By Dr Charlie Reinhardt

Crop injury
due to various stress factor combinations

Soil-applied herbicides, which exert their herbicidal action on weeds following absorption by plant roots, exhibit considerable variation in respect of the period for which their residues can remain biologically active in soil.

A sunflower seedling of the 2015/16 season with injury symptoms that may have been caused by some or all of the following factors acting separately, or together, in various permutations: heat/sunlight/drought, soil-borne herbicide residues and herbicides applied in current season.

Ideally, a soil-applied herbicide should retain its herbicidal action for as long as possible within the season it was applied, but not for so long that there is risk for herbicide carry-over in soil to the following season. Soil-borne herbicide residues should have lost their biological activity, i.e. herbicidal potency, by the time a susceptible follow-up crop is established.

The period for which herbicides remain active in soil is referred to as 'herbicide persistence', also expressed as 'herbicide half-life'. It is measured in days, weeks or months and used for estimating the period of effective weed control, as well as for judging the time that must lapse following herbicide application in a crop before a different, susceptible follow-up crop can be established safely.

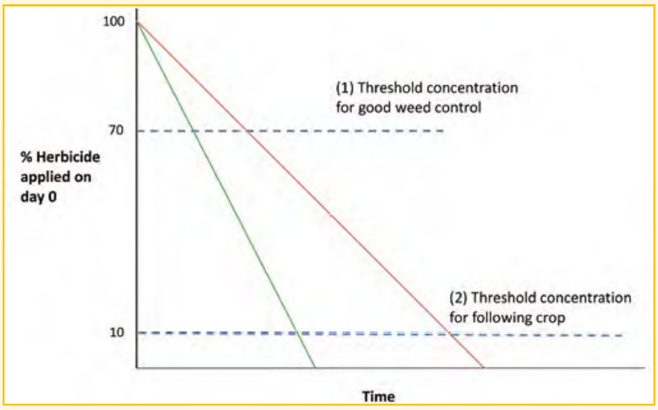
The time required to lapse before a follow-up crop – which is susceptible to soil-borne residues of herbicides applied in the preceding crop – can be planted safely, is termed 'waiting period'. Waiting periods are stipulated on the labels of products containing herbicides for which there is risk for carry-over to a following crop.

Variable herbicide loss rates

Waiting periods that are stipulated for a particular herbicide differ from crop to crop, because crops, just like weeds, can differ in their susceptibility to a herbicide. The time for which a herbicide retains its herbicidal activity in soil determines both the period of weed control efficacy and the waiting period for safe establishment of the follow-up crop.

The hypothetical relationship between herbicide concentration in soil and the time for which effective weed control can be expected, and the relationship between herbicide concentration and 'waiting period', are depicted in *Figure 1*.

Figure 1: The influence of differential rates of herbicide dissipation on (1) duration of weed control and (2) safe period for establishing the follow-up crop.



Based on the theoretical rate of herbicide dissipation (loss) in soil shown by the graph (green line), any factor or factors that would cause a reduction in herbicide dissipation rate (red line) would lead to a longer period of effective weed control, which will be offset by the requirement of a longer waiting period in order to avoid the risk for soil-borne herbicide residues causing damage to the susceptible follow-up crop.

Factors with key roles in determining herbicide loss rates in soil, are the following:

- **Herbicide dosage:** Overdosing might increase the period of effective weed control during the season in which the herbicide is applied, but it could mean that the safe waiting period applying to the follow-up crop no longer applies and should be extended. Underdosing will have directly opposite effects.
- **Excessive overhead water supply** (irrigation or rainfall) could shorten both the period of effective weed control and the required waiting period, provided that the excessive supply of water through the process of leaching removes substantial amounts of soil-borne herbicide from the root zones of both weeds and follow-up crop.
- **High microbial activity in soil** is likely to boost herbicide loss rate, because most soil-applied herbicides are prone to breakdown (decomposition) by micro-organisms that feed on organic molecules, which includes virtually all synthetic herbicides. Soil properties

that promote the numbers and activity of micro-organisms are high organic matter content, moisture content, and pH levels that are neither acidic nor alkaline.

- Certain **herbicides** (e.g. the s-triazines such as atrazine and terbuthylazine) are more sensitive to chemical breakdown than microbial decomposition. Since chemical reactions occur in water medium, drought conditions will likely have a retarding effect on the rate of chemical breakdown of s-triazine herbicides, very similar to reduced loss rates under drought conditions for herbicides that are prone to microbial breakdown, e.g. the triketone and related herbicides such as mesotrione, tembotrione and topramezone.

Prolonged periods of low soil moisture content, combined with low microbial activity, which typifies drought conditions, could lead to an unusually low rate of herbicide dissipation, and hence can cause herbicides to persist for unexpected long periods.

Influence of the drought

Exceptionally dry soil conditions and periodic excessive maximum temperatures, which prevailed across large parts of the maize production region in 2015/16, have characterised what has been called the "worst drought since 1901".

Low soil microbial activity, coupled with low chemical breakdown of herbicides in soil, could have contributed to increased herbicide persistence, and hence, higher residue carry-over in those areas worst affected by the drought. Under such exceptional conditions, the waiting periods stipulated on herbicide labels possibly did not provide adequate protection against carried-over herbicide residues on certain fields in certain areas.

Several cases of suspected herbicide damage to crops such as sunflower and dry beans were reported earlier this year, and in most cases the perceived culprit was mesotrione, which was applied extensively in the preceding season on maize fields. Scant attention was given to the real possibility of atrazine and terbuthylazine having carried over from where it is often used in maize to augment the weed control provided by mesotrione.

In 2015/16, blame that was levelled mainly at mesotrione included such nonsensical opinions as: "Coarser mesotrione molecules of generic products persist for longer than finer mesotrione ones of originally patented products."

In fact, a molecule of any type of matter is consistent in terms of both chemical composition and size, otherwise it cannot be called a molecule, nor can it exhibit the activity it was designed for. Soil persistence of mesotrione in generic products and in original patent products will be the same for similar dosages used under similar environmental conditions.

Waiting period

In a unique study on mesotrione carry-over conducted in South Africa, Allemann and Molomo (2016) concluded that the nine-month waiting period stipulated for dry beans on mesotrione product labels was adequate for averting crop injury following the herbicide's use in maize.

The possible contribution of herbicides, which was applied anew in 2015/16, to crop injury experienced in the current season cannot be ignored. Environmental conditions that are unfavourable to normal growth and development of summer crops – i.e. unusually high maximum temperatures, high-intensity sunlight and dry soil – have characterised both early and late plantings of crops grown in rotation with maize.

Such unfavourable environmental conditions could have caused direct crop injury, and/or may have predisposed those crops to herbicide damage, possibly not only from herbicide residues carried over from the previous maize crop, but also due to those herbicides applied anew in the current crop – or perhaps due to both sets of herbicides acting together on the susceptible crop.

The combination of high maximum temperature, high light intensity, and dry soil probably caused direct damage to crops in the 2015/16 season. Additional exacerbating stress factors could have included herbicide residues carried over from the 2014/15 season, and/or herbicides applied anew in the current (2015/16) season.

Diagnosis of symptoms

Injury symptoms on crops which resemble others, cloud not only the separation of herbicide effects, but also thwarts the diagnosis of symptoms caused by herbicides and those associated with adverse climatic factors – drought and heat stress in particular.

For instance, molecules called 'active oxygen radicles' are the toxic by-products of drought and heat stress on the one hand, and the same oxidation agents responsible for the injury and death of plants that are susceptible to photosynthesis-inhibiting herbicides, e.g. atrazine and terbuthylazine (Bagwat and Bhattacharjee, 2005; Smirnoff, 2005; WSSA, 2014).

Therefore, visible injury symptoms on sunflower seedlings cannot simply be attributed to a particular stress factor – at least not without proper investigation.

This discussion represents a rather complex explanation of crop damage that has been experienced in certain regions in the current growth season. In an exceptional season characterised by unusual environmental conditions, oversimplified explanations will understandably fail to shed light on the challenges that were experienced, and unfortunately casts aspersions on herbicide products without which crop production will be impossible.

Weed resistance to herbicides is a research focus at the University of Pretoria, with Dr Charlie Reinhardt as project leader. To learn more, visit the website *www.up.ac.za/sahri.* Dr Reinhardt is an extraordinary professor of weed science at the University of Pretoria and dean of the Villa Academy. Contact him on 011 396 2233 or email creinhardt@villaacademy.co.za, or visit *www.villaacademy.co.za* for more information.