Herbicide Tolerance in Agricultural Crops

Background

Weed control is essential in crop systems, as unwanted plants reduce yield by competing with crops for water, sunlight, and vital nutrients. Farmers use multiple strategies to control weeds. One option is through manual removal and/or plowing. However, manual labor by hoeing is laborious and costly, and use of farm machinery for weed removal uses fuel, disturbs the soil and contributes to total carbon and greenhouse gas emissions. Alternatively, agricultural weeds can be controlled by the use of herbicides. Herbicides are chemicals that kill weeds or prevent their ability to grow. These compounds range in their degree of specificity for weed targets. Broad-spectrum herbicides kill most types of plants that they come in contact with, while narrow-spectrum or selective herbicides are toxic only a specific set of plant species[1]. Common lawn herbicides containing 2,4-D are examples of selective herbicides that in this case kill broadleaf weeds without harming grasses.

While breeders work to develop crop varieties that are better able to compete with weeds, herbicides are important tools to enable farmers to achieve maximum yield potential. Increasing crop yield is a matter of concern, as the world population will increase to 9.1 billion people by 2050 and this population increase correlates with a necessary food production increase of 70% from current production levels[2]. In order to meet this demand, we must consider sustainable options in which land use is minimized and yield and nutrient value are maximized. Through the use of genetic modification, crops with greatly enhanced tolerance to herbicides may be produced, thus making biotechnology an important option to consider in order for modern agriculture to feed the world.

What is herbicide tolerance?

Herbicide tolerance refers to a plant's ability to resist the toxic effects of a certain herbicide. Plants that are herbicide tolerant (HT) can continue to grow and thrive even in the presence of the applied chemical. Methods in biotechnology assist traditional breeding by allowing a precise alteration or an addition of a desirable trait to already favored plant cultivars. In general, plant herbicide resistance is achieved by incorporating a gene that confers resistance to an herbicide from a microorganism into the plant. When the plant has this new gene, it can make a new protein that resists the toxic effects of the herbicide. For example, the broad-spectrum herbicide glyphosate blocks the formation of certain amino acids that are necessary building blocks of proteins for a healthy plant. More specifically, glyphosate inactivates the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), which is vital for aromatic amino acid formation[3]. In order to overcome this susceptibility, scientists have isolated a gene encoding EPSPS from bacteria that is not inhibited by glyphosate and introduced it into crop plants. The bacterial EPSPS protein allows the plant to make the amino acids it needs even in the presence of glyphosate. This permits farmers to apply the broad-spectrum herbicide over both the crop and the weeds, killing the weeds while not harming the crop. Subsequent plowing generally is not needed, which often stimulates additional weed seed germination. This reduces the number of trips farmers must make over their fields and saves fuel and labor.

Benefits of herbicide-tolerant plants

HT plants provide economical and ecological benefits to farmers, consumers, and the land on which they are grown. Since the advent of HT crops resistant to glyphosate in the mid 1990's, soil

tillage (plowing) of land for soybeans alone has diminished by 23% by those who previously practiced conventional tillage[4]. Reduced tilling helps to preserve soil nutrients and organic matter and reduces soil erosion. Greater availability of soil nutrients also correlates with a reduction in energy-requiring fertilizer production and application. Low or no-till practices enabled by herbicide-tolerant crops have contributed toward saving 1.2 million kg of CO_2 emissions due to fuel consumption alone in 2008, and total CO_2 emission reductions were equivalent to removing 6.4 million cars from the roads for a year[5]. Since the advent of glyphosate-resistant crops, glyphosate has become the most frequently used herbicide. This herbicide is much less toxic to other organisms per unit of active ingredient compared to narrow-spectrum herbicides previously necessary for complete weed control[6]. Owing to greater yield per area cultivated, herbicide-tolerant crops also require less land to be used for farming. The 29.6 million metric tons of biotech soybean, maize, cotton, and canola produced in 2008 would have required 10.5 million additional hectares if biotech crops had not been utilized[7]. Engineering plants to become herbicide tolerant is a major technological innovation that has real benefits for agricultural sustainability.

Soybean – The most widely utilized herbicide-tolerant crop in production today is the Roundup Ready® soybean. Roundup Ready (RR) soybeans are resistant to the broad-spectrum herbicide Roundup that contains the active ingredient glyphosate[8]. In 2008, herbicide-tolerant soybeans accounted for 92% of total soybean area planted in the U.S. and a similar or greater percentage in Argentina[5]. This high demand is due to increased yields and decreased costs for farmers who are choosing herbicide-tolerant seeds.

Corn – Two separate traits have been generated through genetic engineering to produce herbicide tolerant corn. In addition to the RR technology in corn, other herbicide-tolerant corn contains a gene encoding an enzyme from the microorganism *Streptomyces*. When the *bar* gene from *Streptomyces* is expressed in corn, it forms the enzyme phosphinothricin acetyl transferase, or PAT. PAT is capable of degrading glufosinate, the active compound found in the herbicides Liberty® and BASTA®[9]. Herbicide-tolerant corn has led to decreased costs associated with herbicide treatment, as fewer types of herbicides are needed for weed control. Some countries have also seen increases of up to 15% in yield when growing herbicide-tolerant corn in comparison to non-tolerant varieties[10].

Cotton – RR cotton was first grown commercially in 1997. The primary benefit of this technology is a reduction in costs to the farmer, as opposed to the enhanced yields that are seen in other crops. Today HT cotton is grown in Australia, Argentina, South Africa, Mexico and the U.S. where there have been a total net farm income gains of $855 million[5].

Canola – Weeds are a significant issue for growers of canola, as they can reduce yield and decrease the quality of the crop. HT canola has provided farmers with a less expensive and easier form of weed control for their product[10]. Canada was the first country to commercially grow HT canola and today 83% of their total crop is GM[5]. In 2008, the farm level impact of this technology in canola was $392 million.

Future Issues for HT Technology

It is important to note that, like all technologies, HT crops are not a 'magic bullet' for agricultural sustainability. Continuous reliance on a single herbicide has often resulted in the development of resistance in the target weeds[11]. Although more slow to develop than for some other herbicides,

cases of glyphosate-resistant weeds have been reported[12], owing largely to the high selection pressure caused by treatment with only one broad-spectrum herbicide[13]. Seed companies, chemical companies and farmers are working together to develop crop varieties and management practices that allow rotation of different herbicides to delay the development of weed resistance. Varieties with resistance to multiple herbicides are becoming available to allow farmers greater flexibility in managing both weeds and weed herbicide resistance. It is important that these practices be adopted and widely employed in order to retain the effectiveness of herbicides that combine broad utility with low environmental toxicity. This is particularly important for HT crops that enable further benefits through reduced plowing, conserving both fuel and soils. Agricultural sustainability requires the integration of multiple approaches to protect crops from weeds and pests, and HT crops are an important tool in this overall effort.

References

1. ISAAA. Herbicide tolerance technology: Glyphosate & glufosinate. http://www.isaaa.org/resources/publications/pocketk/document/Doc-Pocket%20K10.pdf (2006).
2. FAO. 2050: A third more mouths to feed. http://www.fao.org/news/story/0/item/35571/icode/en/ (2009).
3. Huynh, Q.K., Kishore, G.M. & Bild, G.S. 5-enolpyruvyl shikimate 3-phosphate synthase from escherichia coli: Identification of lys-22 as a potential active-site residue. *Journal of Biological Chemistry* **263**, 735-739 (1988).
4. Givens, W.A., Shaw, D.R. et al. Survey of tillage trends following the adoption of glyphosate-resistant crops. *Weed Technology* **23**, 150-155 (2009).
5. Brookes, G. & Barfoot, P. Gm crops: Global socio-economic and environmental impacts 1996-2008. *PG Economics Ltd* http://fundacion-antama.org/wp-content/uploads/2010/04/001-2010-global-gm-crop-impact-study-final-April-2010.pdf (2010).
6. Fernandez-Cornejo, J. & McBride, W.D. Adoption of bioengineered crops. *Agricultural Economic Report No. 810* http://www.ers.usda.gov/Publications/AER810/ (2002).
7. James, C. Global status of commercialized biotech/gm crops: 2008 *International Service for the Acquision of Agri-biotech Applications (ISAAA)* **Brief 39** (2009).
8. Padgette, S.R., Kolacz, K.H. et al. Development, identification, and characterization of a glyphosate-tolerant soybean line. *Crop Science* **35**, 1451-1461 (1995).
9. Tan, S., Evans, R. & Singh, B. Herbicidal inhibitors of amino acid biosynthesis and herbicide-tolerant crops. *Amino Acids* **30**, 195-204 (2006).
10. Brookes, G., Yu, T.H., Tokgoz, S. & Elobeid, A. The production and price impact of biotech corn, canola, and soybean crops. *AgBioForum* **13**, 25-52 (2010).
11. Powles, S.B. & Yu, Q. in Annual review of plant biology, vol 61. Vol. 61 317-347(2010).
12. Johnson, W.G., Davis, V.M., Kruger, G.R. & Weller, S.C. Influence of glyphosate-resistant cropping systems on weed species shifts and glyphosate-resistant weed populations. *European Journal of Agronomy* **31**, 162-172 (2009).
13. Pedigo, L.P. & Rice, M.E. Plant biotechnology: Ecological case studies on herbicide resistance. *Trends in Plant Science* **11**, 324-328 (2006).
14. Graef, F. Agro-environmental effects due to altered cultivation practices with genetically modified herbicide-tolerant oilseed rape and implications for monitoring. A review. *Agron Sustain Dev* **29**, 31-42 (2009).

Written: June 1, 2010, by Jennifer Gray, Jamie Shattuck and Kent Bradford
Last Updated: December 12, 2010

Additional References

Graef, F. Agro-environmental effects due to altered cultivation practices with genetically modified herbicide-tolerant oilseed rape and implications for monitoring. *Agron Sustain Dev* **29**, 31-42 (2009).