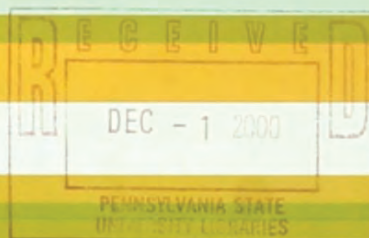




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Association for the Plant Protection Sciences

Crop Protection

Special Issue: XIVth International Plant Protection Congress (IPPC)



Volume 19 Nos. 8-10 Sep-Dec 2000



Crop Protection

Aims and Scope

The editors of CROP PROTECTION especially welcome papers describing an interdisciplinary approach showing how different control strategies can be integrated into practical pest management programmes.

CROP PROTECTION particularly emphasizes the practical aspects of control in the field, and includes work which may lead in the near future to more effective control. The journal does not duplicate the many existing excellent biological science journals, which deal mainly with the more fundamental aspects of plant pathology, applied zoology and weed science. CROP PROTECTION covers all practical aspects of pest, disease and weed control, including the following topics:

- Control of diseases of crop plants caused by microorganisms
- Control of animal pests of world crops
- Control of weeds
- Assessment of pest and disease damage
- Epidemiology of pests and diseases in relation to control
- Development of pesticides

- Biorational pesticides
- Effects of plant growth regulators
- Pesticide application methods
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- Environmental effects of pesticides
- Importance and control of postharvest crop losses
- Economic considerations
- Biological control
- Agronomic control methods
- Integrated control
- Pest management
- Interrelationships between different control strategies
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Current use of transgenic herbicide-resistant soybean and corn in the USA

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Abstract

The objective of this paper is to outline the current use of herbicide-resistant soybean and corn in the United States and describe the ramifications of utilizing these crops derived from biotechnology. The popular press and news articles detail the positions of consumers, environmental advocates, and the agriculture industry. Recent concerns expressed by consumers throughout the world have affected how herbicide-resistant crops are viewed and thus potentially the adoption of the technology. The paper will focus on the benefits and risks of using herbicide-resistant soybean and corn, specifically constructs that confer resistance to glyphosate. Glufosinate-resistant crops will also be discussed. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Transgenic; Biotechnology; Glyphosate

1. Introduction

The use of herbicide-resistant crops in the United States has increased, primarily due to the adoption of glyphosate-resistant soybean. Currently, there are over 1000 glyphosate (*N*-(phosphonomethyl) glycine) resistant soybean varieties available (Lawton, 1999). This has resulted in a dramatic change in weed management tactics in the US and a marked increase in glyphosate use. New licensing agreements by Monsanto with many companies will potentially increase glyphosate use. Interestingly, corn hybrids that are resistant to glyphosate have not been widely accepted to date in the US. Furthermore, there has been little adoption of corn or soybean cultivars transgenically resistant to other herbicides such as glufosinate (2-amino-4-(hydroxymethylphosphinyl) butanoic acid).

No weed resistance to glyphosate in corn and soybean production fields has been documented to date. However, glyphosate does not have soil residual characteristics. As a result, multiple in-season applications are often necessary to provide acceptable weed control and will likely provide sufficient selection pressure for the development of glyphosate-resistant weed populations. Furthermore, multiple applications cause a greater risk of off-target movement of glyphosate, and thus represents a significant environmental risk.

Recently, the use of transgenic crops has caused considerable public controversy. While many US producers may reconsider the use of transgenic soybeans and corn, others do not intend to alter the decision to use these genetically modified organisms (GMOs) (Swoboda, 2000).

The debate surrounding transgenic crops focuses on many issues. The most recent, and perhaps pervasive, issue relates to consumer acceptance of the technology. Consumers seemingly have not embraced the benefits of GMOs. The failure of the GMO “Flavr Savr” tomato, one of the first commercial transgenic products, and the current debate about herbicide-resistant corn and soybean suggests that consumers do not recognize the benefits attributed to GMOs (Larson, 1999). Transgenic crops are reported to enhance the chemical dependency of agriculture, thus eroding sustainable agriculture and rural America (Strange and Miller, 1994). Herbicide-resistant crops and subsequent herbicide use potentially represent a major environmental, economic and ecological concern, and critics of the technology favor sweeping restrictions to limit the adoption of GMOs (Goldburg et al., 1990).

Supporters of transgenic crops indicate that GMOs are no different than “traditional” crop technology and offer considerable economic and environmental advantages (Burnside, 1996). Other researchers suggest that transgenic soybean and corn systems will provide better weed management options even when effective strategies already exist (Wileut et al., 1996).

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Perhaps, the greatest issue for transgenic crops is the impact on international trade (Juma et al., 1999). The considerable debate between the biotechnology industry, the scientific community, and world consumers reflects different strategies and assessments of the technology. Each group views the risks and benefits of transgenic plants differently and suggests the need for a consistent regulatory mechanism, particularly for the US, Europe and Japan. The lack of functional governance represents a major problem for agricultural biotechnology, the acceptance of transgenic crops, and the utilization of foodstuffs derived from GMOs.

The objective of this paper is to review the current status of transgenic soybean and corn use in the US, describe the benefits ascribed to the GMO technology, assess the risks, particularly those detailed by world consumers, and conclude with suggestions for the future. Much of the information used to develop this manuscript was anecdotal and found in the popular press. However, these sources of information are vital to fully understanding the issues, given the importance of the world consumer in the acceptance and use of transgenic crop technology.

2. Current status of transgenic soybean and corn

2.1. Soybean

In 1996, Monsanto indicated that approximately 0.4 million ha of glyphosate-resistant soybean were planted; 3.6 million ha in 1997 and 11.3 million ha in 1998 (John Goette, pers. comm.). Duffy (1999) reported that 40% of the Iowa soybean crop was glyphosate resistant in 1998. The author estimates that 50-60% of the Iowa soybean crop was transgenic in 1999. Across the US, an estimated 12-14 million ha of glyphosate-resistant soybeans were planted (Lawton, 1999). This represents approximately \$240-\$280 million in technology fees. Currently, there are glyphosate-resistant soybean varieties available from more than 200 seed companies (Lawton, 1999).

Non-GMO soybean accounted for approximately 30-35% of the US soybean supply in 1999 (Otte, 1999). Due to recent concerns about the acceptance of GMOs in world trade, the percentage of non-GMOs may increase in the future and growers may receive a premium of \$0.002-\$0.009 kg⁻¹ for non-GMO soybean (Otte, 1999). Japan has offered a \$0.01-\$0.02 kg⁻¹ premium for non-GMO, food-grade soybean, and has a futures contract for non-GMO soybeans on the Tokyo Grain Exchange (Olson, 2000).

Japan likely will establish a food labeling tolerance of 5% GMO in food products. Maintaining the integrity of a non-GMO crop is difficult, given the predominance of GMO soybean in the US. Furthermore, few grain handlers are set up to segregate GMO soybeans from

non-GMO soybean (Swoboda, 2000). Segregation represents a considerable logistical problem and added cost to the farmer and grain handler. Only 2% of the market was identity preserved in 1999 (Olson, 2000).

Europe has purchased an estimated 90 billion kg of US soybean annually (Anderson, 1999). However, recent export data suggest that export of soybean meal to Europe has dropped 90% compared to 1998 (Olson, 2000). Furthermore, soybean and soybean meal exports to Europe were 28 and 77%, respectively, lower in 1998 than in 1997. Other principal suppliers of soybean to Europe include Argentina and Brazil. The use of GMO soybean in Argentina is widespread, however the Brazilian Agriculture Ministry has indicated that GMO soybean are not widely grown in Brazil (Larson, 1999). Despite the government policy, an estimated 30% of the Brazil soybean crop is GMO (Anderson, 1999).

2.2. Corn

Corn hybrids that are resistant to glyphosate have not been widely adopted. Estimates suggest that 1.6-2 million ha of glyphosate-resistant corn were planted in 1999 (John Goette, pers. comm.). While glufosinate-resistant corn has been available for several years, these hybrids have not been widely used by US farmers. Good alternative weed management programs, questionable yield potential, lack of consistent efficacy, and phytotoxicity to specific hybrids slowed the adoption of herbicide-resistant corn. However, the use of other transgenic traits, primarily *Bacillus thuringiensis* (Bt), has been widely accepted. Thus, GMO corn hybrids represented 23% of Iowa corn in 1998 (Duffy, 1999). The percentage of GMO corn in 1999 was estimated to approach 50%, again attributable primarily to Bt hybrids (Larson, 1999).

Europe typically imports 2.45 billion kg of US corn (Edwards, 1999). As experienced with transgenic soybean, US corn exports have dropped approximately \$400 million in 1998 due to fears about GMOs. This created a major problem for the grower, as GMO corn appeared to provide a significant profit, compared to non-GMO corn (Duffy, 1999).

2.3. World transgenic crop production

The issue of GMOs does not affect only the US. There were more than 27 million ha of GMO crops grown in 1998 (Larson, 1999). This represented a 10-fold increase from 1996. Approximately, 40 million ha were planted with transgenics in 1999 (Persley and Siedow, 1999). Over 20 crop species had transgenic varieties. Approximately, 15% of the land planted with transgenics was in developing nations. The global market for transgenic crops was \$75 million in 1995 and grew to an estimated \$1.84 billion in 1998. Proponents suggest that transgenic crops, primarily soybean and corn, represent the solution to

feeding the growing world population without compromising the ecology of the environment. Environmentalists argue that GMOs have risks that are not fully understood and may threaten the health of people, and diminish ecological diversity. Regardless, it appears that transgenic crops will continue to be important to the US in the immediate future.

3. Weed management practices for transgenic soybean and corn

3.1. Soybean

AgrEvo chose not to register glufosinate resistant soybean thus leaving the transgenic market to Monsanto. While DuPont/Pioneer will likely offer transgenic soybeans with output traits, no other transgenic soybean, other than glyphosate resistant, are currently available. Monsanto initially claimed growers could use their GMO soybean and one application of glyphosate to provide satisfactory control of weeds. Their advertising reported that early season weed interference was less important for soybean, and thus glyphosate applications could be delayed without risking a loss of yield. These claims have not been realized consistently.

For example, Iowa was extremely wet and planting was delayed until late in the spring 1996. As a result, most postemergence herbicide applications were made in late June and July, after most weed emergence had occurred. Thus, a single application of glyphosate, particularly in narrow-row (less than 50 cm) culture, was very effective and met grower expectations for weed control (Owen, 1997).

When planting dates are earlier, as is common in the Midwest, often a single application of a postemergence herbicide will not provide weed control that meets growers' expectations. This has generally been the situation in Iowa in 1997, 1998, and 1999. While many growers have attempted to use a single glyphosate application, their success has not been consistent. Importantly, when growers delayed the initial application until after most weeds have germinated, yield was lost due to weed interference. Furthermore, growers in the Midwest do not necessarily ascribe to the concept of "biologically necessary" weed management.

While weed scientists have developed a massive database describing integrated weed management (IWM) strategies and recommend control of weeds up to a level that eliminates potential interference with crop yield ("biologically necessary" weed management), growers must consider other factors. More than 50% of the land under cultivation in Iowa is rented. Thus, esthetics becomes a significant consideration to the renter/farmer. Also, important is management of the soil weed seed reservoir. Later emerging weeds such as common

waterhemp (*Amaranthus rudis*) will produce considerable numbers of seeds. Thus transgenic soybean offer an opportunity to make multiple applications of herbicides and effectively control weeds. The author estimates that the number of in-crop, postemergence glyphosate applications approached two or more, on the average, in Iowa during 1999.

As transgenic soybean and glyphosate became the predominant marketforce, other companies have attempted to develop products and market positions that will allow them to remain economically viable. These products include premix combinations (i.e. imazethapyr and glyphosate), proprietary glyphosate products, and products positioned to provide early season weed control prior to postemergence applications of glyphosate (i.e. metolachlor and metribuzin). Whether these strategies will be successful remains to be seen.

University weed scientists recognize the need for residual weed management and make recommendations to resolve grower's risks attributable to the reliance on a single postemergence glyphosate application. These recommendations include the use of a residual herbicide applied preplant or preemergence, alternative strategies such as cultivation and rotary hoeing, and the inclusion of residual herbicides with glyphosate. Grower acceptance of these recommendations has been mixed, but as the consistency of weed control from glyphosate systems declines, it is likely that these alternative strategies will be more widely adopted. The specific examples of weed control problems attributable to transgenic soybean systems will be discussed later in this paper.

3.2. Corn

The weed control strategies for transgenic herbicide-resistant corn have been somewhat different than with soybean. Typically, corn is planted earlier and viewed to be more susceptible to early interference from weeds. Thus, companies have suggested the need for herbicides that provide residual control, in addition to the non-residual, non-selective herbicide for which the GMO was developed. The residual herbicides are promoted for preplant or preemergence application and may include the non-residual, non-selective herbicide. There are a number of premix products commercially available. These include glufosinate and atrazine, and glyphosate and atrazine. It is anticipated that more premixes will be available in the future.

The performance of transgenic corn systems, similar to those discussed for soybean systems, has been less than consistent. Most of the transgenic herbicide-resistant corn, to date, has been glufosinate-tolerant hybrids. The author observed a number of situations where the glufosinate caused unacceptable phytotoxicity to the corn. While the hybrids were certified as resistant to glufosinate, the expression of the trait was not sufficient

or consistent enough to provide an acceptable margin of safety and an estimated 2-4% of the plants were affected.

Furthermore, glufosinate, at the application rates currently registered, has not consistently controlled weeds. Typically, applications have been to larger weeds, and in fields with extremely high weed populations. Also, AgrEvo positioned glufosinate systems for management of difficult weeds such as woolly cupgrass (*Eriochloa villosa*). As glufosinate does not readily translocate in plants, effective weed coverage was critically important. Failures with glufosinate were generally due to delayed applications to larger weed resulting in poor coverage. Furthermore, as glufosinate has been relatively costly and second applications were not considered an option by growers.

Glyphosate-resistant hybrids have recently become available to growers. However, grower response has not been as favorable as with glyphosate-resistant soybean. Growers are less willing to accept weeds existing with seedling corn, and applications are needed earlier than in soybean. Thus, Monsanto has positioned glyphosate-resistant corn with a residual soil-applied herbicide. Premix combinations with glyphosate are under development by Monsanto and will become the basis for weed management systems in glyphosate-resistant corn.

Another consideration with early glyphosate-resistant corn hybrids was a lack of tolerance. Monsanto did not initially allow second applications of glyphosate and restricted the amount of glyphosate that could be applied to the hybrids. Injury was observed on a number of the hybrids initially available. Furthermore, these glyphosate-resistant hybrids were not perceived to have an acceptable yield potential. It is anticipated that future hybrids will express glyphosate resistance at a higher level and have better yield characteristics.

The use of soil-residual herbicides in combination with postemergence applications of the non-selective, non-residual herbicides will provide growers with an exceptional opportunity to effectively manage weeds. Importantly, the inclusion of alternative weed management strategies is common in Midwest corn production systems, which further improves the success of transgenic corn production systems. While it is possible to rely solely on postemergence applications of the non-selective, non-residual herbicide for weed control in transgenic corn production, this strategy has not been consistent, nor is it widely recommended by university weed scientists.

4. Benefits attributable to transgenic herbicide-resistant soybean and corn

Transgenic herbicide-resistant crops have a number of benefits for growers and consumers. Transgenic soybean and corn are included in agricultural technology to

increase productivity primarily by reducing inputs, and thus production costs (Persley and Siedow, 1999). Furthermore, glyphosate and glufosinate demonstrate favorable environmental and toxicological characteristics (Owen, 1994).

Duffy (1999) reports lower production costs for transgenic soybean. Growers reported that they primarily planted glyphosate-resistant soybean for improved weed control. Herbicide costs for the transgenic soybean were 30% lower than for non-GMO soybean. Another benefit from the transgenic soybeans was greater herbicide application timing flexibility.

Growers have generally experienced consistent control of weeds from glyphosate in glyphosate-resistant soybean and corn. Importantly, growers have perceived the lower potential for crop phytotoxicity to be a significant benefit for transgenic crops. However, a multi-state, multi-year study supported by the Soybean Research Development Council suggested that soybean injury attributable to protoporphyrinogen oxidase (PPO) inhibitor herbicides does not consistently result in lower soybean yields (Owen, unpublished). Experiences in the Midwest would also suggest that control of perennial weeds such as hemp dogbane (*Apocynum cannabinum*) has been improved with the adoption of glyphosate-resistant corn and soybean.

Generally, transgenic soybean and corn represent an opportunity for improved weed management (Wilcutt et al., 1996). Transgenic soybeans and corn may also increase the adoption of alternative weed management practices (Burnside, 1996). However, a survey, conducted in conjunction with the Aldo Leopold Center for Sustainable Agriculture at Iowa State University, indicated that an increase in alternative strategies for weed management in response to transgenic crops was unlikely (Owen, 1994).

Weed resistance is increasing rapidly throughout the world. Resistance to ALS inhibitor herbicides has developed across the US in many weedy species, but in particular, the Midwest. ALS-resistant populations of common waterhemp are found frequently and the populations are rapidly increasing (Owen, 1997). The use of transgenic soybean and corn may represent an excellent strategy to manage the resistant weed populations. Importantly, the non-residual, non-selective herbicides for the transgenic crops are reported to have a low potential for the evolution of resistant weed populations (Anonymous, 1997).

Perhaps, the greatest benefit for transgenic technologies in soybean and corn has not yet been realized. This benefit is improved output traits and ultimately grains will have specific nutritional characteristics that will be economically beneficial to agriculture. Reports of improved nutritional qualities for rice (*Oryza sativa*) indicate the high potential for transgenic crops to resolve malnutrition throughout the world (Guerinot, 2000).

Larson, 1999; Ye et al., 2000). The same potential exists in transgenic soybean and corn (Walt Fehr, pers. comm.).

5. Risks associated with transgenic herbicide-resistant soybeans and corn

Cook (1999) listed six risk issues for transgenic crops. The list included the risk of gene transfer, weediness, trait effects, genetic and phenotypic variability, expression of genetic material from pathogens and worker safety. For example, moving transgenes encoding allergens into a crop could have adverse health effects (Persley and Siedow, 1999). However, several of these risk issues likely do not directly relate to transgenic soybean and corn.

There is little likelihood of gene transfer from either soybean or corn to weedy plants, thus conferring resistance in weeds to the non-selective, non-residual herbicides (Grooms, 1999). However, there is a risk that transgenic crops could become volunteer weeds (Owen, 1994). Furthermore, pollen movement may result in the transfer of herbicide resistance to non-GMO corn, which could then become an unanticipated volunteer weed problem.

Despite industry claims that the transgenic systems do not represent a risk for the development of herbicide-resistant weed populations (Anonymous, 1997), many scientists feel that the selection pressure from the target herbicides is sufficient to cause, at the least, shifts in weed populations to species that are not effectively controlled (Duke et al., 1991; Holt, 1994; Radosevich and Holt, 1984). Numerous common waterhemp and velvetleaf (*Ahutilon theophrasti*) control problems have been reported in glyphosate-resistant soybeans in Iowa (Owen, 1997). Some of these problems likely reflect poor management strategies on the part of growers, however differential tolerance to glyphosate has been confirmed in some common waterhemp populations (Ian Zelaya, pers. comm.). Hess (1996) indicated that weed control problems for IWM systems based on transgenic soybean and corn are due to a lack of knowledge about the ecology and biology of weed/crop interactions.

Herbicide drift is a risk for all herbicides, but due to multiple in-crop applications, may be a greater risk for the transgenic crops (Owen, 1994, 1997). As the currently available target herbicides for transgenic soybean and corn do not have selectivity for most plants, slight drift from these herbicides may cause greater and more noticeable damage than drift from other herbicides. Herbicide drift complaints and subsequent litigations continue to increase in Iowa (Charles Eckerman, pers. comm.). Glyphosate drift complaints represent a significant number of the total complaints in Iowa.

Another concern for transgenic soybean and corn is whether or not the same yield potential exists compared to the non-GMO varieties and hybrids (Powell, 1999).

Harper (1997) reported that glyphosate-resistant soybean have the same yield potential as glyphosate-sensitive varieties. Furthermore, competition between seed companies will result in better yields for GMO hybrids and varieties (Duvick, 1996). However, Marking (1999) summarized Midwest University soybean yield trials and concluded that there was a "yield drag" associated with glyphosate-resistant varieties. A 4% yield penalty was associated with the glyphosate-resistance trait, compared to conventional varieties (Oplinger et al., 1999).

Tauer and Love (1989) modeled the impact of transgenic crops on production costs and predicted that despite claims of better weed management, higher yield potential, and improved economic risk, these traits would not have a significant effect on economic returns when the technology was widely adopted. However, they also predicted that early adopters would benefit economically from the GMO crops. Duffy (1999) validated these claims and indicated that no differences existed for economic returns for GMO and non-GMO soybean. The potential reduction in yield potential and the added seed cost for transgenic soybean and corn may require growers to reassess whether the anticipated weed management benefits outweigh other associated risks.

Perhaps, the most significant risk attributable to transgenic soybean and corn is the loss of marketability for GMO grain. The export markets for these crops are significant; Japan purchases almost a third of corn exported from the US, and the European Union purchases approximately 40% of the US soybean exported (Turner, 1999). The lack of acceptance towards transgenics expressed by these customers puts future export sales at considerable risk (Anderson, 1999; Edwards, 1999). The inability of growers and grain companies to effectively segregate GMOs from non-GMOs also places the export of "traditional" crops to customers who desire non-GMOs in jeopardy (Olson, 2000; Otte, 1999, and Swoboda, 2000). The lack of tolerances for GMO contamination to non-GMO crops does not help the situation (Olson, 2000).

6. Consumers and transgenic herbicide-resistant soybean and corn

The United States Food and Drug Administration (FDA) regards transgenic soybean and corn the same as non-GMO crops (Kilman, 1999). Thus, GMOs have been deemed safe to eat. However, some consumers worldwide have determined that these transgenic crops are not desirable and have labeled them "Frankenstein" foods (Klee, 1999). The debate lacks scientific credibility on many levels. Nevertheless, consumers have made their voices heard, and a segment of the food industry has reacted negatively towards transgenic crops (Kilman, 1999). While consumer resistance to transgenic crops was

mainly an issue in Europe and Japan, some US consumers have expressed similar concerns, and some US companies have responded accordingly.

One of the main problems is whether or not processed foods are GMO-free. Labeling the genetic content of the grain and processed products has been proposed as a solution to consumer fears (Moschini, 1999). There has been governmental support for volunteer labeling of transgenic grain, and products. The lack of tolerances does not appear to support labeling GMO content as a possible solution to consumer's fears. Furthermore, given the problems with grain segregation, it is unlikely that labeling can be effectively accomplished.

7. Conclusions

Transgenic herbicide-resistant soybean have become a standard production practice in the US and advocates predict that transgenic herbicide-resistant corn will follow. Most of the transgenic herbicide-resistant soybean and a portion of transgenic herbicide-resistant corn have traits that confer resistance to glyphosate. A small percentage of the transgenic corn is for glufosinate resistance. While there are many benefits attributable to herbicide-resistant crops, there are also risks. The greatest concern expressed by the consumers of agricultural products addresses the safety of foods from transgenic crops. Science has not been able to successfully answer this concern, and the agricultural industry has not been effectively responsive to consumer fears. Grain handlers and processors have placed some restrictions on transgenic crops in an attempt to meet the concerns of consumers.

It does not appear that the debate about transgenics will soon end. Furthermore, the consumers' fears appear to be escalating, thus increasing the potential risk for growers who must market the transgenic soybean and corn. The author suggests that the rapid increases in the use of transgenic soybean and corn will slow and may decline in the near future. The uncertainty of a profit, and the possible loss of a market, will cause many growers in the US to switch to crops without transgenic traits.

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