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Herbicide Site of Actions and Potential Damage to Zea mays and Glycine max.

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Herbicide Site of Actions and Potential Damage to *Zea mays* and *Glycine max*.

By

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Introduction

With the development of 2,4-D in the 1940s, farmers were able to selectively kill broadleaves in corn (*Zea mays*). 2,4-D was an effective and powerful tool that allowed farmers to reduce the time spent cultivating cornfields. The development of herbicides allowed farms to increase in size due to the reduction in the time spent interrow-cultivating. Monsanto's introduction of glyphosate-resistant (Roundup Ready) soybean (*Glycine max*) in 1996 continued the expansion of farm size. Glyphosate-resistant crops allowed farmers to adopt a "spray and forget" weed management program that was widely adopted. The simplified weed management programs were successful until glyphosate-resistant weeds evolved.

Although glyphosate was not the first herbicide that weeds developed herbicide resistance, the loss of glyphosate effectiveness created a sense of urgency for farmers. Farmers began to rethink their herbicide management to stay ahead of the challenges herbicide-resistant weed populations create. To combat resistant weed populations, farmers and professionals typically include additional herbicides in their weed management programs. This increases the likelihood of herbicide incompatibility, antagonism, and crop damage. A comprehensive understanding of herbicide mode of actions, site of actions, and potential crop damage is needed to make proper chemical recommendations and reduce the likelihood of crop damage.

Topic Selection

My interest in this topic comes from the professional experiences I have encountered since graduating with my Bachelor's Degree and entering the agricultural industry. In my current role as a district chemical representative, I work directly with farmers and professionals on crop protection products and fertilizer recommendations. I have come to the realization that a high percentage of farmers do not have a comprehensive understanding of how herbicides interact with plants. For example, farmers often are not able to properly identify the symptoms of herbicide damage to corn and soybeans. I have also observed a relatively high percentage of professionals who do not have a proper understanding of herbicide sites of action.

Several issues arise from farmers and professionals not having a complete understanding of herbicide sites of action, herbicide behavior within plants, and associated injury symptoms. Frequently farmers solely rely on information they receive from their local chemical provider. This can result in them obtaining incomplete or incorrect information. I frequently receive calls from concerned farmers who assume their weeds were not dying after an herbicide application, when in fact, the herbicides were working properly but required more time to kill the weed. This can lead to them incorrectly identifying a field problem and making a wrong decision, which can ultimately result in a loss in revenue.

Another serious issue that impacts the majority of farming operations in the Midwest is herbicide-resistant weeds. Helping farmers and other professionals understand herbicide sites of action will help reduce the dependency and repetitive use of the same sites of action, which may select weeds resistant to herbicides. Frequently I see recommendations that rely on the same site of action year after year. I often find farmers or professionals that switched active ingredients but stayed with the same site of action. This confusion is increased with the abundance of trade names for the same active ingredient. By furthering education and understanding of herbicide sites of action, we can reduce the frequent use of the same site of action within corn and soybean operations.

Why A Learning Module?

Previous work has been published by several universities and companies describing herbicide site of action and potential crop damage. These publications help professionals and farmers alike in furthering their understanding of herbicide mode of action and crop damage from these herbicides. However, when I entered the chemical sales field, I was unable to find a compresence learning tool that included pertinent information along with images of the damage for common herbicides used in corn and soybeans.

I chose a professional learning module for my creative component for its ability to provide comprehensive information to a live audience or be printed for a quick field guide. Images in the learning module aid in the visualization of plant symptoms caused by herbicides. With nine modes of action, sixteen sites of action, and countless trade names for herbicides commonly used in corn and soybean operations throughout Illinois and Iowa, it is easy to become overwhelmed by this information. A learning module allows for continual exposure to the information that enables the audience to retain the information provided steadily. A learning module also offers the best option for updating, adding, and replacing information as the industry evolves.

My goal for this creative component is to help both farmers and professionals in the agriculture industry. Identifying herbicide damage to crops in the field can be difficult due to the extensive interactions among herbicides, soil types, environment, and other production practices. This learning module will provide a consolidated comprehensive presentation and document that I will be readily updating to provide more current information as the industry changes to my audience.

Objectives

1. Improve farmers' and agricultural professionals' understanding of herbicide site of action.
2. Present information in a format comprehendible by people with little knowledge of herbicide mode and site of action.
3. Present a complete list of herbicide sites of action commonly used in corn and soybean in the Midwest.
4. Include common chemical family, the active ingredient, and brand names when applicable to aid with association and information retention.
5. Provide an understanding of injury symptoms of commonly used herbicides.

About the Learning Module

In my learning module, I will include all sites of action of herbicides used within row crop corn and soybean production. I will also include common brand names, active ingredients, or chemical family for the corn and soybean chemicals in the site of action when applicable. I will only include herbicides that are commonly used in corn and soybean production in the Midwest, mainly Illinois and Iowa. However, there is little difference between the herbicides used across the United States.

Within the professional learning module, I will include pictures of corn and soybean depicting herbicide injury symptoms. The purpose of this visual aid is to improve the understanding herbicide injury, along with being a quick field reference. I will attempt to use as many personal pictures of herbicide damage as possible that I have collected throughout my career. This will be very challenging, due to the rarity that some herbicide damage occurs in corn and soybeans. To add to the difficulty, some herbicide damage is dependent on particular weather and precipitation patterns. For the herbicide damage that I am unable to use my photos for, I will be relying on open sources and will properly cite each.

Herbicide mode of action refers to the biological process disrupted by herbicides. Disruption of this process ultimately results in plant death. Examples of modes of action include inhibition of photosynthesis, amino acid synthesis, and lipid synthesis. Knowledge of herbicide mode of action is essential in diagnosing situations where a herbicide is suspected of damaging plants.

Herbicide site of action refers to the specific compound, usually a protein, that is targeted by the herbicide. When a herbicide binds to the site of action, the compound is unable to function, resulting in disruption of the biological process (mode of action) that causes plant death. Site of action is more precise than the mode of action. There are approximately 30 herbicide sites of action, but less than 15 are commonly used in Midwestern agriculture. Example of sites of action used in corn and soybean include HPPD (HG 27), glutamine synthetase (HG 10), and the D2 protein of photosystem II (HG 5, 6 and 7). The Herbicide Group (HG) numbers found on most herbicide labels are a classification system developed by the Weed Science Society of America.

Herbicides will be grouped initially by mode of action, and then sites of action within the modes of action will be described.

Herbicide Site of Action

Lipid Synthesis Inhibitor

Herbicide Group 1: ACCase inhibitors are herbicides with limited soil activity used for postemergence grass control, including volunteer corn in soybean**.** There are two distinct chemical families of ACCase inhibitors: aryloxyphenoxypropionate (FOPs) and cyclohexanedione (DIMs). Corn hybrids with the Enlist trait (2,4-D resistance) are also resistant to the FOP herbicides, but not the DIMs. Group 1 herbicides inhibit the acetyl-CoA carboxylase (ACCase) enzyme that is involved in the synthesis of fatty acids, a type of lipid. Fatty acids are required for plant development and are the primary components of cell membranes. ACCase Inhibitors are absorbed through the foliage and transported through the phloem to the growing points of the plant. Symptoms take several days to develop and appear initially on new growth. The distinctive symptom for ACCase inhibitors is rotting of the growing point within the whorl. This symptom is easiest to observe on grasses more than 4 inches tall and volunteer corn. Low doses associated with drift or sprayer contamination can cause sporadic chlorotic, bleach spotting, or necrotic spots on grass leaves emerging after exposure.

Amino Acid Synthesis Inhibitors

Herbicide Group 2: ALS Inhibitors are used for both preemergence and postemergence weed control in corn and soybeans. Group 2 herbicides can be absorbed by foliage and roots, and translocate by both phloem and xylem. Group 2 herbicides inhibit acetolactate synthase (ALS), an enzyme involved in the synthesis of branched-chain amino acids. The lack of branched-chain amino acids prevents the production of proteins, initially disrupting growth at growing points where demand for protein synthesis is greatest. Symptoms of ALS inhibitors in plants are highly variable, and include chlorosis, stunting, and necrosis. Root symptoms include reduction of root hairs or lateral roots, and 'bottle-brush" appearance. A distinctive symptom on soybean is presence of red veins on the underside of leaves.

Glyphosate is the only active ingredient in herbicide Group 9: EPSPS inhibitor, and is a non-selective herbicide applied postemergence. In the Midwest it is used for weed management in Roundup Ready corn and soybeans, and also for burndown applications in no-till. Glyphosate has limited soil activity due to tight binding to soil colloids. EPSPS is a component of the shikimic acid pathway that produces amino acids and a wide range of other compounds. Glyphosate is transported through the phloem to growing points after it is absorbed by plant foliage. Glyphosate is relatively slow-working, and symptoms appear five to seven days after application on new growth. Symptoms include discoloration of foliage, chlorotic bands on new leaves, leaf wilting, and death.

Growth Regulators

Herbicide Group 4: Growth regulator herbicides are used in both corn and soybean. They are primarily used as postemergence herbicides, but some products have soil activity. The site of action for Group 4 herbicides is the auxin receptor site. These herbicides mimic the action of a natural growth hormone (indole acetic acid), resulting in a hormonal imbalance within susceptible plants. Group 4 herbicides disrupt plant growth via several growth processes such as cell elongation, cell division, and protein synthesis. Although monocots can metabolize synthetic auxins or restrict translocation, certain species are sensitive to synthetic auxins.

Symptoms of growth regulators vary depending on the susceptibility of the plant, growth stage, and the herbicide dose. Susceptible soybean exhibit symptoms of leaf cupping, strapping, and epinasty. The extent of the damage is dependent on the concentration of the herbicide contacting the plant. A low-dose of dicamba to non-resistant soybean will cause leaf cupping, while a direct application can result in epinasty and eventually death. Symptoms in corn include rolled leaves, abnormal brace roots, goose-necking, and stalk brittleness which can lead to green snap. Corn injury is more common during periods of rapid growth.

Herbicide Group 19: Diflufenzopyr is an auxin transport inhibitor available in package mixes with dicamba, a growth regulator herbicide. Use of diflufenzopyr with dicamba increases accumulation of dicamba in cells, allowing equivalent control with lower rates of dicamba. The site of action is unknown, and injury symptoms are typical of dicamba used alone.

Photosystem II Inhibitors

Herbicide Groups 5, 6, and 7: Photosystem II Inhibitors interfere with the transfer of electrons in photosynthesis by binding to the D1 protein. This disruption results in the formation of toxic compounds, free radicals, in the chloroplast that disrupt cell membranes. Group 5, 6, and 7 herbicides all bind to the D1 protein but differ slightly in where they attach to this protein. Soil-applied photosystem II inhibitors translocate through the apoplast (xylem), moving upward through the vascular tissues to expanded leaves.

Some products are used only postemergence (e.g. HG 6: bentazon, bromoxynil), whereas others may be used either preemergence or postemergence (e.g. HG 5: atrazine). The symptoms from the three herbicide groups are the same. With preemergence applications, symptoms develop on older leaves since these leaves accumulate more herbicide than emerging leaves and are photosynthetically active. Dicotyledons can show interveinal chlorosis with yellowing or browning of the leaf margins, whereas on grasses symptoms develop on leaf tips.

Nitrogen Metabolism

Glufosinate is the only product in Herbicide Group 10: Glutamine synthetase inhibitors, and is a non-selective, postemergence herbicide with minimal translocation in the plant. It is degraded rapidly in the soil, resulting in no soil activity. Glufosinate inhibits glutamine synthetase, an enzyme that incorporates ammonia into organic compounds. The accumulation of ammonia results in a disruption of photosynthesis and the production of toxic compounds that disrupt cellular integrity. Glufosinate can be applied to corn and soybeans with the Liberty Link trait.

Glufosinate symptoms can develop within hours after application, appearing as chlorosis followed by necrosis. Glufosinate is a contact herbicide with limited translocation; thus, symptoms are limited to leaves contacted by the spray.

Carotenoid Synthesis Inhibitors

Herbicide Group 27: Hydroxyphenyl pyruvate dioxygenase inhibitors (HPPD) disrupt the synthesis of carotene pigments. One function of carotene pigments is the protection of chlorophyll from toxic compounds; thus, HPPD inhibitors result in the destruction of chlorophyll and bleaching of susceptible plants. Plant necrosis is a result of free radicals in the plant that cause the deterioration and disruption of cellular membranes. HPPD inhibitors are applied preemergence and postemergence and are absorbed by plant roots, shoots, and leaves. Root-adsorbed HPPD inhibitors are translocated to the shoots of plants. The distinctive symptom of HPPD inhibitors is the bleaching of foliage, at lower rates chlorosis may be evident.

Cell Membrane Disrupters

Herbicide Group 14: Protoporphyrinogen oxidase inhibitors (PPO) kill plants by inhibiting enzymes involved in the synthesis of chlorophyll. As a result, compounds are produced that disrupt membranes. PPO inhibitors are applied preemergence and postemergence for control of dicots along with select monocots. Susceptible plants typically show injury symptoms within one or two days after application. Symptoms include necrotic lesions or speckling on leaves. PPO inhibitors have little translocation, and symptoms are limited to foliage contacted by spray droplets. Preemergence applications can cause girdling of soybean hypocotyls and necrosis of cotyledons and plumules. Injury is most common when rainfall occurs while soybean are breaking through the soil surface (cracking).

Herbicide Group 22: The photosystem I inhibitor, paraquat, is used in corn and soybean production as a pre-plant or preemergence burndown herbicide. Paraquat is a non-selective herbicide that kills green tissue contacted by the herbicide. Cell membranes are destroyed by highly reactive compounds formed when electron transfer in photosystem I is disrupted. Injury symptoms include necrotic lesions where paraquat contacts the leaves, with complete coverage plant death will occur.

Root Growth Inhibitors

Herbicide Group 3: Root inhibitors are pre-plant or preemergence herbicides that inhibit the assembly of microtubules, structures involved in cell division. The site of action for the herbicides is tubulin, a small protein that polymerizes to form the microtubules. Group 3 herbicides are used primarily in soybean, but pendimethalin can be used preemergence in corn. Disruption of cell division results in reduced root growth and swollen root tips in susceptible plants. Group 3 herbicides are not translocated within the plant, stunting of aboveground growth is due to a reduced root system. The herbicides are often referred to as "yellow products" due to their distinctive yellow color.

Seedling Shoot Growth Inhibitors

Herbicide Group 15: Very Long Chain Fatty Acid Inhibitors (VLCFA) inhibit the synthesis of lipids involved in membranes and other functions. VLCFA inhibitors are used for preemergence weed management in corn and soybeans. The actual process by which plant death occurs is not entirely understood. VLCFA inhibitors have minimal translocation and are primarily active on germinating seeds. Damage symptoms in soybean include heart-shaped leaflets or a "draw-string effect." Corn plants may leaf out underground or have leaves unfurl improperly.

Value of the Learning Module

The value of this learning module to increase knowledge of herbicide sites of action and potential crop damage by farmers, persons entering the agricultural industry, and industry professionals. My vision for this learning module is based on what would have benefited me when I was first entered the agricultural industry. I focused on information that I, and other professionals, felt were lacking in our formal education. We felt there was not a sufficient amount of time dedicated to herbicide mode and site of action and their processes during our undergraduate degrees. I will be using this learning module as an education tool to promote more informed professionals and farmers.

Summary

With the continual increase in resistant and tolerant weed populations, herbicide site of action, knowledge, and understanding is a vital asset for farmers and professionals alike. Due to the limited number of sites of action, it’s difficult to prevent continual use of the same products, but using multiple sites of actions reduces the reliance on specific sites of action. This includes using chemicals with different sites of action to achieve proper weed management programs. Having a broad knowledge of herbicide site of action will allow for the use of multiple herbicides to reduce the occurrence of resistance weed without causing crop damage in the process.

My overall objective was to present information about herbicide sites of action and the potential they have to damage corn and soybean. To adequately understand how herbicides work, you must have a basic knowledge of the processes they disrupt. Knowing herbicide processes will allow for one to know where to search for damage. I hope that I have provided a comprehensive tool to be used as an educational module for professional presentations and also serve as a quick reference in the field.

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