SESSION 7B

HERBICIDE TOLERANT CROPS: THEIR VALUE IN WORLD AGRICULTURE

Chairman and Session Organiser	Dr J B Sweet *National Institute of Agricultural Botany, Cambridge, UK*
Papers	7B-1 to 7B-3

Herbicide resistant tropical maize and rice: Needs and biosafety considerations

J Gressel
Plant Sciences, Weizmann Institute of Science, Rehovot, Israel

ABSTRACT

African tropical maize is plagued by the root parasitic witchweeds (*Striga* spp.), which cannot be controlled by selective herbicides while underground. Seed dressings of imazapyr and pyrothiobac provide season long control on imidazolinone-resistant maize, which allow traditional interplanting of legumes. It is also proposed to control *Striga hermonthica* directly by deleterious transposons. The acute weed problems of direct seeded rice, especially feral and weedy *Oryza* spp and herbicide-resistant *Echinochloa* spp could be controlled by herbicides in transgenic resistant rice. The inevitable introgression of the resistance genes into feral and weedy rices can theoretically be mitigated by using tandem constructs with genes deleterious to weedy rices spliced to the resistance genes.

MAIZE AND WITCHWEEDS

Maize is now the major staple grain in sub-Sahara Africa. Weed control in this subsistence maize is (fe)manual; women spend 80% of waking hours weeding this crop, without removing the witchweeds (*Striga* spp.). These root-attaching phytotoxic parasitic weeds are a major sink for crop photosynthates (Ransom *et al.*, 1996), debilitate crop growth and yield, up to total loss. Tens of flower stalks appear per maize plant, each bearing tens of thousands of seeds. The potential yield of maize without *Striga* and without fertilizer is double the current yield and can be doubled again by using fertilizers (Gressel *et al.*, 1996a). Berner *et al.* (1995) cite evidence that in western Africa "about 40 million ha in cereal production are severely and 70 million ha are moderately infested by *Striga* spp., with $7 billion lost yield, detrimental to the lives of over 100 million people". Removing flower stalks reduces re-infestation, but only marginally reduces damage inflicted on the current crop. Maize seed can become contaminated with *Striga* seed during harvest, and marketed corn seed is commonly contaminated with *Striga* seeds (Berner *et al.*, 1994). Contaminated crop seed is probably the major form of *Striga* dispersal. Sulfonylurea herbicides affecting ALS (acetolactate synthase) give some control of *Striga* in normal sorghum and maize (Adu-Tutu & Drennan, 1991). However crop growth is sensitive to higher rates, leaving little margin for farmer error.

It has been hypothesized that biotechnologically-derived crops with resistance due to a modification of the target site of the herbicide could be used for parasitic weed control (Gressel, 1992). This target site resistance concept was borne out with the parasitic broomrapes (*Orobanche* spp.) using model crops containing transgenes for resistance to chlorsulfuron (an ALS inhibitor), glyphosate (an inhibitor of enol-phoshate-shikimate phosphate synthase leading to the synthesis of aromatic amino acids and other aromatic compounds), and asulam (an inhibitor of dihydropteroate synthase; Joel *et al.*, 1995). Routine field applications of herbicides to resistant crops would be too expensive for most

African farmers and would not fit their cropping systems, including intercropping. Point applications were tested that might allow less total herbicide use, but at very high local concentrations. Such high concentrations could only be possible as dressings to seeds possessing target site resistance, as only these have a sufficient magnitude of resistance, and would allow intercropping. Seed dressings have been tested for parasitic weed control on crops that metabolized the herbicides so repeated post-emergence treatments were required for season-long control (Jurado-Exposito *et al.*, 1996; Berner *et al.*, 1994). A few of nine imidazolinone and sulfonylurea herbicides inhibiting ALS provided season long *Striga hermonthica* control when applied to imidazolinone resistant maize seed as a drench at planting (Abayo *et al.*, 1998). Seed priming (soaking) with glyphosate and seed coating with ALS inhibitors have been shown to control parasitic weeds on target-site resistant crops (Berner *et al.*, 1997; Gressel and Joel, 1997), including maize. ALS target-site resistant maize was developed from a tissue culture mutation (Newhouse *et al.*, 1991), which bears a mutation of try552leu (Bernasconi *et al.*, 1995) and is marketed in the homozygous form as IR (imidazolinone-resistant) maize. Maize with ALS target site resistance derived from pollen mutagenesis bears a mutation of ala133thr and is marketed in the U.S.A. in the heterozygous form as IT (imidazolinone tolerant) (Greaves *et al.*, 1993). IR maize can withstand higher levels of imidazolinone herbicides than IT maize (Wright and Penner, 1998).

Striga control on seed-dressed herbicide resistance maize

Kanampiu *et al.* (1999) have showeed that the magnesium salt imazapyr effects season long control at less than 0.5 mg a.e. per seed (45g a.e./ha) when the homozygous 3245IR maize seeds were dressed by priming (soaking) and planted either wet or dry, or dressed by adhesive or dust surface coating, and to drench-dressing of seed in planting holes, as well as post emergence herbicide treatment (Kanampiu *et al.* 1999). Pyrithiobac was at least as effective as imazapyr. The heterozygous ALS-resistant 8326IT corn succumbed to all doses used. With crop seed dressing there is no need to spray, with the concomitant ecological advantage that no herbicide is applied off-target. Additionally, the procedure is non-disruptive to intercropping with legumes, if the legume seeds were planted >15 cm from treated maize (Kanampiu *et al* in press). Maize, by exuding *Striga* germination stimulants, acts as a trap crop, depleting *Striga* seed reservoirs and possibly allowing rotation with other cereals.

Models predict that five resistant *Striga* plants/ha will emerge in the first year of treatment with herbicide (Gressel *et al.*, 1996b). A strict regime of hand pulling before seed-set will be needed to preclude the rapid build-up of resistance, or resistant *Striga* will cover fields in 3 to 5 years. Roguing will also assist in depleting the seed bank by preventing its replenishment. Transgenic maize with other genes for target-site herbicide resistance should also be useful for controlling *Striga* as part of an integrated program to delay the evolution of herbicide resistance in *Striga*.

Biosafety considerations with herbicide resistant maize

The mutant IR maize described does not come under biosafety regulations in most of the world. There are no weedy relatives of maize that herbicide resistance could move to from transgenics; in Mexico there are wild (not weedy) relatives that barely interbreed, and adding a gene for herbicide resistance should not render any weedier. Herbicide-resistant maize would not be an uncontrollable volunteer weed in the following crop, as herbicides are hardly used in the tropics at present, but this could eventually be a problem that would be readily solved.

TAC-TICS for *Striga* control

Striga hermonthica, the major *Striga* spp. attacking maize is not a wild species; it is a truly co-domesticated man-made contrivance, just like maize. In its present evolutionary state it is not more competent than maize to exist in the wild as it can only grow on crops; it has few wild hosts. There is ample evidence that it evolved recently from *S. aspera*, a parasite of many wild species, but is not a pernicious weed. It would be useful to reverse evolution; i.e. to force *Striga* back to being an innocuous wild plant. We propose that it is possible, using genetic engineering to debilitate *Striga* (Gressel & Levy 1999). If this solution is successful, it will integrate with and facilitate other successful control mechanisms, leading to more durable control. It is proposed to disperse genes that will be deleterious when turned on: genes that mimic herbicide action; that inhibit plant growth; that render super-susceptibility to herbicides; that participate in host recognition; or modulate hormone levels. The seminal concept by Pfeifer and Grigliatti (1995) proposed a means for controlling pests with TAC-TICs: "Transposons with Armed Cassettes for Targeted Insect Control". They suggested transforming insects with a gene, which if activated by a chemically-induced promoter, would debilitate the insect. We termed these assisted-suicide genes as "*kev*" (Kevorkian) genes. They postulated that releasing a few transgenic pests would be sufficient if the transgenes are coupled in a multicopy transposon. They suggested that the farmers use their normal methods of pest control during the period of transposon transmission throughout the population, and then chemically activate the promoter. The concept modeled for insects seems to be appealing for *Striga* if the proper *kev* genes and /or promoters can be found; the transposons available; the weeds can be easily engineered; and most importantly, if safety considerations can be met. *Striga hermonthica* is singularly appropriate for this technology as it must be cross pollinated.

The Ac/Ds transposon family, originally found in maize, has been shown to be active in all the heterologous plant systems where it has been introduced (see Kunze, 1996). Ac is preferentially transposed during DNA replication, increasing its copy number while it transposes. The dominant *kev* genes can be introduced into a transposon cassette in high copy number and transformed into *Striga* to generate debilitated weeds after chemical induction. These *kev* parents can be sown together with maize. There are many possible *kev* genes available that, when partially inhibited, cause the accumulation of lethal metabolites in plants, and are targets for known herbicides. Antisensing or overexpressively co-suppressing the gene encoding the enzyme can kill the plant when turned on (Höfgen *et al.* 1995).

Chemically-induced genes that cause pollen sterility a generation hence have been proposed for protecting crop varieties (the "terminator" genes of the popular press), could be considered as *kev* genes. When disseminated by transposons, they would prevent seed set but *Striga* would damage the crop. This approach could be used in conjunction with herbicide-resistant maize; to eliminate late season *Striga* escapes that cause little damage as well as any herbicide-resistant *Striga* that evolves. The competition among *Striga* plants is quite fierce, both to fertilize and during the "self thinning" period when seedlings establish. Individuals bearing genes that are essentially unfit would be rapidly eliminated from the population.

Known antiweediness genes that limit competitiveness between weed and weed, and weed and crop are described in Gressel (1999) and have been proposed for use in tandem with useful genes for rice (see below). Such genes under chemically induced promoters could be used as part of *kev* constructs.

A wide variety of promoters are available for chemically inducing the expression of genes in plants (Gatz & Lenk, 1998). No good chemical inducers of plant genes are known as yet that would fulfill the requirements of the original TAC-TIC concept for *Striga*. An applied *kev* inducer would have to be translocated through the plant from the foliage to the *Striga* attached to the roots. The best known inducers are not translocated, or would affect the crop.

RICE, A CROP WITH WEED PROBLEMS

Traditionally, the main method of weed control was to hand plant rice from nurseries into weed free, flooded paddies. Workers willing to perform this labour are becoming rarer as better paid jobs become available. The use of direct seeding of rice is increasing leading to problems from global "millennial" weeds, e.g.: (1) *Echinochloa* spp. – always problem weeds, but are now evolving resistance to the rice herbicides used for their control; (2) the sedges (nut and other) that were never well controlled by any herbicide chemistry and are expanding; (3) the red and weedy rices that were never controlled by selective herbicides.

Propanil was useful until resistance evolved in all major areas where it was used (Gressel and Baltazar 1996). Resistance was thought to be nigh impossible and improbable to the widely used chloroacetamide and thiocarbamate herbicides butachlor and thiobencarb (Gressel and Baltazar, 1996). It was thus surprising when reports of *Echinochloa* resistant to these herbicides came from China (Huang & Gressel, 1997), particularly because there was cross resistance, and it was claimed that there are 2 M ha of such resistant *Echinochloa*.

Direct seeding of rice favoures the sedges and sedge control is not good with current herbicides. Effective chemical control of sedges is only achieved with systemic herbicides that will penetrate the storage organs. However there are genes available to confer resistance to a few systemically-translocated herbicides that kill sedges.

The genetic, morphological, and phenological similarities of the weedy rices to domestic rice has encouraged their association. The weedy rices shatter most of their seeds before cultivated rice is harvested, creating large seedbanks. Weed seed is also harvested, contaminating rice seed and the seed germinates over a number of years. The weedy rices are generally naturally resistant to the same herbicides as domestic rice. The easiest way to obtain selectivity among domestic and weedy strains as well as closely related species is to engineer resistance into the crop, and it has already been shown that red rice is easily controlled by glufosinate in transgenic *bar* rice (Oard *et al.*, 1996).

The fear of introgression of rice transgenes to weedy rices

These millennial weed problems provide the rationale for considering transgenic herbicide-resistant rice, but the rice could transfer transgenes to weedy rices by pollination (Kling, 1996). The crosses into cultivated rices from other *Oryza* spp. typically required hand pollination (without competing species-specific pollen), "rescue" of embryos by cultivating in tissue culture medium, and most progeny were sterile or of low fecundity. Conversely, rice easily cross pollinates into the weedy and feral con-specific forms. The magnitude of risk of introgression from transgenic herbicide resistant rice is a function of which weedy rice species grows in or near cultivated rice. As long as the weedy rice is controlled by the herbicide, the potential to hybridize is low. There was less than 1% red rice survival following herbicide treatment in an experiment using glufosinate resistant transgenic rice mixed with wild red rice. The competition with rice further reduced red rice seed set on the remaining plants, and none of the progeny were resistant (Zhang *et al.*, 1999). The problems of introgression ensue with unsprayed border weeds or during seasons when the herbicide is not used, as well as when the few remaining weedy rice plants pollinate rice yielding partially feral F_1 hybrids. There is no logical risk of introgression beyond *Oryza* spp. (as some proponents of horizontal (intergeneric and beyond) gene transfers claim. If this possibility existed, the native rice genes for herbicide resistances would have moved long ago to other species. Risk analyses are best performed using decision trees that require answering a series of fixed questions (Gressel & Rotteveel, 1999); this can considerably lessen bias factors in decision making. Such an analysis suggests that the risks are unacceptably high where the con-specific weedy rices are a problem. Risks are far fewer with non-AA genome weedy rice species, due to the incompatibility barriers that made it so hard to transfer genes to rice (as described in Gressel, 2000). As there are ways to mitigate the positive effects of having herbicide resistance introgress into weeds, it would be wise to allow releases of single gene transgenics only where the risk is exceedingly low (i.e. where no AA genome rices are present as weeds), but not where con-specific weedy and feral rices abound.

Mitigating introgressed genes

Two types of strategies prevent introgression of transgenes from rice to weedy rices. One utilizes genetic placement of the transgenes in ways that prevent introgression, the other links mitigating (TM) genes to the gene of choice to render weeds less fit. The gene placement failsafes include the use of hybrids. If a dominant transgene for herbicide resistance is placed in the male sterile line used for producing hybrid rice, there will be no possibility of introgression in crop-production areas, if this line produces no viable pollen. Seed production areas where the male sterile line is restored must be kept free of related weedy rices. If the transgene for herbicide resistance is placed on the mitochondrial or plastid genomes (Daniell *et al.*, 1998), there should be little possibility of gene flow, due to maternal inheritance of these genomes. Large-scale experiments should be performed in rice to ascertain whether the frequency of paternal transfer of maternal traits is sufficiently low to justify using this strategy.

Transgenetic Mitigation (TM)

The concept of using genetic, engineering to mitigate selective advantages of introgressed transgenes in weedy species (Gressel, 1999) is based on three premises: (1) tandem constructs of genes act as tight linkage groups, and gene segregation, or loss, is rare; (2) there are traits that are either neutral or positive for domestic rice that could be deleterious to weedy or wild rices; (3) because weedy rices are strongly competitive amongst themselves, and have a large seed output, even mildly-deleterious traits are lost from populations. Thus, if the herbicide resistance gene engineered into a crop is flanked by transgenetic mitigation (TM) genes in a tandem construct, the overall effect would be deleterious after introgression into weeds.

Even if one of the TM genes disappears, the other flanking TM gene will still provide mitigation. TM traits utilizing differences between rice and weedy rices include:

Seed dormancy. Weedy rice seeds typically have secondary dormancy, with seeds from one harvest germinating throughout the following seasons. This evolutionary risk-spreading strategy maximizes fitness while reducing losses due to sib competition (Hyatt and Evans, 1998). A single gene controls the predominant, hull-imposed dormancy in rice. Some cultivars have too strong dormancy and thus anti-dormancy genes would be useful for the crop. Transgenically abolishing secondary dormancy is thus positive or neutral to domestic rice, but deleterious to the weedy rices.

Seed ripening and shattering. Most weedy rice seeds "shatter" to the ground, insuring replenishment of the soil seed bank. Domestic rice has been selected for non-shattering (Price *et al.*, 1996). Uniform ripening and anti-shattering genes are deleterious to weeds, neutral for rice (which ripens uniformly and does not easily shatter) (Ling-Hwa & Morishima, 1997). *Dwarfing* has been especially valuable in generating "green revolution" rice based on increasing the harvest index; the ratio of grain to straw. Genetically-engineered height reduction is available, using genes relating to brassinosteroid (Schaller *et al.*, 1998) or gibberellin production (Lange, 1998) or recognition (Peng *et al.*, 1999), or with shade avoidance (Robson *et al.*, 1996). The response to shading is stem elongation, which is advantageous for competing with other species, but not in a weed-free crop stand where only siblings compete. Dwarfing is disadvantageous for weeds that cannot overgrow the crop. Some potential genes for TM traits exist only as named heritable traits, others are mapped to positions on chromosomes, and a few are characterized as sequenced genes. The genes already available for use in TM constructs are summarized in Gressel (1999; 2000).

Herbicide resistance in weedy rices allows them to compete with the crop in the presence of the herbicide. Will TM traits actually mitigate that advantage? Weedy rices typically produce hundreds of seeds that compete to replace a single plant; the selection for high competitive fitness is intense. While any marginally-advantageous transgene introgressing into a weed will proliferate and spread through a population (Thill & Mallory Smith, 1997), the disadvantage of TM traits can balance against the advantage of the primary trait. When the primary gene has a strong advantage (e.g. for herbicide resistance), there may be a need for herbicide or crop rotation so that the TM genes can effect mitigation, after introgression occurs.

Regulatory considerations with transgenic rice

Hybridization between cultivated and wild rices and hence gene introgression of herbicide tolerance to wild rices occurs readily (Sankula *et al.*, 1998), and the hybrid progeny had greater shattering and dormancy (Lindscombe *et al.*, 1998), insuring that they would be fixed in the population. This increase in weediness was expected, yet would have been prevented if TM traits had been added in tandem constructs. Thus, one wonders at the desire to rapidly bring such varieties to "non-regulated" status, and to release herbicide-resistant transgenic rice varieties (Van Wert, 1998). Where there is a strong risk of introgression, it would be advisable to consider a regulatory-mandated delay in allowing the use of single primary genes without failsafes or TM genes, in such situations.

ACKNOWLEDGEMENTS

The author thanks Drs. Fred Kanampiu and Avi Levy for their permission to discuss unpublished research and concepts. The author is the Gilbert de Botton professor of plant sciences, and his research on *Striga* has been funded by the Rockefeller Foundation, on introgression by the EU INCO program with an OECD grant to construct decision trees.

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Herbicide tolerant oilseed rape in Europe: The FACTT programme

E J Booth
SAC, Craibstone Estate, Bucksburn, Aberdeen, AB21 9YA, UK

M Green
ADAS High Mowthorpe, Duggleby, Malton, North Yorkshire, YO17 8BP, UK

G de Both
Plant Genetic Systems N.V., Nazarethse Steenweg 77, B 9800 Astene (Deinze), Belgium

ABSTRACT

FACTT (Familiarisation and Acceptance of Crops incorporating Transgenic Technology) is a 4-year project, initiated in 1996, with the aim of evaluating and demonstrating transgenic crops. Hybrid oilseed rape tolerant to the herbicide glufosinate ammonium (Liberty) was selected as the model transgenic crop for the project, which involves partners from all major rapeseed growing countries in the European Union. A series of agronomic studies are being undertaken within FACTT, including conventional variety testing, herbicide, fertiliser, fungicide and sowing date evaluations, as well as demonstration projects. Preliminary results indicate that transgenic herbicide tolerant oilseed rape does not differ significantly from conventional types except for the modified trait. The herbicide trials have showed that, despite a large range in response to herbicide application, the use of herbicide tolerance combined with the glufosinate ammonium treatment may offer a useful alternative means of weed control. Some additional management considerations for herbicide tolerant crops within the rotation will be required to achieve the full benefits from this transgenic technology.

INTRODUCTION

FACTT (Familiarisation and Acceptance of Crops incorporating Transgenic Technology) is a 4 year project which has been partly funded by the European Union. It was initiated in 1996 in response to the large amount of transgenic, also known as genetic modification (GM) work being carried out on numerous crops within Europe. This work has enabled the introduction of many desired traits into plant breeding programmes. On a world wide basis commercial production of transgenic crops has developed apace in many countries, increasing from approximately 2.8 million ha in 1996 to over 28 million ha in 1998 (James, 1997 and 1998) with a further increase expected in 1999. Finished products from plant breeding programmes are now available within Europe, however commercial production is still awaited. It was considered that prior to adopting transgenic crops, the issues involved in growing these types should be considered first-hand by direct interest groups, and the FACTT programme seeks to contribute to the available information. Herbicide tolerant oilseed rape is amongst the closest to commercialisation in Europe and was therefore selected as the example crop. Two traits developed by transgenic technology are demonstrated in FACTT; hybridisation and tolerance to the herbicide glufosinate ammonium (Liberty). These traits are combined in the oilseed rape varieties used which have been developed by Plant Genetic Systems, Belgium.

The FACTT programme has several objectives; firstly to evaluate transgenic oilseed rape which is tolerant to a specific herbicide, under conventional agronomic practices, and also to evaluate the response of the transgenic oilseed rape to changes in agronomic practices. Other aims are to provide demonstration sites for familiarisation purposes and to communicate results and information to groups such as farmers, extension organisations, the processing industry and the support industry such as merchants and breeders.

The project involves 21 partners from 6 EU member states and encompasses the main oilseed rape growing areas in the EU. For the purposes of FACTT these were divided into 4 regions; Germany, the UK, France/Belgium and Denmark/Sweden. Partners include major research and also extension/advisory organisations to enable dissemination of information. In the UK, the partners are SAC, ADAS, Arable Research Centres (ARC) and the National Institute of Agricultural Botany (NIAB) and the UK programme is co-ordinated by the Home-Grown Cereals Authority.

MATERIALS AND METHODS

Agronomic field trials with both winter and spring sown oilseed rape are being undertaken by partners in all of the member states represented. There are 5 trial series. The conventional trials examine oilseed rape under 'standard' agronomic practice and compare conventional open pollinated varieties with conventional hybrids and transgenic herbicide tolerant hybrids, with the objective of documenting any differing characteristics. In UK trials, conventional varieties are selected from those used as controls in the UK National List variety trials. The herbicide trials examine the utilisation of the herbicide tolerance trait of the test transgenic type, assessing the effectiveness of the new weed control scheme. Two conventional herbicide regimes, selected as representative of each site, are compared with an untreated control and use of glufosinate ammonium herbicide, using 2 herbicide tolerant varieties. In the UK, metazachlor (Butisan) and benazolin and clopyralid (Benazalox) are used as the core herbicides in the 2 conventional herbicide regimes, for all sites bar the winter oilseed rape ARC site in 1996/97, where propyzamide (Kerb) is used instead of benazolin and clopyralid as the second conventional herbicide regime.

In addition, trials designed to focus on specific inputs or management practices relevant to hybrids are undertaken. Evidence available at the beginning of the FACTT programme suggested that hybrids have certain characteristics which may have an impact on agronomic practices and trials on fungicide response, sowing date and nitrogen fertiliser response are also in progress.

All trials are conducted under best local practice conditions with pest control schemes, growth regulator treatments, S, P and K fertiliser regimes and seeding rates applied at the appropriate level specific for the region in question. Winter and spring sown trials are located in Aberdeenshire, North Yorkshire and Cambridgeshire for SAC, ADAS and NIAB respectively. ARC sites are located in Lincolnshire for winter sown trials and Hampshire for spring sown trials.

RESULTS AND DISCUSSION

Information from the final year of trials is not yet available, hence this paper gives a preliminary view of results based on data from 2 seasons. The presentation of results concentrates on UK data, and where appropriate reference is made to the overview from the complete European database.

The conventional winter varieties performed in line with results from official UK variety trials, with the conventional hybrids Synergy and Pronto giving a yield advantage over open pollinated varieties, such as Apex and Falcon, in both years (Table 1). Two of the 3 transgenic hybrid types included in the trials performed on the same level as open pollinated varieties, and one, PGS W2, gave a yield similar to conventional hybrids. This reflected results from the European database and demonstrates that it is not possible to rank the transgenic hybrid types as a group, rather it is necessary to compare the individual varieties. Other agronomic assessments such as vigour and maturity showed that there was little difference between the transgenic varieties and conventional varieties, although the data from the 1997/98 season may suggest a slightly higher vigour score for hybrids in general.

Table 1. Performance of winter oilseed rape varieties in the UK

Variety		Seed yield (as % of yield mean)		Vigour (1-9) weak - vigorous		Maturity (1-9) late - early	
Variety Name	Variety type	1996/97	1997/98	1996/97	1997/98	1996/97	1997/98
Apex	OP	99	99	7.4	6.9	6.4	7.0
Falcon	OP	98	94	6.5	6.7	6.8	7.7
Nickel	OP	104	-	5.4	-	3.8	-
Alpine	OP	-	(96)	-	(7.7)	-	(7.2)
Pronto	RH	(109)	109	(7.1)	7.8	(5.2)	6.8
Synergy	CH	107	107	6.6	7.9	5.8	7.0
PGS W1	TH	98	99	7.1	7.8	7.2	7.0
PGS W2	TH	108	103	6.6	7.7	6.1	7.5
PGS W3	TH	98	92	6.8	7.5	6.8	6.9
yield mean (t/ha)		4.40	3.70				

OP - open pollinated, RH - restored hybrid, CH - composite hybrid, TH - transgenic hybrid, ( ) indicates data was available from only 3 of the 4 sites.

For spring sown varieties in the UK, there was little difference between the overall yield of conventional open pollinated and hybrid varieties (Table 2), although there was a large variation in variety performance across sites. At many sites in other parts of Europe the hybrids did show a yield advantage. The 3 transgenic varieties at the UK sites gave a yield on par with conventional varieties, with PHY 31 (now called Archimedes) producing the best overall yield of the transgenic varieties. Vigour and maturity scores from this series of trials did not identify hybrids or transgenics as having a particular advantage, although Hybridol, the conventional restored hybrid did tend to be associated with earlier maturity, as are several hybrids on the UK recommended list (Anon, 1999). The transgenic varieties tested here are the first from transgenic breeding programmes to near commercialisation and further agronomic improvements are likely for subsequent transgenic varieties.

In general the results from preliminary trials showed no indication that transgenic herbicide tolerant types differed significantly from conventional types except from the modified trait.

Table 2. Performance of spring oilseed rape varieties in the UK

Variety		Seed yield (as % of yield mean)		Vigour (1-9) weak - vigorous		Maturity (1-9) late - early	
Variety Name	Variety Type	1997	1998	1997	1998	1997*	1998
Aries	OP	103	96	6.1	6.6	4.2	6.7
Spok	OP	105	102	5.9	6.5	3.5	6.0
Acrobat	OP	(105)	(90)	(6.0)	(5.9)	(6.0)	(7.4)
Hybridol	RH	111	100	7.9	7.7	5.5	6.7
Triolo	CH	102	103	7.2	5.9	4.2	5.4
PHY22	TH	97	99	6.7	6.4	5.6	7.1
PHY31	TH	98	106	6.8	6.3	4.9	7.5
PHY35	TH	96	101	6.6	6.1	5.5	7.6
yield mean (t/ha)		2.03	2.13				

OP - open pollinated, RH - restored hybrid, CH - composite hybrid, TH - transgenic hybrid, ( ) data limited to 3 sites only, * data based on 2 sites (SAC and ADAS) only.

Data for herbicide trials are presented as the range in response and also the mean response to herbicide application compared to the untreated control for the 4 UK sites. With regard to the winter sown trials, a large site to site range in response to herbicide application was observed, particularly in 1997/98 (Table 3). When the mean yield response to herbicide was considered, it can be seen that glufosinate ammonium and metazachlor were associated with an increased yield, compared to the untreated yield in both seasons. The benazolin and chlopyralid/propyzamide treatment had little effect on mean yield response over all sites in both seasons. For the 1997/98 season, the application of glufosinate ammonium resulted in a marginally larger yield response than metazachlor, with little difference between glufosinate and metazachlor in the 1996/97 season.

For the spring oilseed rape trials again there was a large variation in response to herbicide application and again there tended to be greater variation in the 1998 harvest season (Table 4). For trials conducted in 1997, metazachlor and benazolin and chlopyralid had little effect on resulting mean yield response, whereas the application of glufosinate ammonium resulted in a mean yield advantage over all sites. In the 1998 season, the figures reflecting the lower extreme of response range were all derived from one site. Here, growing conditions throughout the season were poor and it is suggested that this may have predisposed the plants to phytotoxic stress from herbicide application. The large responses also observed this season were again from one individual site, where weed pressure was high. The resulting mean response for this season shows little effect of any of the herbicide treatments

Table 3. Mean yield response of 2 winter transgenic oilseed rape varieties to herbicide treatment on a site-by-site basis, UK sites (% yield of untreated).

Treatment	1996/97		1997/98	
	Yield response		Yield response	
	range	mean	range	mean
Metazachlor	95 - 113	104	92 - 128	106
Benazolin and clopyralid /Propyzamide	94 - 106	101	94 - 109	102
Glufosinate ammonium	97 - 109	105	89 - 140	110

Table 4. Mean yield response of 2 spring transgenic oilseed rape varieties to herbicide treatment on a site-by-site basis, UK sites (% yield of untreated).

Treatment	1997		1998	
	Yield response		Yield response	
	range	mean	range	mean
Metazachlor	95 - 107	101	80 - 107	98
Benazolin and clopyralid	93 - 105	98	87 - 111	100
Glufosinate ammonium	99 - 120	108	88 - 113	102

Six out of the 11 sites across Europe where the herbicide trial was carried out with winter oilseed rape in 1996/97 showed that the application of herbicide had a significant effect on yield. In the 1997/98 season, 8 of the 12 winter sown trials had a significant effect on yield. Where weed control had a significant impact, the untreated control tended to have a lower yields, and at some sites there was an indication that glufosinate ammonium may give yield benefits above conventional herbicides (Booth *et al.*, 1999). For the spring oilseed rape trials, where a significant effect of herbicide on yield was noted, the glufosinate ammonium treatment tended to be associated with the higher yields. The inconsistency in response to herbicide noted in the current trial series is a common feature of oilseed rape herbicide work as noted elsewhere, e.g. Walker *et al.* (1990). These trials indicate that the transgenic feature of the varieties has not altered this response pattern.

Results from the fungicide, sowing date and fertiliser trials again show no indication that transgenic herbicide tolerant types differ significantly from conventional types in agronomic response. Aspects relating to the particular response of hybrids from these trials will be discussed elsewhere (Green and Booth, 1999).

Glufosinate ammonium has been shown to produce a slightly better mean response than other herbicides in the UK trials presented in this paper. It also offers the possibility of control of Brassica weeds within the oilseed rape crop and a rotational control of herbicide resistant grass weeds. The herbicide tolerant strategy would offer an alternative means of weed control, which may be useful in circumstances where conventional herbicides are less effective, such as conditions of low soil moisture and high organic matter. The use of this technology, with broad spectrum, short-lived herbicides could substitute for soil residual herbicides with potential environmental benefits.

At present limited data is available on the economics of using herbicide tolerant crops in the UK and details of margins over herbicide and any additional costs to the grower from using this technology will be needed before a full assessment of gross margins implications can be made. With regard to management on the farm, the introduction of herbicide tolerant oilseed rape would necessitate some additional management within the crop rotation. Control of herbicide tolerant volunteers by another herbicide in following crops and accurate record keeping will be required before these types can be introduced. It may also be advantageous to use isolation distances between herbicide tolerant types and conventional types, similar to those used for high erucic acid rapeseed, to minimise cross pollination. Providing these measures are taken, herbicide tolerant oilseed rape offers the potential of a useful alternative weed control strategy for the grower.

ACKNOWLEDGMENTS

Part of the funding for this work was provided by the European Union.

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The value and exploitation of herbicide-tolerant crops in the US

F L Baldwin
University of Arkansas Cooperative Extension Service, Little Rock, Arkansas 72203 USA

ABSTRACT

Herbicide-tolerant crops represent a revolutionary breakthrough in weed control in the US. While debate continues in some countries over the acceptance of GMOs, the area of herbicide-tolerant crops, some of which are GMOs and some of which are mutants or selections, continues to increase. In soybean, the estimated area planted to glyphosate-tolerant cultivars is fifty per cent of the US total. Weed control programmes using glyphosate have offered broader-spectrum weed control, better control of certain species, control of larger weeds, and increased production efficiency and simplicity for the grower. Grower acceptance of the cultivars and certain side issues surrounding the seed has been much slower than acceptance of the weed control. This has prevented the planted area from being even greater. Grower use of bromoxynil-tolerant and glyphosate-tolerant cotton is fifty per cent or greater in some cotton-producing states. This use is also expected to increase as improved cultivars are released. Grower acceptance of herbicide-tolerant corn has been slower than that for cotton or soybean. There are more herbicide-tolerant choices in corn (maize). At present, growers apparently do not perceive the herbicide-tolerant corn to have an advantage over traditional programmes. However, as better genetics become available and legal problems are worked out with glyphosate-tolerant corn, the acceptance is expected to increase rapidly. At present, no herbicide-tolerant rice cultivars are on the market. However, development of glufosinate-tolerant, imazethapyr-tolerant and glyphosate-tolerant rice cultivars is well underway. In research programmes, all three have shown promise for controlling red rice (*Oryza sativa*), the major weed problem in the US, as well as a broad spectrum of other problem weeds. In spite of issues such as outcrossing and acceptance of GMOs, it is expected that this technology will be rapidly accepted by growers. It is also expected that herbicide-tolerant rice may have a greater economic benefit to growers by allowing rice to be grown on land where it otherwise cannot.

INTRODUCTION

In the history of herbicide use in the US, many examples can be cited for herbicide discoveries which revolutionized weed control in a given crop. Atrazine in corn, propanil in rice, and trifluralin in cotton and soybean are offered here. In the past decade or so, new herbicide registrations have slowed tremendously in the major crops, and few have been of the type to take weed control to new levels. It is this author's belief that herbicide-tolerant crops, especially those tolerant to glyphosate, represent the next revolutionary breakthrough in weed control.

In this paper, herbicide-tolerant crop technology in four major crops (corn, cotton, soybean and rice) will be discussed. An overview of current weed control technology, gaps in the current technology, the status of herbicide-tolerant crop technology, the advantages and disadvantages and grower acceptance of the technology will be presented for each crop. The topic is presented based upon practical field experiences by the author and discussions with various co-workers.

There is a huge debate over the consumer acceptance of genetically modified (GM) crops in some countries. The ultimate acceptance or rejection of these crops will affect usage by growers. Neither the opinion of this author nor the content of this paper will have any bearing on this issue. As a result, there will be little discussion of consumer acceptance in this paper. However, this author feels that technology will ultimately prevail.

CORN

In corn (maize), herbicide-tolerant cultivars on the market include those tolerant to glyphosate, glufosinate, sethoxydim (SR) and imazethapyr/imazapyr. Herbicide-tolerant corn technology has been on the market for several years longer than that in soybean but grower acceptance has been much greater in soybean. The current herbicide technology in corn is very economical and has fewer weed control gaps compared with the technology in other crops. However, both annual and perennial grass weeds often escape the traditional programmes. The core herbicide programme for corn for nearly forty years has been atrazine. A traditional weed control programme includes an acetamide herbicide, such as metolachlor, mixed with atrazine. This represents a very cheap, broad-spectrum soil applied treatment. In addition, there are numerous, economical post-emergence treatments available to control weeds which have escaped. While the continued registration of atrazine has been a topic of debate for several years, it does not appear it will be lost in the near future. As long as inexpensive atrazine is available, it will be difficult for some of the new corn technology to gain a foothold in the market.

To date, the imidazolinone-tolerant corn has been the most widely accepted. However, the same herbicides are used in soybean rotation, and the development of ALS-resistant weeds is a major problem with this technology. The SR corns have a fit where post-emergence grass control is needed. While this fits the major technology gap, the lack of high-yielding cultivars has limited the use of this technology. When combined in a programme with atrazine, glufosinate has performed well in research trials with glufosinate-tolerant corn. However, at current glufosinate prices, the cost of the programme is not competitive with traditional programmes. Glyphosate-tolerant corn has not been planted on any significant area. Legal issues limited planting in 1999.

At present, growers either do not perceive the herbicide-tolerant corns to have an advantage over conventional programmes, or they are not satisfied with the new technology at the current stage of development. The lack of acceptance of GMOs has had more effect in corn than in soybean. At present, some large grain processors are not accepting GM corn. This has not been the case in soybean. Of the herbicide-tolerant crop options available, Roundup Ready® has the most potential, owing to the broad spectrum of control and low cost of glyphosate. Glyphosate fits the escaped grass scenario perfectly and will control escaped broadleaf weeds as well. In addition, glyphosate and glufosinate can be applied to the tolerant corn cultivars with greater crop safety over a wider range of growth stages than most of the current post-emergence herbicides. These hybrids perform as well as the best conventional hybrids. Therefore, once the legal issues with glyphosate-tolerant corn are resolved, and acceptance of GMOs increases, it is predicted that their use will increase rapidly.

A typical weed control programme in corn in the future will likely consist of atrazine, followed by glyphosate, or an atrazine plus glyphosate tank mix. The programme is too simple not to dominate the market. The corn herbicide market will change rapidly from an atrazine core market to a dual core market of atrazine and glyphosate. While atrazine has not been banned in corn, there are individual areas where it cannot be used or is severely restricted owing to certain characteristics or location. Glyphosate will have a huge impact in these areas. A grower may also choose to plant glyphosate-tolerant corn for protection against glyphosate drift from glyphosate-tolerant soybean.

COTTON

In cotton, the two herbicide-tolerant cultivars are those tolerant to glyphosate and to bromoxynil. Compared with corn and soybean, the choice of traditional herbicides for cotton has been limited. The dinitroaniline herbicides have provided good annual grass control and the ACC'ase-inhibitor herbicides are available for escaped annual grasses and Johnson grass. Substituted urea herbicides have been used primarily for control of broadleaf weeds. However, control has often been incomplete.

The major technology gap in cotton has been the lack of a broad-spectrum, selective, over-the-top herbicide for broadleaf weeds that escape the soil-applied herbicide program. The bromoxynil resistant cotton is limited by the US Environmental Protection Agency to ten per cent of the US cotton crop area. This is due to a restriction of the herbicide rather than a restriction of the transgenic cultivar.

Bromoxynil provides excellent control of *Ipomea* and *Xanthum* species, which are major problems in the Mississippi River delta cotton-growing region. In addition, the bromoxynil-tolerant BXN® 47 cultivar, adapted to this region, has been one of the highest-yielding cultivars in University of Arkansas variety performance trials the past two years. In Arkansas, in 1999, approximately fifty per cent of the total cotton area was planted with this bromoxynil-resistant cotton. This is possible because the ten per cent restriction applies to the US total rather than to individual state totals. Where it is used, bromoxynil is integrated into a programme with other herbicides. A typical programme would be trifluralin and fluometuron applied to the soil, followed by one or two over-the-top applications of bromoxynil followed by a late season, post-directed treatment such as cyanazine.

Glyphosate-tolerant cotton has been limited to around fifteen per cent of the area in the Mississippi River delta growing region primarily due to the lack of a widely accepted cultivar. However, the area grown is increasing. In the southeastern US, acceptance has been greater (over fifty per cent of the planted area in some states), owing to better-adapted cultivars and weed species such as sicklepod (*Cassia obtusifolia*). In general, cotton does not have an equal level of glyphosate tolerance compared with soybean . The current label restricts the over-the-top treatments to cotton no larger than the five true-leaf stage. From that point, directed sprays of glyphosate are required. However, the crop safety of the later-directed sprays has been a matter of debate, as pollination and fruit shed problems have sometimes occurred. This has slowed grower acceptance. Since glyphosate is a much broader-spectrum herbicide than bromoxynil, and is not restricted by the EPA in terms of area that may be treated, it is expected that the area planted to glyphosate-tolerant cotton will increase rapidly as better cultivars (especially those having both glyphosate-tolerant and Bt genes) are developed for each region. In addition, the major seed companies are owned by or affiliated with Monsanto. This can influence the availability of the cutlivars to growers and GM crop use will also probably increase for this reason. With glyphosate-tolerant cotton, herbicide programmes used by growers may consist of only glyphosate but may often include other herbicides as described previously for GM cotton.

RICE

To date, there are no herbicide-tolerant rice cultivars grown commercially in the US. However, at least three (glufosinate, imazethapyr/imazapyr and glyphosate-tolerant cultivars) are in the developmental stages.

This author is from a state, Arkansas, that has nearly fifty per cent of the current US rice area. In addition, rice is currently the most profitable crop in Arkansas as well as other southern rice-producing states. Because of this, growers desire to expand the crop area. The inability to control red rice (*Oryza sativa*) in drill-seeded rice (*Oryza sativa*), has prevented such expansion. In drill-seeded rice, red rice can be managed only through crop rotation, thus limiting the area available for rice production. Current research has shown that all three herbicide-tolerant rice programmes can provide excellent control of red rice, as well as a broad spectrum of other weeds, in both drill-seeded and water-seeded rice. Cultivar development and herbicide registration are well underway for glufosinate and imazethapyr. It is projected that limited areas of both technologies could be planted by 2001 or 2002. Development of glyphosate-tolerant rice appears to be a couple of years behind the others and Monsanto's intent on developing the concept for drill-seeded rice remains somewhat unclear, owing to concerns that the tolerance gene could spread to red rice by outcrossing. However, glyphosate-tolerace research was begun in drill-seeded rice in 1999.

This author considers that herbicide-tolerant rice has the greatest chance to increase value to producers. In corn, cotton and soybean, the herbicide-tolerant crop simply offers a weed control alternative to conventional weed-control programmes and, to date, the bottom-line economics with herbicide-tolerant and conventional programmes have been similar. However, a herbicide-tolerant rice can allow the crop to be grown on land too heavily infested with red rice for current production. This can allow a more profitable crop to be grown on a given plot of land.

Since rice is a directly consumed food crop, the controversy over GMOs may have a greater impact. Also, the outcrossing issue of the tolerance genes to red rice is more intensely debated than the issue of simply selecting for resistance by weeds in other crops. Rice experts in the southern US feel the incidence of outcrossing is very low. Also, if more than one of the herbicide-tolerant rice technologies is developed, the outcrossing can be managed through crop rotation and rotation of the tolerant-rice technologies. In order for the herbicide-tolerant rice technology to compete with existing weed control programmes, the technology must be economical and the cultivars must be as good as those currently on the market. In order for this to occur, the herbicide tolerance must be introduced much earlier in the breeding programme than is currently the case. If the technology is not economical and the cultivars are not state-of-the-art, this technology will be used only in the most severely infested field of red rice.

SOYBEAN

To date, the crop in which herbicide-tolerant technology has had the most impact has been soybean. While glufosinate-tolerant and STS® (tolerance to sulfonylurea herbicides) technologies are available in soybean, the major impact has been with glyphosate-tolerant soybean and that will be the focus of this discussion. The weed species in soybean crops vary in the US, depending upon the region of the country. However, in all regions, the spectrum consists of several different annual broadleaf and grass weeds, perennial weeds such as Johnson grass and several broadleaf species. For this reason, weed control programmes in soybean typically require multiple applications of two to four different herbicides. Even with such herbicide programmes, weed control gaps exist in soybean production.

Research was begun with glyphosate-tolerant soybean at the University of Arkansas, and other major universities in 1993. By 1994, glyphosate programmes were the experimental standard with which all other weed control programmes must be compared. The primary reason has been the broad spectrum of control provided by glyphosate, the capability to control certain species better than any available herbicide, and the capability of controlling some weed species over a much wider range of growth stages compared with available herbicides. For example, in Arkansas, two properly timed applications of glyphosate will provide seventy per cent or greater control of all thirty-three major weed species that can commonly infest soybean. This is generally true for most soybean producing-states as well. Glyphosate also provides much better control of some major species, such as sicklepod and palmer pigweed (*Amaranthus palmeri*) than any other registered herbicide. Similar examples could be cited for other states.

The first year of farmer use of glyphosate-tolerant soybean was 1996, with much more seed available in 1997. By 1998, seed was available in sufficient quantities for any grower who wished to purchase glyphosate-tolerant cultivars. A straw poll of agronomists in several major soybean-producing states indicated between thirty and fifty per cent of the area planted to glyphosate-tolerant cultivars in 1998. If one averages numbers from University experts and industry reports in the US, it appears the planted area of glyphosate-tolerant soybean is at least fifty per cent of the total in 1999.

While this represents an enviable market share, the weed control potential would suggest the planted area could be much greater. For example, the glyphosate-tolerant soybean area in Argentina is reported to be ninety per cent or more. Owen (1997) of Iowa State University, stated that "adoption has been slower than anticipated, expectations have been higher and growers have failed to recognize changes in management skills necessary to receive maximum benefits from the technology." Conversely, in the opinion of some other experts, adoption has been more rapid than expected. It is this author's opinion that planted area would currently be much greater without some of the side issues surrounding the technology.

In general, grower acceptance has fallen into two distinct categories: (1) weed control and (2) choice of cultivar and associated issues. Having weed control options tied to choice of cultivar has been a huge learning experience. In general, farmers have been happy with the weed control. Two properly timed glyphosate applications have generally provided excellent overall weed control. Some of the hard to kill species, such as the morning glory (*Ipomoea* spp.), hemp sesbania (*Sesbania exaltata*) and yellow nutsedge (*Cyperus esculentus*) escape if the first application is applied too late. Many growers have not recognized the need for early application timing and some attempt to make it a "one shot" approach to weed control. When this happens in the southern US, failure can result. Also, late germinating, shade tolerant weeds such as tall waterhemp (*Amaranthus tuberculatus*) may emerge after the glyphosate application and escape. For these reasons, more growers are integrating other herbicides, especially those with soil residual activity, into glyphosate-tolerant programmes. Therefore, the term "roundup ready" does not mean that glyphosate is the only herbicide used.

In contrast to improved weed control, a primary disadvantage has been drift of glyphosate to adjacent crops. Corn, rice and cotton are all very susceptible to glyphosate and one or more of these crops are commonly grown adjacent to soybean. Glyphosate may severely injure or kill susceptible crops in the seedling stages, and also can be a powerful reproductive growth inhibitor. For example, when a drift occurs to rice in reproductive growth stages, foliar symptoms may not occur. However, weeks later, sterile grain heads may emerge so that yields are reduced.

Growers have often been unhappy with cultivar performance and many of the side issues associated with glyphosate-tolerant seed. In the rush to bring new cultivars to the market as quickly as possible, some glyphosate-tolerant cultivars have been released with much lower yield potential and adaptability compared with the better conventional ones. Initially, seed companies were reluctant to enter glyphosate-tolerant cultivars into University variety testing programmes, while they eagerly entered conventional cultivars in the same programmes. This made it impossible for growers to obtain unbiased yield comparisons for cultivars. This trend is changing and most companies are now entering the glyphosate-tolerant cultivars into the University programmes.

In 1998, eighty-seven glyphosate-tolerant cultivars or thirty per cent of the total entries, were submitted for testing at the University of Arkansas. All major seed companies entered glyphosate-tolerant cultivars in University of Arkansas trials in 1999. The yield potential of the better glyphosate-tolerant cultivars is now approaching that of the better conventional ones. In Arkansas there currently remains a difference in favour of the highest-yielding conventional cultivars, over the highest-yielding glyphosate-tolerant ones. It should be noted that increased weed control in glyphosate-tolerant programmes may often offset the potential yield differences.

In addition to yield concerns, there have been other issues associated with the technology, such as "technology fees" placed on seed and "grower contracts". As companies place technology into the seed, both are likely to be the wave of the future and farmer acceptance and reaction to this has been mixed at best. The glyphosate-tolerant technology has been most farmer's first experience with cultivars that were patented. Previously, farmers could save their own planting seed for the next year. With patented cultivars, they cannot. Again, farmer reaction to this has been very mixed. With the current low-cost production practices, some growers wish to save seed to reduce production costs. Some growers openly accept and support the company position, whereas others have openly defied it. Private investigators have sometimes been used to enforce the company position. There has been a public advertising campaign by Monsanto to announce names and penalties of farmers caught saving seed and encouraging other farmers to turn in violating neighbours. Farmer reaction to a perceived threat of monopoly by large companies such as Monsanto (owning both the herbicide and the seed companies) and to terms such as "terminator genes" has been very mixed. US grower reaction to growers in countries such as Argentina not having contracts and technology fees being able to save seed and paying much lower prices for glyphosate, has also been mixed. In the current economic conditions of farmers in the US, this is viewed by some as being extremely unfair.

In general economic terms, where equal weed control can be achieved with glyphosate-tolerant and conventional weed control programmes, bottom line returns from both have been similar. Low-, medium- and upper-end weed control costs are similar in the two types of programmes when the technology fee is added to the herbicide cost in the glyphosate-tolerant programme. This assumes two glyphosate applications are required. In areas where growers commonly achieve good weed control with one glyphosate application, the glyphosate-tolerant programme may be slightly less expensive. In situations where the glyphosate-tolerant programme offers increased weed control, then economics favour this. In addition to bottom line economics, there can be management advantages from an efficiency or simplicity standpoint. Where glyphosate-tolerant programmes consist only of one or two applications of glyphosate, a grower may consider this a much more simple, efficient weed-control programme and may choose it even while there may be no bottom-line economic advantage.

CONCLUSIONS

Herbicide-tolerant rapeseed is currently on the market and other herbicide-tolerant crops, such as wheat and sugar beets, are being developed. In simple weed-control terms, the broad-spectrum herbicides such as glyphosate and glufosinate have tremendous advantages over existing technology.

Hindsight is always perfect and criticism is easy. However, the way some of the issues have been dealt with by industry have slowed the adoption of the technology. In time, many or all of these issues will be resolved. It is predicted by this author that over the next five years, the area of glyphosate-tolerant soybean grown will be eighty per cent or greater in many states. A similar figure is realistic for herbicide-tolerant cotton. While the adoption in corn (maize) may be slower, the technology is too good not to ultimately dominate this market as well.

This author predicts that the herbicide-tolerant crop technology will be dominated by glyphosate. Love it or hate it, but it is simply the best all-around herbicide ever developed. It is consistent, extremely broad spectrum, perceived to be environmentally "friendly," and will become extremely inexpensive. The extent of the use of glyphosate-tolerant crops in the US has already left competing companies scrambling to figure out a way to either be used in a programme or as a tank mix partner with glyphosate. Many of the companies are in the midst of drastic budget reductions, owing to loss of sales.

The factors limiting the use of glyphosate-tolerant crops do not include the herbicide qualities of glyphosate. As these non-glyphosate issues are resolved, one has to honestly ask "why would a farmer not plant a glyphosate-tolerant crop?" This does not have to mean he would use only glyphosate, or in some cases, any glyphosate. However, why would he not want that option?

The challenge for weed scientists and the agricultural community in general is not whether to use the glyphosate-tolerant technology, but how to use it most effectively in a manner to extend its usefulness as many years as possible in the future. Overuse of the technology in all crops can certainly lead to resistance and species shifts. It is this author's concern that competitive products and companies may not survive the initial glyphosate onslaught. If not, there may not be an alternative herbicide when they will ultimately be needed.

REFERENCE

Owen M D (1997). North American developments in herbicide tolerant crops. *Proceedings of the 1997 Brighton Crop Protection Conference – Weeds* **3**, 955-963.