TRANSGENIC CROPS 'HOW WILL THEY IMPACT ON HERBICIDE RESISTANCE AND ITS MANAGEMENT?'

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Summary Transgenic crops which have resistance to herbicides will be available in Australia in the future.

Weeds and grasses which have a major impact on Australian agriculture and which are resistant to herbicides are already present in Australia.

The introduction of transgenic crops must be done taking into account the fact that resistance by weeds to some of the herbicides for which resistant crops are being developed are already present in Australia.

Integrated Weed Management Strategies are already in place for a range of crops and weeds. Their importance will continue and may even increase with the introduction of herbicide resistant crops because there is a risk of over-use of herbicide for which crops are tolerant. If this occurs, there could be serious implications for further resistance and residues in crops and soil.

To ensure the advantages offered by transgenic crops are not lost requires co-operation across a wide range of personnel including regulators, researchers, agronomist, extension personnel and the general public.

INTRODUCTION

Transgenic crops which have resistance to herbicides are already a commercial reality overseas and will be in Australia in the future.

Resistance of weeds and grasses to herbicides is now a reality in Australia. The introduction of herbicide resistant crops will have a controlled introduction and have benefits for Australian agriculture, whilst the development of resistance has occurred haphazardly, has been uncontrolled and with no obvious benefits to Australian agriculture.

The introduction of transgenic crops which are resistant or tolerant to herbicides should offer advantages to Australian agriculture.

The benefits offered to Australian agriculture (as a result of the introduction of transgenic crops which are resistant or tolerant to herbicides) will only flow if all aspects relating to crop and pasture production are considered, reviewed, accepted and managed (irrespective of whether or not the system will have herbicide resistant crops) and the impacts of their introduction recognised.

In this paper it is intended to consider the effect that the introduction of crop and pasture plants resistant to herbicides has on resistance development and how it impacts on strategies introduced to manage and prevent the development of resistance. In addition, the possible effect on other issues, such as crop and soil residues, should also be considered.

CURRENT SITUATION

Sustainable management of weed populations is critical in world agriculture (Powles *et al.* 1996), however, this management is made more difficult when some or all of the weed populations are resistant to herbicides. Up until 1982, weed resistance was not a problem in Australia, but since that time, weed resistance, particularly in the southern cropping regions has become a major issue.

The development of resistance has lead to the establishment of integrated weed management strategies which rely on the use of:

- rotational crops
- alternation of herbicide modes of action
- reducing plant numbers
- reducing seed set
- increased crop competition etc.

These strategies are aimed at all crops and herbicide mode of actions, including those that are being incorporated into transgenic crops.

Herbicide resistance in Australia has developed primarily because of overuse of herbicides with the same mode of action. This occurred in both monocultural cropping situations and in areas where crop rotations are practised. In these instances, the use of Group A, B and L herbicides has lead to the development of resistance weeds.

In other instances broadleaf weeds have developed resistance to the Group B herbicides (Boutsalis and Powles 1994) with some broadleaf weeds. This occurred it is postulated because of the residual nature of some members of this group, i.e. sulfonylureas in situations where soil and climate conditions have reduced the herbicide breakdown, thus increasing selection pressure (Ciba-Geigy 1995).

Crops resistant to the following herbicides are being developed in Australia and overseas:

- glyphosate – Group M
- glufosinate – Group N
- bromoxynil – Group C
- ALS inhibitors – Group B

In addition, two hybrids of canola which are resistant to the triazine herbicides have recently been released in Australia (Agseed personal communication).

From the above list it has been postulated that the risk of resistance developing to glyphosate and glufosiate is low (Kishore and Shah 1988, Waters 1991, Rasche 1995). However, the recent announcement from Charles Sturt University (Pratley personal communication) that annual ryegrass, *Lolium rigidum*, has developed resistance to glyphosate is disturbing and must cause concern to those who saw the development of transgenic crops as the answer to all weed management problems.

This recent development only supports the belief that transgenic crops with herbicide resistance will not allow the return to simple, uncomplicated weed management solutions.

Where herbicide resistant crops are introduced, it will offer growers increased flexibility in managing their weed problems (Powles *et al.* 1996). It will also, in some situations, improve efficacy because it will allow the use of herbicides with improved activity against some weed problems.

However, the herbicide transformed into the crop will not always cover all weed problems. This is particularly the case where the weed spectrum is made up from a diverse range and, in this situation, the advantages are reduced (Medd *et al.* 1995).

The use of integrated weed management strategies will be just as critical and the need to have sound extension methods in place is even greater.

Currently there are general strategies available which encompass the general principles of integrated weed management and these have been prepared to cover as wide a range of situations as possible.

The AVCARE Herbicide Resistance Action Committee has, in conjunction with researchers, prepared specific strategies for Group A and Group B herbicides. These strategies are:

Group A (fops and dims) herbicides

1. Apply only one application of a Group A herbicide per crop per season. Fops and dims are both Group A herbicides and carry the same high resistance risk.
2. Where a Group A herbicide has been used on a particular paddock for control of annual ryegrass, do not use the same group in the following season, irrespective of the performance it gave.
3. Where resistance to group A herbicides is confirmed by herbicide resistance testing, use other control methods to reduce populations to manageable levels and apply other herbicide groups in a future integrated approach.
4. Ensure that surviving weeds from any treatments do not set seed.

NB. The above recommendations are designed to delay the onset of resistance to Group A herbicides. For more information about resistance prevention, see your local agronomist or advisor.

Group B (ALS inhibitor) herbicides

1. Apply only one application of a Group B herbicide per crop per season. If a Group B herbicide has been applied as a pre-emergent application, DO NOT apply any further Group B herbicides to that crop. Make any further post-emergent applications with herbicides from a different group.
2. In the following seasons, preferably use herbicides from a different group.
3. If a post-emergent application is made with a Group B herbicide, this should preferably be as a tank-mix with another mode of action that controls or has significant activity against the target weed. If any further applications are required in that season, it should be with a non-ALS mode of action herbicide that controls the target weed.
4. A Group B herbicide may be used alone on flowering wild radish only if a Group B herbicide has not been previously used on that crop.
5. Ensure that surviving weeds from any treatments do not set seed.

NB: A) These strategies should be incorporated into an Integrated Weed Management (IWM) Program. B) The above recommendations are designed to delay the onset of resistance to Group B herbicides. For more information about resistance prevention, see your local agronomist or advise.

These specific strategies were prepared because these herbicide groups are considered to be the ‘at risk modes of action’.

AVCARE, in conjunction with the CRC for Weed Management Systems and GRDC have produced a chart: Herbicide Mode of Action Groups.

The details contained in the chart are as follows:

Herbicide product labels carry a letter code A, B, C etc. which relates to their mode of action and will assist in avoiding resistance. ‘It’s as easy as A, B, C’ etc. groupings on the label.

1. Observe the new A, B, C, etc. groupings on the label.
2. Check this chart of Herbicide Groups.
3. When using herbicides, ensure that you rotate between crops.
4. Keep accurate spraying records for each paddock.
5. Seek advice and move information.

Group A. Inhibitors of fat (lipid) synthesis – ACC'ase inhibitors:
Aryloxyphenoxypropionates ('fops'): Correct®, Digrass®, Fusilade®, Fusion®, Gallant®, Hoegrass®, Nugrass®, Puma S®, Targa®, Topik®, Tristar®, Verdict®
Cyclohexanediones ('dims'): Achieve®, Falcon®, Fusion®, Grasp®, Select®, Sertin®, Sertin® Plus

Group B. Inhibitors of the enzyme acetolactate synthase – ALS Inhibitors:
Sulfonylureas: Ally®, Amber® Post (also contains terbutryn a Group C herbicide), Associate, Brushkiller, Brush-Off®, Cutt-Out™ (also contains glyphosate – a Group M herbicide), Express®, Glean®, Harmony® M, Logran®, Londax®, Lusta, Nugran®, Oust®, Renovate™, Siege®
Imidazolinones: Arsenal®, Spinnaker®
Sulfonamides: Broadstrike®, Eclipse®

Group C. Inhibitors of photsynthesis at photosystem II:
Triazines: Agtryne® MA (also contains MCPA – a Group I herbicide), Amber® Post (also contains triasulfuron – a Group B herbicide), Bladex®, Gesagard®, Igran®, atrazine, simazine, terbutryn
Triazinones: Lexone®, Sencor®, Velpar®
Ureas: Afalon®, Bandit®, Carrotex®, Graslan®, Karmex®, Krovar® (also contains bromacil – a Group C herbicide), Tribunil®, Probe®, Tupersan®, Ustilan®, diuron, linuron
Nitriles: Buctril® 200, Jaguar® (also contains diflufenican – a Group F herbicide), Totril®, Unyvnox®, bromoxynil
Benzothiadiazoles: Basagran®
Acetamides: Ronacil®
Uracils: Hyvar®, Krovar® (also contains diuron – a Group C herbicide), Sinbar®
Pyridazinones: Pyramin®
Phenyl-pyridazines: Tough®

Group D. Inhibitors of tubulin formation:
Dinitroanilines: Credit®, Surflan®, Stomp®, Yield®, trifluralin
Benzoic acid: Chlorthal, Dacthal®

Group E - Inhibitors of mitosis:
Thiocarbamates: Avadex® BW, Eptam®, Ordram®, Tillam®, Vernam®
Carbamates: chlorpropham
Organophosphorus: bensulide

Group F. Inhibitors of carotenoid biosynthesis:
Nicotinanilides: Brodal®, Jaguar® (also contains bromoxynil - a Group C herbicide), Tigrex® (also contains MCPA - a group I herbicide)
Triazoles: amitrole
Pyridazinones: Solicam®

Group G. Inhibitors of protoporphyrinogen oxidase:
Diphenyl ethers: Blazer®, Goal®
Oxadiazoles: Ronstar®

Group H. Inhibitors of protein synthesis:
Thiocarbamates: Saturn®

Group I. Disrupters of plant cell growth:
Phenoxys: Barrel® (also contains bromoxynil – a Group C herbicide, dicamba – a Group I herbicide), Buctril® MA (also contains bromoxynil – a Group C herbicide), Tigrex® (also contains diflufenican – a Group F herbicide), Tillmaster® (also contains glyphosate – a Group M herbicide), Tordon® 242, Tordon® 75-D, 2,4-D, 2,4-DB, MCPA
Benzoic acids: Banvel®, Sandoban® (also contains glyphosate – a Group M herbicide), dicamba
Pyridines: Garlon®, Lontrel®, Tordon® 242, Tordon® 75-D, Starane®

Group J. Inhibitors of fat synthesis:
Alkanoic acid: Frenock®, TCA, dalapon

Group K. Herbicide with multiple sites of action:
Amides: Devrinol®, Dual®, Enide®, Kerb® WP, Ramrod®
Carbamates: Asulox®, Betanal®, Carbetamex®
Amino propionates: Mataven®
Benzofurans: Daconate®, Tramat®
Phthalamates: Alanap®
Nitriles: dichlobenil

Group L. Inhibitors of photosynthesis at photosystem I:
Bipyridyls: Diquat, Gramoxone®, Nuquat, Reglone®, Spray Seed®, paraquat

Group M. Inhibitors of EPSP synthase:
Glycines: Cut-Out™ (also contains metsulfuron methyl – a Group B herbicide), Glyfos®, Roundup®, Tillmaster® (also contains 2,4-D – a Group I herbicide), Touchdown®, Sandoban® (also contains dicamba – a Group I herbicide), glyphosate

Group N. Inhibitors of glutamine synthetase:
Glycines: Basta®

DISCUSSION

With the introduction of transgenic crops, these specific strategies and chart will need revision to ensure they are still applicable.

This will be complicated by the fact that crops with resistance to herbicides will not be released simultaneously. As a result, the strategies will have to take into account the influence of the crop in the rotation, the expected use pattern of the herbicide in question taking into account the weed spectrum and distribution.

With the introduction of herbicide resistant crops, it is highly likely that the herbicide to which the crop is resistant will be used more extensively, particularly if the weed spectrum is such that the herbicide will provide control of the major species.

The greater use and reliance upon a reduced number of herbicides is one of the risks seen with the introduction of herbicide resistant crops (Burnside 1992). If, for example, lupins with resistance to glyphosate were introduced into Western Australia, we could expect to see greater use of this herbicide in a wheat/lupin rotation than is currently occurring, with usage through all parts of the rotation.

Glyphosate would be ideally suited in this rotation because of the importance of annual ryegrass (*Lolium rigidum*) and wild oats (*Avena* spp.) as weeds in both wheat and lupins and because of the excellent performance of glyphosate against these problems.

In the wheat phase, glyphosate could be used preplant and in the lupin phase it could be applied both pre- and post-planting. Thus, the selection pressure would be increased significantly.

As previously indicated, it appears that annual ryegrass can develop resistance to glyphosate. Unless due care and attention is paid to adhering to IWM strategies, we could, within a short period of time, have widespread resistance to glyphosate. This would be a similar situation to that which occurred with the Group A herbicides which were used in all phases of the wheat/lupin rotation, leading to the development of resistance to diclofop methyl by annual ryegrass in 1982 (Heap and Knight 1982).

Thus, consideration should be given to developing specific strategies for the use of all herbicides for which herbicide resistant crops are under consideration. This must consider and take into account how the crop is integrated in cropping programs.

Some of these crops and herbicides are:

Glyphosate	cotton, lupins, soybean
Glufosinate	lupins, canola, maize, soybean
Bromoxynil	cotton, canola
ALS Inhibitors	cotton, maize, canola
Triazines	canola

The other issues which will have impact is the development of 'volunteer' weeds.

In cropping rotations, i.e. where there is a limited or no pasture phase, there has been the development of volunteer weeds as a problem in following crops, e.g. lupins or field peas, as a weed problem in the following cereal crop in a legume/cereal rotation.

If the volunteer weed is tolerant to a herbicide normally used on the fallow or in the crop, then this could create a major management problem. This needs to be considered on the development of IWM strategies.

Increased usage of specific herbicides, resulting from the introduction of herbicide tolerant crops, could have impacts on residues in both crops and soils because of the possible increased usage.

Two areas of concern are:-

1. Residues in harvested crops exceeding the approved levels, particularly if the use pattern is outside that used in establishing MRLs and WHPs.
2. Soil residues exceeding the established plant back periods because of increased usage and application (Walker *et al.* 1995).

These aspects must be considered during the establishment of IWM strategies. The potential to increase residues in the soil of residual herbicides has implications or plant back periods and can increase selection pressures. Hence, overuse must not occur.

CONCLUSIONS

The development of herbicide resistant crops offer a number of advantages which will provide increased flexibility to users.

This increased flexibility will result particularly where alternate herbicides which control the weed spectrum can then be used in these crops. It will have particular application where weed resistance is already present.

If the introduction of these crops is not undertaken utilizing a well considered integrated weed management program, then it is highly likely that weed resistance will increase. Without this control, there could be an increase in volunteer crops as weeds and residues in crops and soils could exceed approved limits with disastrous effects from both an agronomic and trade point of view.

The introduction of these crops requires close collaboration between the organization developing the herbicide tolerant crop, the herbicide manufacturers, the researcher, the agronomist, the extension personnel, the users, regulators and the general public to ensure the advantages are not lost because of overuse or lack of confidence of what is a useful technological innovation.

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