HOW DOES HERBICIDE RESISTANCE EVOLVE?

Herbicides do not cause resistance by changing the plant's genetic material, but by applying selection pressure.

Sometimes individual plants within a population have rare, but naturally occurring characteristics that allow them to survive herbicide applications (i.e. mutations, gene upregulation, etc.). The herbicides SELECT for the survival of these plants in a population. This is an evolutionary process that happens over time.

Application of herbicide on to the weeds

Kills the susceptible populations

Resistant population survives

Resistant population passes on its traits to future generations

Resistant population starts to exist is greater numbers

Resistant population dominates

Sustained use of either the same herbicide or herbicides with the same site of action, favors survival and reproduction of resistant population.

Contact Breanne Tidemann (breanne.tidemann@agr.gc.ca) for more information.

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HERBICIDE RESISTANCE

AN INTRODUCTION

WHAT IS IT?

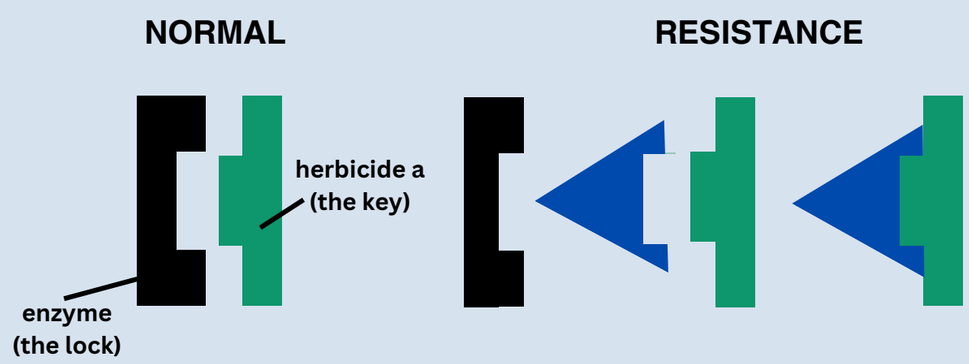
Herbicide resistance is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type.

TYPES OF RESISTANCE

Resistance occurs when the processes required for the herbicide to work are modified.

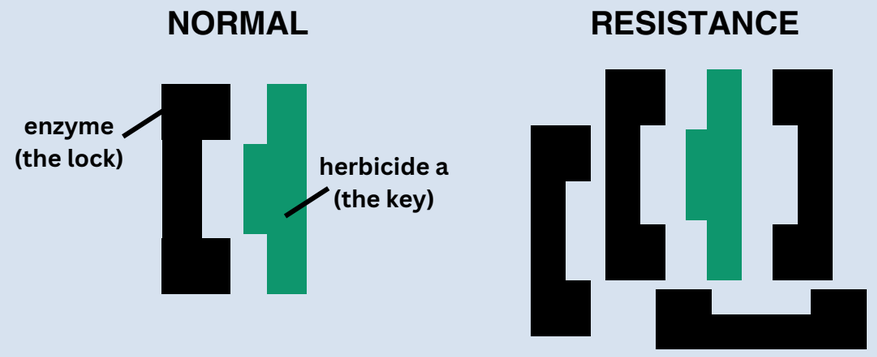
- Some of the processes by which resistance occurs can be compared to a lock and key. The key will not work on the lock anymore if:
  i. The lock is slightly modified (Altered Target Site)
  ii. There are too many locks and only one key (Upregulation of Target Site)
  iii. The key is broken (Metabolic)
  iv. The key is put away somewhere it is not accessible (Compartmentalization)
  v. The key is not able to be used in all the locks throughout the house (Reduced Translocation)
  vi. The key is not able to be inserted into the lock because something is blocking the entrance (Reduced Absorption)

COMPARTMENTALIZATION (PUT AWAY KEY)



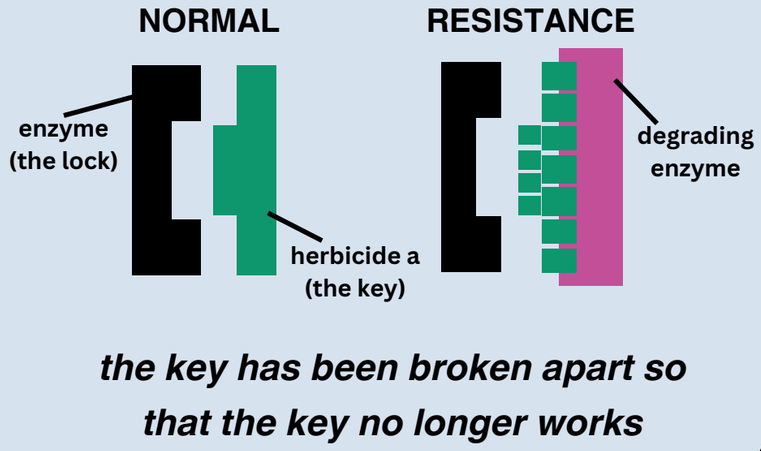
the key has been put away in a bag so that the key no longer can be used

UPREGULATION OF TARGET-SITE (INCREASED NUMBER OF LOCKS)



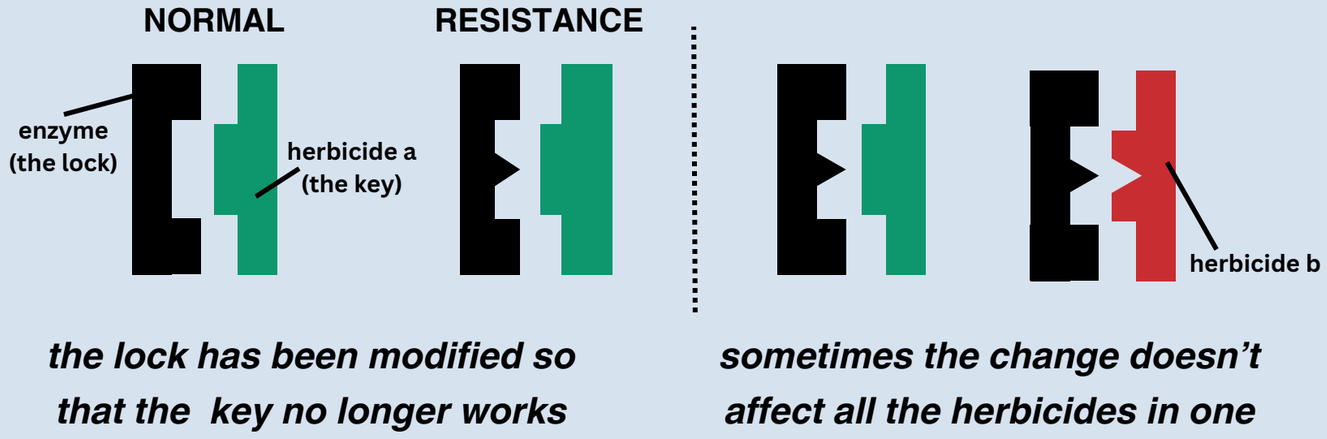
only one key but a lot of locks

METABOLIC (BROKEN KEY)



the key has been broken apart so that the key no longer works

TARGET-SITE (MODIFIED LOCK)



the lock has been modified so that the key no longer works

sometimes the change doesn't affect all the herbicides in one group

There are many mechanisms of resistance. You can't tell by looking at a resistant plant which mechanism it has. However the mechanism is important as it determines if the resistance is to one herbicide, one herbicide mode of action, or multiple modes of action.

RESOURCES

1. https://doi.org/10.1074%2Fjbc.REV120.013572
2. https://doi.org/10.3390%2Fplants8100382
3. https://doi.org/10.3390%2Fplants8100417

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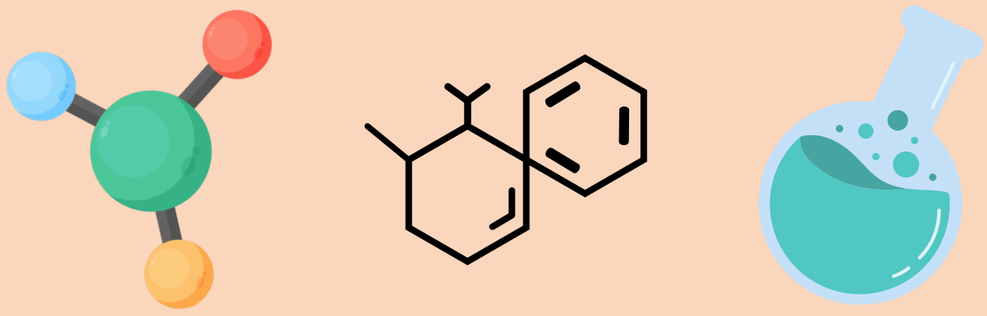
INTEGRATED
WEED MANAGEMENT

WHAT IS IT?

Integrated weed management (IWM) is a comprehensive approach that combines various weed management strategies including cultural, biological, chemical and physical methods.

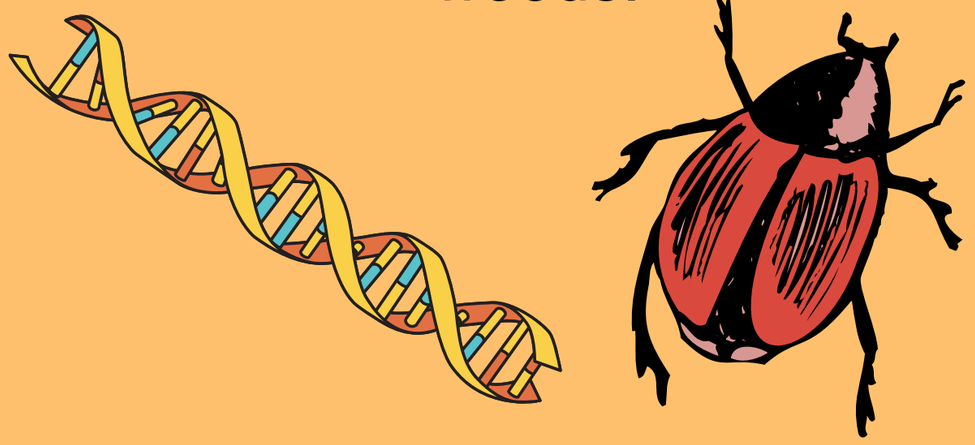
CHEMICAL

This involves the use of chemical substances, such as herbicides, that are designed to disrupt the growth and development of weeds.



BIOLOGICAL

This method involves the use of living organisms, most often insects or pathogens, to control or suppress weeds.



PHYSICAL

This involves mechanical methods that remove, damage or bury weeds and their seeds such as tillage, mowing, electricity and lasers.

CULTURAL

This involves manipulating the crop environment to make it less favorable for weed growth such as using diverse crop rotation, cover cropping and increased seeding rates.

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BIOLOGICAL

STRATEGIES OF WEED MANAGEMENT

WHAT IS IT?

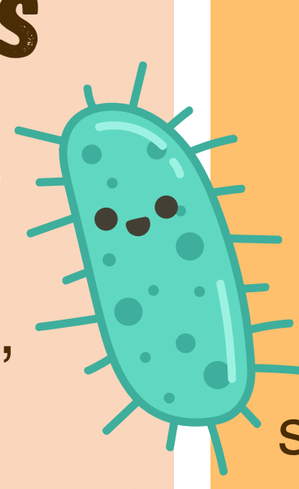
This method involves the use of living organisms, most often insects or pathogens, to control or suppress weeds

GRAZING ANIMALS

Introduce grazing animals that preferentially consume weeds. Important to note that not all weed seeds are destroyed by digestion, and some animals digest seeds better than others

BIOLOGICAL AGENTS

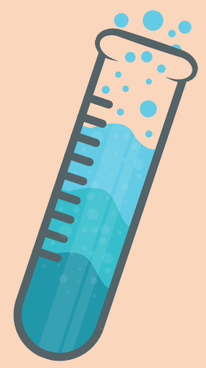
Introduce or enhance populations of natural enemies like predatory insects such as beetles or weevils, or pathogens that target specific weeds.



Biological control uses living organisms to control weeds so there are challenges to storing, transporting and applying/releasing the organisms while keeping them alive in an economical, practical manner.

ALLELOPATHY

Chemicals released by plants that affect the growth, development or germination of other nearby plants



SELECTIVITY CONUNDRUM

Is described as the challenge in achieving a balance between effectively controlling target weeds while minimizing the impact on non-target plants. This is a result of specificity. Although this is beneficial, this can also make this method harder to use as often more than one agent is needed to target all the different target weeds.

Biological controls are more commonly used in perennial environments like pastures and natural areas. Annual crops are high disturbance and a difficult environment for introduced insects and diseases to survive. In Canada our cold winters also pose a survival challenge

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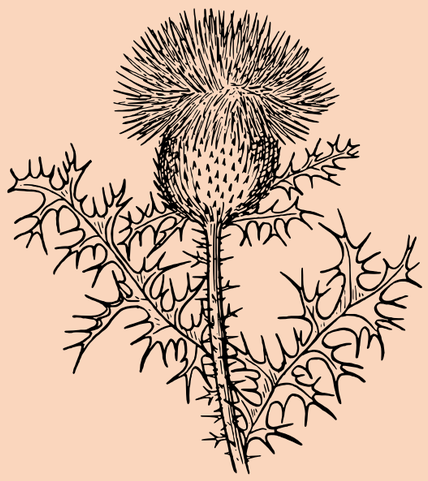

CULTURAL
STRATEGIES OF WEED MANAGEMENT

WHAT IS IT?

This involves manipulating the crop environment to make it less favorable for weed growth such as using diverse crop rotation, cover cropping, plant density and row spacing. Other cultural strategies include things like planting depth, planting speed, fertility rate and placement decisions.

CROP ROTATION

Planting different crops in sequence on the same field, disrupts weed life cycles. Also, using crops with different life cycles (perennial vs. annual, fall planted vs. spring planted) is most effective. Weeds quickly adapt to consistent environments so diversity in cropping rotations is important.

COVER CROPPING

Planting crops in the time between main crops being grown to cover soil surface and suppress weed growth through shading and competition. It is the most effective where growing seasons are long enough to allow the cover crop to accumulate substantial biomass. There can be challenges in Canada with short growing seasons and limited moisture.

PLANT DENSITY AND ROW SPACING

Increasing the number of plants and modifying the spacing between rows to create a more competitive crop by minimizing the the available sunlight for weed growth. Plant density, in particular, shows consistent ability in research to reduce weed densities and biomass.

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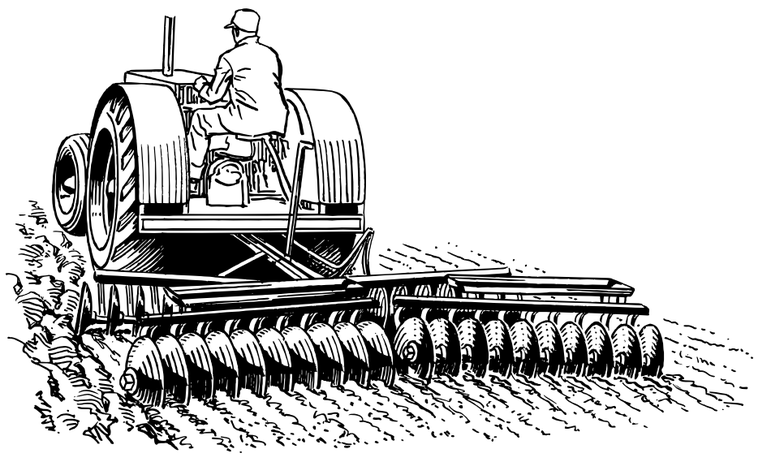
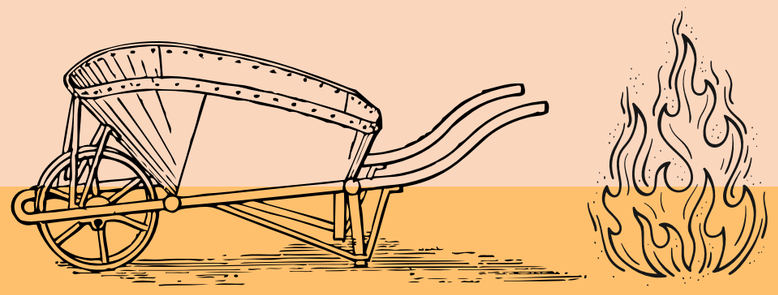


PHYSICAL

STRATEGIES OF WEED MANAGEMENT

WHAT IS IT?

A method that involves mechanical strategies that remove or damage weeds such as hoeing, mowing, cultivating, and mulching. Modern physical strategies in development include electricity, fire, lasers, impact mills and robots. This strategy targets both weed plants and weed seed.



HAND REMOVAL

To cut or chop plants or move soil in order to disrupt and move weeds via hoeing, hand pulling, machetes, etc. This is not as common in Canadian agriculture, but does happen in high value crops.

MOWING

Cutting weeds at or near ground level to suppress weed growth and prevent seed production

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CULTIVATION

Uproots or buries weeds and seed through methods such as tillage including discs, cultivators and ploughs. It’s most effective on small seeded weeds

MULCHING

Applying mulches to suppress weed growth by preventing sunlight penetration and providing a barrier for weed emergence. There are 2 categories, organic such as bark and compost, and inorganic such as plastic or “weed barrier” fabrics. Mulching is more common in horticulture crops.

HARVEST WEED SEED CONTROL

Manage the weed seeds still in the field at harvest and prevent dispersal through methods such as the chaff cart and seed impact mill.

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TARGET SITE
HERBICIDE RESISTANCE

WHAT IS IT?

How is resistance acquired?

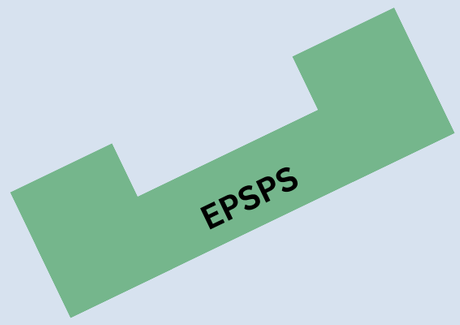
- Changes in the nucleotide sequence (instructions), also known as mutations, that are responsible for creating the target site (end product).
- Mutations can present in different ways for example, as deletions (part of the instructions are deleted), substitutions (part of the instructions are replaced) or duplications (part of the instructions are copied to another part).

What is target site resistance?

- The target site is where the herbicide acts. In target-site resistance, a change occurs to this site that prevents the herbicide from binding or interacting at its site of action. As a result, the effect of the herbicide is reduced or eliminated.

AN EXAMPLE USING 5-ENOLPYRUVYLSHIKIMATE-3-PHOSPHATE SYNTHASE (EPSPS)

- EPSPS is the target enzyme for glyphosate
- EPSPS is key in the shikimate pathway. The shikimate pathway produces products that are vital for plant growth and development



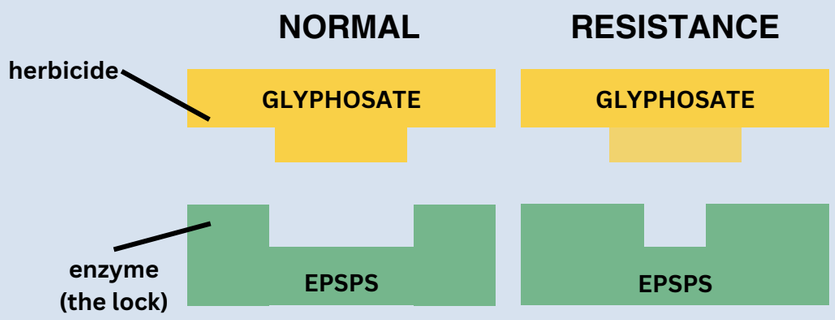
MODIFICATION

What is it?

- Changing the target site so that the herbicide cannot access it, thus leaving the herbicide ineffective

Where does the mutation occur?

- Known EPSPS target site mutations are Pro-106 to Ser, Thr, Ala, or Leu
- Pro-106 provides part of the molecular structure at the active site
- Changing Pro-106 = changing spacing in the active site.



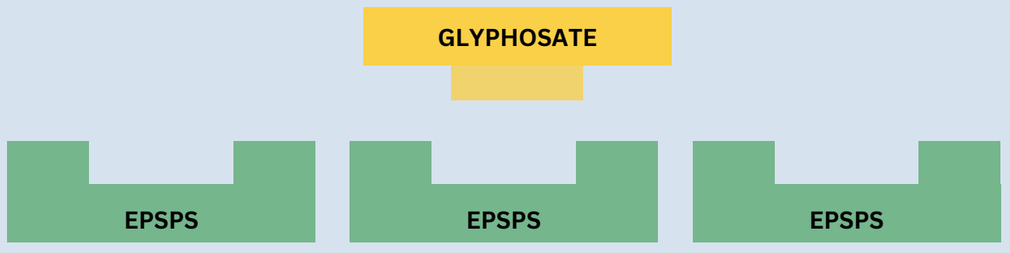
UP-REGULATION

What is it?

- Increased expression of the target site, there are extra gene copies in the DNA sequence which results in increased expression, requiring more herbicide

How does this happen?

- As a result of higher EPSPS mRNA (instruction) expression.
- More instructions = more products to create = more herbicide needed for the same effect



RESOURCES

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TARGET SITE
HERBICIDE RESISTANCE

AN EXAMPLE USING PROTOPORPHYRINOGEN OXIDASE (PPO)

- The PPO enzyme, is required for catalyzing the last step of plant heme and chlorophyll biosynthesis.
- The inhibition of the PPO enzyme leads to the accumulation of intermediates and eventually highly reactive oxygen species.

MODIFICATION

What is it?

- Changing the target site so that the herbicide cannot access it, thus leaving the herbicide ineffective.

Where does the mutation occur?

- Deletion of a Gly codon at position 210
  - This is proposed to partially unravel an α-helix adjacent to the PPO active site, enlarging the active-site cavity.
- Substitutions of Arg-128 (or 98, depending on the numbering system) to Leu, Gly, or Met.

FUN FACTS

- Target site mutations are easier to identify and understand.
- Management recommendations have been based on understanding of target site resistance
- The first DNA change conferring evolved target-site resistance to be confirmed was to triazines in 1983, over 25 years after the first report of herbicide resistance.
- One plant can have both target and non-target site mechanisms.
  - Typically test for target site first
  - Even if target site resistance is identified, it is also possible that there is non target site resistance.
- The most common target site mutation is in the ALS enzyme
  - Pro-197 mutations are one of the most frequent mutations in resistant plants.
    - 40% of ALS resistant species have this mutation

RESOURCES

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NON-TARGET SITE
HERBICIDE RESISTANCE

WHAT IS IT?

How is resistance acquired?

- As a result of selection pressure created by herbicide applications over time to diverse weed populations.

What is non-target site resistance?

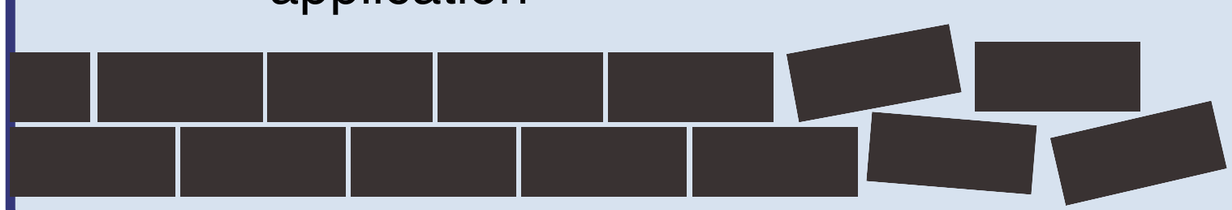
- Non-target-site resistance encompasses any mechanism that reduces the amount of herbicide that reaches the target site.
- Changes are not made to the target site enzyme, however changes are made in the plant that affect the ability of the herbicide to interact with the target site enzyme.

COMPARTMENTALIZATION

An example of this is with glyphosate. ABC transporter proteins have been proposed to sequester glyphosate via active glyphosate transport

METABOLIC

- An example of this is with ACCase. ACCase is a crucial enzyme that catalyzes the formation of malonyl CoA, a product needed for de novo fatty acid biosynthesis, and is essential for plant survival. ACCase-inhibitors (herbicides) cause problems in malonyl CoA formation in sensitive grass species, ultimately leading to plant death.
- Metabolic resistance involves the increased activity of enzyme complexes.
    - **Cytochrome P450s (CYP450s)**
        - It is likely that metabolism of ACCase-inhibitors occurs through a wheat-like detoxification pathway mediated by CYP450s
    - **Glutathione S-transferases (GSTs)**
        - Also been documented to govern the metabolic resistance to ACCase-inhibitors
        - There can be greater GST activity in resistant plants following ACCase-inhibitor application

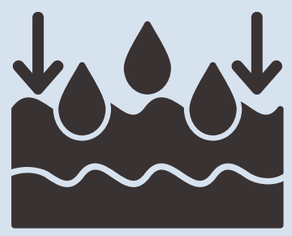


TRANSLOCATION

Modified translocation, can be increased or decreased. An example for decreased translocation is 2,4-D in oriental mustard that was retained in the treated leaves. An example of increased translocation is MCPA in wild radish that showed rapid translocation to the roots away from target site.

ABSORPTION

Properties of the leaf cuticle or other structural barriers can affect the ability of the herbicide to enter.



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