WHICH STAGE IS YOUR PADDOCK AT?

STAGE I

ALL HERBICIDES WORK

Problems develop and weeds persist because:

- Avoiding sprays due to long dormancies and multiple germinations
- A mentality of being happy to accept low numbers of survivors in crops and pastures
- A dollars per hectare attitude to control

Preventing the problem developing

- Use top label rates only
- Use single MoA treatments sparingly
- IWM approach paramount along with a zero tolerance to weed seed set

$14 TO $21

STAGE II

NO OVERT RESISTANCE BUT CONTROL IS MORE DIFFICULT

Herbicides struggle to kill weeds compared to the old days

The tell-tale signs

- Esters working better than amines
- Weeds take longer to die
- Need to spray earlier on smaller, younger weeds
- Failures occurring to low rate single MoA herbicide treatments
- Group B herbicides starting to break

Preventing the problem developing

- Use double and triple MoA treatments
- Use top label rates only
- *IWM approach paramount - must adopt zero weed seed management practices*

$14 TO $27

STAGE III

LEVELS OF RESISTANCE TO INDIVIDUAL MOA ONLY

Early stages of multiple resistance

The tell-tale signs

- Group B herbicides largely ineffective
- Group F or group I resistance developing, both can occur as sub-populations within the psddock
- No stacked resistance

Preventing the problem developing

- Use triple MoA treatments for consistent robust control
- Use top label rates only
- Adopt a two spray strategy to control escapes and subsequent germinators.
- *IWM approach paramount - must adopt zero weed seed management practices*

$21 TO $47

STAGE IV

HIGH LEVELS OF INDIVIDUAL MOA RESISTANCE

First stages of stacked multiple resistance

The tell-tale signs of the problem

- Group B herbicides non-functional
- Multiple group F and I resistance
- Failures occur with double MoA treatments with low levels of FI stacking present

Preventing the problem developing

- MUST use triple MoA treatments for consistent robust control
- Use top label rates only
- Use a two spray strategy to control escapes and subsequent germinators
- Group H imperative in control program- ideally as 2nd spray
- *IWM approach paramount - must adopt zero weed seed management practices*

$44 TO $55

STAGE V

HIGH LEVELS OF STACKED MULTIPLE RESISTANCE (FI)

The mature problem

The tell-tale signs

- Group B herbicides non-functional
- High levels of multiple group F and I resistance
- Moderate to high levels of BI, BF and FI stacking
- Failures occur with triple MoA FIC treatments

Controlling the problem

- MUST use triple MoA treatments only
- MUST use top label rates only
- Use a two spray strategy to control escapes and subsequent germinators
- Group H imperative as 2nd spray control program, extreme populations require 2 group H treatments.
- *IWM approach paramount - must adopt zero weed seed management practices*

$59+

STAGE VI

HIGH LEVELS OF STACKED MULTIPLE RESISTANCE (FI AND HI)

The mature problem

The tell-tale signs

- High levels of multiple group B, F and I resistance
- Moderate to high levels of BI, BF and FI stacking of failures occur with triple MoA FIC treatments
- First signs of HI stacking

Controlling the problem

- MUST use triple MoA HIC at top label rates only
- Use a two spray strategy to control escapes and subsequent germinators

STAGE VII

NO HERBICIDES WORK (PENDING STAGE)

The mature problem

The tell-tale signs

- Complete loss of all commercial herbicides

Controlling the problem

- Chemical control no longer the primarily means of weed control in paddocks

TOTAL COST REQUIRED TO EFFECTIVELY CONTROL AND MANAGE

KEY WORDS, DEFINITIONS AND TERMINOLOGY

[1] **Single** MOA resistance:
a term given to a plant population that has plants resistant to a particular MOA herbicide.

[2] **Multiple** MOA resistance:
a term given to a plant population that has plants resistant to more than one MOA herbicide.

Multiple resistance develops in a number of ways. One common way is by heightened metabolism, mutations enabling plants to better detoxify herbicides even though they may belong to different MOA groups. A second common way is where a population historically develops resistance to one MOA and in time develops resistance to a second MOA. In both cases individual plants are resistant to more than one MOA. It is also possible to find plant populations that have some plants resistant to one MOA and others resistant to another MOA, in other words while the population itself may exhibit multiple resistance individual plants do not. A recent survey of herbicide resistance in Wild radish in Western Australia, conducted by AHRI, found that a majority of populations had multiple resistance. The survey tested the susceptibility of the populations to single MOA herbicide treatments, determining the presence of multiple resistance in these populations but not determining if individual plants were multiply resistant. The presence of high levels of resistance to a number of MOA herbicides normally implies that multiply resistant plants are likely present but does not categorically confirm this. While resistance to Group I (phenoxies) and Group F (PDS Inhibitors) has occurred concurrently in Wild radish over the last fifteen years, the Nufarm data base strongly suggests that these resistances have developed independently.

[3] **Unstacked** multiple MOA resistance is a term given to a plant population that has plants individually resistant to herbicides with a different MOA – in other words has subpopulations of plants each resistant to a single MOA herbicide. Nufarm has specifically employed this term to describe Wild radish populations with two subpopulations, one resistant to Group I chemistry the other Group F chemistry

[4] **Stacked** multiple resistance is a term given to populations that have independently developed resistance to herbicides with a different MOA and then through co-existence eventually interbred to produce individual plants resistant to more than one herbicide group. (Diebold. S and Tardif. F, 2006). Nufarm has specifically employed this term to describe Wild radish populations that have through cross pollination developed a third subpopulation where plants are simultaneously resistant to both Group I chemistry and Group F chemistry (Group FI). Plants resistant to Group I and F simultaneously could develop by other means (for example: mutations that reduce herbicide uptake or heighten sequestering that happen to impact both Group I and Group F.

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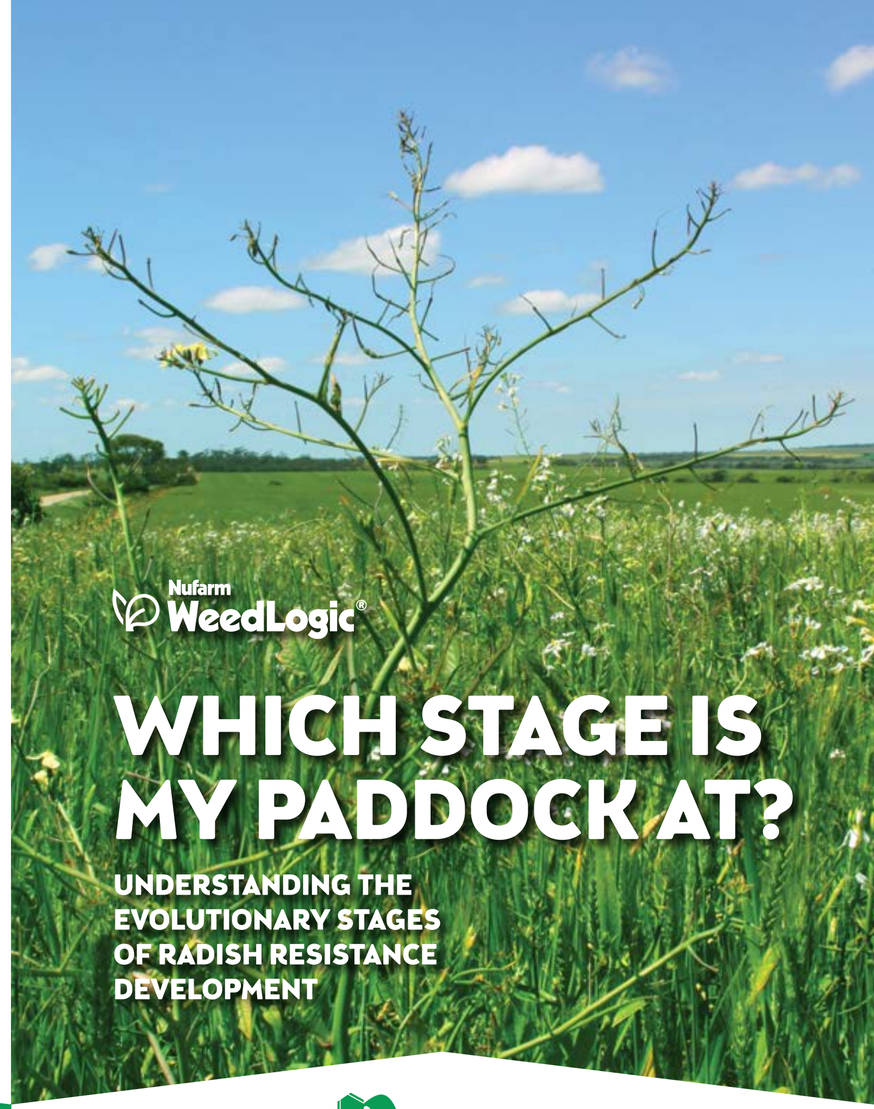
Nufarm Grow a better tomorrow.



Nufarm WeedLogic®

WHICH STAGE IS MY PADDOCK AT?

UNDERSTANDING THE EVOLUTIONARY STAGES OF RADISH RESISTANCE DEVELOPMENT

Nufarm Grow a better tomorrow.

BACKGROUND

The evolutionary and progressive development of herbicide resistant wild radish has been mapped from 1999 to 2013 with more than 180 trials being conducted by Nufarm across Western Australia. Through the genetic profiling of the different wild radish populations encountered in these trials, Nufarm has identified specific 'Radish Resistance Development (RRD) Stages', which help define where these paddocks are in this evolutionary process. By understanding the progression of resistance, the complexities and many interactions associated with problematic radish, populations can now be simplified, allowing growers to more readily formulate effective control strategies based on these RRD Stages.

The RRD Stages reflect the time these paddocks have been farmed and the herbicide regimes they have been exposed to. The stages track the evolution from single[1] mode of action (MOA) resistance through multiple[2] unstacked[3] MOA resistance to multiple stacked[4] MOA resistance in populations which have a very complex mix of these resistances. What transpires is a progressive loss in ability to control the species to a point where populations with a significant number of 'stacked' plants are presently dependent on new chemistry (Group H) to achieve satisfactory control. Prior to this new chemistry there was no effective chemical means available to control these populations.

DEFINING THE RADISH RESISTANCE DEVELOPMENT STAGES

The following RRD Stages are proposed to essentially describe the evolution of resistance according to the biology of the radish plant and define what is required for management. Table 1 provides a summary of the modes of action that are effective and the cost to manage depending on the RRD Stage.

RRD Stage 1:

Truly susceptible populations.

All chemistries registered for use on wild radish perform as well as they did at their development.

RRD Stage 2:

Partially susceptible populations.

All registered chemistries still control wild radish and there are no overt signs of resistance.

There are a number of clear indications suggesting that control is being impacted. For example: the gap between the performance of phenoxy esters and amine herbicides has widened, there is a longer kill time (once 2-3 weeks now takes 6-8 weeks and more) and there is a need to spray earlier on smaller weeds for effective control.

Effective control of RRD Stage 2 with one spray is currently from $14/ha, ideally with two sprays from $21 to $27/ha.

RRD Stage 3:

Single MOA resistant and multiple unstacked resistant populations.

Multiple resistance common but no signs of stacked multiple resistance (except for Groups B-I)
Obvious resistance in a population to a single herbicide group (be it Group B, I or F), or evidence of multiple resistance (Group B, I and F subpopulations). There is moderate to high Groups B-I I stacking but no Groups F-I stacking. Using a full label rate, a Group FI mixture and especially a Group FIC herbicide mix will give consistent robust weed control.

Effective control of Stage 3 can range from $21 to $27/ha based on current costs.

RRD Stage 4:

High level of individual MOA resistance with the 1st stages of stacked multiple resistance to Groups F-I.

Group B herbicides largely non-functional and there is multiple Group I and F resistance with low levels of F-I stacking. Given that sulfonylurea Group B resistance has now been present for more than 20 years, both the F and I subpopulations are likely to have stacked resistance with the resistant B subpopulation. The only option is for growers to use a FIC treatment at full label rate, or to introduce alternative chemistry (Group H). The adoption of a two spray strategy is imperative, due to seed bank issues.

Effective control of Stage 4 can range from $44 to $55/ha based on current costs.

RRD Stage 5:

High levels of stacked Groups F-I multiple resistance. FIC treatments are no longer effective alone.

Group B herbicides are non-functional. Multiple Group B, I and F resistance with moderate to high levels of stacking. Group H and C3 (Bromoxynil) herbicides are the only truly 'fully' functioning MOA. Growers must use a FIC treatment at full label rate and must use a two and possibly three spray strategy:
(i) FIC early followed by H, ideally HCI or
(ii) Group HC followed by Group HCI and
(iii) Late registered glyphosate in crop treatment

Effective control of Stage 5 is $59/ha based on current costs.

RRD Stage 6: Anticipated future stage:

Pyrasulfotole needs to be used in strong HIC 3 MOA mixtures at full label rates because of low levels of HI stacking.

Current knowledge suggests that Stage 6 may be imminent. Two populations of wild radish in WA have recently shown an unexpectedly high tolerance of Precept which may suggest the first signs of Groups H-I stacking. Whilst resistance to Group H is not yet confirmed, these populations are highly resistant to phenoxies indicating a tolerance to Group H chemistry (Source: Boutsalis, P. 2014).

RRD Stage 7: Anticipated future stage:

All known herbicide MOA groups have now been exhausted. High levels of stacked Groups H-I multiple resistance. FIC treatments no longer effective. Chemical control no longer the primary means of weed control in these paddocks.

When resistance develops to Group H chemistry there will be no effective modes of action remaining. RRD stage 7 would be similar to RRD 5 - pyrasulfotole no longer works even in strong HIC mixtures because levels of HI stacking are high. Nufarm have previously documented and experienced a number of paddocks where it was impossible to grow cereal crops with RRD Stage 5 genetics prior to the release of group H - a sobering experience where no modes of action work.

Precautionary note: it is important to note that Bromoxynil, Group C3 is now the basis and the all important 2nd and 3rd MOA in co-mixes of all early post emergent treatments in cereals which features in all stages. Bromoxynil requires an effective MOA mix partner to be fully effective. To date, there has been not detected resistance to Bromoxynil which is now under considerable selection pressure with most other MOA being lost with resistance. Bromoxynil resistance will significantly impact the RRD stages. To ensure longevity of Bromoxynil the best Management Guidelines outlined must be adhered to.

TABLE 1: MODES OF ACTION THAT ARE EFFECTIVE IN THE CEREAL PHASE AND THE COST TO MANAGE DEPENDING ON THE RESISTANCE DEVELOPMENT STAGE.

Stage	M of A's available	Multiple Stacking	Cost 1st Spray	Cost 2nd Spray	Total Cost ($)
1	B- su, sa, imi, G, C2, O, I, C3, F, H	No	14	7	14 - 21
2	B- su, sa, imi, G, C2, O, I, C3, F, H	No	14 - 20	7	14 - 27
3 a*	F, I, C3, H, G	Yes - BI	14 - 20	7 - 27	21 - 27
4 b*	C3, H F, I *	Yes - BI, FI	14 - 20	30 - 35	44 - 55
5 b*	C3, H I *	Yes - BI, FI	27	32+	59+
6	C3, H I *	Yes - BI, FI, HI	32+	32+	64+
7	none	Yes - BI, FI, HI	No effective options available		

a* MUST be mixtures of Multiple MOA, can be 2 modes but ideally 3 modes more robust
b* Group H MUST be second spray as cannot rely on Group I as 2nd or salvage spray
* added as 3rd mode of action in addition to

Source: Nufarm, 2014. Indicative of 2013 recommended retail price of herbicides. Excludes spraying costs.

Integrated Weed Management

Based on what we know about the evolution of resistance, it is crucial that Integrated Weed Management techniques are implemented before resistance develops, or immediately if any level of resistance has been determined. These measures include ensuring effective control with every chemical spray, adopting as many IWM recommendations as possible (outlined in the Herbicide Resistance Management Strategies brochure found on the CropLife Australia website), and adopting harvest seed management strategies. The only sustainable approach is to ensure that all phases of the rotation are robust, weed-free outcomes to ultimately achieve a zero seed set policy.

Nufarm WeedLogic™
A strategic program for managing resistant wild radish

Weedlogic ™ has been developed to provide a simplified understanding of what is happening with radish populations and what is required to manage them. By understanding the various genetic profiles of populations based on the evolutionary stages of resistance development, a strategy
can be formulated to effectively grow weed free crops. This approach and philosophy is a major advance in managing problematic radish populations.

The Weedlogic program is based on the premise of understand, recognise, identify and act. There are three key steps to the program:
(1) conduct resistance testing thus establishing resistance profiles of the individual populations on the farm,
(2) define the RRD Stages and
(3) formulate and implement an effective agronomic and herbicide strategy.

To learn more about the program and how to use it ***log in to the Nufarm Weedlogic™ web site (pending).***

What is required to prevent the problems from developing further

While Weedlogic™ builds a 'Stages' solution pattern, explains logically what is happening and how control programs become more expensive and difficult, a proactive approach is essential. The objective must be for zero seed set in every crop, every phase and every year. This will ensure the decay and erosion of the seed-bank, regardless whether the population has yet to develop resistance or whether it contains problematic resistance genetics. This way the problem is completely overcome. Growers are urged not delay or wait for higher stages of resistance to develop before implementing change but to adopt additional practices over and above the basic control requirements as soon as possible, either on a whole farm basis or a paddock by paddock basis within budgetary constraints.

Best Management Practice guidelines would be not to rely solely on new chemistries, but to alternately use old and new chemistry across a population to minimise selection pressure. Adoption of IWM and harvest seed set management becomes an important adjunct to halting continued resistance development to these new chemistry regimes.

For a proactive approach to achieving complete control and management of wild radish the following basic principles should be adhered to:

- **Use triple MOA treatments to ensure consistent robust control**
- **Use top label rates only**
- **Use a two spray strategy to account for subsequent germinators and escapes from the first spray. If possible use old chemistry (FIC treatments) in the first spray and new chemistry (H based treatments in the second spray)**
- **Resistance test survivors to know what genetics you are dealing with in the future.**
- **True IWM and harvest weed seed management practices are paramount in conjunction to an effective herbicide regime.**
- **Aim for zero seed set and zero seed shed.**