Herbicide technologies for the future: A look at resistance

By Dr Charlie Reinhardt

In her controversial book, *Silent Spring*, Rachel Carson questioned human attempts to control the natural world by means of synthetic pesticides. The 1960s saw the advent of the so-called green revolution, which was characterised by the doubling of yields of major grain crops, thanks mainly to frenzied development of improved and novel technologies that spawned more efficient cultivars, fertilisers and pesticides.

The concomitant improvement in food security, farmer profits and livelihoods, as well as the upliftment of rural communities that those technological advancements brought, represented to Carson "a smooth superhighway on which we progress with great speed, but at its end lies disaster".

Plant toxins

Even though insecticides, fungicides and bactericides bore the brunt of Carson's eloquent and generally well-motivated treatise, 'plant toxins' (herbicides) did not escape attention and she described them as containing some very dangerous chemicals. She also mentioned that careless use in the belief they are 'safe' can have disastrous results.

Her words proved to be prophetic because, over time, 'dangerous' herbicides have been identified, systematically deregistered and even banned. Such processes are ongoing as evidenced by the progressive withdrawal of paraquat, which for many decades was a stalwart herbicide for diverse applications in crop production, forestry and vegetation control in non-crop settings the world over.

According to the British Crop Protection Council's publication *The Pesticide Manual: A World Compendium*, the herbicidal properties of paraquat dichloride were discovered in 1955 and the herbicide was first marketed in 1962 (the year in which Carson's book was published).

Resistance and species shifts

In modern agriculture one of the most vexing and economically harmful natural factors facing crop production, is weed resistance to herbicides. Herbicide resistance in weeds is linked to the biology and genetics of plants, but the human factor coupled with the injudicious use of herbicides is generally accepted to be the main driver for evolvement of herbicide resistance.

In 1962 Carson dealt mainly with insecticide resistance, such as resistance to DDT. She only briefly touched on the phenomenon of species shifts that occur in weed communities in response to herbicides with selective action, such as the use of 2,4-D. These caused a long-term 'shift' in the weed community, from initial domination by broadleaf weeds, to eventual domination by grass weeds.

Species shifts in weed communities is not the same as herbicide resistance. The former should, however, be regarded as a red flag in terms of resistance potential because both phenomena feed on overuse of a single herbicide mode of action for several years. Insecticide resistance was already well established in the 1950s, but herbicide resistance was only recognised as an equally serious problem in the 1990s.

Today, 501 cases of confirmed herbicide resistance have been recorded; 257 weed species and 167 herbicides are involved across 93 crops in 70 countries, including South Africa.

Balanced weed control

By the 1960s the herbicide industry was industrious in response to the species shift phenomenon. When early herbicide specialists for broadleaf weed control, for example 2,4-D (in small grains and maize) and atrazine (in maize) caused shifts from broadleaf weed to grass and nutsedge weed dominance, the acetanilide group (e.g. alachlor, acetochlor, metolachlor) as specialist grass and nutsedge herbicides came to the fore.

In maize, for example, herbicide combinations that included a triazine such as atrazine, and an acetanilide such as metolachlor, became popular and was effective in dealing with the species shift problem. In small grains, from the 1970s onwards, the sulfonylurea (e.g. chlorsulfuron, triasulfuron) and aryloxyphenoxy propionic acid (e.g. diclofop, clodinafop) groups of herbicides became dominant in that market by providing balanced weed control.

Unfortunately, the small grains market was eventually hit hardest by the evolvement of resistance in many important weed species to herbicides belonging to both the sulfonylurea and aryloxyphenoxy propionic acid groups.

In soya beans, one sulfonylurea herbicide, chlorimuron-ethyl, is registered. Worldwide there are 59 cases of weed resistance linked to this herbicide, and although several of the weed species involved also occur in South Africa, no case has yet been recorded in the country.

The herbicide imazethapyr, which is also registered for use in soya beans, has the same site of action as sulfonylureas, namely the acetolactase synthase (ALS) enzyme. Worldwide there are 132 cases of resistance recorded for imazethapyr, but none yet in South Africa.

Dosages and efficacy

One great success of the agrochemical industry in the last six decades has been the vast reduction in the amounts of chemicals applied for weed control, from kilograms to grams of active ingredients per hectare. For some of the ALS inhibitor herbicides, the registered dosage rates are less than 50g a.i. ha^{-1} and in some cases even below 10g a.i. ha^{-1}. Such developments bode well for the future because it provides environmental benefits of lower doses without weed control efficacy being compromised.

Cobb and Reade (2010) present an intriguing calculation in support of their postulation that at least another order of magnitude may be achieved in reducing herbicide dosage to less than 1g/ha in future. They concede that their calculation or model is based on some major assumptions and extrapolations that may not be scientifically sound in all respects.

The model postulates that for a weed infestation level of 1 million plants per hectare (100 plants per $1m^2$), the amount of herbicide required could be as low as 1×10^{-6} g (one-millionth of a gram) per hectare. Is it farfetched to expect that herbicide field rates measured in milligrams per hectare could be feasible in future? If imagination and innovation can take humankind progressively deeper into space, why would there not be like-minded people in the agrochemical industry who are working on unimaginable breakthroughs in herbicide technology at this very moment?

Banking on innovation

For the past three to four decades the herbicide industry has been severely challenged by constraints in product innovation, including lag in the discovery of novel sites of herbicide activity (current list is 19, with an additional 33 demonstrated experimentally); time lapsed from discovery to market; global competitiveness; and the impact of new environmental legislation, all of which drive up costs.

The impact of glyphosate-tolerant crops on the global herbicide market included the demise of some companies and the merging of others, which contributed to a dramatic slowdown of herbicide research and development in most multinational companies.

In 2016, Dr Hermann Stübler of Bayer AG powerfully articulated the future prognosis at the 7th International Weed Science Conference in Prague as follows: "For the coming ten to 15 years, we have to manage the portfolio of available functioning herbicides intelligently within the framework of strengthened integrated weed management concepts." This means farmers must throw every weed control method at their disposal into the fray in a scientifically sound way.

Looking to the future

In the foreseeable future the surest way in which herbicide efficacy can be improved without increasing herbicide dosage, is the use of adjuvants that increase or promote the herbicide uptake of plants and even subsequent translocation in the plant system. This goes hand in hand with best practices of high precision in the application of products at times when environmental conditions and the physiological state of target plants are all conducive to optimal herbicide activity. This is easier said than done, but it is a necessity and should be considered as part of precision agriculture.

Meanwhile, the introduction of the next novel herbicide(s) is awaited with great anticipation. The last of this kind, with brand-new site of action, were the 4-hydroxyphenylpyruvate dioxygenase enzyme inhibitors that came onto the market in the mid-1980s.

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