Impact of herbicide resistant crops in the Americas – a southern prospective

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Summary Herbicide resistant soybean (*Glycine max* (L.) Merr.) and cotton (*Gossypium hirsutum* L.) cultivars make up the vast majority of the planted areas in the southern USA. Roundup Ready™ soybean cultivars were first available to farmers in 1997, and were planted on nearly 50% of the soybean area by 1999. Roundup Ready™ cotton seed was first available to farmers in 1997, and achieved over 50% market-share by 2000. The market share for the technology in both crops continues to increase. Herbicide resistant cultivars are currently being developed and registered for other crops such as rice (*Oryza sativa* L.), corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.).

Many disadvantages or negatives, both real and perceived, can be cited for herbicide resistant or GMO crops. However the speed of acceptance by the American farmer speaks for itself. From a weed management standpoint, the technology is simply far superior to traditional weed control technology.

To date in the southern USA, most of the weed resistance problems have been managed by rotating to other existing herbicides or by new herbicide registrations. The registration of new herbicides has declined to nearly zero. Herbicide resistant crops have provided another tool for managing herbicide resistant weeds. The current concern is, with Roundup Ready cotton and soybean market-shares reaching 80% in many states, problems with weed resistance and weed shifts will occur. There is a concern in the scientific community over how these problems will be managed. The superiority of the Roundup Ready technology makes it difficult for a farmer to rotate to alternative technologies.

To date, weed resistance and species shifts with the Roundup Ready crops have not been a problem. In addition, none of the horror stories being promoted by environmental groups, about the development of super-weeds and such, have proven to be true.

INTRODUCTION

The era of modern weed control in the USA began with the introduction of organic herbicides in the mid-1940s. The discovery of herbicides such as atrazine in corn, propanil in rice, and trifluralin in cotton and soybean in the 1950s and 1960s began a herbicide revolution that continued through the early 1990s. This has allowed farmers to control weeds in an effective and economical manner. The herbicide revolution made possible the tremendous yield increases in crops to be realised through advances in plant breeding, fertility, disease control and etc.

Currently in the USA, crop prices are at an all-time low, while production costs remain at record highs. In this situation, the farmer can only survive through increased production efficiency. This can be accomplished through increased yields, reduced costs or a combination of the two. In the major crops of the southern USA, herbicide costs have traditionally been among the highest input costs in growing the crop. Therefore, in order for the farmer to increase efficiency, much of this increase must be achieved in the area of weed control. In the past decade, the introduction of new herbicides has diminished tremendously for the major crops, and few have had the biological spectrum, the crop selectivity, or the novel mode of action that is necessary for new levels of weed control or breakthroughs in efficiency to be achieved. This author believes herbicide resistant crops represent the new weed control revolution that must sustain farmers for the foreseeable future.

SOYBEAN

The herbicide resistant crop revolution in the southern USA began with glyphosate resistant (Roundup Ready™) soybean. The authors began working with Roundup Ready soybean when seed became available to academic researchers for broad-scale testing in 1994. At that time there was a general feeling that glyphosate would be weak on morning glory species (*Ipomoea* spp.), hemp sesbania (*Sesbania exaltata* (Raf.) Cory), and nutsedge species (*Cyperus* spp.). Most of this was a result of previous research and experiences on larger weeds in no-till situations, since that was where most of the glyphosate had been used. However, once research began, and glyphosate began to be applied to small weeds, in sequential applications, and in a crop that formed a rapid canopy, the results were quite surprising. Most researchers found that the difficult-to-control weeds cited earlier, could be controlled with sequential applications of glyphosate. If the papers published in *Proceedings of the Southern Weed Science Society*, *Weed Science*, and *Weed Technology*, from 1995 until the present are extensively reviewed, one will find that sequential applications of glyphosate have provided weed control equal to or greater than established standards on most any combination of weed species and production practices tested. Until the introduction of the Roundup Ready technology, soybean growers in the southern USA often were required to use programs with as many as four different herbicides to achieve acceptable weed control. A typical weed spectrum consists of several annual grass species along with several broadleaf weeds. These typically required a combination of soil-applied and post-emergence herbicides for control. In addition, many fields either are infested with Johnson grass (*Sorghum halepense* (L.) Pers.) or red rice (*Oryza sativa* L.), a weed that infests rice but must be controlled in the rotated crop. These weeds often required one or two herbicide applications in addition to those required for the annual grass and broadleaf weed species present. Even then, weed species such as sicklepod (*Cassia obtusifolia* L.) and Palmer amaranth (*Amaranthus palmeri* S.Wats.) were not being effectively controlled with conventional technology. The Roundup Ready concept changed all of this. Two applications of Roundup®, or other labelled glyphosate product, will accomplish all of the above in a much more simple and efficient manner. As early as 1995, this author was calling the technology a 'miracle' in his weekly popular press column.

The Roundup Ready technology was introduced to farmers in the USA in 1995. With this introduction there were questions about yield drag with the varieties, companies refusing to place the Roundup Ready varieties in University variety testing programs, technology fees on the seed, and patents that prevented farmers from saving their seed. However these 'growing pains' were quickly overcome. The adoption of the technology was limited only by the availability of seed. This simply meant the farmer perceived the weed control advantages to far outweigh any early drawbacks.

Table 1. Adoption of Roundup Ready soybean in the USA[1].

Year	% of US area
1996	2
1997	13
1998	37
1999	47
2000	54
2001	68
2002	74

[1] Data for 1996–2000 from Carpenter and Gianessi (2001). Data for 2001 and 2002 from March 28, 2002 USDA/NASS Prospective Plantings Report.

The adoption of Roundup Ready soybean technology in the USA is illustrated in the table below.

The rapid adoption of the Roundup Ready technology is based first on superior weed control. Many of the weed control guides published by Land Grant Universities in the USA contain individual weed response rating tables for the various herbicides recommended (Baldwin *et al*. 2002). It is not uncommon for these response ratings to be a '7' or higher (on a 0 to 10 scale where 10 is complete control) for every weed species listed in the publication from any state chosen. No single herbicide or combination of herbicides can match this spectrum of control. In addition to superior weed control offered by glyphosate, farmers have reported they chose Roundup Ready soybeans to increase yields, reduce pesticide costs, to increase flexibility in planting and to adopt a more environmentally friendly practice (The Context Network 2000). Carpenter and Gianessi reported that the reason soybean growers are switching to new programs is the simplicity and flexibility of a weed control program that relies on one herbicide to control a broad spectrum of weeds without crop injury or crop rotation restrictions (Carpenter and Gianessi 1999). They further report that the Roundup Ready weed control program for soybean fits into ongoing trends toward post-emergence weed control and adoption of conservation tillage practices and narrow row spacing. Baldwin reported the rapid grower adoption in the south has been due to a number of different factors that include lower herbicide input costs, a simpler, yet more efficient system for weed control, better control of hard-to-kill weeds such as sicklepod and Palmer amaranth and overall very broad spectrum weed control (Baldwin 2000). When questioned why other farmers might seize on this technology, farmers often observed that the Roundup Ready technology 'makes a good farmer out of a bad farmer' (The Context Network 2000). One often hears 'it takes the thinking out of weed control – just spray Roundup once a week until there in nothing left in the field but soybeans'. This author may receive as high as 50 telephone calls per day from farmers and consultants during the production season. Late season calls are usually about salvage control of large weeds. I simply do not receive salvage weed control calls from growers who plant Roundup Ready soybeans.

Economically, the short term benefits to the farmer have been tremendous. Weed control cost with two applications of glyphosate, including the technology fee, can be half that of a conventional system. In addition, yields may be increased due to better weed control. Carpenter and Gianessi report that in 1999, the use of Roundup Ready technology in the USA resulted in a net gain of $216 million to soybean farmers with a corresponding decrease in herbicide applications per year of 19 million (Carpenter and Gianessi 2001). With the continued rapid adoption since 1999, and the continued rapid decrease in glyphosate prices, one must assume these figures are much greater today.

Along with the positive impact of the technology on the farmer, there have been other impacts and all may not prove positive in the future. One impact has been a tremendous devaluation of the herbicide business in the USA. The tremendous increase in market share of glyphosate was accompanied by corresponding loss of market by competing companies. Competing companies decreased the cost of many standard herbicides by as much as 50% overnight. Even this could not recover market share for most of these herbicides. This has resulted in tremendous turmoil in the herbicide industry and a rapid decrease in the investment in the search for new technology. One must be concerned over the long term impact of this trend.

While the advantages of the Roundup Ready technology have been overwhelming, there are disadvantages. One has been drift of glyphosate to susceptible crops. Soybeans in the south are grown in close proximity to rice, corn, grain sorghum (*Sorghum bicolor* L.), and cotton. This has resulted in an increase in off-target damage complaints. However a better understanding among growers, better spray application technology and the adoption of Roundup Ready™ corn and cotton are minimising the problem. There are also major concerns in the academic community about the overuse of a single herbicide system. To date there have been no major resistance problems and there are no known weedy relatives for gene flow to occur from soybean. In fact the result of glyphosate tolerant soybean on resistance management has been positive. It has provided an excellent means of controlling weeds resistant to the ALS-inhibitor herbicides and others. However, history teaches that weed shifts and resistance will occur. In fact, glyphosate resistance has been documented in horseweed (*Erigeron canadensis* L.), a major weed no-till production (Hayes 2000). While weed scientists strongly encourage farmers to rotate herbicides, it is difficult to convince a farmer to rotate away from a technology that is far superior. In addition, it is difficult for many farmers to look long term at the present time. Many are uncertain whether or not they will be in business in the future. Therefore many are farming for this year and will worry about future problems when they occur. This factor combined with the decrease in the search for new technology and the loss of current herbicides because of lost market share causes one to wonder how some of the future weed problems will be solved.

COTTON

The cotton producing region of the USA is the southern states, California and Arizona. Until the development of herbicide resistant cotton varieties, the farmer had even more difficulty controlling weeds in cotton than described for soybean. The weed spectrum is similar in the two crops in any given area. Again, this required a combination of herbicides and even then some weed species were very difficult to control. Another factor that made weed control in cotton more difficult compared to soybean, was the lack of a broad spectrum broadleaf herbicide that could be applied over the top of cotton. Therefore post-emergence weed control had to be accomplished with very inefficient and time consuming directed sprays. A typical cotton weed control program in the south consisted of four to six spray trips using as many as six different herbicides. This resulted in 4–6 kg ha^{-1} of active herbicide being applied.

There have been two herbicide resistant crop technologies registered for use in cotton, and a third is expected. The first technology registered was the BXN™ cotton resistant to bromoxynil. It quickly became popular in a few states where the morning glory species are a major problem. However the technology was limited due to a very narrow spectrum of control. The next technology introduced was Roundup Ready™ registered for use in 1997. In cotton this technology is not quite as straight forward to use as it is in soybean. Because of potential problems with pollination, glyphosate can only be applied over the top of cotton through the 4-leaf stage, and must be directed to the base of the plant during later applications. However, even with this restriction, the technology has been adopted in cotton essentially as rapidly as in soybean. This is illustrated in the table below.

Table 2. Adoption of herbicide resistant cotton in the USA[1].

	Percent of US area					
	1997	1998	1999	2000	2001	2002
Roundup Ready cotton	4	21	37	54	32	36
Roundup Ready/Bollgard™ Stacked Gene cotton	–	–	–	–	24	23
BXN cotton	1.2	5.8	7.8	7.2	–	–

[1] Data for 1997–2000 from Carpenter and Gianessi (2001). Data for 2001 and 2002 from March 28, 2002 USDA/NASS Prospective Plantings Report. The figures for 2001 and 2002 are actually for herbicide resistant cotton so they could include a very minor amount of BXN.

The estimates of Roundup Ready cotton planted in some states are as high as 80%. The reasons for the rapid adoption are much the same as those cited for soybean. They include better weed control, simplicity, convenience, and a better fit into no-till and reduced tillage systems. Another reason sometimes given for planting Roundup Ready cotton is for self preservation – that is protection from drift of glyphosate from neighbouring fields.

The disadvantages of the technology are also similar to those in soybean. In the majority of the cotton producing states, most cotton farmers are also soybean farmers. It is very common for an individual farmer to have 100% of his cotton and soybean area planted to Roundup Ready cultivars. This will likely compound the likelihood of weed shifts and resistance occurring. However the superiority and simplicity of the system makes it very difficult for a farmer to change programs. This will likely provide weed scientists with a tremendous challenge in the future. One thing that may help in cotton is the development of Liberty-Link™ cotton which is resistant to glufosinate. Registration is expected as early as 2003, and this can provide a broad spectrum weed control system that can be rotated with Roundup Ready cotton to help with resistance management.

RICE

Rice is grown primarily in the states of Arkansas, California, Louisiana, Mississippi, Missouri and Texas. Roughly half of the production area is in one state – Arkansas. A broad spectrum of grass, broadleaf, sedge and aquatic weed species infest rice. In many states, including Arkansas, the number one weed problem is red rice. It is the same genus and species as production rice but has an inferior grain type that makes it a weed. Red rice causes tremendous yield and quality losses and can not be controlled with standard herbicide programs. In general, excellent traditional weed control programs have been available for controlling most rice weed species other than red rice. However, propanil resistant barnyard grass (*Echinochloa crus-galli* (L.) Beauv.) is a rapidly increasing problem, and some populations of propanil resistant barnyard grass have also been confirmed resistant to quinclorac. Resistance to fenoxaprop has been reported in another *Echinochloa* species in California. Therefore, the need for a selective herbicide for controlling red rice as well as new herbicides for *Echinochloa* resistance management has resulted in the development of herbicide tolerant rice cultivars. To date, rice cultivars resistant to glufosinate, glyphosate and imazethapyr have been available for research purposes. The glufosinate and glyphosate resistant cultivars are transgenic, and the imazethapyr tolerant cultivars were developed through mutation breeding. The glufosinate resistant technology has been tested extensively but is currently not being commercially developed and the future for it is uncertain. A glyphosate resistant rice cultivar was available for efficacy testing one year and withdrawn from academic research programs. It is widely rumoured that the development of this technology will resume but only time will tell. Both the glufosinate and glyphosate resistant technologies proved very capable of controlling red rice as well as a broad spectrum of other weeds (Baldwin *et al.* 2000). The imazethapyr tolerant technology became commercially available in 2002. It is marketed as Clearfield™ rice and the imazethapyr is sold under the trade name of Newpath®. The co-author has conducted extensive research with this technology for a Ph.D. Dissertation project. The technology has proven capable of controlling red rice as well as several other troublesome grass, sedge and aquatic weed species (Dillon *et al.* 2000). Because the currently available cultivars are more tolerant to soil applications than post-emergence applications of imazethapyr, a soil application followed by a post-emergence application is required. A tank mix partner is usually required in the post-emergence treatment to broaden the spectrum of control. The newer cultivars currently being developed have complete resistance to post-emergence treatments. It is anticipated that when these are commercially available, the most consistent treatment will be two post-emergence applications. The current estimates for 2002 are that 60,000 hectares of Clearfield rice have been planted. This is a much lower estimate than earlier anticipated. However the area planted to the technology is expected to rapidly increase as the newer, more tolerant cultivars become available starting next year.

The most obvious drawback to any resistant rice technology is that of gene flow from the resistant rice to the red rice. The co-author has worked extensively with this issue and found that gene flow between the imazethapyr resistant rice and red rice has occurred in her research plots (Dillon *et al.* 2002). While the out-crossing percentages have been far below 1%, managing gene flow in the field is going to prove challenging. It was hoped that at least one of the other resistant rice technologies would be registered about the same time as the Clearfield rice. This would provide for a rotation among resistant technologies. However, this did not happen and it is yet to be seen if either of the others will be registered at all. Therefore the preservation of the Clearfield technology will depend upon the effectiveness in a given field, rotation to alternate crops and other stewardship strategies that will be implemented.

CORN AND WHEAT

Corn is an important crop to farmers in the southern USA but the crop area is small compared to that in the Midwestern states. It is anticipated that herbicide resistant corn will be thoroughly discussed in Dr. Owen's paper (Owen and Zelaya 2002, these proceedings).

Wheat production in the southern USA could be considered small, when compared to production in the western and Midwestern states. However, it is a very important crop in the south with much of it being double-cropped with soybean. One of the most difficult to control weeds in southern wheat production is diclofop resistant ryegrass (*Lolium* spp.). To date, this resistant population has not shown the high levels of resistance to some of the ALS-inhibiting herbicides that the populations in Australia are reported to have. However, most of these herbicides have restrictions that prevent double-cropping with conventional soybean varieties. The first herbicide resistant wheat registered will be Clearfield™ wheat and the first registered herbicide will be imazamox sold under the trade name of Beyond®. Repeated applications of imazamox have been reasonably effective on susceptible and resistant populations of ryegrass, and the use of this herbicide will allow any soybean cultivar to be double-cropped. It is not felt by this author, however, that the use of Clearfield wheat is a long-term solution to the resistant ryegrass problem. Wheat has traditionally been a low input crop from a weed management standpoint. It is not known, at this point, if growers will view the higher input costs for the Clearfield wheat as acceptable.

Monsanto is known to be developing Roundup Ready™ wheat. To date, this author is not aware of any academic testing conducted in the south. The challenge with this technology will again not likely be one of efficacy, but rather if it can be priced competitively in a crop where farmers have traditionally spent very little for herbicides.

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