GROWNOTES

SPRAY APPLICATION MANUAL FOR GRAIN GROWERS

Module 2
Product requirements

Thinking about how products work and factors that can affect their performance

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Key points

There are several things that can influence how well a spray application is going to work. Some of these include the:

- **characteristics of the target (growth stage, stress, genetic traits);**
- **environmental conditions before, during and after spraying;**
- **choice of product (mode of action and formulation);**
- **rate of product used;**
- **application volume, sprayer set-up and spray quality;**
- **water quality and adjuvant selection; and**
- **choice of tank mix partners.**

If just one of these factors is less than ideal you can end up with a poor result. When several of these factors are less than ideal the outcome may be a spray failure.

It is important that all applicators have an understanding of how each of these factors can affect – either alone or in conjunction with each other – the outcome of the spray job.

PLAY VIDEO

Target, timing and technique

1. Getting the pesticide to where it works

Most farm chemicals work by affecting a particular mechanism within the target. Usually this involves disrupting or blocking a particular biochemical pathway within a plant or target pest.

The particular mechanism or biochemical pathway that the pesticide or herbicide affects is the basis for the mode of action group it is assigned to. This means that herbicides or pesticides that belong to the same mode of action group affect the same mechanism or biochemical pathway within target pests or weeds.

Target pests or weeds may respond in a similar way to products from the same mode of action group, which is the basis for many resistance mechanisms. However, there are many things that can affect a product's ability to get to the site within the pest or plant where it has a biological effect.

For example, with a foliar application of a herbicide, the condition of the plant at the time of spraying, as well as the plant's response to the environment after spraying, can have a large impact on the ability of the product to enter the plant, and to subsequently move within the plant to the actual target site where it produces the biological response.

1.1 Dose transfer

The process of getting the product from the spray tank to the actual site within the plant or pest where it impacts on the biochemical pathway is often referred to as 'dose transfer'.

For a successful dose transfer to occur many things must come together. The application equipment must be right, the conditions must be suitable, the target weed or pest must be susceptible and the product must be able to get onto or into the target and then move to the site within the pest or weed where the product does its job.

The steps involved in getting a herbicide to the target site within a plant are summarised in Table 1.

Table 1 Factors involved in getting herbicide to the target and the effectiveness of spray operation.

Steps in dose transfer	Operational, weed and environmental influences	Mode of action, formulation and adjuvant effect
Formation of spray droplets (atomisation)	Carrier application volume Pressure Nozzle selection	Spray solution surface tension Spray solution specific gravity
Transport to target	Boom height above target Travel speed Environmental conditions Crop or stubble 'architecture'	Spray quality affects drying and mass of the droplets
Deposition	Carrier volume Nozzle selection Crop or stubble 'architecture' Leaf orientation and shape	Herbicide mode of action Flow rate Spray quality (droplet spectrum)
Retention	Droplet velocity and energy Leaf surface character Environmental conditions e.g. temperature, humidity	Droplet size Spray solution surface tension
Uptake	Leaf epicuticular wax Age of cuticle Species differences Environmental conditions	Surface character Wetting Drying Spreading Surface tension
Translocation in plant	Species differences Growth stage Plant physiology Environmental conditions	Uptake efficiency Contact phytotoxicity
Toxicity of herbicide	Inherent character of the herbicide	

Source: adapted from Zabkiewicz (2000)

Dose transfer can be broken into three general processes:

- **landing the droplets – droplet formation, deposition and retention;**
- **uptake and translocation of the chemical; and**
- **the biological effect.**

2. Landing the droplets

Whether the spray droplets actually hit the target is determined by the size, energy and trajectory of the droplets, and the size and shape of the target.

2.1 Droplet movement near the target

Small droplets (very fine or fine spray qualities) have low mass and energy, so gravity has little effect on them.

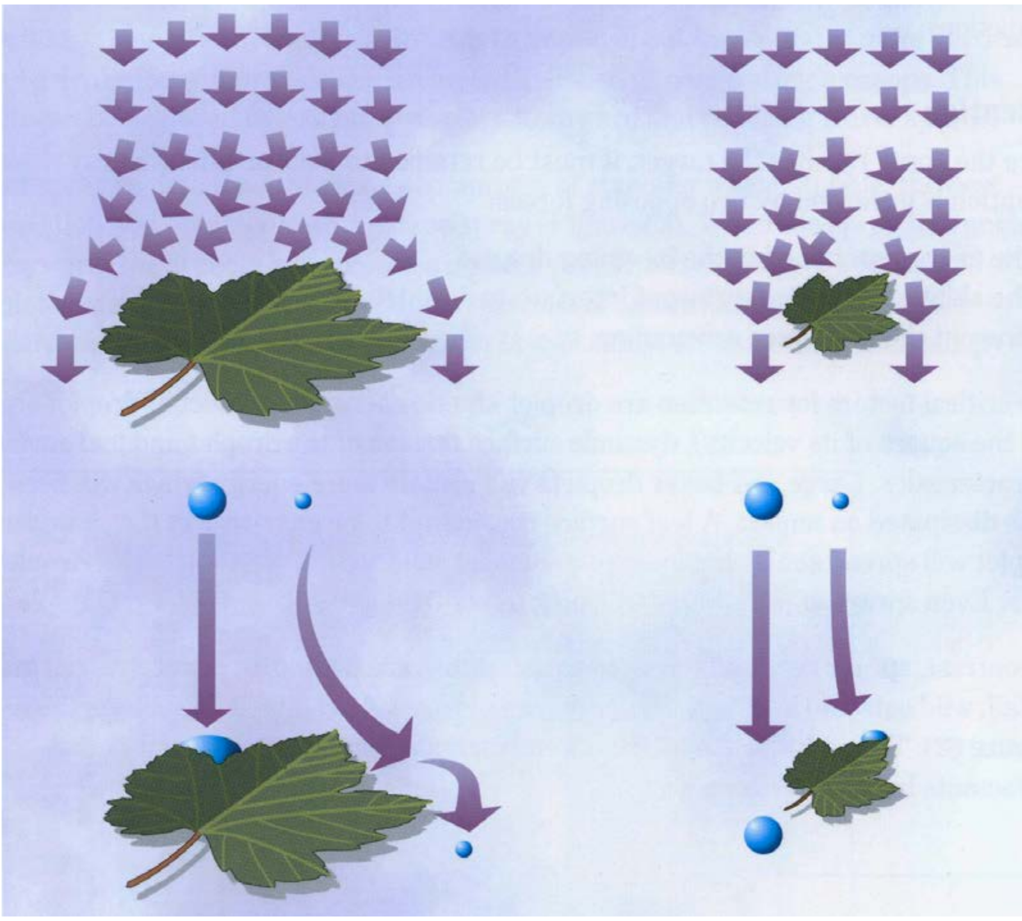
The movement of small droplets results from being carried by prevailing air flows, which means they have the potential to move with the flow of air around leaves and may not hit the target, particularly if the leaf is large and broad.

Large droplets (coarse spray quality or larger), usually have enough momentum (mass and velocity) to overcome air resistance and hit the target.

Some targets, such as cereals, stubble and larger grasses, are relatively easy to hit, while other small, thin targets, such as two-leaf grass seedlings, are difficult to hit.

Large, broad leaves can be hard to hit with small droplets due to air flow around the leaf, while they are easier to hit with larger droplets.

Figure 1 Air flow around different sized and shaped leaves.



For more information on droplet energy and trajectory go to Module 3: Nozzle design and function

The impact of nozzle choice on droplet retention is further discussed in Module 3: Nozzle design and function

2.2 Retention of droplets – impact of leaf surface

The retention of droplets on a leaf surface is determined by the physical and chemical properties of the droplet (for example, momentum and surface tension), as well as the characteristics of the leaf surface easy or hard-to-wet (Table 2).

Whether a leaf is hard or easy to wet is determined by a combination of leaf surface characteristics, such as the presence of a cuticle with water-repellent waxes and/or trichomes (microscopic hairs), as well as the size and angle of the leaf. Cuticle type varies greatly between species.

Hard-to-wet surfaces are more likely to cause large droplets to bounce off.

For more information on the process of droplet formation and factors affecting deposition and retention go to Module 3: Nozzle design and function

Table 2 Some easy-to-wet and hard-to-wet weeds.

Easier to wet	Harder to wet
Amaranthus spp.	Amsinckia
Brome grass	Annual ryegrass
Datura	Annual phalaris
Deadnettle	Barnyard grass
Docks	Capeweed
Erodium spp.	Canola (volunteer)
Emex / doublegee	Cleavers
Faba beans	Clover
Feathertop Rhodes grass	Euphorbias / spurges
Malvaceae weeds, mallows, volunteer cotton, sidas	Fat hen
Melons	Fleabane
Mustards	Field peas
Prickly lettuce	Fumitory
Saffron thistle	Heliotrope, white
Sweet summer grass	New Zealand spinach
Turnip weed	*Oxalis* spp.
Variegated thistle	Sow thistle
Volunteer cereals	Toadrush
Wild oats	Vetch
Windmill grass	Vulpia
	Wild radish
	Wireweed

3. Uptake and translocation of herbicides

3.1 Formation of herbicide deposit on leaf

Once a spray droplet lands on a leaf surface, most formulations will tend to cause the droplet to spread. The amount the droplet will spread depends on the surface tension of the spray solution and the characteristics of the leaf surface.

Droplets with a low surface tension (high surfactant loading) will spread more easily than droplets with a higher surface tension (such as oil-based formulations).

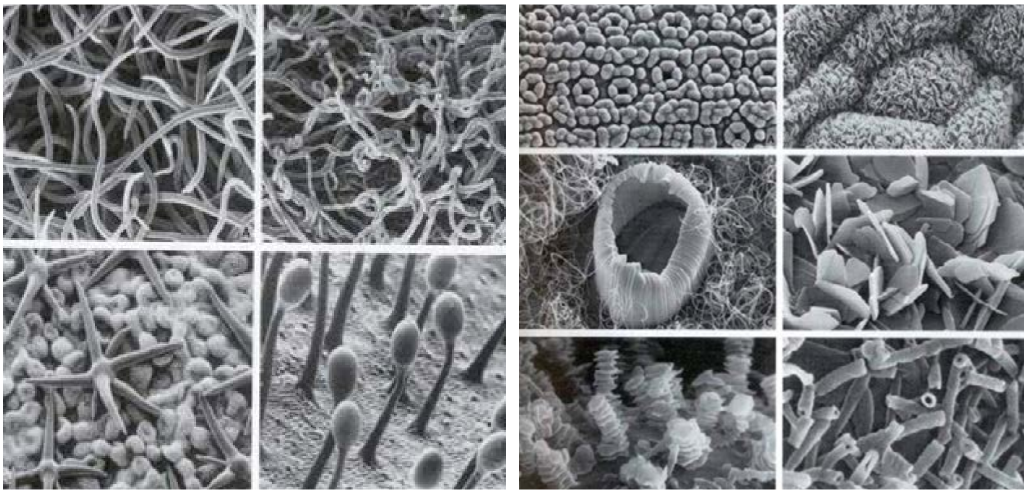
After spreading, the droplets may begin to dry out, due to the evaporation of water from the droplet. Small water-based droplets and those that spread easily will tend to dry out faster than large droplets.

In order for herbicides based on water-soluble formulations to enter the leaf they must remain dissolved in the water droplet. Once the water has evaporated from the droplet a crystalline deposit remains and movement of the herbicide into the leaf stops, unless it is capable of being re-wet by high humidity, dew or light rain.

The uptake of oil-based (lipophilic) herbicide formulations (for example, emulsifiable concentrates such as esters) is less affected by the evaporation of water from the spray droplet because they are able to move into the leaf via a different pathway from water-based sprays.

Leaf surfaces can be covered by many structures and different types of wax that can impact on droplet contact with the leaf surface and the uptake of products by the plant.

Figure 2 Electron micrographs (high-definition macro photos) of different deposits on leaves.



3.2 Movement of herbicides to plant site of action

Foliar herbicides

Foliar-applied herbicides have to move through the leaf or stem cuticle and epidermis into the target cells within the plant.

For most applications, very little herbicide moves into a plant via the stomata (pores in plant leaves used for gas exchange).

Soil-applied herbicides move from the soil solution into plant roots and shoots. This movement is primarily by diffusion.

Definition of 'diffusion'

The movement of atoms or molecules from an area of higher concentration (herbicide droplet) to an area of lower concentration (water-filled inside of the leaf). Herbicide molecules can move across a cell membrane by **diffusion**.

The leaf cuticle is designed to restrict water loss from the leaf to the stomata and not through the leaf surface. The cuticle is made up of a range of waxes and fatty acids and/or small hairs (trichomes) depending on the species and the environmental conditions the plant has experienced. The cuticle is rarely solid and its structure should be considered more like a sponge.

Figure 3 Waxy and hairy leaf surfaces.

Hairs and other structures can prevent small water-based droplets from contacting the leaf surface, reducing uptake of products. The addition of some adjuvants can improve the droplet contact with the plant or leaf surface.

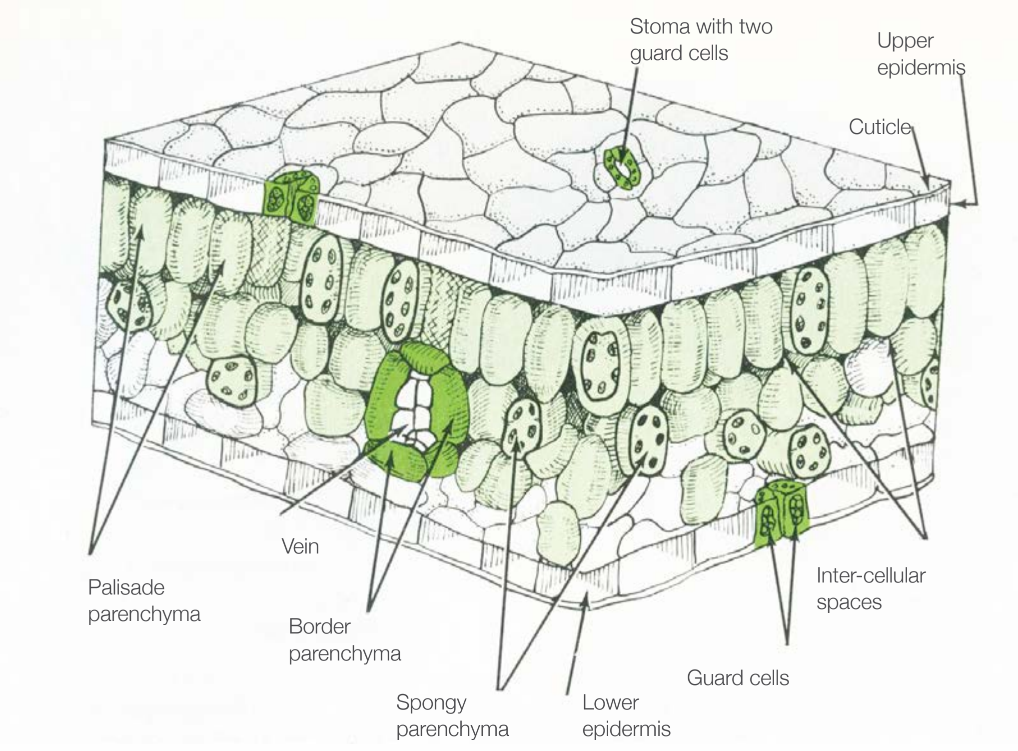
Photos: Andrew Storrie

Surface tension of the droplet and the characteristics of leaf surface both influence droplet spread. Adjuvants that lower surface tension can improve droplet spread to allow for greater uptake of the product by the plant.

Many herbicides are formulated as 'pro-herbicides' to improve their movement through the cuticle. Once inside the plant they are converted to the active herbicide. A good example of this is 2,4-D, which is formulated as either an ester, various forms of the amine, or as an acid to improve plant uptake. The active form of 2,4-D is 2,4-D acid, which is poorly absorbed by plants. Group A "fop" herbicides are also formulated as 'pro-herbicides' to improve absorption by plants.

Water-soluble formulations move through cuticular pores along what is called the 'aqueous route'. Low humidity and moisture stress break the continuity of this pathway, reducing the ability of these herbicides to enter the plant. Oil-based formulations move through the lipid route and are less affected by moisture stress.

Figure 4 Cross section of a leaf



Cross-section of a plant leaf.

Once through the cuticle and epidermis the herbicide enters the water-filled section surrounding the cells (apoplast).The herbicide must then enter the cytoplasm of target cells to get to the site of herbicide action.

Soil-applied herbicides

Soil-applied herbicides are either taken up by plants through their roots or the emerging shoots of seedlings. The water solubility of soil-applied herbicides determines how they need to be applied. For example, trifluralin (Group D) is totally water insoluble and does not move in the soil so must be placed where it will come into contact with germinating weed seeds.

Other herbicides, such as metolachlor, are quite water soluble so can move down the soil profile to weed seeds with moisture from rain or irrigation. Water-soluble herbicides therefore require less incorporation.

Water solubility is an important consideration, particularly where heavy stubble loads exist. Products that bind strongly to organic matter and have low water solubility require droplets to be deposited onto the soil surface, or for the stubble to be incorporated. This can have implications for the sprayer set-up, nozzle choice, spraying speed and incorporation technique.

3.3 Herbicide activity inside the plant

Plant cells are surrounded by a membrane through which oil-soluble herbicides pass quickly into the cell cytoplasm by simple diffusion, while water-soluble herbicides move more slowly.

Herbicide solubility

How a herbicide moves within a plant is determined by its solubility and whether it is a weak acid. Some herbicides dissolve easily in water (are hydrophilic), for example, glyphosate, while others dissolve well in an organic solvent or oil (are lipophilic), for example, clethodim.

Herbicides that are intermediate in their properties and can dissolve in both oil and water tend to be the most mobile within a plant, for example, 2,4-D.

Weak acid herbicides are those that easily lose a hydrogen ion (H^+) when dissolved in water. Their solubility is determined by the pH of the plant sap (apoplast). The pH outside the cells tends to be more acidic (about pH 5.5 and contains more H^+), which makes weak acid herbicides more oil soluble. This enables them to pass through the cell membrane into the cell cytoplasm (facilitated diffusion).

Distribution of the herbicide within the plant

Once inside the plant, translocated herbicides are distributed via either the xylem or the phloem. These are distribution systems for nutrients within the plant.

Figure 5 Diagram of a plant showing the xylem and phloem movement systems. In plants, herbicides can move via the phloem or xylem transport systems.

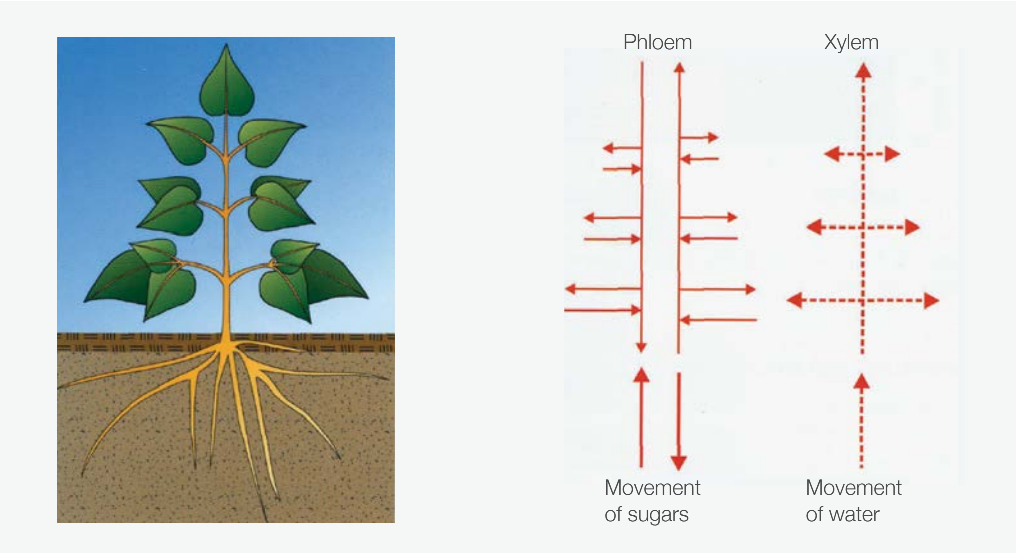


Diagram of plant with xylem and phloem showing direction of movement.

The xylem is a plumbing system for the movement of water and minerals from the roots to the shoots and is a one-way system. Flow in the xylem is determined by environmental conditions such as available soil water, humidity, temperature and light intensity.

Herbicides must be water soluble to move in the xylem.

Most soil-applied herbicides move from the roots to the leaves and shoots through the xylem and out to the edges of the leaves.

The phloem is a system of living cells that distributes sugars and amino acids throughout the plant and is a two-directional system. Herbicides that move within the phloem are of intermediate solubility, or are weak acids, as they must be able to enter the living phloem cells.

4. Biological effect: how the herbicide kills the plant

Herbicides kill plants by blocking particular biochemical pathways, which leads to the accumulation of toxic compounds within the plant.

Some of these toxic compounds damage cell membranes, causing desiccation, such as the photosynthesis inhibitors paraquat (Group L) and atrazine (Group C).

Synthetic auxin herbicides (Group I) are thought to kill plants through causing undifferentiated growth by disrupting the normally tightly controlled regulatory systems within a plant.

5. Impact of environmental factors on herbicide activity

Environmental conditions can influence the growth and physiology of weeds and the action of the herbicide, as well as the interaction between the weed and the herbicide.

Water-soluble (hydrophilic) herbicides tend to be more strongly affected by environmental factors than oil-soluble (lipophilic) herbicides.

However, there can be large interactions between temperature and humidity and, unfortunately, past weed research has often not taken this relationship into account by varying and measuring both temperature and humidity within experiments.

5.1 Light

Light intensity has been found to affect the development of the plant cuticle and plant growth.

High light intensities can reduce the effectiveness of many herbicides by increasing the thickness and changing the composition of the cuticle. Thick cuticles usually impact on water-soluble herbicides more than oil-soluble herbicides.

High light intensities may actually increase the levels of control of soil-applied Group C herbicides by increasing plant transpiration, which increases xylem movement. Light is also required for mode of action Group C (for example, atrazine), Group L (for example, paraquat) and Group G (for example, carfentrazone) to activate the herbicide.

Group A ‘dim’ herbicides, such as clethodim, are rapidly degraded on the leaf and in the spray tank by ultraviolet light.

Decreasing light intensity increases the ratio between shoots and rhizomes, which leads to better control of perennial weeds through better herbicide interception and more phloem-transported herbicides translocating to the root system.

Low light intensities tend to reduce the rate of photosynthesis, which can affect the ability of the plant to regrow from the effects of a herbicide.

Play YouTube video: Introduction to Photosynthesis (Explanation of photosynthesis and carbon fixation)

5.2 Temperature

Temperature has a major influence on herbicide effectiveness by affecting the development of the plant cuticle, plant morphology (that is, physical form and external structure) and physiology (internal processes).

Normally the rate of herbicide uptake increases with air temperature, although the total amount absorbed usually doesn't change.

Other physiological processes are also affected by temperature, depending on whether the plants have a C3 or C4/CAM carbon cycle.

High temperatures and low moisture levels cause the plant to stop transpiring by closing down its stomata. This causes a deficit of carbon dioxide in the plant, which shuts down the energy production within the plant and leads to a process called photorespiration.

Fleabane heat and moisture stress.

Photo: Andrew Storrie

C4 and CAM plants have an additional biochemical stage that allows them to store carbon from carbon dioxide as a four-carbon molecule to use for energy when the stomata are closed due to high temperatures. Most weeds are C3 plants and grow best between 15°C and 30°C, with photosynthesis and growth declining above 30°C (lack of CO_2). C4 plants keep photosynthesis operating above 30°C and at higher light intensities. Grasses and sedges make up about 80 per cent of C4 weeds.

Table 3 Examples of C3 and C4 weeds.

C3 weeds	C4 weeds
Annual ryegrass (*Lolium rigidum*)	Barnyard grass (*Echinochloa* spp.)
Annual phalaris (*Phalaris* spp.)	Johnson's grass (*Sorghum halepense*)
Brome grass (*Bromus* spp.)	Feathertop Rhodes grass (*Chloris virgata*)
Wild oats (*Avena* spp.)	Couch (*Cynodon dactylon*)
Fathen (*Chenopodium album*)	Crowsfoot grass (*Eleusine indica*)
Deadnettle (*Lamium amplexicaule*)	Crab grass (*Digitaria sanguinalis*)
Spiny emex (*Emex australis*)	Liverseed grass (*Urochloa panicioides*)
European bindweed (*Convolvulus arvensis*)	Stinkgrass (*Eragrostis cilianensis*)
	Sweet summer grass (*Brachiaria eruciformis*)
	Witch grass (*Panicum capillare*)
	Purple nutsedge (*Cyperus rotundus*)
	Most *Amaranthus* spp.
	Most spurges (*Euphorbia* spp.)
	Cathead (*Tribulus terrestris*)
	Pigweed (*Portulaca oleraceus*)

Research on awnless barnyard grass *(Echinochloa colona)* in Australia has shown that, for both glyphosate-susceptible and glyphosate-resistant populations, higher temperatures (35°C /30°C versus 25°C /20°C) reduce the plant's susceptibility to glyphosate by 2.5 times at approximately 70 per cent relative humidity.

Reduced glyphosate effectiveness at temperatures above 30°C is thought to be a result of increasing upward flow within the plant reducing downward translocation.

However, glyphosate is generally more effective at lower temperatures due to better translocation through the plant, slower plant metabolism and slower plant growth.

5.3 Frost

Severe frosts can damage plant leaf surfaces, potentially reducing the uptake of herbicides.

Translocated herbicides, such as Group A, Group B and Group I herbicides, can also have their effectiveness reduced when applied before or after a frost, most probably due to reduced phloem transport. Group A herbicides are very slowly translocated in the phloem, even under favourable conditions, so plants that have been stressed by frost will translocate the herbicide even slower.

The effectiveness of any herbicides applied at lower rates (either intentionally or through poor application) will be greatly affected by any plant stress.

PLAY VIDEO

Weather monitoring using a hand held meter

5.4 Humidity

Humidity has a major influence on herbicide uptake through three processes:

- **amount of epidermal wax – plants grown under higher humidity have less epidermal wax than the herbicides must penetrate;**
- **aqueous path through the cuticle – higher humidity conditions hydrate the cuticle, making a continuous pathway for water-soluble (polar/hydrophillic) herbicides. Oil-soluble herbicides are less affected by this aspect of humidity; and**
- **droplet survival (life of droplets) – higher humidity can extend the life of droplets, increasing the amount of time that the herbicide has to pass through the cuticle and epidermis.**

Adjuvants can have a big influence on droplet survival and on the movement of herbicides through the plant cuticle and epidermis.

Adjuvants do not affect the actual inherent translocation capability or the toxicity of a herbicide's active ingredient.

5.5 Soil moisture

Moisture-stressed plants tend to have smaller leaves and thicker cuticles that contain more wax.

This can affect the amount of herbicide retained on the leaf, as well as the amount that is able to be absorbed into the leaf.

Moisture stress also leads to a decline in photosynthesis, respiration and transpiration in the plant. Herbicides reliant on transport within the xylem, such as those from Group C, will be particularly affected.

All soil-applied herbicides will be greatly affected by moisture stress as they rely on the soil–water film to make contact with roots and emerging shoots of seedlings.

Moisture-stressed young fleabane.

Photo: Andrew Storrie

Herbicides that must be converted to an active form within the plant will also be strongly affected by moisture stress.

Some examples of herbicides that are converted within the plant include diclofop, fluazifop and 2,4-D.

One study looking at the absorption and translocation of glyphosate applied to the perennial weed milkweed (*Asclepias syriaca*) at 25 and 13 per cent soil moisture found that the well-hydrated plants absorbed 44 per cent and translocated 20 per cent of the glyphosate, while the stressed plants absorbed 30 per cent and translocated 7 per cent. Moisture stress caused a significant reduction in both absorption and translocation of glyphosate, which in turn had no effect on the height and biomass of moisture-stressed plants.

In the same experiment, wiping the leaf with water or chloroform prior to herbicide application increased the absorption of glyphosate three-fold for moisture-stressed plants and two-fold for well-hydrated plants compared with unwiped leaves. Translocation out of the leaf was unaffected at both soil moisture treatments. This showed that the moisture-stressed weeds had more impervious cuticular waxes than the well-hydrated plants.

Research in northern NSW looking at the efficacy of glyphosate application on moisture-stressed awnless barnyard grass and liverseed grass (in relation to the timing of receiving 80 millimetres of simulated rain) found that best control was achieved when the weeds were watered six days before, or one or four days after, the glyphosate application.

5.6 Wind

Wind can lead to leaf-surface damage of both crop and weeds, which can result in increased absorption of some herbicides.

Wind at lower humidity can lead to faster drying of droplets, which reduces herbicide absorption.

5.7 Precipitation

Dew

Dew can reduce herbicide effectiveness by causing herbicide to run-off leaves. The level of runoff is influenced by leaf surface wettability, spray formulation and application volume.

A dry leaf surface on some crop types may be able to handle more than 1000 litres per hectare without producing run off. Whereas run off from an already wet leaf surface can easily occur if the spray formulation has a low surface tension (that is a high surfactant loading) and the application volume is particularly high.

Dew on canola plants.

Photo: Andrew Storrie

However, if spray can be retained on a wet leaf surface, the uptake of water-soluble herbicides will be maximised due to the fully hydrated cuticle.

Re-wetting of spray deposits by dew can also improve herbicide effectiveness as long as there is no run off from the leaves.

Rain

Rain has the greatest effect on herbicide application if it occurs soon after application.

The effect rainfall will have on the herbicide application is not just related to the total volume; rainfall intensity and duration are also very important factors.

Water-soluble herbicides tend to need longer rain-free periods, while oil-based herbicides need shorter rain-free periods because the oil-based herbicides are quickly absorbed by the waxes within the plant cuticle. Paraquat and diquat are the exceptions to this rule: while they are water soluble they are also taken up extremely quickly by plants.

Research in northern NSW that looked at the effect of glyphosate (450 grams/litre) rate and rain-fast period found that small awnless barnyard grass (*E. colona*) was effectively controlled with 255g active ingredient per hectare and more than 22 hours without rain, 450g a.i./ha and more than 10 hours without rain, 675g a.i./ha and more than four hours without rain and 900g a.i./ha and more than one hour without rain.

This was probably the result of increased diffusion across the cuticle and epidermis and due to the higher concentration gradient associated with increasing the rate of glyphosate used.

The impact of rain on herbicide effectiveness varies greatly with weed species. Generally it is determined by the weed's susceptibility to the herbicide (lower dose of herbicide needed to kill it) and the rain-fastness of the herbicide being applied.

6. Herbicide use

There is a temptation amongst growers and agronomists to mix multiple products in the spray tank to reduce the number of spray passes required in a season. It is not uncommon for spray mixes to contain two or three herbicides, an insecticide, a fungicide and liquid fertiliser, plus one or two adjuvants.

While this might seem an efficient use of time, the applicator may be getting into unknown territory once more than three products are mixed.

There can be chemical incompatibilities and mode-of-action antagonism that lead to suboptimal control or total spray failure.

How the mixes react is heavily influenced by the temperature of the mix and water quality. Sometimes these 'spray cauldrons' can lead, at best, to blocked filters all the way through to tanks full of solid mix.

Mixing a large number of active ingredients and adjuvants can have unexpected consequences including clogging the tank.

Photo: Rob Buttimor

To avoid spray failures it is good to understand what chemicals and active ingredients are in the herbicides, and how the herbicides actually kill the plants.

Always read the label for directions of use and compatibilities. It is also very useful to refer to state crop management notes or GRDC publications related to specific crops and products.

6.1 What is in the herbicide container?

Herbicides come in a range of formulations, determined by the herbicide's solubility in water and the use for which it is intended. A container of herbicide contains the active ingredient plus a range of chemicals called inert ingredients. Herbicides are formulated to be:

- **as biologically effective as possible over a range of conditions;**
- **physically and chemically stable;**
- **easy to mix;**
- **compatible with a limited number of other products; and**
- **a stable spray solution in a range of water qualities.**

To do this the active ingredient is mixed with a range of other chemicals such as solvents, emulsifiers, wetters, dispersants, safeners, buffers, dyes and stanching agents, for example, paraquat.

Herbicides are already complex products before the operator even considers tank-mixing them with other products.

7. How herbicides work: selectivity

The selectivity of a herbicide varies between and within mode-of-action groups. For example, products such as glyphosate and paraquat are non-selective, that is, they kill most plants they contact. On the other hand there can be a lot of variability in selectivity within a mode of action. For example in Group A, haloxyfop will kill most grasses, while others such as diclofop will kill grass weeds in grass crops. There are also broadleaf herbicides, such as within Group B and Group I, that will kill most broadleaf plants, while others in the same mode of action will control broadleaf weeds in broadleaf crops.

This selectivity depends on the plant's ability to break down the herbicide before it gets to the target site. Crop selectivity is often because the crop can break the herbicide down faster than the weed. However, with trifluralin and some other herbicides the crop is as sensitive as the target weeds, so a physical separation of the crop and the herbicide is the mechanism for selectivity.

Many herbicides, such as those in Group A, have another chemical called a 'safener' added, which helps protect the crop from injury.

Often herbicide selectivity is reduced when plants are under environmental stress, such as waterlogging or low temperatures, as the crop cannot break the herbicide down fast enough before being damaged by the herbicide.

Crop tolerance can also be affected by herbicide tank mixes. For example, mixing a Group A fop with a Group I can increase metabolism of the Group A herbicide in the grass weed and reduce the level of control.

7.1 Modes of action

Herbicides are grouped into modes of action. The mode of action is how the herbicide kills the plant, that is, which biochemical pathway is being disrupted. All herbicides within a single mode of action kill the weeds by targeting the same enzyme pathway. In Australia herbicides are divided into 19 groups from A to Z.

The mode-of-action system was initially developed to help manage the development of resistance to herbicides, however it now also gives good information on what herbicides require to work effectively.

See Croplife Australia http://www.croplife.org.au/wp-content/uploads/2015/09/2016-Herbicide-MOA-Table.pdf

Other countries use a range of numbering systems to distinguish herbicide modes of action.

By knowing a herbicide's mode-of-action group a grower will know what environmental and spray conditions are required for the optimum performance of the herbicide. For example, poorly translocated herbicides such as bromoxynil (Group C) and paraquat (Group L) and those with slow uptake and translocation like clethodim (Group A) will require better levels of spray coverage than well-translocated herbicides such as glyphosate (Group M) and 2,4-D (Group I).

Some herbicides are not compatible in a tank mix due to their chemical requirements. For example, tank-mixing glyphosate with trifluralin creates the problem that glyphosate is fully translocated and needs time for the herbicide to be absorbed and moved to its site of action, while trifluralin is highly volatile and needs soil incorporation within 4 to 24 hours depending on the rate applied. For growers applying trifluralin immediately in front of the planter a much better tank-mix partner is paraquat or paraquat plus diquat, due to their rapid absorption and activity in weeds.

8. Timing of herbicide applications

One of the basic principles of weed control is that small weeds are easier to control than large weeds.

GRDC In-crop herbicide guide

However, spraying too early, such as trying to control 1.5-leaf annual ryegrass or phalaris, can reduce control because these plants present a very small, hard-to-hit target.

Control can be greatly improved by delaying application to the 2-to-3-leaf stage. This also allows time for more weeds to emerge, so a larger proportion of the weed population will be controlled with one herbicide application.

Image of mixed weed sward where larger plants have survived

Photo: Andrew Storrie

Some benefits of spraying small weeds include:

- **young, small weeds are often more susceptible to herbicides – for example, flaxleaf fleabane (*Conyza bonariensis*) is relatively easy to control with label rates of herbicides at up to 5-centimetre diameter rosettes, but after that effective herbicide control tends to become highly variable;**
- **reducing the risk of yield losses to competition between weeds and crops;**
- **difficulty obtaining uniform coverage of large weeds;**
- **older plants can have thicker or hairier cuticles, which slow or prevent herbicide absorption – for example fleabane;**
- **older plants can be better at breaking down herbicides before they get to the target site – a number of studies have shown that herbicide resistance is stronger in older plants; and**
- **delaying initial applications until weeds are taller than 10cm may complicate the implementation of secondary control strategies if the weeds survive the first application through environmental stress, poor application or herbicide resistance.**

Note that not all small weeds are easy to control as they might be small due to environmental stress.

Soil-applied herbicides used at crop-selective rates must be applied to the soil before weeds have established because they are most effective on germinating seeds and emerging seedlings. Larger weeds can grow their roots below the herbicide band or are able to out-grow the effects of the herbicide at these rates. Higher herbicide rates that are used for total vegetation control will control established annual weeds, however they still give poor control of perennial weeds that use vegetative reproduction such as tubers and rhizomes.

8.1 Time of day

The effectiveness of some herbicides can be influenced by the time of day the herbicides are applied. Much of this effect goes back to how the herbicides are absorbed and translocated within the plant, as well as their mode of action. Refer to page 10 in this module, 'Impact of environmental factors on herbicide activity'.

The bipyridil herbicides paraquat and diquat are the most affected by time-of-day application. Due to their rapid activation in the presence of sunlight, applying bipyridil herbicides late in the afternoon or after dark increases the time between absorption and activation. This gives the herbicide more time to translocate before being activated by sunlight.

There is some evidence that glyphosate is more reliable when applied during daylight hours. Most of these environmental effects can be minimised by using a robust rate of herbicide and applying under the best possible conditions.

9. Summary

Spray application is only one part of getting a product to work. When planning any spray job, careful consideration has to be given to product uptake and translocation, the condition of the target and the environmental factors that will impact on the result.

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NEXT MODULE

SPRAY APPLICATION MANUAL FOR GRAIN GROWERS

Module 3 Nozzle design and function How nozzle choice impacts on spray application

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