Understanding Herbicide Mode of Action and Injury Symptoms
Learning Objectives

1. Understand how herbicides are classified
2. Discuss importance of knowing herbicide mode of action
3. Describe the role of group numbers in preventing herbicide resistance
4. Recognize common injury symptoms
Herbicides

- Chemicals used to kill undesirable vegetation (weeds)
- Prevent or stop normal plant growth and development

Photo: Garo Goodrow, Penn State
Understanding How Herbicides Work

Select the proper product:

- Know what type of vegetation will be controlled
- Know the crops and sites where it can be used
- Know which application techniques and methods to use
- Prevent herbicide resistant weeds
- Prevent damage to desirable vegetation
- Diagnose injury symptoms
Understanding How Herbicides Work

• Helps provide a basic understanding of chemical properties
  o Water solubility – leaching/runoff potential
  o Vapor pressure – volatility
  o Dissipation/degradation pathways – persistence (half-life)

• Environmental and toxicity characteristics
  o Human and wildlife impacts

Photo: MD Dept. of Agriculture – Pesticide Regulation Sect.
How Are Herbicides Classified?

Herbicides can be classified in several ways:

- Weeds or vegetation controlled
- Crops or sites labeled for use
- Timing or method of application
  - e.g., preemergent vs. postemergent OR soil vs. foliar
- Mode of action
- Chemical families
How Are Herbicides Classified?

• Other properties:
  • Ionic properties — acid, base, neutral
  • Mobility in plants (translocation) — nonmobile, xylem, phloem, both
  • Soil residual characteristics — short vs. intermediate vs. long
Herbicide Application Methods

• Foliar applied (Post)
  o Controls existing weeds with some to no residual activity
  o Reactive (“wait and see”) approach
  o Activity depends on:
    ▪ Weed species
    ▪ Growth stage
    ▪ Climatic conditions
Herbicide Movement in Plants

- Foliar applied
  - Mobile moves with water (xylem) and sugars (phloem)
  - Truly systemic
Herbicide Movement in Plants

• Foliar applied
  o Nonmobile works at area of absorption
    • Contact
Herbicide Movement in Plants

Soil applied

- Mobile—moves away from site of absorption
  - Root to shoot
- Nonmobile—enters roots/shoot but does not move

Photo: MD Dept. of Agriculture – Pesticide Regulation Sect.
Mode of Action

• How a herbicide controls a plant
• The process from the time of application involves the plant’s:
  o Absorption of the herbicide either:
    ▪ At the point of direct contact (no movement)
    ▪ By translocating throughout the plant (systemic)
  o Metabolism of the herbicide
  o Biological response to the herbicide
• Herbicides with same MOA usually affect the plant’s growth and development in the same way with similar symptoms
Plant Structures and Processes

- Herbicides are designed to attack plant structures or processes including:
  - Photosynthesis (production of food)
  - Pigments (chlorophyll produces energy, others capture light)
  - Respiration (produces energy)
  - Transpiration (movement of water)
  - Amino acids (proteins for growth and development)
  - Lipids (cell membranes and stores energy)
  - Hormones (growth and development)
## Mode of Action

<table>
<thead>
<tr>
<th>Mode of Action (MOA)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipid biosynthesis inhibitors</td>
<td>fluazifop-P, sethoxydim</td>
</tr>
<tr>
<td>Amino acid (protein) biosynthesis inhibitors</td>
<td>glyphosate, imazapyr</td>
</tr>
<tr>
<td>Plant growth regulators</td>
<td>2,4-D, dicamba</td>
</tr>
<tr>
<td>Photosynthesis inhibitors</td>
<td>atrazine, hexazinone</td>
</tr>
<tr>
<td>Nitrogen metabolism disrupter</td>
<td>glufosinate-ammonium</td>
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<tr>
<td>Pigment inhibitors</td>
<td>clomazone, amitrole</td>
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<tr>
<td>Cell membrane disrupters</td>
<td>paraquat</td>
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<tr>
<td>Seedling growth inhibitors – root</td>
<td>trifluralin, pendimethalin</td>
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<tr>
<td>Seedling growth inhibitors – shoot</td>
<td>acetochlor, metolachlor</td>
</tr>
<tr>
<td>unknown</td>
<td>fosamine, pelargonic acid</td>
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</table>
Mode of Action

• Many labels reference “Mode of Action” and “Resistance Management”

Mode of Action

Sethoxydим, the active ingredient in Segment II, is a graminicide which inhibits the enzyme acetyl CoA carboxylase (ACCase), resulting in cessation of fatty acid synthesis which is essential for new growth. Segment II rapidly enters the targeted grass weed through the foliage and translocates throughout the plant. Whole plant death occurs over approximately 3 weeks. Sethoxydим is classified in Group 1 by the Weed Science Society of America (WSSA) and Group A by the Herbicide Resistance Action Committee (HRAC).

Resistance Management

Weed resistance to ACCase-inhibiting herbicides (Group 1), is known to occur, and populations of resistant biotypes are known to exist. Resistance management practices include:
Site of Action

• Herbicides are further broken down by their specific “Site or Mechanism of Action”
  o This is the location in the plant where the herbicide interferes with plant growth and development
• Herbicides in the same chemical family normally have the same site of action
• The rotation of herbicides with different sites of action helps prevent the development of resistant weeds
Site of Action

• Abbreviation system designates the specific enzyme or process that is disrupted
  o ACCase – Lipid synthesis inhibitors
  o ALS – Amino acid biosynthesis inhibitors
  o EPSP – Amino acid biosynthesis inhibitors
  o PSII – Photosystem II
Mode and Site of Action

• Coding system developed by the National Weed Science Society of America (WSSA) to group herbicides by mode of action and site of action

Specimen labels for education purposes
Chemical Family

• Further broken down by chemical family (More than 20 different families)

• Based on chemical structure (several families may have the same MOA)
  o Plant Growth Regulators
    ▪ Phenoxy
    ▪ Benzoic
    ▪ Carboxylic acid
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Lipid biosynthesis inhibitors</td>
<td>1</td>
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<td>aryloxyphenoxypropionate</td>
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<td>Fusilade</td>
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<td>quizalofop</td>
<td>Assure II, Targa</td>
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<td></td>
<td></td>
<td>clethodim</td>
<td>Select, Arrow</td>
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<td></td>
<td></td>
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<td>sethoxydim</td>
<td>Posto</td>
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<td>Amino acid biosynthesis inhibitors</td>
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<td>ALS enzyme</td>
<td>sulfonylurea</td>
<td>chlorimuron</td>
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<td>9</td>
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<td>glycine</td>
<td>glyphosate</td>
<td>Roundup</td>
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<td>Plant growth regulators</td>
<td>4</td>
<td>IAA like (auxins)</td>
<td>phenoxy</td>
<td>2,4-D</td>
<td>Weedone</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>benzoic acid</td>
<td>Banvel, Clarity</td>
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<td></td>
<td>dicamba</td>
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<td></td>
<td></td>
<td>carboxylic acid</td>
<td>clopyralid</td>
<td>Stinger</td>
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<td>fluoroxypry</td>
<td>Starane</td>
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<td>Photosynthesis inhibitors (pslachlor)</td>
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<td>triazine</td>
<td>atrazine</td>
<td>Aatrex</td>
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<tr>
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<td></td>
<td></td>
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<td>simazine</td>
<td>Princep</td>
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</table>
Recognizing Common Injury Symptoms

• Understanding the mode of action is important for:
  o Diagnosing crop injury
  o Identifying off-target damage
  o Developing weed control programs to manage resistance

Photo: MD Dept. of Agriculture – Pesticide Regulation Sect.
Plant Growth Regulators
Group 4
# Herbicide Mode and Site of Action

<table>
<thead>
<tr>
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<tbody>
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<td>Plant growth regulators</td>
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<td>IAA like (auxins)</td>
<td>phenoxy</td>
<td>2,4-D</td>
<td>Weedone</td>
</tr>
<tr>
<td></td>
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<td>dicamba</td>
<td>Banvel, Clarity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>carboxylic acid</td>
<td>clopyralid fluroxypyr</td>
<td>Stinger Starane</td>
</tr>
</tbody>
</table>
Plant Growth Regulators: Group 4

- Examples: 2,4-D; MCPA, MCPP
- Good control on most annual/perennial broadleaves
Plant Growth Regulators: Group 4

- Primarily foliar applied, some soil activity, systemic
- Be cautious of drift, and volatilization, onto sensitive crops/plants
Plant Growth Regulators: Group 4

- Most products have label warnings or restrictions for:
  - Sensitive crops
  - Weather conditions

Photos: MD Dept. of Agriculture – Pesticide Regulation Sect.
Plant Growth Regulators: Group 4

- Label warnings or restrictions on sensitive crops

**SENSITIVE CROP PRECAUTIONS**

BANVEL may cause injury to desirable trees and plants, particularly beans, cotton, flowers, fruit trees, grapes, ornamentals, peas, potatoes, soybeans, and many other crops. Use it during their development or growing stage. FOLLOW THE PRECAUTIONS LISTED BELOW WHEN USING BANVEL:

- **DO NOT** treat areas where either possible downward movement into the soil or surface washing may cause contact of BANVEL with the roots of desirable plants such as trees and shrubs.

- The rate of drift is influenced by temperature inversions. **DO NOT** spray near sensitive plants if wind is gusty or in excess of 5 mph and moving in the direction of adjacent sensitive crops. Leave an adequate buffer zone between area to be treated and sensitive plants. Coarse sprays are less likely to drift out of the target area than fine sprays.

- Use coarse sprays to avoid potential herbicide drift. Select nozzles, which are designed to produce minimal amounts of fine spray particles. Examples of nozzles designed to produce coarse sprays via ground application are Delavan Raindrops, Spraying Systems XR flat fans, or large capacity flood nozzles such as D10, TK10, or greater capacity tips. Keep the spray pressure at or below 20 psi and the spray volume at or above 20 GPA, unless otherwise required by the manufacturer of drift-reducing nozzles. Consult your spray nozzle supplier concerning the choice of drift-reducing nozzles.

- Agriculturally approved drift-reducing additives may be used.

- To avoid injury to desirable plants, **equipment used** to apply BANVEL should be thoroughly cleaned (See **PROCEDURE FOR CLEANING SPRAY EQUIPMENT**) before reusing to apply any other chemicals.

All crop uses of BANVEL are intended for a normal growing interval between planting and harvest. No crop rotation restrictions exist if normal harvest of treated crop has occurred. If this interval is shortened, such as in cover crops that will be plowed under, do not follow up with the planting of a sensitive crop.

Crops growing under stress conditions such as drought, poor fertility, or foliar damage due to hail, wind or insects, can exhibit various injury symptoms that may be more pronounced if herbicides are applied.
Plant Growth Regulators: Group 4

- Label warnings or restrictions regarding weather conditions

**SENSITIVE CROP PRECAUTIONS**

BANVEL may cause injury to desirable trees and plants, particularly beans, cotton, flowers, fruit trees, grapes, ornamentals, peas, potatoes, soybeans, sunflowers, tobacco, tomatoes, and other broadleaf plants when contacting their roots, stems or foliage. These plants are most sensitive to BANVEL during their development or growing stage. FOLLOW THE PRECAUTIONS LISTED BELOW WHEN USING BANVEL.

- **DO NOT** treat areas where either possible downward movement into the soil or surface washing may cause contact of BANVEL with the roots of desirable plants such as trees and shrubs.

**temperature inversions exist. DO NOT** spray near sensitive plants if wind is gusty or in excess of 5 mph and moving in the direction of adjacent sensitive crops. Leave an adequate buffer zone between area to be treated and sensitive plants. Coarse sprays are less likely to drift out of the target area than fine sprays.

- XR flat fans, or large capacity flood nozzles such as D10, TK10, or greater capacity tips. Keep the spray pressure at or below 20 psi and the spray volume at or above 20 GPA, unless otherwise required by the manufacturer of drift-reducing nozzles. Consult your spray nozzle supplier concerning the choice of drift-reducing nozzles.

- Agronomically approved drift-reducing additives may be used.

**DO NOT** apply BANVEL adjacent to sensitive crops when the temperature on the day of application is expected to exceed 85°F as drift is more likely to occur.

All crop uses of BANVEL are intended for a normal growing interval between planting and harvest. No crop rotation restrictions exist if normal harvest of treated crop has occurred. If this interval is shortened, such as in cover crops that will be plowed under, do not follow up with the planting of a sensitive crop.

Crops growing under stress conditions such as drought, poor fertility, or foliar damage due to hail, wind or insects, can exhibit various injury symptoms that may be more pronounced if herbicides are applied.
Plant Growth Regulators: Group 4

- Affects growth in newest stems and leaves
  - Disrupts protein building and normal cell division
  - Multiple sites affected

- Plant “grows” itself to death
Plant Growth Regulators: Group 4

- **Common symptoms:**
  - Twisted and malformed stems
  - Leaf cupping and crinkling
  - Brittle stems
  - Leaf roll
  - Others
Amino Acid Biosynthesis Inhibitors Groups 2 and 9
## Herbicide Mode and Site of Action

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<tbody>
<tr>
<td>Amino acid biosynthesis inhibitors</td>
<td>2</td>
<td>ALS enzyme</td>
<td>sulfonylurea</td>
<td>chlorimuron halosulfuron nicosulfuron</td>
<td>Classic Permit Accent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>imidazolinone</td>
<td></td>
<td>imazamox imazaquin imazethapyr</td>
<td>Raptor Scepter Pursuit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>triazolopyrimidine</td>
<td></td>
<td>cloransulam flumetsulam</td>
<td>FirstRate Python</td>
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<tr>
<td></td>
<td>9</td>
<td>EPSP enzyme</td>
<td>glycine</td>
<td>glyphosate</td>
<td>Roundup</td>
</tr>
</tbody>
</table>
Amino Acid Biosynthesis Inhibitors: Groups 2 and 9

• Amino acids are the backbone of protein – both structurally and biochemically
• Two different types:
  o ALS enzyme inhibitors (Group 2)
  o EPSP enzyme inhibitors (Group 9)
• Both have different ways to control susceptible plants
Amino Acid Biosynthesis Inhibitors: Group 9 — EPSP enzyme

- Example: glyphosate
- Non-selective – Good control on most broadleaves and especially grasses
- Prevents plant from creating certain amino acid
Amino Acid Biosynthesis Inhibitors: Group 9 — EPSP enzyme

• 20 amino acids are necessary for plants to create proteins
• Proteins (comprised of 500 to thousands of amino acids) are vital for all plant physiological functions
• Stop ANY amino acid formation
  ➢ stop protein synthesis
  ➢ stop growth
  ➢ plant dies
Normal Plant Function

PEP (Molecular substrate) + S-3-P (Molecular substrate) + EPSP Synthase (Enzyme) → EPS-3-P (Product)

The product is essential in the formation of 3 amino acids: tryptophan, phenylalanine, tyrosine
Glysophate Applied to Plant

PEP (Molecular substrate) + S-3-P (Molecular substrate) + EPSP Synthase (Enzyme)

Glysophate (molecule)

PEP and S-3-P cannot be combined

The 3 amino acids: tryptophan, phenylalanine, tyrosine, cannot be formulated
Glyphosate Resistance (RoundUp Ready®) In Genetically Modified Crops

PEP and S-3-P cannot be combined

Glyphosate interferes with the substrates combining

Glyphosate cannot bond with genetically modified enzyme

EPSP Synthase (Enzyme with Glyphosate)

EPSP Synthase (Enzyme modified with bacteria)
Amino Acid Biosynthesis Inhibitors: Group 9 — EPSP enzyme

- Efficient translocation to root system
- No soil activity, no carryover concerns
Amino Acid Biosynthesis Inhibitors: Group 9 — EPSP enzyme

- Normal function of enzyme is blocked, inhibiting protein building
- Systemic activity; young leaves are affected first
Amino Acid Biosynthesis Inhibitors: Group 9 — EPSP enzyme

• Symptoms include:
  o Newest growth turns yellow to reddish
  o Plant slowly browns and dies

• Slow acting:
  o 7-10 days for symptoms to appear
Amino Acid Biosynthesis Inhibitors: Group 9 — EPSP enzyme

- Resistance issues

6.0 WEED RESISTANCE MANAGEMENT

Glyphosate, the active ingredient in this product, is a Group 9 herbicide based on the mode of action classification system of the Weed Science Society of America. Any weed population can contain plants naturally resistant to Group 9 herbicides. Weed species resistant to Group 9 herbicides can be effectively managed by using another herbicide from a different Group, or by using other cultural or mechanical methods.

6.1 Weed Management Practices

To minimize the occurrence of glyphosate-resistant biotypes, observe the following weed management practices:

- Scout your fields before and after herbicide application.
- Start with a clean field, using either a burndown herbicide application or tillage.
- Control weeds early when they are relatively small.
- Incorporate other herbicides (e.g., a selective and/or a residual herbicide) and cultural practices (e.g., tillage or crop rotation) into your weed management program, where appropriate.

6.2 Management of Glyphosate-Resistant Biotypes

Appropriate testing is needed to determine if a weed is resistant to glyphosate. Call 1-800-ROUNDUP (1-800-768-6387) or contact your Monsanto Company representative to determine if resistance in any particular weed biotype has been confirmed in your area, or visit the Internet www.weedresistancemanagement.com or www.weedscience.org. For more information see the “ANNUAL WEEDS RATE SECTION” and “PERENNIAL WEEDS RATE SECTION” of this label.

Since the occurrence of new glyphosate-resistant weeds cannot be determined until after product use and scientific confirmation, Monsanto Company is not responsible for any losses that result from the failure of this product to control glyphosate-resistant weed biotypes.

The following good agronomic practices can reduce the spread of confirmed glyphosate-resistant biotypes:

- If a naturally occurring resistant biotype is present in your field, apply this product in a tank-mix or sequentially with an appropriately labeled herbicide with a different mode of action to achieve control.
- Cultural and mechanical control practices (e.g., crop rotation or tillage) can also be used as appropriate.
Pigment inhibitors
Groups 13 and 27
# Herbicide Mode and Site of Action

<table>
<thead>
<tr>
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<th>Trade Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigment inhibitors</td>
<td>13</td>
<td>inhibits carotenoid biosynthesis</td>
<td>isoxazolidinone</td>
<td>clomazone</td>
<td>Command</td>
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<td>27</td>
<td>4-HPPD enzyme</td>
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<td>isoxtrotole</td>
<td>Balance</td>
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<td></td>
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<td></td>
<td>triketone</td>
<td>mesotrione tembotrione topramezone</td>
<td>Callisto Laudis Impact</td>
</tr>
</tbody>
</table>
Pigment Inhibitors: Groups 13 and 27

- **Group 13:** Controls small seeded, annual broadleaves and grasses
  - Example: Command

- **Group 28:** Controls primarily broadleaves
  - Example: Balance
Pigment Inhibitors: Groups 13 and 27

• Application varies depending on product
  o Command, Predict, and Balance are preemergent only
  o Calisto has preemergent and postemergent activity
  o Impact and Laudis are postemergent only

• Requires incorporation by rainfall, irrigation, or tilling (mechanical means) to activate
Pigment Inhibitors: Groups 13 and 27

- Interfere with normal chlorophyll formation
  - Command and Predict inhibit diterpene biosynthesis
  - Balance, Callisto, Impact, and Laudis inhibit the 4-HPPD enzyme
Pigment Inhibitors: Groups 13 and 27

- Command and Predict vapors can cause injury (bleaching) to surrounding plants
Pigment Inhibitors: Groups 13 and 27

- Affected plant tissue turns white or does not emerge at all
- Older tissue is affected first
Pigment Inhibitors: Groups 13 and 27

• Label warning, precautions, and restrictions about off-site movement

SPECIAL PRECAUTION
Off-site movement of spray drift or vapors of Command® 3ME herbicide can cause foliar damage to making applications. Read all instructions in the APPLICATOR PRECAUTIONS and SPRAY DRIFT PRECAUTIONS.

DIRECTIONS FOR USE
It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

SPRAY DRIFT PRECAUTIONS
Non-target spray drift of Command 3ME herbicide should be avoided to prevent whitening of desirable plants. Drift is influenced by many factors which include wind speed, spray pressure, particle size, nozzle type, and boom height.

• Do not apply when weather conditions favor drift.
• Use a minimum spray volume of 10 gallons per acre.
• Use the lowest possible boom height while maintaining a uniform spray pattern, in conjunction with nozzle type, size, operating pressure and volume that meet a droplet size classification of coarse or greater.

Refer to Spray Drift Management Section for additional instructions.
Pigment Inhibitors: Groups 13 and 27

- Label restrictions
- Require buffers around sensitive sites
- Do not apply when winds are above 10 mph

**APPLICATION PRECAUTIONS IMPORTANT**

FAILURE TO OBSERVE THE PRECAUTIONS IN THIS SECTION OF THE LABEL MAY RESULT IN INJURY TO SENSITIVE PLANTS

- The microencapsulation of clofamazone, the active ingredient in Command 3ME, is intended to minimize movement away from the site of application. Avoid making applications when spray particles may be carried by air currents to areas where sensitive crops and plants are growing, or when temperature inversions exist. Leave an adequate buffer zone between the area to be treated and desirable plants. Coarse sprays are less likely to drift out of the target area than fine sprays.

- Foliar contact with spray drift or vapors may cause foliar whitening or yellowing of sensitive plants. Symptoms are generally temporary in nature, but may persist on some plant species.

Application precautions must be taken as follows:

- Do not apply aerially or through irrigation equipment.
- Observe all buffer restrictions.
- Do not apply Command 3ME within 1,200 feet of the following areas: Towns and Housing Developments, Commercial Fruit/Nut or Vegetable\(^1\) Production, Commercial Greenhouses or Nurseries.

\(^1\)Except for peppers, pumpkins, succulent peas, sweet corn, sweet potato, and winter squash.

Before application, determine air movement and direction.

- Do not apply in winds above 10 miles per hour.

- Do not apply Command 3ME herbicide to non-field areas including fence rows, waterways, ditches, and roadsides.

- When moving spray equipment to noncontiguous sites, do not allow spray solution to spray or drip from tanks, hoses, fittings or spray nozzles and tips.

Refer to individual crop use directions for additional requirements.
Pigment Inhibitors: Groups 13 and 27

- Label restrictions identify what crops can follow these MOA applications to prevent carryover

ROTATIONAL CROP RESTRICTIONS

Rotate to Crops as listed below, otherwise crop injury may occur.
Refer to section headed “Rotational Cropping Precautions.”

NOTE: When using Command 3ME with other registered herbicides always refer to rotational restrictions and precautions on the other product’s label.
Summary

Herbicide modes of action

• Herbicides are classified based on specific properties, such as mode of action
• The herbicide’s mode of action determines its effects on the plant and potential risks
• Use Group Numbers to pick products with different modes of action to help prevent herbicide resistance
• Know the symptoms of various herbicide modes of action to diagnose herbicide injury
Presentation prepared by:
Bill Riden, Ed Crow, and Jon Johnson, Penn State Extension, Pesticide Education Program

Sources:
Dr. William Curran, Weed Scientist, Penn State University.
Dwight Lingenfelter, Weed Science Program, Penn State University
Ed Crow, Penn State Extension, Pesticide Education Program

Photos: Penn State Extension Pesticide Education Program; Maryland Department of Agriculture – Pesticide Regulation Section; Art Gover, Penn State

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