
Bicep (Lite) MAGNUM	metolachlor atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Boundary	S-metolachlor metribuzin	15 VLCFA 5 PSII(A)	soybeans
Brash	dicamba 2,4-D	4 GR 4 GR	pasture, wheat, sorghum
Breakfree	acetochlor	15 VLCFA	corn
Breakfree ATZ (Lite)	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn
Broadaxe	s-metolachlor sulfentrazone	15 VLCFA 14 PPO	sunflower, soybeans
Bromox + Atrazine	bromoxynil atrazine	6 PSII(C) 5 PSII(A)	corn, sorghum
Bronate	bromoxynil MCPA	6 PSII(C) 4 GR	small grains
Brozine	bromoxynil atrazine	6 PSII(C) 5 PSII(A)	corn, sorghum
Buctril	bromoxynil	6 PSII(C)	corn, sorghum, small grains alfalfa
Buctril+Atrazine	bromoxynil atrazine	6 PSII(C) 5 PSII(A)	corn, sorghum
Butyrac	2,4-DB	4 GR	soybeans, alfalfa
Cadet	fluthiacet	14 PPO	corn, soybeans
Callisto	mesotrione	27 HPPD	corn
Callisto GT	mesotrione glyphosate	27 HPPD 9 EPSP	corn
Callisto Xtra	mesotrione atrazine	27 HPPD 5 PSII(A)	corn
Camix	S-metolachlor mesotrione	15 VLCFA 27 HPPD	corn
Canopy	chlorimuron metribuzin	2 ALS 5 PSII(A)	soybeans
Canopy EX	chlorimuron tribenuron	2 ALS 2 ALS	soybeans
Capreno	tembotrione thiecarbazone	27 HPPD 2 ALS	corn
Capstone	aminopyralid triclopyr	4 GR 4 GR	pasture
Carnivore	MCPA clopyralid bromoxynil	4 GR 4 GR 6 PSII(C)	wheat

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Chaparral	aminopyralid metsulfuron	4 GR 2 ALS	pasture
Charger Max ATZ	S-metolachlor atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Chateau	flumioxazin	14 PPO	alfalfa
Chism	metsulfuron chlorsulfuron	2 ALS 2 ALS	pasture
Cimarron Max	metsulfuron 2,4-D dicamba	2 ALS 4 GR 4 GR	pasture
Cimarron Plus	metsulfuron chlorsulfuron	2 ALS 2 ALS	pasture
Cimarron X-tra	metsulfuron chlorsulfuron	2 ALS 2 ALS	pasture
Cinch	S-metolachlor	15 VLCFA	corn, sorghum, soybeans, cotton, sunflower
Cinch ATZ (Lite)	S-metolachlor atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Clarity	dicamba	4 GR	corn, sorghum, small grains
Classic	chlorimuron	2 ALS	soybeans
Clearmax	imazamox MCPA	2 ALS 4 GR	Clearfield wheat
Cobra	lactofen	14 PPO	soybeans
Colt	fluroxypyr clopyralid	4 GR 4 GR	wheat
Colt+Salvo	2,4-D fluroxypyr	4 GR 4 GR	wheat
Colt+Sword	MCPA fluroxypyr	4 GR 4 GR	wheat
Command	clomazone	13 DOXP	soybeans, fallow
Confidence	acetochlor	15 VLCFA	corn
Confidence Xtra	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn
Corvus	isoxaflutole thiencarbazone	27 HPPD 2 ALS	corn
Cotoran	fluometuron	5 PSII(B)	cotton
Crossbow	triclopyr 2,4-D	4 GR 4 GR	pasture
Crusher	rimsulfuron thifensulfuron	2 ALS 2 ALS	corn
Curtail	clopyralid 2,4-D	4 GR 4 GR	small grains, pasture
Curtail M	clopyralid MCPA	4 GR 4 GR	wheat
Define	flufenacet	15 VLCFA	corn
Degree	acetochlor	15 VLCFA	corn
Degree Xtra	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Dimetric	metribuzin	5 PSII(A)	soybeans, alfalfa
Display	carfentrazone fluthiacet	14 PPO 14 PPO	cotton harvest aid

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Distinct	dicamba diflufenzopyr	4 GR 19 ATI	corn
Double Up B&D	bromoxynil 2,4-D	6 PSII(C) 4 GR	wheat
Dual MAGNUM	S-metolachlor	15 VLCFA	corn, sorghum, soybeans, sunflower, cotton
Edition Broadspec	thifensulfuron tribenuron	2 ALS 2 ALS	wheat
Edition TankMix	thifensulfuron tribenuron	2 ALS 2 ALS	wheat
Engenia	dicamba	4 GR	Xtend soybeans, Xtend cotton
Enlist Duo	Glyphosate 2,4-D	9 EPSP 4 GR	Enlist corn, Enlist soybeans, Enlist cotton
Enlite & Envive	flumioxazin chlorimuon thifensulfuron	14 PPO 2 ALS 2 ALS	soybeans
Eptam	EPTC	8 LS	alfalfa
Eradicane	EPTC	8 LS	corn
Escort	metsulfuron	2 ALS	pasture, noncropland
Expert	atrazine S-metolachlor glyphosate	5 PSII(A) 15 VLCFA 9 EPSP	corn, sorghum
Express	tribenuron	2 ALS	small grains
Extreme	imazethapyr glyphosate	2 ALS 9 EPSP	glyphosate-resistant soybeans
Facet	quinclorac	4 GR	sorghum, fallow
FieldMaster	glyphosate acetochlor atrazine	9 EPSP 15 VLCFA 5 PSII(A)	corn
Fierce	flumioxazin pyroxasulfone	14 PPO 15 VLCFA	soybeans, corn
Fierce XLT	flumioxazin pyroxasulfone chlorimuron	14 PPO 15 VLCFA 1 ALS	soybeans
Finesse	chlorsulfuron metsulfuron	2 ALS 2 ALS	small grains
Finesse Grass& Broadleaf	chlorsulfuron metsulfuron flucarbazone	2 ALS 2 ALS 2 ALS	small grains
FirstRate	cloransulam	2 ALS	soybeans
Flexstar	fomesafen	14 PPO	soybeans
Flexstar GT	fomesafen glyphosate	14 PPO 9 EPSP	glyphosate-resistant soybeans
Forefront HL	aminopyralid 2,4-D	4 GR 4 GR	pasture
Full Deck	MCPA fluroxypyr clopyralid	4 GR 4 GR 4 GR	wheat
FulTime NXT	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn
Fusilade DX	fluaziflop	1 ACCase	soybeans, cotton

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Fusion	fluaziflop fenoxaprop	1 ACCase 1 ACCase	soybeans, cotton
G-Max Lite	dimethenamid-P atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Gangster	flumioxazin chloransulam	14 PPO 2 ALS	soybeans
Garlon	triclopyr	4 GR	pasture
Glean	chlorsulfuron	2 ALS	small grains
GlyMix MT	glyphosate 2,4-D	9 EPSP 4 GR	fallow
Gramoxone Inteon	paraquat	22 ED	fallow
Grazon P+D	picloram, 2,4-D	4 GR 4 GR	pasture
Guardsman Max	dimethenamide-P atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Halex GT	s-metolachlor glyphoate mesotrione	15 VLCFA 9 EPSP 27 HPPD	corn
Harmony	thifensulfuron	2 ALS	small grains, soybeans
Harmony Extra	thifensulfuron tribenuron	2 ALS 2 ALS	small grains
Harness	acetochlor	15 VLCFA	corn
Harness Xtra	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn
Harrow	rimsulfuron thifensulfuron	2 ALS 2 ALS	corn
Hoelon	diclofop	1 ACCase	small grains
Hornet	flumetsulam clopyralid	2 ALS 4 GR	corn
Huskie	pyrasulfotole bromoxynil	27 HPPD 6 PSII(C)	small grains, sorghum
Hyvar	bromacil	5 PSII(A)	noncropland
Impact	topramezone	27 HPPD	corn
Instigate	mesotrione rimsulfuron	27 HPPD 2 ALS	corn
Intensity	clethodim	1 ACCase	soybeans, alfalfa, cotton, sunflower
Intimidator	s-metolachlor metribuzin fomesafen	15 VLCFA 5 PSII(A) 14 PPO	soybeans
Journey	imazapic glyphosate	2 ALS 9 EPSP	noncropland
Karmex	diuron	7 PSII(B)	alfalfa, cotton, noncropland
Keystone NXT (LA)	acetochlor atrazine	15 VLCFA 5 PSII(C)	corn
Landmark	sulfometuron chlorsulfuron	2 ALS 2 ALS	noncropland
Lariat	alachlor atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Latigo	2,4-D dicamba	4 GR 4 GR	wheat wheat

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Laudis	tembotrione	27 HPPD	corn
Leadoff	rimsulfuron thifensulfuron	2 ALS	corn
Lexar EZ	S-metolachlor atrazine mesotrione	15 VLCFA 5 PSII(A) 27 HPPD	corn, sorghum
Liberty	glufosinate	10 GS	Liberty Link crops
Linex	linuron	5 PSII(A)	soybeans
Lumax EZ	S-metolachlor atrazine mesotrione	15 VLCFA 5 PSII(A) 27 HPPD	corn, sorghum
Marksman	dicamba atrazine	4 GR 4 GR	corn, sorghum
Marvel	fomesafen fluthiacet	14 PPO 14 PPO	soybeans
Maverick	sulfosulfuron	2 ALS	wheat
MCPA	MCPA	4 GR	small grains
Metri	metribuzin	5 PSII(A)	soybeans, alfalfa
Milestone	aminopyralid	4 GR	pasture
Milestone VM	aminopyralid triclopyr	4 GR 4 GR	pasture
Moxy	bromoxynil	6 PSII(C)	corn, sorghum, small grains, alfalfa
Nimble	thifensulfuron tribenuron	2 ALS 2 ALS	small grains
NorthStar	primisulfuron dicamba	2 ALS 4 GR	corn
Olympus	propoxycarbazone	2 ALS	wheat
Opensight	aminopyralid metsulfuron	4 GR 2 ALS	noncropland
OpTill	saflufenacil imazethapyr	14 PPO 2 ALS	soybeans
OpTill Pro	salfufenacil imazethapyr dimethanamid-p	14 PPO 2 ALS 15 VLCFA	soybeans
Option	foramsulfuron	2 ALS	corn
Orion	florasulam MCPA	2 ALS 4 GR	wheat
Osprey	mesosulfuron	2 ALS	wheat
Oust	sulfometuron	2 ALS	noncropland
Outlaw	2,4-D dicamba`	4 GR 4 GR	wheat
Outlook	dimethenamid-P	15 VLCFA	corn, sorghum, soybeans
Overdrive	dicamba diflufenzopyr	4 GR 19 ATI	pasture
Overtime ATZ (lite)	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn
Panoflex	thifensulfuron tribenuron	2 ALS 2 ALS	soybeans
Parallel (PCS)	metolochlor	15 VLCFA	corn, sorghum, sunflower, cotton, soybeans

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Parallel Plus	metolachlor atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Pastora	nicosulfuron metsulfuron	2 ALS 2 ALS	bermudagrass
PastureGard HL	triclopyr fluroxypyr	4 GR 4 GR	pasture
Pathfinder II	triclopyr	4 GR	pasture
Peak	prosulfuron	2 ALS	sorghum, wheat
Permit	halosulfuron	2 ALS	corn, sorghum
Permit Plus	halosulfuron thifensulfuron	2 ALS 2 ALS	corn, fallow
Phoenix	lactofen	14 PPO	soybeans
Plateau	imazapic	2 ALS	noncropland
Poast, Poast Plus	sethoxydim	1 ACCase	soybeans, alfalfa, cotton, sunflower
PowerFlex	pyroxsulam	2 ALS	wheat
Pramitol	prometon	5 PSII(A)	noncropland
Prefix	S-metolachlor fomesafen	15 VLCFA 14 PPO	soybeans
Prequel	rimsulfuron isoxaflutole	2 ALS 27 HPPD	corn
Princep	simazine	5 PSII(A)	noncropland, corn
Priority	halosulfuron carfentrazone	2 ALS 14 PPO	corn, sorghum
Propel ATZ (Lite)	dimethenamid-P atrazine	15 VLCFA 5 PSII(A)	corn, sorghum
Prowl H2O	pendimethalin	3 MT	corn, soybeans, sunflower, cotton
Pulsar	dicamba fluroxypyr	4 GR 4 GR	small grains
Pummel	metolachlor imazethapyr	15 VLCFA 2 ALS	soybeans
Pursuit	imazethapyr	2 ALS	soybeans, corn, alfalfa
Python	flumetsulam	2 ALS	corn, soybeans
Quelex	halauxifen florasulam	4 GR 2 ALS	wheat
Range Star	dicamba 2,4-D	4 GR 4 GR	pasture
Raptor	imazamox	2 ALS	soybeans, alfalfa
Rave	triasulfuron dicamba	2 ALS 4 GR	wheat
Realm Q	rimsulfuron mesotrione	2 ALS 27 HPPD	corn
Redeem R&P	triclopyr clopyralid	4 GR 4 GR	pasture
Reflex	fomesafen	14 PPO	soybeans
Reglone	diquat	22 ED	aquatic, crop dessicant
Remedy Ultra	triclopyr	4 GR	pasture
Report Extra	chlorsulfuron metsulfuron	2 ALS 2 ALS	small grains

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Require Q	rimsulfuron dicamba	2 ALS 4 GR	corn
Resist	metribuzin chlorimuron	5 PSII(A) 2 ALS	soybeans
Resolve Q	rimsulfuron thifensulfuron	2 ALS 2 ALS	corn
Resource	flumiclorac	14 PPO	corn, soybeans
Rezult	bentazon sethoxydim	6 PSII(C) 1 ACCase	soybeans
Rifle	dicamba	4 GR	corn, sorghum, small grains
Rifle Plus	dicamba atrazine	4 GR 5 PSII(A)	corn, sorghum
Rifle-D	dicamba 2,4-D	4 GR 4 GR	corn
Roundup products	glyphosate	9 EPSP	fallow, glyphosate-resistant crops
Roundup Xtend	glyphosate dicamba	9 EPSP 4 GR	Xtend soybeans, Xtend cotton
Rowel	flumioxazin	14 PPO	soybeans, corn
Rowel FX	flumioxazin chlorimuron	14 PPO 2 ALS	soybeans
Sahara	imazapyr diuron	2 ALS 7 PSII(B)	noncropland
Scepter	imazaquin	2 ALS	soybeans
Scoparia	ixoxaflutole	27 HPPD	Fallow
Section	clethodim	1 ACCase	soybeans, alfalfa, cotton, sunflower
Select (Max)	clethodim	1 ACCase	soybeans, alfalfa, cotton, sunflower
Sequence	S-metolachlor glyphosate	15 VLCFA 9 EPSP	corn, soybeans
Sharpen	saflufenacil	14 PPO	corn, sorghum, soybeans, wheat, cotton
Shotgun	2,4-D atrazine	4 GR 5 PSII(A)	corn, sorghum
Sinbar	terbacil	5 PSII(A)	alfalfa
Solida	rimsulfuron	2 ALS	corn
Solstice	mesotrione fluthiacet	27 HPPD 14 PPO	corn
Sonalan	ethalfluralin	3 MT	soybeans, sunflower
Sonic	sulfentrazone cloransulam	14 PPO 2 ALS	soybeans
Spartan	sulfentrazone	14 PPO	sunflower
Spartan Charge	sulfentrazone carfentrazone	14 PPO 14 PPO	sunflower
Spike	tebuthiuron	7 PSII(B)	noncropland
Spirit	primisulfuron prosulfuron	2 ALS 2 ALS	corn
Stanza	clopyralid flumetsulam	4 GR 2 ALS	corn
Staple	pyrithiobac	2 ALS	cotton

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Starane (Ultra)	fluroxypyr	4 GR	small grains, corn, sorghum, fallow
Starane Flex	fluroxypyr florasulam	4 GR 2 ALS	wheat
Starane+Sword	fluroxypyr MCPA	4 GR 4 GR	small grains, fallow
Statement	metolachlor fomesafen	15 VLCFA 14 PPO	soybeans
Status	dicamba diflufenzopyr	4 GR 19 ATI	corn
Steadfast (Q)	nicosulfuron rimsulfuron	2 ALS 2 ALS	corn
Sterling Blue	dicamba	4 GR	small grains, corn, sorghum, pasture
Stinger	clopyralid	4 GR	small grains, pasture, corn
Storm	acifluorfen bentazon	14 PPO 6 PSII(C)	soybeans
Stout	nicosulfuron thifensulfuron	2 ALS 2 ALS	corn
Stratos	dicamba atrazine	4 GR 5 PSII(A)	corn, sorghum
Streamline	aminocyclopyrachlor metsulfuron	4 GR 2 ALS	noncropland
Supremacy	fluroxypyr thifensulfuron tribenuron	4 GR 2 ALS 2 ALS	wheat
Surestart II	acetochlor flumetsulam clopyralid	15 VLCFA 2 ALS 4 GR	corn
Surmount	picloram fluroxypyr	4 GR 4 GR	pasture
Surpass NXT	acetochlor	15 VLCFA	corn
Surveil	flumioxazin cloransulam	14 PPO 2 ALS	soybeans
Synchrony XP	chlorimuron thifensulfuron	2 ALS 2 ALS	soybeans
Tackle	imazethapyr glyphosate	2 ALS 9 EPSP	glyphosate resistant soybeans
Tailspin	fluroxypyr triclopyr	4 GR 4 GR	pasture
Tailwind	metolachlor fomesafen	5 PSII(A) 14 PPO	soybeans
Targa	quizalop	1 ACCase	soybeans, alfalfa, sunflower
Throttle	chlorsulfuron sulfometuron sulfentrazone	2 ALS 2 ALS 14 PPO	noncropland
ThunderMaster	imazethapyr glyphosate	2 ALS 9 EPSP	glyphosate resistant soybeans
TNT Broadleaf	thifensulfuron tribenuron	2 ALS 2 ALS	small grains
Tordon	picloram	4 GR	pasture, noncropland, fallow

** See back page for WSSA Site of Action and Classification Number information.*

Herbicide	Active Ingredients	WSSA Site of Action Classifications*	Labeled Crops
Torment	fomesafen imazethapyr	14 PPO 2 ALS	soybeans
Treflan	trifluralin	3 MT	soybeans, sunflower, alfalfa, cotton
Triple Flex II	acetochlor flumetsulam clopyralid	15 VLCFA 2 ALS 4 GR	corn
Trivence	flumioxazin chlorimuron metribuzin	14 PPO 2 ALS 5 PSII(A)	soybeans
Trump Card	2,4-D fluroxypyr	4 GR 4 GR	wheat
Trust	trifluralin	3 MT	soybeans, sunflower, alfalfa, cotton
Ultra Blazer	acifluorfen	14 PPO	soybeans
Valor	flumioxazin	14 PPO	soybeans, sorghum, corn
Valor XLT	flumioxazin chlorimuron	14 PPO 2 ALS	soybeans
Velpar	hexazinone	5 PSII(A)	alfalfa, noncropland
Velpar AlfaMax (Gold)	hexazinone diuron	5 PSII(A) 7 PSII(B)	alfalfa
Verdict	saflufenacil dimethenamid-P	14 PPO 15 VLCFA	corn sorghum
Viewpoint	imazapyr aminocyclopyrachlor metsulfuron	2 ALS 4 GR 2 ALS	noncropland
Vise	metolachlor fomesafen	15 VLCFA 14 PPO	soybeans
Volley ATZ (Lite)	acetochlor atrazine	15 VLCFA 5 PSII(A)	corn
Voucher	fluroxypyr MCPA	4 GR 4 GR	wheat
Warrant	acetochlor	15 VLCFA	soybeans, cotton
WeedMaster	dicamba 2,4-D	4 GR 4 GR	fallow, pasture
Weld	MCPA fluroxypyr clopyralid	4 GR 4 GR 4 GR	wheat
WideMatch	clopyralid fluroxypyr	4 GR 4 GR	small grains
Wildcard Xtra	bromoxynil MCPA	6 PSII(C) 4 GR	wheat
XtendiMax	dicamba	4 GR	Xtend soybeans, Xtend cotton
Yukon	halosulfuron dicamba	2 ALS 4 GR	corn, sorghum
Zemax	mesotrione s-metolachlor	27 HPPD 15 VLCFA	corn
Zidua	pyroxasulfone	15 VLCFA	corn, soybeans, wheat, cotton
Zorial	norflurazon	12 PDS	alfalfa, cotton

** See back page for WSSA Site of Action and Classification Number information.*

*WSSA Site of Action and Classification Number

1 ACCase = acetyl-CoA carboxylase inhibitor
2 ALS = acetolactate synthase inhibitor
3 MT = microtubule assembly inhibitor
4 GR = growth regulator
5 PSII(A) = photosystem II, binding site A inhibitor
6 PSII(C) = photosystem II, binding site C inhibitor
7 PSII(B) = photosystem II, binding site B inhibitor
8 LS = lipid synthesis inhibitor, not ACCase
9 EPSP = enolpyruvyl-shikimate-phosphate synthase inhibitor
10 GS = glutamine synthetase inhibitor
12 PDS = phytoene desaturase synthesis inhibitor
13 DOXP = deoxyxylalose phosphate synthase inhibitor
14 PPO = protoporphyrinogen oxidase inhibitor
15 VLCFA = very long chain fatty acid synthesis inhibitor
19 ATI = auxin transport inhibitor
22 ED = photosystem 1 electron diverter
27 HPPD= hydroxyphenylpyruvate dioxygenase synthesis inhibitor

References

Anderson, W. P. 1996. Weed Science: Principles (3rd edition). West Publishing Co., St. Paul, MN. 388 pp.

Ashton, F. M. and A. S. Crafts. 1981. Mode of action of herbicides. Wiley-Interscience, New York, NY. 525 pp.

Shaner, D.L. ed. 2014. Herbicide handbook. Weed Science Society of America, Champaign, IL. 513 pp.

Gunsolus, J. L., and W. S. Curran. 2002. Herbicide mode of action and injury symptoms. North Central Regional Extension Publication 377.

Ross, M. A. and C. A. Lembi. 1985. Applied weed science. Burgess Publishing Co., Minneapolis, MN. 340 pp.

Dallas E. Peterson
Weed Science Specialist

Douglas E. Shoup
Crops and Soils Specialist
Southeast Kansas

Curtis R. Thompson
Weed Science Specialist

Mithila Jugulam
Weed Physiologist

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

Publications from Kansas State University are available at: *www.ksre.ksu.edu*

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

C715 May 2015

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and United States Department of Agriculture Cooperating, John D. Floros, Director.