Herbicide Tolerance Technology: Glyphosate and Glufosinate


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Ask any farmer and he will surely tell you that weeds are a constant problem. Weeds not only compete with crops for water, nutrients, sunlight, and space but also harbor insect and disease pests; clog irrigation and drainage systems; undermine crop quality; and deposit weed seeds into crop harvests. If left uncontrolled, weeds can reduce crop yields significantly.

Farmers can fight weeds with tillage, hand weeding, herbicides, or typically a combination of all techniques. Unfortunately, tillage leaves valuable topsoil exposed to wind and water erosion, a serious long-term consequence for the environment. For this reason, more and more farmers prefer reduced or no-till methods of farming.

Similarly, many have argued that the heavy use of herbicides has led to groundwater contaminations, the death of several wildlife species and has also been attributed to various human and animal illnesses.

Weed Control Practices

The tandem technique of soil-tilling and herbicide application is an example of how farmers control weeds in their farms.

Generally, they till their soil before planting to reduce the number of weeds present in the field. Then they apply broad-spectrum or non-selective herbicides (one that can kill all plants) to further reduce weed growth just before their crop germinates. This is to prevent their crops from being killed together with the weeds. Weeds that emerge during the growing season are controlled using narrow-spectrum or selective herbicides. Unfortunately, weeds of different types emerge in the field, and therefore, farmers have to use several types of narrow-spectrum herbicides to control them. This weed control method can be very costly and can harm the environment.

Researchers postulated that weed management could be simplified by spraying a single broad-spectrum herbicide over the field anytime during the growing season.

Development of Glyphosate and Glufosinate Herbicide Tolerant Plants

Herbicide tolerant (HT) crops offer farmers a vital tool in fighting weeds and are compatible with no-till methods, which help preserve topsoil. They give farmers the flexibility to apply herbicides only when needed, to control total input of herbicides and to use herbicides with preferred environmental characteristics.

Technology Background

How do these herbicides work?


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These herbicides target key enzymes in the plant metabolic pathway, which disrupt plant food production and eventually kill it. So how do plants elicit tolerance to herbicides? Some may have acquired the trait through selection or mutation; or more recently, plants may be modified through genetic engineering.

Why develop HT crops?

What is new is the ability to create a degree of tolerance to broad-spectrum herbicides - in particular glyphosate and glufosinate - which will control most other green plants. These two herbicides are useful for weed control and have minimal direct impact on animal life, and are not persistent. They are highly effective and among the safest of agrochemicals to use. Unfortunately, they are equally effective against crop plants. Thus, HT crops are developed to have a degree of tolerance to these herbicides.

How do Glyphosate and Glufosinate HT crops work?

1. Glyphosate-tolerant crops
Glyphosate herbicide kills plants by blocking the EPSPS enzyme, an enzyme involved in the biosynthesis of aromatic amino acids, vitamins and many secondary plant metabolites. There are several ways by which crops can be modified to be glyphosate-tolerant. One strategy is to incorporate a soil bacterium gene that produces a glyphosate tolerant form of EPSPS. Another way is to incorporate a different soil bacterium gene that produces a glyphosate degrading enzyme.

2. Glufosinate-tolerant crops
Glufosinate herbicides contain the active ingredient phosphinothricin, which kills plants by blocking the enzyme responsible for nitrogen metabolism and for detoxifying ammonia, a by-product of plant metabolism. Crops modified to tolerate glufosinate contain a bacterial gene that produces an enzyme that detoxifies phosphinothricin and prevents it from doing damage.

Other methods by which crops are genetically modified to survive exposure to herbicides including: 1) producing a new protein that detoxifies the herbicide; 2) modifying the herbicide's target protein so that it will not be affected by the herbicide; or 3) producing physical or physiological barriers preventing the entry of the herbicide into the plant. The first two approaches are the most common ways scientists develop herbicide tolerant crops.

Safety Aspects of Herbicide Tolerance Technology

Toxicity and Allergenicity

Government regulatory agencies in several countries have ruled that crops possessing herbicide tolerant conferring proteins do not pose any other environmental and health risks as compared to their non-GM counterparts.

Introduced proteins are assessed for potential toxic and allergenic activity in accordance with guidelines developed by relevant international organizations. They are from sources with no history of allergenicity or toxicity; they do not resemble known toxins or allergens; and they have functions, which are well understood.

Effects on the Plants

The expression of these proteins does not damage the plant's growth nor result in poorer agronomic performance compared to parental crops. Except for expression of an additional enzyme for herbicide tolerance or the alteration of an already existing enzyme, no other metabolic changes occur in the plant.

Persistence or invasiveness of crops

A major environmental concern associated with herbicide tolerant crops is their potential to create new weeds through outcrossing with wild relatives or simply by persisting in the wild themselves. This potential, however, is assessed prior to introduction and is also monitored after the crop is planted. The current scientific evidence indicates that, in the absence of herbicide applications, GM herbicide-tolerant crops are no more likely to be invasive in agricultural fields or in natural habitats than their non-GM counterparts (Dale et al., 2002).

The herbicide tolerant crops currently in the market show little evidence of enhanced persistence or invasiveness.

Advantage of Herbicide Tolerant Crops

- Excellent weed control and hence higher crop yields;
- Flexibility – possible to control weeds later in the plant's growth;
- Reduced numbers of sprays in a season;
- Reduced fuel use (because of less spraying);
- Reduced soil compaction (because of less need to go on the land to spray);
- Use of low toxicity compounds which do not remain active in the soil; and
- The ability to use no-till or conservation-till systems, with consequent benefits to soil structure and organisms (Felsot, 2000).

A study conducted by the American Soybean Association (ASA) on tillage frequency on soybean farms showed that significant numbers of farmers adopted the “no-tillage” or “reduced tillage” practice after planting herbicide-tolerant soybean varieties. This simple weed management approach saved over 234 million gallons of fuel and left 247 million tons of irreplaceable topsoil undisturbed.

Current Status of Herbicide Tolerance

From 1996 to 2014, HT crops consistently occupied the largest planting area of biotech crops. In 2014 alone, HT crops occupied 102.6 million hectares or 57% of the 181.5 million hectares of biotech crops planted globally. The most common are the glyphosate and glufosinate tolerant varieties. The following table shows countries that have approved major HT crops for food, feed, and/or cultivation.

Crop	**Countries**
Alfalfa	*Australia, Canada, Japan, Mexico, New Zealand, Philippines, Singapore, South Korea, United States of America (USA)*
Argentine Canola	*Australia, Canada, Chile, China, European Union (EU), Japan, Mexico, New Zealand, Philippines, Singapore, South Africa, South Korea, Taiwan, USA*
Carnation	*Colombia, EU, Malaysia*
Chicory	*USA*
Cotton	*Argentina, Australia, Brazil, Canada, China, Colombia, Costa Rica, EU, Japan, Mexico, New Zealand, Paraguay, Philippines, Singapore, South Africa, South Korea, Taiwan, USA*
Creeping bentgrass	*USA*
Flax, Linseed	*Canada, Colombia, USA*
Maize	*Argentina, Australia, Brazil, Canada, China, Colombia, Cuba, EU, Honduras, Indonesia, Japan, Malaysia, Mexico, New Zealand, Panama, Paraguay, Philippines, Russian Federation, Singapore, South Africa, South Korea, Switzerland, Taiwan, Thailand, Turkey, USA, Uruguay, Vietnam*
Polish Canola	*Canada*
Potato	*Australia, Canada, Japan, Mexico, New Zealand, Philippines, South Korea, USA*
Rice	*Australia, Canada, Colombia, Honduras, Mexico, New Zealand, Philippines, Russian Federation, South Africa, USA*
Soybean	*Argentina, Australia, Bolivia, Brazil, Canada, Chile, China, Colombia, Costa Rica, EU, India, Indonesia, Japan, Malaysia, Mexico, New Zealand, Paraguay, Philippines, Russian*

	Federation, Singapore, South Africa, South Korea, Switzerland, Taiwan, Thailand, Turkey, USA, Uruguay
Sugar beet	*Australia, Canada, China, Colombia, EU, Japan, Mexico, New Zealand, Philippines, Russian Federation, Singapore, South Korea, USA*
Wheat	*Australia, Colombia, New Zealand, USA*

Source: ISAAA's GM Approval Database. http://www.isaaa.org/gmapprovaldatabase/.

A literature review conducted by the Council for Agricultural Science and Technology concluded that the environment benefits from the use of HT crops. In the US, for example, no-till soybean acreage has increased by 35% since the introduction of HT soybean. A similar trend is observed in Argentina where soybean fields are 98% planted with HT varieties. The CAST paper entitled "Comparative Environmental Impacts of Biotechnology-derived and Traditional Soybean, Corn and Cotton Crops" is available at http://www.cast-science.org.

For the first 18 years of commercialization (1996-2013), benefits from herbicide tolerant crops are valued at US$ 54.9 billion, 41% of global biotech crop value of US$ 133 billion, and for 2013 alone at US$ 7.9 billion or 39% of global value of US$ 20.4 billion.