THE IMPACT OF DEVELOPING HERBICIDE RESISTANT CROP PLANTS

R.J. Field[1], A.J. Conner[2], M.H. Foreman[1]
[1] Department of Plant Science, Lincoln University, Canterbury, New Zealand
[2] New Zealand Institute for Crop & Food Research Ltd, Lincoln, Canterbury, New Zealand.

Summary. A wide range of technical approaches allows the production of crop plants that are genetically modified to be resistant to a specific herbicide. The agricultural applications of herbicide-resistant crops are wider than simple weed control. The development and introduction of this new technology offers opportunities for enhancing the quality and quantity of both seed and crop production systems.

Wide scale introduction of herbicide resistant crops would have some marked advantages for weed management and hence crop production. The possible environmental impacts associated with developing herbicide resistance in crop plants are examined and the gene flow of herbicide resistance to weeds is judged to be a negligible threat. Specific case studies of genetically modified crops with herbicide resistance demonstrate that there may be marked environmental and production advantages in the new technology. It can be reasonably claimed that the new technology could promote the replacement of some existing herbicides by those that are toxicologically and environmentally more acceptable.

INTRODUCTION

It is possible to develop herbicide-resistant plants by conventional plant breeding techniques. However, recent advances in cellular and molecular biology of plants greatly simplify the development of herbicide resistance in a wide range of crops. The ease with which these genetic manipulations can be made has opened up a number of new applications for herbicide-resistant crops in seed production and agronomic practice, in addition to providing an alternative strategy to conventional weed control.

The potential of this technology has raised public concerns that the development of herbicide-resistant crops could result in the greater use of herbicides. In addition, significant management concerns include the potential transfer of genes encoding herbicide resistance from crops to weeds, and the persistence of volunteer crop plants. Advocates of the technology have generally argued that developing crops with resistance to selective herbicides will have the positive effect of reducing overall herbicide use by promoting the use of more effective and environmentally acceptable chemicals. This paper examines the environmental impacts associated with developing herbicide resistance in crop plants.

DEVELOPMENT OF HERBICIDE RESISTANT CROPS

Genetic variation for different tolerance responses to a variety of herbicides has been detected in a range of crop species. Herbicide tolerance can be cytoplasmically inherited, qualitatively inherited as single dominant or recessive alleles, or quantitatively inherited with several to many loci with varying degrees of additive and dominance gene action. The development of crop plants with improved tolerance to herbicides has been possible by conventional breeding and selection using both qualitatively and quantitatively inherited genes. Herbicide tolerant plants have also been successfully developed through applications of cell culture. Protoplast fusion has proved especially useful for the development of herbicide-tolerant plants by transferring chloroplasts that encode resistance to triazine herbicides, whereas *in vitro* cell selection has allowed new sources of mutant genes to be developed.

The recent development of transgenic plants via genetic engineering offers considerable potential for the development of herbicide resistance. The rapid development of this technology has already resulted in over 135 regulatory approved field trials on transgenic plants with herbicide resistance in a wide range of crops (1).

APPLICATIONS OF HERBICIDE-RESISTANT CROPS

To control weeds the degree of herbicide selectivity to the crop must be sufficient to allow the application of a herbicide at concentrations capable of eliminating weeds, while having minimal or no effect on the economic yield of the crop plant. With effective herbicide-resistance in crop plants, herbicide applications can be delayed until weed control is necessary. The benefits of herbicide-resistance are reduced herbicide applications and hence reduced environmental impacts.

Development of herbicide resistant cultivars provides for a number of agronomic opportunities:

- The development of a broad range of herbicide-resistant crops could be important for establishing effective crop rotations, that allow crops to be grown on herbicide-contaminated soils.

- The independent development of herbicide resistance in different lines of the same cultivar or crop offers a novel management approach for the control of crop volunteers.

- Herbicide resistance offers a convenient approach to achieving crop thinning by blending seed of a herbicide-resistant genotype and a herbicide-sensitive genotype and the sowing of a random mixture. Herbicide application at a later date will eliminate the sensitive plants.

- The development of a cultivar with herbicide resistance offers a convenient approach to eliminate from the seed production fields sources of contamination from seed of the same crop or weeds by applying the appropriate herbicide. Marker genes for herbicide resistance can be effectively used to overcome several problems associated with pollen contamination during hybrid seed production.

DEVELOPMENT OF WEED STATUS AND GENE FLOW OF HERBICIDE RESISTANCE TO WEEDS

The most frequently raised concern about the introduction of transgenic herbicide-resistant plants is the possible spread of the resistant gene beyond the sown crop (3). There are two mechanisms for such spread:

Development of weed status. The potential for a transgenic herbicide-resistant crop to develop weed status depends on the reproductive characteristics of the plant species and the crop in the following rotation. The capacity for transgenic plants to persist in ensuing crop rotations is unlikely to be any different from the existing situation for non-transgenic crops, unless the introduction of herbicide resistance confers a change in ecological fitness. Good husbandry will minimise the numbers of volunteers and existing physical or chemical control strategies should eliminate volunteers that appear.

Gene Flow. Emigration of herbicide-resistant genes from the crop has the potential to occur intraspecifically and interspecifically. In both cases gene flow could arise via pollen or seed dispersal.

The dispersal of pollen beyond the source crop depends on the specific plant species although generally pollen travels a negligible distance (2). Traditional plant breeding techniques have recognised this fact and, as a result, set standard isolation distances for specific crops to prevent pollen-based gene flow contamination of crops grown for seed. These isolation standards take into account the pollen dispersal and outcrossing characteristics. The extension of isolation standards to transgenic crops is an appropriate precaution. Independent of the ability for pollen to disperse beyond its source, the significance of pollen-based gene flow is related to the mating system of receptor species. There are many post-zygotic barriers before ultimate seed production, seedling appearance and gene expression. Successful fertilisation and post-zygotic development could readily occur in cases of intraspecific crossing, but in cases of interspecific crossing or hybridization, the frequency of successful fertilisation is very low (Frankel and Galun, 1977).

Seed emigration from the crop is a function of the crop attaining sexual maturity, and the activity of seed-distributing agents. The spread of viable seed from the sown crop offers the opportunity for the establishment of "weed" populations of the transgenic herbicide-resistant plants. Control would be similar to current practice for volunteer plants.

IMPACTS OF INTRODUCING HERBICIDE-RESISTANT CROPS

To illustrate the possible application of herbicide resistance in crops, two case studies, as they apply in New Zealand have been prepared, using examples of herbicide - crop combinations for which specific herbicide resistance has been developed.

Glyphosate-resistant field tomatoes. Field-grown tomato (*Lycopersicon esculentum* L.) is an important processing crop that has significant weed problems. Wide planting and incomplete plant canopy development provide an ideal environment for a wide range of annual and perennial weeds. Weeds reduce crop yield and create problems for mechanical harvesting. Applying glyphosate to genetically-modified tomato plants would allow a very wide spectrum of weeds to be controlled, including perennial species that are difficult to kill. The risk of crop damage, which can occur with existing herbicide recommendations, can be avoided. The use of glyphosate would provide greater flexibility in the timing of applications for weed control compared with the soil-applied treatments of chloramben, diphenamid and trifluralin. The grass-specific herbicides fluazifop (butyl ester) and quizalofop (ethyl ester) must be used in association with a broadleaf herbicide treatment resulting in significantly greater total herbicide usage. Glyphosate has low toxicity and its rapid degradation and lack of persistence in soil and groundwater make it environmentally acceptable. Soil residue problems with existing herbicide recommendations, such as diphenamid, metribuzin and trifluralin, are significant while chloramben is highly water soluble and a potential risk to groundwater.

Chlorsulfuron-resistant potatoes. Potato *(Solanum tuberosum* L.) is a very important fresh market and processing crop with significant weed competition and weed control problems. In addition post-harvest sprouting of non harvested tubers can create a major volunteer potato problem in subsequent crops. Potato is a long duration crop that is planted in wide rows and involves moulding. These factors generate a significant opportunity for weed establishment, reduction in crop yield and interference with harvesting efficiency. Chlorsulfuron controls most broadleaf weeds and importantly offers some flexibility in the timing of application in relation to the stage of weed development. The short term soil residual activity of chlorsulfuron is of benefit in controlling late emerging weeds. The use of chlorsulfuron on potatoes would eliminate the use of some presently registered herbicides that control an inferior spectrum of broadleaf weeds, or may cause crop damage. Chlorsulfuron could be used with great flexibility and at times that correspond to the appearance of weeds - a practice not possible with some existing products, for example bentazone and metribuzin. Chlorsulfuron does not control some broadleaf weeds, such as black nightshade (*Solanum nigrum* L.) nor grass weeds that are potential problems in a potato crop. Large-scale grass weed problems would necessitate the use of a selective grass herbicide, such as fluazifop (butyl ester). Soil residual activity of chlorsulfuron may restrict the planting of subsequent specific crops. No analysis of the potential for groundwater contamination is available but the risk appears to be slight. The occurrence of weeds with specific resistance to chlorsulfuron is a concern and does not argue in favour of selecting this herbicide.

CONCLUSIONS

Overall the impact of developing and releasing herbicide-resistant plants does not impose an additional environmental risk to that already represented by herbicide use. The release of herbicide-resistant plants establishes a more complex but not necessarily greater risk than is presented by current practice. The development of crop plants that are resistant to specific herbicides should also include analysis of the effects of these herbicides on the environment, particularly their soil persistence, potential for leaching to groundwater, or undesirable bio-accumulation characteristics. Resistance in crops to herbicides that pose the least environmental threat should be the target of genetic engineers.

ACKNOWLEDGEMENTS

This project was funded by the Ministry for the Environment.

REFERENCES

1. Chasseray E. and Duesing J. 1992. Agro-food-Industry Hi-Tech 3, 5-10
2. Frankel, R. and Galun, E. 1977. In: Pollination mechanisms, reproduction and plant breeding. Springer-Verlag, New York. pp 281.
3. Tiedje, J.M., Colwell, R.K., Grossman, Y.L., Hodson R.E., Lenski, R.E., Mack R.N. and Regal, P.J. 1989. Ecology 70, 298-315.