Why herbicides are most effective on young weeds

By Dr Charlie Reinhardt

Weeds are wonderous creations of nature – weedy type plants not only survived but over time have evolved miraculous adaptations to all the control methods we humans have exposed them to. Our battle against weeds has seen success and failure. Agricultural technology swayed the battle in our favour with the advent of synthetic herbicides from the 1940s.

Herbicide options, however, began to wane through the 1980s and 1990s, at a time when unique chemistry started to peter out and pesticide residues were detected in natural resources (water, air, atmosphere). Simultaneously, farmers encountered more and more weeds that were hard to control and weeds that had evolved full-blown resistance to herbicides.

Herbicide resistance mechanisms

One way in which weeds develop herbicide resistance (HR) is through exposure to sub-lethal herbicide dosages, i.e. dosages that do not outright kill the target plants (weeds). If either deliberate or unintentional underdosing would persist for three to five seasons, especially if only one herbicide mode-of-action is involved, the evolvement of HR is a real risk.

Overdosing, on the other hand, is also associated with HR in weed populations. Both under- and overdosing therefore promotes the evolvement of HR, the difference being that each 'mistake' exerts selection pressure for evolvement of different mechanisms of resistance in weeds.

Research has shown that underdosing selects for HR mechanisms that involve plant characteristics such as:

- Barriers to herbicide uptake (absorption), e.g. leaf hairiness, wax on leaf surfaces, and cuticle thickness.
- Rate of herbicide translocation inside the plant.
- Inactivation of the herbicide in the plant system.

These plant characteristics are associated with metabolic resistance mechanisms. Overdosing is apparently responsible for selection of target-site resistance in weeds, i.e. where the herbicide site-of-action is a specific enzyme and the mechanism of resistance is natural mutation (genetic aberration) in that enzyme, which makes the enzyme insensitive to the herbicide and therefore confers HR to those individuals (HR biotypes).

For example, if one in a million weed plants in a population has undergone natural mutation at the enzyme which is the herbicide site-of-action, heavy selection pressure exerted through the application of a single herbicide mode-of-action at high dosage, plus high use frequency (several times in one season), will exponentially increase numbers of the HR individuals in around three to five years.

Glyphosate is a prime example of a herbicide that suffered this fate due to its high popularity and high usage levels in numerous crop and non-crop systems the world over.

Over- and underdosing

Overdosing with herbicide is arguably totally under human control because herbicide and dosage selection, sprayer calibration, and design of the weed control programme are all management or technology factors.

Underdosing, which is either deliberate or unintentional, can be associated with management or technology (human), biological (plant) and environmental (climate, soil) factors, which occur singly, or as most often is the case, in various permutations. We will not deal in detail with the more well-known human or technology factors that result in underdosing, such as calibration errors and ineffective herbicide application.

Biological underdosing

It has been explained why underdosing with herbicides, for whatever reason, is linked to poor weed control, herbicide resistance (HR) in particular. Henceforth, the focus will be on the generally accepted fact that young weeds are more effectively controlled by herbicides than older plants, especially mature plants near or at the flowering stage.

Weed age and size (morphological characteristics): Plant age equates to plant size because biomass is accumulated over time as the plant grows. Arguably the most common source of farmer complaints regarding herbicide performance is poor or inadequate weed control of weeds that were sprayed at a growth stage well beyond that which is considered ideal for maximum herbicide efficacy. The ideal growth stage for post-emergence herbicide application is often stated on product labels.

In practice, however, label recommendations on weed growth stage is seldom adhered to by advisors and users alike. In defence of those who give scant or zero attention to label recommendations on weed growth stage, weed age/size is seldom, if ever, uniform on a crop field. This is especially true for perennial crop and zero-tillage systems where mechanical weed control (tillage) is not an option and weed age/size can range from just emerged seedlings to plants in flower.

Tillage is the venerable equaliser of weed age/size because weeds must re-establish after a tillage operation, resulting in a relatively uniform weed age/size scenario that lends itself far better to compliance with label recommendations.

Bigger, older plants have denser canopies with overlapping leaves that result in mostly those leaves in the top parts of canopies being able to intercept herbicide spray droplets, with leaves lower down in the canopy intercepting little or no droplets.

Of course, for a contact herbicide such as paraquat this variation in spray droplet interception is bound to lead to weed survival, but even in the case of a fully systemic herbicide such as glyphosate this differentiation in spray interception in a weed canopy can result in poor weed control.

Systemic herbicides applied post-emergence must first be absorbed by plant foliage or plant roots and then internally translocated to the site-of-action. In the case of glyphosate, which has only post-emergence activity, this is an enzyme (EPSP synthase) situated mainly in the leaves.

Dilution of herbicide molecules

Limited interception of spray droplets by leaves in certain parts of a weed canopy will mean that for glyphosate to reach most of its target enzyme, the herbicide molecules will need to be translocated from those leaves that intercepted the spray droplets to those leaves that did not, thus constituting a dilution effect on glyphosate within the plant system.

Such dilution of herbicide molecules boils down to unintentional underdosing, because for the herbicide to kill the weed, a critical amount of herbicide molecules must accumulate to reach herbicidal concentration at the site-of-action (EPSPS enzyme in the case of glyphosate).

For systemic herbicides to reach their full potential in terms of weed control efficacy, they should also be translocated from the intercepting foliage to underground plant parts such as bulbs, rhizomes and roots. For soil-applied herbicides the translocation route is basically reversed, from roots to foliage, and the same principles as for foliar-applied herbicides apply.

Failure to reach herbicidal (plant-killing) concentration at the site-of-action is likely to result in weed regrowth from those plant parts where this critical concentration was not attained. When herbicides are applied beyond the ideal weed growth stage there is often an initial phytotoxic effect, which is visible in the form of injury symptoms.

In cases of effective weed control, such symptoms intensify over time and plants die; with ineffective weed control the injury symptoms might persist but plants do not die, or only parts die off, and eventually there is recovery from injury that renders control inadequate.

Growth rate of weeds (physiological characteristics): Plant age and growth rate are negatively correlated. Growth rate, and hence physiological processes, is highest in young, actively growing plants and progressively slows down as plants mature. Growth is at its lowest rate during the reproductive (flowering) stage. Plants that are actively growing generally absorb more of the applied herbicide and translocate it more rapidly and in higher amounts compared to older plants.

Cell and tissue differentiation (anatomical characteristics): Young (meristematic) plant tissue dominate where growth occurs most actively, i.e. at the growth points on foliage and roots. In young plants the ratio of meristematic to mature tissue is higher than in older plants. Meristematic tissue acts as sinks for carbohydrates and water, as well as for other compounds (e.g. herbicides) dissolved in water.

For herbicides and carbohydrates alike, the source in the source-sink relationship is the point of herbicide entry into plants, i.e. foliage for post-emergence herbicides and underground plant parts (e.g. roots) for pre-emergence herbicides. The source-sink relationship is strongest in young plants compared to older plants, which at least partly explains why herbicides are more effective on younger than on older weeds.

Leaf morphological characteristics determine uptake of foliar-applied herbicides: Young plants tend to have thinner cuticles (protective 'skin' layer on top of the first layer of leaf cells) and less wax on leaf surfaces than older plants. Uptake of a foliar-applied herbicide such as glyphosate, which is highly water-soluble, will therefore be more rapid through a young leaf compared to an older leaf. To optimise uptake of most foliar-applied herbicides the use of adjuvants of various types is usually necessary.

A case has been made for application of herbicides at growth stages stipulated on herbicide labels. Failure to adhere to these recommendations will inevitably result in inadequate weed control, with evolvement of herbicide resistance as the worst-case scenario.

Although environmental factors (climate, soil) play a big role in contributing to unintentional underdosing with herbicides, limited space does not allow discussion at this stage. It suffices to point out that factors such as temperature and soil moisture influence plant growth rate, and also modify those physiological and morphological characteristics that determine herbicide efficacy.

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