How Herbicides Function
How Herbicides Function

How Herbicides Function
Herbicide Movement to the Target
Herbicide Binding
Herbicide Selectivity
Herbicide formulations
Herbicide compatibility
Herbicide toxicity/withholding periods
Adjuvants and dyes
Key Points from Herbicide Function
How Herbicides Function

The herbicide molecule inhibits one step within a biochemical pathway which eventually results in plant death for the weed.

Selectivity mechanisms keep the non-target plant safe.

Generally, many processes must occur before the herbicide reaches the site of action.

Understanding the processes helps to make sense of what can and does occur in the field.
How Herbicides Function – a multi-step process

Understanding processes separately and together explains “real life”
– The sum of individual processes determines overall activity

Each step (ring) is a process. Notice similarities between foliar and soil applications

Success with one process does not always assure the herbicide will work well

Desired effect on an enzyme target is different for a weed (to kill) and the non-target plant (to keep safe)
How Herbicides Function
– a multi-step process

Focusing on the uptake and translocation processes
– Two processes with different characteristics

The foliar and soil pathways have different entry points (e.g. leaves versus roots)

Chemical, environmental and application factors influence herbicide movement in plant

The chemical properties of the herbicide determine if it has systemic of contact action
Herbicide Movement to the Target
– two pathways: root and foliar

Root pathway
– Upward movement via xylem
– Herbicide enters via root
– Driven by transpiration

Foliar pathway
– Translocation via the phloem
– Herbicide enters via leaves
– driven by photosynthesis

Consider factors that influence the movement in each pathway
Herbicide Movement to the Target – root pathway characteristics

Factors affecting movement via the root pathway

<table>
<thead>
<tr>
<th>Beneficial factors</th>
<th>Detrimental factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Herbicide</strong></td>
<td><strong>Binding to soil</strong></td>
</tr>
<tr>
<td>Soluble in soil water</td>
<td>Soil pH</td>
</tr>
<tr>
<td></td>
<td>Organic mater</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td><strong>Extreme weather</strong></td>
</tr>
<tr>
<td>Good soil moisture</td>
<td>Plant stresses</td>
</tr>
<tr>
<td>Fast transpiration</td>
<td></td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td><strong>Poor coverage</strong></td>
</tr>
<tr>
<td>High water volume</td>
<td>Uneven incorporation</td>
</tr>
<tr>
<td>Activation via rain / tillage</td>
<td></td>
</tr>
</tbody>
</table>
Herbicide Movement to the Target – foliar pathway characteristics

Factors affecting translocation via the foliar pathway

<table>
<thead>
<tr>
<th>Beneficial factors</th>
<th>Detrimental factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide</td>
<td></td>
</tr>
<tr>
<td>● Penetrates leaf wax</td>
<td>● Works too fast (may limit uptake)</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
</tr>
<tr>
<td>● Promotes active growth</td>
<td></td>
</tr>
<tr>
<td>● Low plant stress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Cloudy, cool weather</td>
</tr>
<tr>
<td></td>
<td>● Plant stresses</td>
</tr>
<tr>
<td></td>
<td>● Rainfall</td>
</tr>
<tr>
<td>Application</td>
<td></td>
</tr>
<tr>
<td>● Low drift</td>
<td></td>
</tr>
<tr>
<td>● Correct adjuvant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Poor equipment</td>
</tr>
</tbody>
</table>
Herbicide Movement to the Target – pathways vs. systemic action

**Systemic herbicides**
- chemical properties make it systemic
- translocated in foliar path
- uptake is critical, will translocate

**Contact herbicides**
- chemical properties make it immobile
- not translocated out of leaf
- coverage is critical, won’t translocate

Herbicide applied to the foliage are not always systemic
Herbicide Movement to the Target – review of key points

Two pathways for herbicide movement to the target

Root pathway
- Herbicide enters via root, upward movement via transpiration
- Herbicide movement supported by good growing conditions

Foliar pathway
- Herbicide enters via leaves, photosynthesis drives translocation
- Herbicide movement supported by good growing conditions

Foliar herbicides may be systemic or contact
- Chemical properties determine the ability to translocate
Herbicide Binding
– cell components and function

Each plant cell is multi-site chemical factory

Thousands of biochemical reactions are carried out simultaneously
Inhibition of a single step in a biochemical pathway can kill the cell
– Herbicides are designed to inhibit one step
How Herbicides Function
– a multi-step process

Focusing on the herbicide binding to target process
– Binding results in non-functional enzyme and eventually death

Plant cells are chemical factories with many enzymes doing the work

Herbicides are designed to bind specifically to key enzymes in a biochemical pathway

Once bound, the non-functional enzyme stops pathway leading to cell/plant death
Herbicide Binding
– possible fates of herbicide in cell

- Degradation
- Storage (sequestration)
- Vacuole
- Herbicide activity
- Desired for weed control
- Bound to other cell components
Herbicide Binding
– the “lock and key” analogy

Normally, precursors temporarily bind to enzymes
- “Lock and key” analogy very specific binding requirements

When designed correctly, herbicides will bind to the enzyme
- Herbicides bind strongly making enzyme unavailable and non-functional for the normal function
Herbicide Binding – binding stops normal function

Unbound target (normal function)

Enzyme function is to convert precursors to products used in plant growth and function

Bound target (non-functional)

- Non-functional enzymes can cause many problems in plant cell:
  - Accumulation of toxic precursors
  - Starvation of later enzymes
- Eventually results in plant death
Herbicide Binding
– review of key points

Binding results in non-functional enzyme and eventually cell and plant death

The plant cell
– Herbicides inhibit one enzyme in a biochemical pathway

Herbicide binding to the target enzyme
– Once bound, the enzyme is non-functional

Non-functional enzymes causes several main problems
– Accumulation of toxic precursors
– Starvation of later enzymes and processes
– Either situation results in plant death
How Herbicides Function
– a multi-step process

Focusing on the herbicide *not* binding to the target
– details of herbicide selectivity in non-target plants

Plant safety or “Selectivity”:

Metabolic basis
- degrade herbicide

Avoidance basis
- reduce or eliminate herbicide contact with non-target plants (correct application method)

Target basis
- target enzyme in non-target plant is different than weed
Herbicide Binding
– possible fates of herbicide in cell

- Degradation
- Storage (sequestration)
- Desired for non-target plant safety
- Herbicide activity
- Bound to other cell components
Herbicide Selectivity
– three key mechanisms

Selectivity: Killing weeds without injuring the non-target plants

Metabolic selectivity
– Degradation of herbicide by metabolic enzymes
– Safeners boost activity of metabolic enzymes

Positional selectivity
– Herbicide and non-targeted are physically separated

Target selectivity
– Non-target plant enzymes structurally different than weed enzymes (e.g., broadleaf vs grass)
Herbicide Selectivity – metabolic basis

Herbicides in plants are degraded by specialized enzymes that attack foreign molecules
- The herbicide is destroyed before it binds to the target
- Plants can also be genetically modified by bacterial genes to either tolerate or produce degrading enzymes

Crops have more herbicide degrading enzyme than weeds

<table>
<thead>
<tr>
<th>Species</th>
<th>relative amount of degrading enzymes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>182.4</td>
</tr>
<tr>
<td>Sorghum</td>
<td>102.1</td>
</tr>
<tr>
<td>Giant Foxtail (Setaria)</td>
<td>52.1</td>
</tr>
</tbody>
</table>

Also, the enzyme capacity is often higher in crops that weeds
**Herbicide Selectivity**  
– metabolic basis

**Crop:** Particularly high activity of degradative enzymes  
– decrease concentration at active site  
– inactivate herbicide rapidly  
– prevent binding to target  
– keep crop safe

**Weed:** Low activity of degradative enzymes  
– higher concentration of herbicide at active site  
– herbicide slowly inactivated  
– intensive binding to target  
– full weed control

*Case Study: Flufenacet metabolism in corn and sorghum*
Herbicide Selectivity  
– flufenacet metabolism study

Metabolic research with flufenacet
– herbicide intended primarily for soil application
– taken up primarily by the roots and translocated to the meristematic tissues
– cell division inhibitor, oxyacetamide chemistry, Group K
– metabolism in corn by glutathione conjugation
– symptoms in corn are strong plant stunting and leaf curling
– complete reversal of the inhibitory effects in corn by simultaneous treatment with dichloroacetamide safeners (eg dichlormid) by competing with herbicides for the same site of action
– The rates of metabolism of flufenacet in the shoots and the roots of different grass species can differ
Herbicide Selectivity – flufenacet metabolism study

Flufenacet metabolism in roots of two grasses

Corn roots rapidly metabolized flufenacet
Sorghum roots were very slow

Flufenacet metabolism in shoots of two grasses

Corn shoots rapidly metabolized flufenacet
Sorghum shoots were very slow

Herbicide Selectivity – metabolic basis

Non susceptible plants avoid damage by degrading the herbicide quickly.

- Slow degradation in weed - high concentration kills cells
- Fast degradation in crop - damage unlikely

Herbicide application

Herbicide concentration in plant cell

Damaging concentration

Time
**Herbicide Selectivity**

– safeners boost metabolism

Safeners induce degradation enzymes in crop
- Chemicals that target weeds and increase the tolerance level of crop plants to herbicides
- Allow herbicides to be applied at higher rates whilst protecting the crop
- Unique chemicals causing plant to produce more degradation enzymes
- Must be taken up in the plant to be effective
- Used for soil and foliar herbicides
- Safeners categorised into 3 groups:
  - Dichloroacetamide (eg dichlormid, benoxacor, furilazole, dietholate)
  - Oximes (eg cyabetrinil, oxabetrinil, fluxofenim, flurazole, naphthalic anhydride)
  - Fenclorin, fenchlorazol
- Growth inhibition in some plants caused by oxyacetamide, tetrazolinone or chloroacetamide herbicides can be completely reversed with a combination of the amino acids proline and arginine or oleic acid
- Furilazole (a dichloroacetamide faster) has very good safening effect on sulfonyleureas (Group B), particularly halsulfuron
- Fenclorin is the safener in pretilachlor (Group K, effective against annual grasses, broad-leaved weeds and sedges in transplanted and seeded rice) to protect rice
Herbicide Selectivity
– safeners boost metabolism

Safeners induce faster degradation of the herbicide
Time Lapse - Mode of Action - Safener

Application Method
Pre-emergence

What to Observe
Sorghum is more sensitive than Corn
Corn grows with or without safener
Sorghum metabolism boosted by safener
Sorghum grows normally with safener

Day: 5

Safener Protecting Sorghum
Pre-emergence
Corn (rear)
Sorghum (front)

Treated  Control
Herbicide Selectivity – avoidance basis

- Selective herbicides are chemicals that are more toxic to one plant than another

- When these herbicides applied to a mix of plants, some are killed while others are either slightly or not at all affected

- Many factors influence the selectivity and activity of herbicides

- 4 main important selectivity factors
  - morphological or structural differences
  - absorption
  - translocation
  - physical differences
Herbicide Selectivity – morphological or structural differences

- Structural differences permit selective application of herbicides
  - Tall plants with chemically tolerant stems allow easy application of herbicides to weeds near the ground level
Herbicide Selectivity – morphological or structural differences

- Protection of the plants growing region from herbicide injury
  - Broadleaf plants have exposed growing tips at the tips of shoots and leaf axils

- Growing points of grasses are near or at the base

- Deep-rooted plants are often tolerant to chemicals which remain primarily in the soil surface allowing shallow-rooted plants to be killed
Herbicide Selectivity – avoidance basis

Isolating the herbicide and deep rooted plant

- Herbicide in top layer – weeds absorb herbicide
- No herbicide below – deep rooted plant avoids uptake

- herbicide absorption results in weed control
- deep rooted plants do not absorb herbicide and are protected from damage
Herbicide Selectivity – morphological or structural differences

• Plant surface differences
  – Waxiness, hairiness of plant may prevent spray droplets from adhering to the leaf
Herbicide Selectivity – morphological or structural differences

- Plant surface differences
  - upper leaf surface of velvetleaf and lambsquarter
  - leaf surface characteristics influence how spray droplets and herbicides interact with the leaf

At lower magnification the globules that give lambsquarter leaves their powdery soft appearance are visible, whereas the 'star-shaped' leaf hairs can be seen on velvetleaf.

At higher magnification it can be seen that the surface of the lambsquarter cuticle is covered with waxy platelets.
Herbicide Selectivity – morphological or structural differences

- Plant surface differences
  - wettability of lambsquarter and velvetleaf leaf surfaces
  - epicuticular wax on the surface of leaves repels water
  - crystalline wax platelets on lambsquarter leaves reduce contact between the spray droplet and leaf, even with surfactants
  - contact was greater between water droplet and velvetleaf leaf surface without surfactant than on lambsquarter with surfactant
  - Application parameters (droplet size, spray additives, etc.) impact herbicide performance more on weeds with difficult to wet leaves than on species with leaf surfaces that are easily wetted
Positional Selectivity – metolachlor case study

Chloroacetamide safety in corn – controlling grass in grass

- Acetamides are a large, important chemical family that inhibit cell division, especially in grasses
- Acetamides are widely used for grass control in corn (which is also a grass)
- Herbicide selectivity often relies on two mechanisms of selectivity:
  - Metabolic – often with safeners to boost safety
  - Avoidance
- Sometimes the crop safety is still marginal…
Positional Selectivity – metolachlor case study

Acetamide injury to corn
- cell division inhibitor
- look for deformed plant
- look for shortened plants

Range of injury symptoms
- All plants from same field
- All the same variety
- Planting depth is only difference
Positional Selectivity – metolachlor case study

Closer view, same plants
- Shallow planting is clear
- Seeding < 2cm = injury
- Seeding > 2cm = safety
- Both metabolism and positional selectivity are beneficial for some herbicides

soil surface at red line
seed depth at blue line
coin is ~ 2.5cm
Positional Selectivity – using shrouded/shielded hoods

To reduce drift and injury

Uses include weed control in:

- Orchards
- Vineyards
- Amenity
- Highways
- Forestry
- Waterways
- Grassland
Herbicide Selectivity – absorption

- Movement of a material into the plant from an external source (usually leaves and roots) = absorption

- For herbicide to be effective must enter the plant
  - Some plant surfaces absorb herbicides quickly
  - Other plant surfaces absorb slowly or not at all

- Herbicide leaf penetration is through the leaf surface or stomates

- Polarity of leaf surface and herbicide used important
  - Waxy cuticle and cellulose of leaves and stems are nonpolar
  - Nonpolar (organic substances) include oils, waxes, 2,4-D ester
    - Polar compounds include water, amino acids, 2,4-D salt

- Nonpolar herbicides absorbed faster than polar herbicides

- Roots absorb polar herbicides the best, nonpolar herbicides are absorbed slowly or not at all
  - Picloram ( ), dicamba ( ) are examples of root-absorbed herbicides
Herbicide Selectivity – positional basis

Key elements to maximize positional selectivity
depth of herbicide incorporation
depth of seeding
spray equipment
  – correct position of herbicide for maximum efficacy
absorption capacity of soils with high organic matter or heavy crop residues require higher herbicide rates
avoid risk of herbicide leaching into non-target root zone
Herbicide Selectivity
– review selectivity mechanisms

Selectivity:
Killing weeds without injuring non-target plants

Metabolic selectivity
– Degradation of herbicide by metabolic enzymes
– Safeners boost activity of metabolic enzymes

Positional selectivity
– Herbicide and non target are physically separated

Target selectivity
– Crop enzymes structurally different than weed enzymes
How Herbicides Function
– a multi-step process

The sum of individual events determines overall efficacy
– details of herbicide selectivity in crops

The specifics of how a herbicide binds to the target enzyme and eventually kills the plant is termed:

“Mode of Action”

This will be illustrated shortly for a selected groups of herbicides
Key Points from Mode of Action

How herbicides function
- Herbicides inhibit one enzyme in a complex biochemical pathway
- How it does that is a multi-step process

Herbicide movement to the target site
- Herbicide move in the root or foliar pathway

Herbicide binding
- When bound to the target enzyme, the plant will eventually die

Herbicide selectivity
- Herbicide binding to target is prevented by metabolic degradation, positional separation, or target differences
Herbicide formulation

- Herbicides are usually formulated prior to use by chemical manufacturers so that the active ingredient applied easily and safely
  - Consist of:
    - **Active ingredient** (the chemical that controls the targeted weed)
    - **Diluent** (help dissolve the active to make it safer, more effective, easier to measure, mix, apply, convenient to handle) (can be water or oil-based solvents)
    - **Inert ingredient** (dusts or granules)
    - **A gas** (aerosols)

- To maintain formulation stability additives are also added such as solvents, emulsifiers, stabilisers and suspending agents

- To improve efficiency of application additional additives (wetting agents, anti-evaporants, thickeners and stickers) are added

- Single active can be sold in several formulations (acid, ester or salt)
Herbicide formulation – Liquid formulations

Most herbicides are formulated as solution – where the active is dissolved in water, an organic solvent, or oil to form a liquid with no suspended particles.

These formulations are further diluted with a carrier liquid (usually water can be petroleum-based eg diesel) prior to spraying.

Will not settle out or separate.

Water quality becomes important as it can influence the stability of the spray mixture.
Herbicide formulation – Liquid formulations
**EMULSIFIABLE CONCENTRATES (EC)**

- **Consists of:**
  - Active ingredient insoluble in water
  - Emulsifying agent
    - Polar - usually poor (acetone & alcohols)
    - Nonpolar - usually good (xylene & kerosene)

- Allow the formulation to be mixed with water to form an emulsion (oil in water) which remains dispersed when mixed with water

Each liter of EC may contain 20 to 80% AI
Used under a wide range of conditions
Herbicide formulation – Liquid formulations
EMULSIFIABLE CONCENTRATES (EC)

• Advantages
  – Easy to handle, transport & store
  – Little agitation required
  – Not abrasive
  – Will not plug screens or nozzles
  – Little visible residue on treated surfaces

• Disadvantages
  – Easy to over or under dose
  – May cause unwanted harm to plants
  – Easily absorbed through skin
  – Cause rubber & plastic to deteriorate
  – Harm painted surfaces
  – Flammable
  – Corrosive
Herbicide formulation – Liquid formulations

EMULSIONS (E)
- Chemical is dispersed in a liquid in which it is insoluble
- Only a few products of this type (eg white oils)

READY-TO-USE (RTU)
- Contain correct amount of solvent
- No further dilution required
- Usually contain small amounts of AI (1% or less)

ULTRA-LOW-VOLUME (ULV)
- Approach 100% AI
- Use as is or with small amounts of water (5 litres or less)
- Used mostly in outdoor applications
  - Agricultural
  - Forestry
  - Ornamental
Herbicide formulation – Liquid formulations
ULTRA-LOW-VOLUME (ULV)

• Advantages
  – Easy to handle, transport & store
  – Little agitation required
  – Not abrasive
  – Will not clog screens or nozzles
  – Little visible residue on treated surfaces

• Disadvantages
  – High drift hazard
  – Need special application equipment
  – Solvents can deteriorate rubber and plastic
Herbicide formulation – Liquid formulations

FLOWABLES (F)

- Are insoluble solids
- Finely ground actives mixed with a liquid plus inert ingredient to form a suspension
- Mixed with water for application

- Advantages
  - Seldom clog nozzles
  - Easy to handle and apply

- Disadvantages
  - Require moderate agitation
  - May leave a visible residue
  - May separate
  - May cake in container or sprayer
Herbicide formulation – Liquid formulations
INVERT EMULSIONS (water-in-oil)

- Water soluble pesticide dispersed in an oil carrier
- Form large droplets which reduce spray drift
- Used in vegetation control along rights-of-ways and to control submerged aquatic weeds
- Invert formulations tend to “stick” to plants
- Structured to float or sink (weighting agent – ammate, sugar or inert salt like sodium sulfate)
- Invert emulsions can be formulated to persist for 72 hours or breakdown in minutes
- Require special equipment, expensive, reduced coverage
Herbicide formulation – Dry formulations

GRANULES (G)

Most are ready-to-use

Granular sizes range from 200 to 2000um diameter (very large granules called grid balls >10000um)

Formulations normally contain granules of mixed sizes

Made from adsorptive materials
  - Attapulgite clay, Fuller’s earth, corn cobs, walnut shells

Active is impregnated onto the granule or is absorbed

Active is usually low (1 to 20%)

Usually applied to soil to control weeds
Herbicide formulation – Dry formulations
GRANULES (G)

Advantages

– Ready to use
– Low drift hazard
– Penetrate dense foliage
– Usually requires simple application equipment
– More accurately placed close to the target plant
– *Usually the safest formulation to handle

Disadvantages

– Will not stick to target (may move with rain)
– May need incorporation into soil
– May need moisture to activate
Herbicide formulation – Dry formulations
PELLETS (P)

• Similar to granular formulations
• All are same size and weight (normally spherical shape)
  – Eg Tordon Picloram Granules (20% picloram)

Granules and Pellets are normally formulated as “slow release’ to extend the period of herbicide activity
Herbicide formulation – Dry formulations

WETTABLE POWDERS (WG)

- In these formulations the active, plus wetting and dispensing additives are in the form of very finely ground particles, 0.5-5.0 um diameter, looks like dust particles

- Dispense readily when mixed with the diluent, usually mixed with water

- Applied as a spray

- 5 to 95% AI

- Do not dissolve in water

- Will settle out unless constant agitation is used
Herbicide formulation – Dry formulations
WETTABLE POWDERS (WG)

Advantages
- Easy to store, transport & handle
- Less skin & eye absorption
- Less odour
- Method of applying insoluble pesticides as a spray

Disadvantages
- Inhalation hazard while mixing
- Requires constant agitation
- Often clog nozzles, filters, spraylines and screens
- Abrasive
- May be difficult to mix and measure
- May leave white deposit on surfaces
**Herbicide formulation – Dry formulations**

**SOLUBLE POWDERS (SP)**

- Look like WP
- Require initial agitation
- Dissolve easily
- Form a true solution in water
- AI ranges from 15 to 95%
- Have all advantages of WP
- Inhalation hazard while mixing
Herbicide formulation – Dry formulations
WATER-DISPERSIBLE GRANULES (WDG) or DRY FLOWABLES (DF)

- Are like WP

- Active is prepared as granule-sized particle

- Must be mixed with water

- Require constant agitation

- Same advantages & disadvantages as WP

- More easily measured & mixed than WP

- Cause less inhalation hazard than WP
Herbicide formulation – Dry formulations

**OTHER FORMULATIONS**

- **MICROENCAPSULATED PESTICIDES (M)**
  - May be liquid or dry surrounded by plastic coating
  - Mixed with water & applied as a spray
  - Capsule slowly releases pesticide
  - Provides a timed release of pesticide

- **FUMIGANTS**
  - Form poisonous gas when applied
  - Some are liquid under pressure, change to gas when released
  - Some are liquid & change to gas when exposed to air
  - Some are solid & change to gas when exposed to water or high humidity

- **AEROSOLS (A)**
  - Small, self-contained units
  - Release pesticide when nozzle valve is triggered

- **SMOKE OR FOG GENERATORS**
  - Machines break the liquid into a fine mist or fog
  - Use a rapidly whirling disk or heated surface
  - Used mainly for insect control

- **DUSTS (D)**
  - Most are ready-to-use
  - Most contain low amounts of AI (0.5 to 10%)
  - Also contain a very fine dry inert carrier (talc, chalk, clay etc.)

- **BAITS (B)**
  - AI mixed with food or other pest attractant
  - Pests killed by eating pesticide contaminated bait
  - AI is usually low (<5%)
Herbicide compatibility

• Mixing of two or more herbicides can cause chemical or physical incompatibility leading to:
  – Application problems
  – Reduced efficacy
  – the production of new phytotoxic compounds

• Wherever possible, mixtures should be avoided unless recommended by the manufacturers or chemicals proven to be compatible

• Common practice to combine two or more herbicides in a spray mixture to save time, labour and machinery costs
Herbicide compatibility

Herbicide compatibility
Chemical incompatibility

- Chemical reaction between components in mixture
- Changes toxicity
  - Synergistic
    - Response induced by the herbicide > predicted sum of the individual herbicide applied alone

<table>
<thead>
<tr>
<th>Active</th>
<th>Rate (kg/ha)</th>
<th>%weed control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloramben</td>
<td>1.68</td>
<td>53</td>
</tr>
<tr>
<td>Chloramben</td>
<td>3.36</td>
<td>69</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>1.12</td>
<td>10</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>2.58</td>
<td>20</td>
</tr>
<tr>
<td>Chloramben + Trifluralin</td>
<td>1.68 + 1.12</td>
<td>97</td>
</tr>
</tbody>
</table>
Herbicide compatibility
Chemical incompatibility

• Chemical reaction between components in mixture
• Changes toxicity
  – Antagonism
    • Response induced by the herbicide < predicted sum of the individual herbicide applied alone

<table>
<thead>
<tr>
<th>Active</th>
<th>Rate (kg/ha)</th>
<th>%weed control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diclofop-methyl</td>
<td>0.84</td>
<td>80</td>
</tr>
<tr>
<td>Diclofop-methyl</td>
<td>1.12</td>
<td>90</td>
</tr>
<tr>
<td>2,4-D</td>
<td>0.56</td>
<td>9</td>
</tr>
<tr>
<td>Diclofop-methyl + 2,4-D</td>
<td>1.12 + 0.56</td>
<td>60</td>
</tr>
</tbody>
</table>

– Additive response
  • Response induced by the herbicide mixture = to the sum total of the responses observed when each herbicide applied alone (eg 40 + 50 = 90)
Herbicide compatibility

- If mixtures contemplated read the manufacturers label instructions

- Where the information is unavailable and mixtures are unavoidable (try mixing the two products on a small scale)

- If untried mixture is going to precipitate best to occur in a bottle than in the spray tank

- Absence of physical changes not foolproof indication of incompatibility

- Order of adding different formulations to tank:
  - Wettable powders and dry flowable first
  - Suspension concentrates and water soluble formulations
  - Then surfactants
  - Lastly spray oils and/or emulsifiable concentrate
Herbicide compatibility

Physical incompatibility

• Formation of precipitates

• Separation of components into layers

• Formation of gelatinous masses or suspended globules

• Physical incompatibility can be observed visually
  – it is highly recommended that a compatibility test be conducted on each batch of herbicides you plan to mix
Herbicide compatibility
Test for physical incompatibility

- Make up 500ml (or other appropriate volume) of herbicide mix in a clear glass using similar proportion of each ingredient as would have been applied to the spray tank

- Invert the container 100 times

- Allow to stand for 30 to 60 minutes

- If no precipitate or absence of oily layer, the mixture can be readily applied

- If precipitate or oily layer is formed, but shaking resolves problem, the mixture can be applied with vigorous agitation

- If precipitate or oily layer is formed and shaking does not resolve the problem, the mixtures should not be mixed together unless compatibility agents are added
Herbicide compatibility

- Always pre-slurry wettable powders
  - if added directly to tank, large globules of un-wetted material often occur
- tank mixtures of wettable powders and emulsifiable concentrates must be done properly
- pre-slurry wettable powders and add to tank that is $\frac{1}{2}$ to $\frac{3}{4}$ full of water
- add emulsifiable concentrate followed by necessary water
Herbicide compatibility
Water quality

- The most common diluent used is water – quality of water on farms is highly variable

- Ideally water should be:
  - Clear (dirty water cause blockage to nozzles and additional wearing)
  - Colourless Odourless
  - Low total solids (solids (clays) can bind to herbicides removing them from the spray mix as sediments eg glyphosate, paraquat)
  - Neutral pH (acid or alkaline water can hydrolyse herbicides – water >pH7 can be reduced by addition of monoammonium phosphate or monopotassium phosphate @ 0.5 to 1.0 g/L water)
  - Low salt levels (high salt levels cause phytotoxicity)
  - “Soft” water (hard water contains calcium and magnesium salts reduce the stability of suspensions or emulsions)
Herbicide compatibility
Test for water quality

• Make up 500ml (or other appropriate volume) of a 1 part herbicide to 9 part water mix in a clear glass

• Invert the container 100 times (shake for 1 to 2 minutes)

• Allow to stand for 30 to 60 minutes

• If water quality good no precipitate or absence of oily layer (ester – water milky, amine – water coloured)

• If water quality poor precipitate, crystallisation or layers observed layer (ester – water in layers, amine – crystals forming in water)

• If suspect water unsuitable a sample of water should be sent off for analysis
Herbicide toxicity

• Herbicides should be handled and applied with care

• Potentially harmful to humans, livestock and the environment

• Three basic properties related to herbicide toxicity
  – Type of hazard associated with each herbicide
  – Herbicide entry into the body
  – Relative toxicity of different herbicides
Herbicide toxicity
Type of hazard associated with each herbicide

- Acute poisoning – occurs rapidly after exposure of some bodily process to the direct chemical
  - Symptoms – muscular spasms, nausea, vomiting, diarrhoea, blurred vision, salivation, difficulty breathing

- Chronic poisoning – caused by repetitive small effects on specific organs – damage can be irreversible or not reversible before the next dose is added to it

- Slow accumulation of herbicides in fat tissues can also produce acute effects
Herbicide toxicity
Herbicide entry into the body

• Dermal (absorption through skin) absorption – most important entry route of herbicides and often not noticed until symptoms occur, occurs during
  » handling of concentrated herbicide
  » during application (if protective clothing not worn)
  – Dermal absorption more likely to occur during hot weather when skin is wet with perspiration and through cuts and abrasions
  – occurs rapidly after exposure of some bodily process to the direct chemical
  – Symptoms – muscular spasms, nausea, vomiting, diarrhoea, blurred vision, salivation, difficulty breathing

• Ingestion (oral absorption) – drinking herbicide, less common, occurs during
  » Sloppy handling during mixing
  » Use of unmarked containers (old drink containers)
  » Blowing out blocked nozzles with mouth
  » Eating, drinking, smoking while handling herbicides

• Inhalation – breathing herbicide spray or fumes is least common route of entry, occurs when
  » Handling highly volatile concentrated herbicides in confined unventilated spaces
Dermal (skin) absorption rates - body does not absorb pesticides at the same rate

- Scalp 3.7
- Forehead 4.2
- Ear canal 5.4
- Abdomen 2.1
- Groin area 11.6
- Forearm 1.0
- Palm 1.3
- Ball of foot 1.6

Forearm absorption rate 1 means head region will absorb pesticide 4 x more rapidly than forearm.
Herbicide toxicity

Relative toxicity of different herbicides

Human or mammalian toxicity levels usually extrapolated from effects on test animals or cases of accidental exposure.

Relative toxicity of a herbicide expressed in terms of median lethal dose or \( \text{LD}_{50} \) (dose needed to kill 50% of the test animals – expressed in mg of active per kg body weight of the test animal (mg/kg). The lower the \( \text{LD}_{50} \) the more toxic the chemical.

Toxic effect of a herbicide is the result of two factors – innate toxicity of the chemical and exposure time of the chemical.

A herbicide could have a very high toxicity rating but present little hazard to the applicator if a very dilute formulation is used or formulation present as granules.

Relative toxicity values for most herbicides vary depending on the route of entry into the body.
## Herbicide toxicity

Table of classification of comparative toxicity of pesticides (lethal amount relates to oral ingestion in a human adult of 70kg)

<table>
<thead>
<tr>
<th>Level of toxicity</th>
<th>Oral LD$_{50}$ (mg/kg)</th>
<th>Lethal amount</th>
<th>Dermal LD$_{50}$ (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely toxic</td>
<td>&lt;5</td>
<td>Few drops</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Highly toxic</td>
<td>5-50</td>
<td>One teaspoon</td>
<td>10-100</td>
</tr>
<tr>
<td>Moderately toxic</td>
<td>50-500</td>
<td>35g or 2 tablespoons</td>
<td>100-1000</td>
</tr>
<tr>
<td>Slightly toxic</td>
<td>500-5000</td>
<td>350g</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>Practically non-toxic</td>
<td>5000-15000</td>
<td>1kg</td>
<td>-</td>
</tr>
<tr>
<td>Relatively harmless</td>
<td>&gt;15000</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

![LD$_{50}$ in rats (mg/kg)]

<table>
<thead>
<tr>
<th>Product</th>
<th>LD$_{50}$ in rats (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caffeine</td>
<td>200</td>
</tr>
<tr>
<td>Alachlor</td>
<td>1 200</td>
</tr>
<tr>
<td>Cyanazine</td>
<td>1 200</td>
</tr>
<tr>
<td>Aspirin</td>
<td>1 750</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>2 200</td>
</tr>
<tr>
<td>Terbutryne</td>
<td>2 380</td>
</tr>
<tr>
<td>Flaprop-isopropyl</td>
<td>&gt;3 000</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>4 320</td>
</tr>
<tr>
<td>Terbacin</td>
<td>5 000</td>
</tr>
<tr>
<td>Asulam</td>
<td>&gt; 5 000</td>
</tr>
<tr>
<td>Imazapyr</td>
<td>&gt; 5 000</td>
</tr>
<tr>
<td>Sulfometuron-methyl</td>
<td>&gt; 5 000</td>
</tr>
<tr>
<td>Chlortoluron</td>
<td>&gt; 10 000</td>
</tr>
</tbody>
</table>

Paraquat LD$_{50}$ – 20 to 150 mg/kg
Herbicide residues/withholding periods

Residues are herbicide deposits that persist after application, or toxic metabolites produced from the original herbicide.

Amount of herbicide residue (mg) per millions parts by weight/volume of commodity (eg ppm or mg/kg)

Some herbicides are rapidly inactivated others (or their by-products) can persist for years.

WP are the recommended interval which needs to elapse between the last application of a agricultural product and harvest, slaughter, grazing or use of milk or eggs for human consumption.

Withholding period calculated from rate of degradation of that herbicide under normal conditions, applied at recommended rate and according to label direction.
# Herbicide withholding periods

<table>
<thead>
<tr>
<th>Product</th>
<th>Active ingredient</th>
<th>Withholding period (days or weeks) before grazing or cutting for hay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access®</td>
<td>triclopyr + picloram</td>
<td>Nil</td>
</tr>
<tr>
<td>Amitrole T®</td>
<td>amitrole + ammonium thiocyanate</td>
<td>Nil</td>
</tr>
<tr>
<td>Basta®</td>
<td>glufosinate</td>
<td>8 weeks</td>
</tr>
<tr>
<td>Baton®</td>
<td>2,4-D</td>
<td>7 days</td>
</tr>
<tr>
<td>Broadstrike®</td>
<td>flumetsulam</td>
<td>3 days – 8 weeks (see label)</td>
</tr>
<tr>
<td>Bromicide 200®</td>
<td>Bromoxynil</td>
<td>8 weeks.</td>
</tr>
<tr>
<td>Bromicide MA®</td>
<td>Bromoxynil* + MCPA</td>
<td>8 weeks.</td>
</tr>
<tr>
<td>Brush-off®</td>
<td>metsulfuron-methyl</td>
<td>Nil</td>
</tr>
<tr>
<td>Casoron G®</td>
<td>dichlobenil</td>
<td>Nil</td>
</tr>
<tr>
<td>Cut-out®</td>
<td>metsulfuron-methyl + glyphosate</td>
<td>Nil</td>
</tr>
<tr>
<td>Daconate®</td>
<td>MSMA</td>
<td>5 weeks</td>
</tr>
<tr>
<td>Fusilade®</td>
<td>fluazifop-P</td>
<td>2–7 weeks (see label)</td>
</tr>
<tr>
<td>Garlon 600®</td>
<td>triclopyr</td>
<td>Nil</td>
</tr>
<tr>
<td>Graslan®</td>
<td>tebuthiuron</td>
<td>Nil</td>
</tr>
<tr>
<td>Grazon DS®</td>
<td>triclopyr + picloram</td>
<td>Nil</td>
</tr>
<tr>
<td>Grazon Extra®</td>
<td>triclopyr + picloram + aminopyralid</td>
<td>Where product is used to control woody weeds in pastures there is a restriction of 12 weeks for use of treated pastures</td>
</tr>
<tr>
<td>Jaguar®</td>
<td>Bromoxynil* + difluufenican</td>
<td>8 weeks</td>
</tr>
<tr>
<td>Kamba 500®</td>
<td>dicamba</td>
<td>7 days</td>
</tr>
<tr>
<td>Kamba M®</td>
<td>dicamba + MCPA</td>
<td>7 days</td>
</tr>
<tr>
<td>Lontrel®</td>
<td>clopyralid</td>
<td>1–12 weeks (see label)</td>
</tr>
<tr>
<td>MCPA 500®</td>
<td>MCPA</td>
<td>7 days</td>
</tr>
<tr>
<td>Oust®</td>
<td>sulfometuron-methyl</td>
<td>Nil</td>
</tr>
<tr>
<td>Primatol Z®</td>
<td>ametryn</td>
<td>No stated withholding period</td>
</tr>
<tr>
<td>Reglone®</td>
<td>diquat</td>
<td>1 day in pasture, 10 days in treated water</td>
</tr>
<tr>
<td>Starane®</td>
<td>fluroxypyr</td>
<td>7 days</td>
</tr>
<tr>
<td>Tordon® 75-D</td>
<td>2,4-D + picloram</td>
<td>1–8 weeks (see label)</td>
</tr>
<tr>
<td>Tordon® Granules</td>
<td>picloram</td>
<td>Nil</td>
</tr>
</tbody>
</table>
# Herbicide withholding periods

<table>
<thead>
<tr>
<th>Herbicides</th>
<th>Grazing/cutting for stock food withholding period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,4-D amine, 2,4-D LVE, 2,4-D ester</td>
<td>7 days</td>
</tr>
<tr>
<td>2,4-DB</td>
<td>7 days</td>
</tr>
<tr>
<td>Atrazine</td>
<td>Pre-emergence 15 weeks (canola); post emergence – 6 weeks; 28 days all other uses</td>
</tr>
<tr>
<td>Aminoproyl/fluroxypyr (Hotshot®)</td>
<td>7 days</td>
</tr>
<tr>
<td>Amitrole</td>
<td>NRD</td>
</tr>
<tr>
<td>Bromoxynil; bromoxynil/MCPA</td>
<td>14 days to 8 weeks - check label - see notes below</td>
</tr>
<tr>
<td>Bromoxynil/diflufenican (e.g. Jaguar®)</td>
<td>14 days - check label - see notes below</td>
</tr>
<tr>
<td>Bromoxynil/pyrasulfotole</td>
<td>5 weeks</td>
</tr>
<tr>
<td>Butafenacil/triasulfuron (e.g. Logran®-Power)</td>
<td>7 weeks</td>
</tr>
<tr>
<td>Butroxydim (e.g. Factor®)</td>
<td>14 days</td>
</tr>
<tr>
<td>Butroxydim/fluazifop (Fusion®/Super)</td>
<td>21 days pasture and canola; 3-7 weeks pulses; ESI 4 days</td>
</tr>
<tr>
<td>Carfentrazone/MCPA (Affinity®) (Hammer®)</td>
<td>14 days</td>
</tr>
<tr>
<td>Chlorsulfuron (e.g. Glean®)</td>
<td>NRD</td>
</tr>
<tr>
<td>Clethodim (e.g. Select®)</td>
<td>21 days</td>
</tr>
<tr>
<td>Clethodim/haloxyfop (Motsa®)</td>
<td>8 weeks</td>
</tr>
<tr>
<td>Clodinofop (e.g. Topik®)</td>
<td>4 weeks</td>
</tr>
<tr>
<td>Clopyralid (e.g. Lontrel®)</td>
<td>7 days, SEE LABEL RE RATE SPECIFIC WHP</td>
</tr>
<tr>
<td>Diclofop-methyl (e.g. Hoegrass)</td>
<td>7 weeks</td>
</tr>
<tr>
<td>Diclofop/fenoxaprop (Tristar®Advance)</td>
<td>7 weeks</td>
</tr>
<tr>
<td>Diclofop/sethoxydim (Decision®)</td>
<td>7 weeks</td>
</tr>
<tr>
<td>Dicamba; Dicamba/MCPA</td>
<td>7 days</td>
</tr>
<tr>
<td>Diffufenican (e.g. Brodal®Options)</td>
<td>14 days</td>
</tr>
<tr>
<td>Diffufenican/MCPA (e.g. Tigrex®)</td>
<td>7 days</td>
</tr>
<tr>
<td>Diquat</td>
<td>1 day</td>
</tr>
<tr>
<td>Diuron</td>
<td>Pulse crops – 35 days, all other crops NRD; ESI 3 days</td>
</tr>
<tr>
<td>Fenoxaprop (e.g. Wildcat®)</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Florasulam/clopyralid (Torpedo®) Florasulam/MCPA (Conclude®)</td>
<td>7 days</td>
</tr>
<tr>
<td>Fluazifop (Fusilade®Forte)</td>
<td>21 days pastures; Canola; 7 weeks pulses SI 7 days (check label)</td>
</tr>
</tbody>
</table>
What is an Adjuvant?

• An adjuvant is any additive used in conjunction with a pesticide to increase biological activity and/or to modify various physical properties of a spray solution.

• Importance of Adjuvants
  – Spray applications are affected by many physical variables:
    
    | Pesticide Stability | Droplet Size |
    | Solubility          | Drift        |
    | Compatibility       | Volatilization|
    | Foaming             | Coverage     |
    | Suspension          | Adherence    |
    | Surface Tension     | Penetration  |

- Adjuvants play a key role in controlling these variables.
Adjuvants classified into four categories

Activator Adjuvants
- Enhance Pesticide Performance
  - Surfactants, Crop Oil Concentrates, Methylated Seed Oils, Fertilizer Solutions, Penetrants

Spray Modifier Adjuvants
- Affects Physical Properties Of Spray Solutions
  - Stickers, Deposition Aids, Drift Retardants, Evaporation Aids

Utility Modifier Adjuvants
- Minimize Handling and Application Problems
  - Compatibility Agents, Buffering Agents, Defoamers, Anti-foams

Utility Products
- Minimize Application Problems
  - Foam Markers, Tank Cleaners
Adjuvants Types

Surfactants (also called spreaders or wetting agents)
- An adjuvant that reduces surface tension between the spray solution droplets and the pest target’s surface, thus providing greater coverage

Crop Oil Concentrates (Mineral oils or Vegetable oils)
- A combination of oil (petroleum or vegetable) and surfactants/emulsifiers (normally non-ionic surfacts). Crop oil concentrates act as penetrants, stickers, spreaders (limited), humectants
- reduce rainfast periods, produce more uniform droplet size (drift reduction), reduce spray evaporation and improve herbicide penetration into waxy leaves

Methylated or Ethylated Seed Oils
- An emulsified methylated or ethylated seed oil. Act as penetrants, spreaders (limited), humectants, etc

Penetrators
- Enhance uptake of herbicides through dissolving waxy cuticles
Adjuvants Types - cont.

**Spreader/Stickers/Extenders**
- Combine spreading and adhesive qualities to improve coverage and retention of pesticide

**Water Conditioning Agents**
- Reduce the antagonistic affects of impurities (Ca, Mg, Mn, Fe, etc.) found in water carrier. Potentially greater pesticide efficacy results

**Humectants**
- Increase the drying time of spray solutions which provides greater time for the pesticide to enter the targets surface. Used during high temperature, low humidity and low spray volume situations

**Drift Control Agents**
- Reduces the amount of fine spray particles that carry pesticide out of target areas. (polyacrylimides, encapsulators, others)
Adjuvants Types - cont.

Deposition Aid
- Reduces the amount of fine spray particles that carry pesticide out of target areas. (polyacrylimides, encapsulators, others)
- Reduces evaporation of the spray droplet; Used during high temperature, low humidity and low spray volume situations

Compatibility Agents
- Compounds that aid in stability and dispersion of various pesticide formulations and spray carrier mixtures reducing the antagonism from other agents in the spray solution
- Most commonly used compatibility agent is ammonium sulfate
- Used to neutralise the effect of hard water on amine formulations such as glyphosate (eg Liaise and Liquid Boost)

Buffer Agents/Acidifiers
- Generally lower the pH of the spray solution and reduce rapid changes in pH either higher or lower.
  - Reduces the degradation of pesticides by chemical hydrolysis (LI700)
  - Some buffers are used to raise the solution pH for greater herbicide solubility

Dyes/Colorants
- Used to alter the color of spray solutions. Used for spot or boom spraying herbicides to detect missed spots or avoid spraying a plant or area twice
Adjuvants Types - cont.

Suspension Agents
   - Extend the period of time a pesticide will remain in suspension and if agitation is stopped for a time, upon agitation they aid in re-suspension of the mixture

Defoaming Agents
   - Suppresses foam of various pesticide solutions, aids in filling tanks

Foaming Agents
   - Used for marking swath width

Extenders
   - Enhance the amount of time the active ingredient remains toxic by increasing resistance to environmental degradation, and may include; Ammonium sulphate; Menthene-based
Adjuvant vs Surfactant

• Terms Adjuvant and Surfactant often used interchangeably in our daily spray discussions

• Surfactants are actually a specific type of adjuvant

• All surfactants are adjuvants, but not all adjuvants are surfactants

• Surfactants
  – Form a “bridge” between unlike chemicals that don’t readily mix
  – Water and oil
  – Water and the wax on a leaf surface
  – Lower the surface tension of spray droplets
  – Allow for more complete spray coverage and sticking on plant surfaces
  – May contain fatty acids to further improve herbicide retention and penetration
Surfactants

Without Surfactant

With Surfactant
Surfactants

- Complex long chain polar molecules
- Composed of alcohols and fatty acids
- Lipophilic “tail” and hydrophilic “head”
- Three general groups
  - Non-ionic
  - Anionic
  - Cationic
Surfactant Activity

Structure
Hydrophilic

Lipophilic

Activity
Oil droplet

Water

Surfactant in water

Surfactant in oil
CONTACT ANGLE

- Contact angle” (CA) is a measurement of a drop of water in contact with a solid surface. When surfactant (wetting agent) is introduced into a solution, surface tension is reduced and the water droplet becomes flatter.

(a) Water drop without surfactant (high surface tension)

(b) Water drop with surfactant (low surface tension)

- The lower the CA produced by the surfactant, the greater the spreading and coverage properties of that spray solution.

- Water has a CA of 93°. Typical surfactant influences the contact angle to 30-45° and a “super wetter” surfactant can reduce contact angles to 15° or less.

Surfactant molecules break the surface tension of water when the water repellent “tail” protrudes through the water surface. Greater the number of molecules the more surface tension is reduced.

© State of Queensland, 2013
Charged Surfactants / Uncharged surfactants

- increases the spread of droplets, or the wetting of waxy or hairy leaf surfaces

  - **Anionic surfactants** have a negative charge and have limited compatibility with pesticides

  - **Cationic surfactants** have a positive charge, found in domestic detergents and limited compatibility with pesticides

  - **Amphoteric surfactants** have both charges and may vary their charge with changes in pH

  - Charged adjuvants may be more effective with salts (glyphosate, 2,4-D amine, etc.)

  - **Non-ionic surfactants** most commonly used in agriculture. Nonreactive (no electrical charge), therefore unaffected in hard water.
    - Remain on the leaf once dry and allow ‘rewetting’ after rain, permitting additional herbicide uptake e.g. BS 1000™, Agral™ 600
    - Usually blended with anionic surfactants to improve wetting properties of EC formulations
Common Active Ingredients of Nonionic Surfactants

- Alcohol Ethoxylates - best biologically, very expensive
- Nonyl Phenol Ethoxylates - good biologically, in 95% of today’s surfactants, being looked at by EPA as a endocrine disrupter.
- Alkyl Octylphenol Ethoxylates - good biologically, expensive
- Alkyl Polysaccharides - good biologically, new chemistry, corn starch base, mixes well with AMS
- Urea Clathrates - good biologically, dry alcohol ethoxylate, expensive
- Fatty Acid Ethoxylates - good biologically, soybean base, may replace phenol ethoxylates
- Tallow Amine Ethoxylates - good biologically, used in Roundup Ultra, partially ties up free ions that can be antagonistic to the glyphosate molecule.
- Phosphate Esters - good biologically, also used in Roundup Ultra, partially ties up free ions that can be antagonistic to the glyphosate molecule.
- Fatty Acids - usually tree oils, biologically active
- EO/PO Block Copolymers (organosilicones) - expensive
- Siloxanes (organosilicones) - expensive
Surfactants/Adjuvants
Factors affecting adjuvant use include:

• Crop safety – addition of an adjuvant can reduce herbicide selectivity and thereby increase crop damage. Not an issue for fallow and pre-emergent herbicides

• Effectiveness or activity – adjuvants usually added to increase herbicide effectiveness
  – Use of the wrong type or rate can reduce effectiveness, by decreasing herbicide retention on leaves

• Water hardness – hard water leads to poor mixing of the chemical with water (major problem with emulsifiable concentrates)
  – High calcium and magnesium ions levels bind with amine formulations causing them to be less soluble and therefore less effective

• Water temperature – low water temperature can lead to gelling in the tank
  – High concentration herbicides (eg 80%) may not mix properly and surfactants may perform poorly.
# Surfactants/Adjuvants

<table>
<thead>
<tr>
<th>Wetters/spreaders</th>
<th>products which increases the spread of droplets, or the wetting of waxy or hairy leaf surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>• non-ionic surfactants</td>
<td>do not ionize in water (not as sensitive to water hardness) - are the most commonly used in agriculture. They are nonreactive (no electrical charge). They remain on the leaf once dry and allow ‘rewetting’ after rain, permitting additional herbicide uptake</td>
</tr>
<tr>
<td>• anionic surfactants</td>
<td>ionize with water to form a negative charge (sensitive to water hardness). Not often used with herbicides.</td>
</tr>
<tr>
<td>• cationic surfactants</td>
<td>ionize with water to form a positive charge - many domestic detergents. Rarely used with herbicides.</td>
</tr>
<tr>
<td>• amphoteric surfactants</td>
<td>can act as either anions or cations, depending on the acidity of the solution</td>
</tr>
<tr>
<td>• organo-silicate surfactants</td>
<td>are usually silicone/surfactant blends of silicone to non-ionic or other surfactants: a few within this classification are composed entirely of silicone (provide a tremendous reduction in surface tension)</td>
</tr>
<tr>
<td>• acidified surfactants</td>
<td>help lower the pH of the spray solution i.e. make solutions more acidic. Most herbicides are most stable when the pH of the solution is between 6 and 7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Penetrants</th>
<th>(improve the transfer of active ingredients from the target surface to interior tissues by dissolving waxy cuticles), which include:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• mineral oil</td>
<td>these products are usually a blend of mineral oil and non ionic surfactant</td>
</tr>
<tr>
<td>• vegetable oil</td>
<td>these products are a blend of vegetable oils and non-ionic surfactant</td>
</tr>
<tr>
<td>• esterified vegetable oil</td>
<td>produced by reacting vegetable oil with alcohol and then blending with a high level of non-ionic surfactant</td>
</tr>
<tr>
<td>• organo-silicate surfactants</td>
<td>are usually silicone/surfactant blends of silicone to non-ionic or other surfactants: a few within this classification are composed entirely of silicone (provide a tremendous reduction in surface tension)</td>
</tr>
<tr>
<td>• acidified surfactants</td>
<td>help lower the pH of the spray solution i.e. make solutions more acidic. Most herbicides are most stable when the pH of the solution is between 6 and 7</td>
</tr>
</tbody>
</table>

| Compatibility agents | material which reduces the likelihood of antagonism from other agents in the spray solution. The most commonly used compatibility agent is ammonium sulfate. It is also used to neutralise the effect of hard water on amine formulations such as glyphosate |
## Surfactants/Adjuvants

### Examples

<table>
<thead>
<tr>
<th>Surfactant Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Spray Oils (1-3% emulsifier)</td>
<td>Ad-Here</td>
</tr>
<tr>
<td>Petroleum Spray Oils (&gt;15% emulsifier)</td>
<td>Uptake</td>
</tr>
<tr>
<td>Vegetable oil (emulsified)</td>
<td>Codacide</td>
</tr>
<tr>
<td>Vegetable oil (esterified and emulsified). Superior wax-modifying characteristics and penetrating ability</td>
<td>Hasten</td>
</tr>
<tr>
<td>Alcohol alkoxylates</td>
<td>BS1000</td>
</tr>
<tr>
<td>Nonyl phenol</td>
<td>Agral</td>
</tr>
<tr>
<td>Octyl phenol</td>
<td>Wetter TX</td>
</tr>
<tr>
<td>Fatty amine ethoxylates</td>
<td>Gly Wetter Plus</td>
</tr>
<tr>
<td>Organo-silicones</td>
<td>Pulse</td>
</tr>
<tr>
<td>Surfactant+ammonium sulfate+vegetable oil ester</td>
<td>Kondemn</td>
</tr>
<tr>
<td>Non ionic+ammonium sulfate+petroleum oil</td>
<td>Hot-up</td>
</tr>
<tr>
<td>Soyal phospholipids (Acidifying/buffering agent)</td>
<td>LI700</td>
</tr>
<tr>
<td>Cationic fatty amine buffering salt+ non-ionic fatty acid ethoxylates and glycerides + canola oil</td>
<td>Envoy</td>
</tr>
</tbody>
</table>