Herbicide-Resistant Weeds in Genetically Engineered Crops

Statement of

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Good afternoon, Mr. Chairman and members of the Committee, and thank you for the opportunity to speak with you today about the economic and environmental effects of the current management of genetically engineered, herbicide-resistant crops in U.S. agriculture. My name is Micheal Owen. I am associate chair and extension weed scientist in the Department of Agronomy at Iowa State University and served as a member of the Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability of the National Research Council. The Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine of the National Academies, chartered by Congress in 1863 to advise the government on matters of science and technology.

Genetically engineered, or GE, crops with resistance to herbicides were introduced in 1996. In 2010, U.S. farmers grew cultivars of soybean, cotton, corn, canola, alfalfa, and sugar beet with genetically engineered resistance to the herbicide glyphosate. Glyphosate is a broad-spectrum, systemic herbicide originally developed and patented by Monsanto and sold under the name Roundup. Though crops have been commercialized with resistance to other herbicides, nearly all genetically engineered, herbicide-resistant crops produced in the United States are resistant to glyphosate, so I will restrict my remarks to this particular trait. I will focus primarily on experiences with herbicide-resistant weeds in soybean, cotton, and corn production as these crops are grown on roughly half of U.S. cropland. It should be noted that weeds represent the most economically-damaging pest complex to agriculture and are ubiquitous to all agricultural systems.

Crops with resistance to glyphosate have been widely adopted by U.S. farmers. In 2010, glyphosate-resistant varieties were grown on approximately 93 percent of soybean acres, 78 percent of upland cotton acres, and 70 percent of corn acres in the United States. As these varieties were adopted, farmers generally substituted the use of glyphosate for other herbicides and weed-management tactics because the GE trait allows these crops to survive glyphosate unharmed (Figures 1–3). The adoption of glyphosate-resistant crops facilitated production success when using no tillage practices. Less tillage can reduce farmers' expenses in terms of time in the field and wear and tear on machinery, and it can improve soil structure and quality as well as reduce soil erosion, which enhances water quality. Because it binds to the soil rapidly, is biodegraded by soil bacteria, and has a very low toxicity to mammals, birds, and fish, glyphosate kills most plants without substantial adverse environmental effects on animals or soil or water quality. The widespread adoption of glyphosate-resistant crops has therefore reduced the use of more toxic (albeit EPA-registered) herbicides in soybean, cotton, and corn fields. However, though fewer types of herbicides have been sprayed since the adoption of glyphosate-resistant crops, the overall amounts of active ingredient[1] in herbicides has not necessarily decreased. Glyphosate is frequently applied in higher doses and with greater frequency than the herbicides it replaced. Thus, the actual amount of active ingredient applied per acre increased from 1996 to 2007 in soybean and cotton but decreased over the same period in corn.

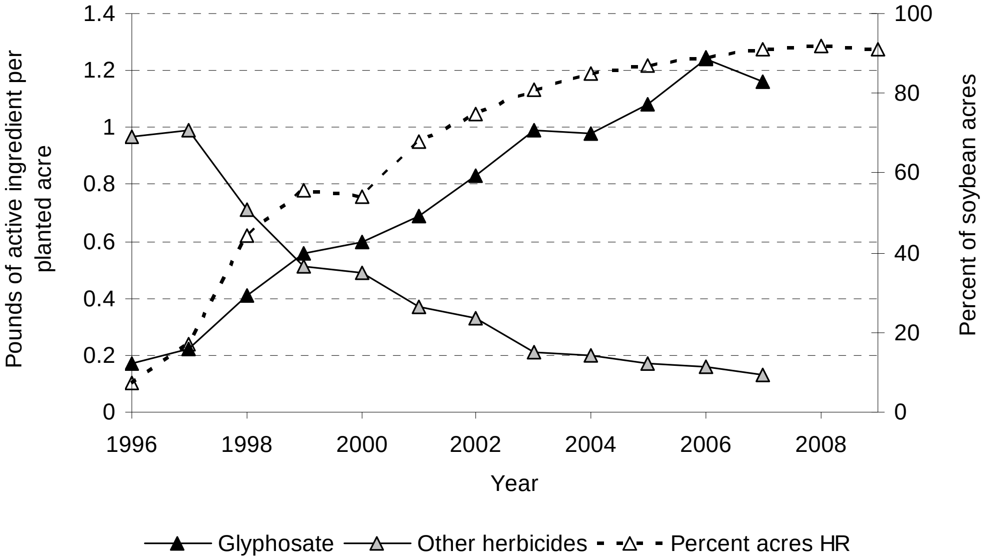

Figure 1. Application of herbicide to soybean and percentage of acres of herbicide-resistant soybean.
Note: The strong correlation between the rising percentage of herbicide-resistant soybean acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
Source: USDA-NASS, 2001, 2003, 2005, 2007, 2009a, 2009b; Fernandez-Cornejo et al., 2009.

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[1] The *active ingredient* is the material in the pesticide that is biologically active. The active ingredient is typically mixed with other materials to improve the pesticide's handling, storage, and application properties.

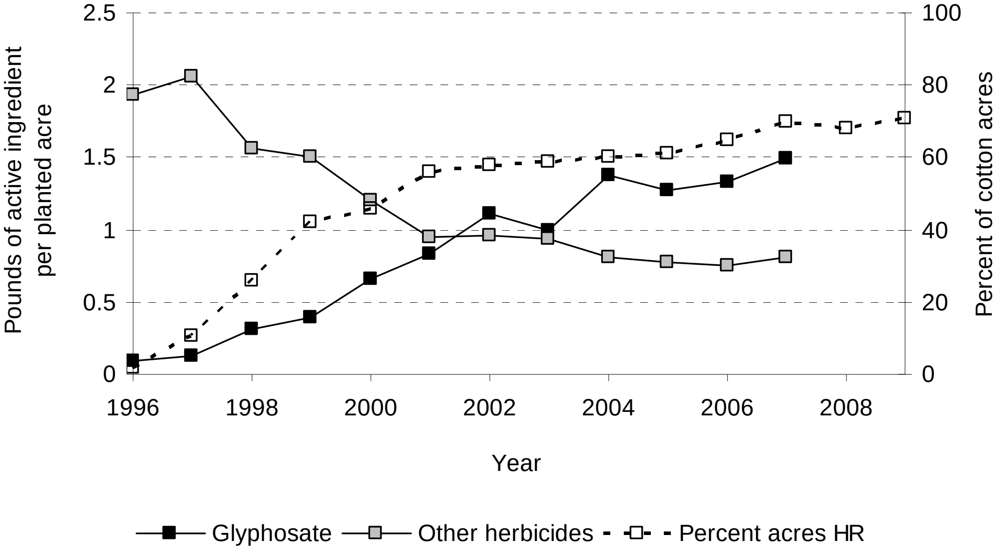

Figure 2. Application of herbicide to soybean and percentage of acres of herbicide-resistant cotton.
Note: The strong correlation between the rising percentage of herbicide-resistant cotton acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
Source: USDA-NASS, 2001, 2003, 2005, 2007, 2009a, 2009b; Fernandez-Cornejo et al., 2009.

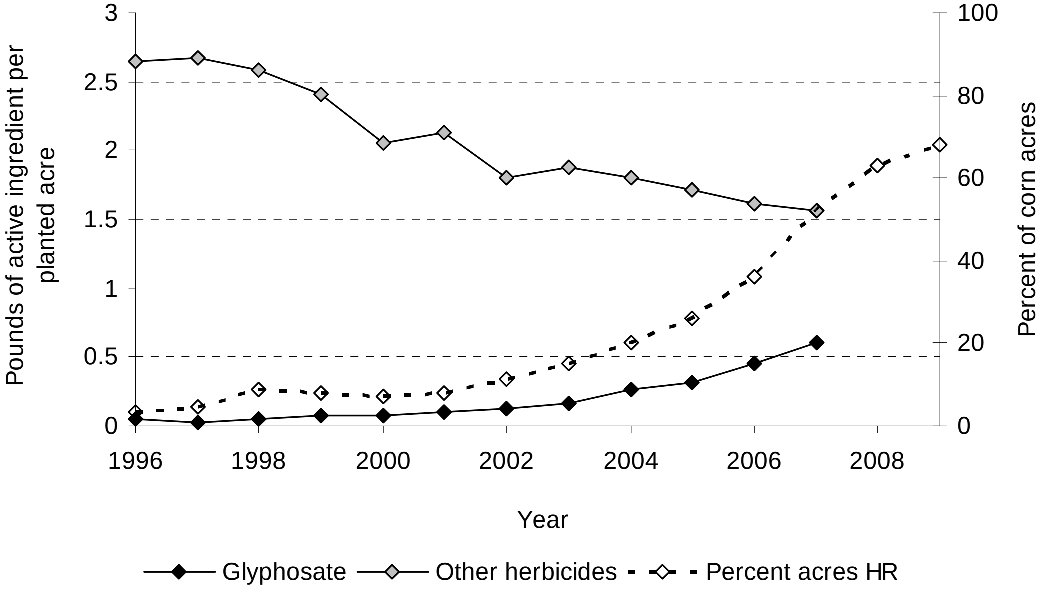

Figure 3. Application of herbicide to soybean and percentage of acres of herbicide-resistant corn.
Note: The strong correlation between the rising percentage of herbicide-resistant corn acres planted over time, the increased applications of glyphosate, and the decreased use of other herbicides suggests but does not confirm causation between these variables.
Source: USDA-NASS, 2001, 2003, 2005, 2007, 2009a, 2009b; Fernandez-Cornejo et al., 2009.

The use of glyphosate in properly managed herbicide-resistant cropping systems is an efficient weed-management practice. However, management decisions have resulted in increased and often exclusive reliance on glyphosate to manage weeds in GE-crop systems and are reducing its effectiveness in some situations due to evolved resistance to glyphosate in some weed species. Glyphosate-resistant weeds have evolved where repeated applications of glyphosate have constituted the only weed-management tactic. Ten weed species in the United States have evolved resistance to glyphosate since the introduction of glyphosate-resistant crops in 1996 compared with seven that have evolved resistance to glyphosate worldwide in areas not growing GE crops since glyphosate was commercialized in 1974 (Figure 4, Table 1). Currently, a total of 19 weeds have evolved resistance to glyphosate worldwide.

Glyphosate-resistant crops are effectively benign in the environment. Gene flow between herbicide-resistant crops and closely related weed species does not explain the evolution of glyphosate resistance in U.S. fields because sexually compatible weeds are absent where corn, cotton, and soybean are grown in the United States. Furthermore, weeds less susceptible to glyphosate are becoming established in some fields planted with herbicide-resistant crops, particularly fields that are treated only with glyphosate (Table 2).

Herbicide-resistant weeds have historically been a problem in corn, cotton, and soybean, and weeds with herbicide resistance are not unique to fields with GE crops. Weeds with either evolved resistance or natural tolerance will proliferate in any field in which the practices are used recurrently and ultimately provide the weed with an ecological advantage. For example, the planting of the same crop year after year or the unvaried use of an herbicide will select for weeds that thrive in those conditions. The concern with glyphosate-resistant crops is that the decision to use glyphosate in every season is accelerating the evolution of weeds with resistance. Because glyphosate-resistant crops are often grown in no-till systems, weeds with resistance are not disturbed by tillage and therefore have a further opportunity to thrive.

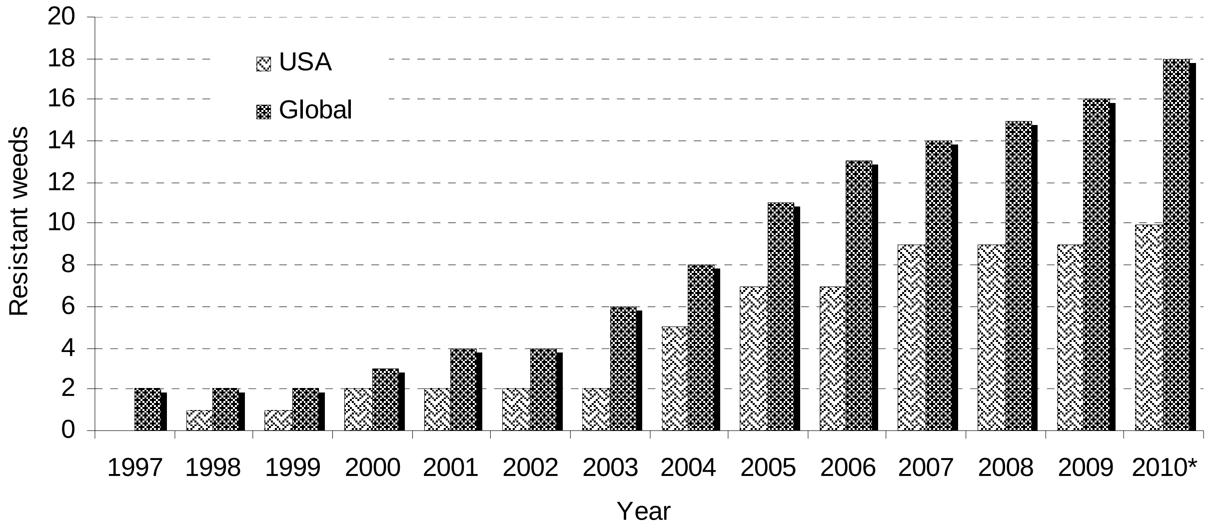

Figure 4. Number of weeds with evolved glyphosate resistance.
*Weed numbers are updated through March 2010.
Source: Adapted from Heap, 2010.

Table 1 Weeds That Evolved Resistance to Glyphosate in Glyphosate-Resistant Crops in the United States

Species	**Crop**	**Location**	**Acreage**[a]
Amaranthus palmeri (Palmer amaranth)	Corn, cotton, soybean	Georgia, North Carolina, Arkansas, Tennessee, Mississippi	200,000–2,000,000
Amaranthus tuberculatus (waterhemp)	Corn, soybean	Missouri, Illinois, Kansas, Minnesota	1,200–11,000
Ambrosia artemisiifolia (common ragweed)	Soybean	Arkansas, Missouri, Kansas	<150
Ambrosia trifida (giant ragweed)	Cotton, soybean	Ohio, Arkansas, Indiana, Kansas, Minnesota, Tennessee	2,000–12,000
Conyza canadensis (horseweed)	Corn, cotton, soybean	14 states	>2,000,000
Kochia scoparia (kochia)	Corn, soybean	Kansas	51-100
Lolium multiflorum (Italian ryegrass)	Cotton, soybean	Mississippi	1000–10,000
Sorghum halepense (Johnsongrass)	Soybean	Arkansas	Unknown

[a] Minimum and maximum acreages are based on expert judgments provided for each state. The estimates were summed and rounded to provide an assessment of the minimum and maximum acreages in the United States. These values indicate orders of magnitudes but do not provide precise information on abundance of resistant weeds.
Source: Data from Heap, 2010.

Table 2 Weeds Reported to Have Increased in Abundance in Glyphosate-Resistant Crops

Species	**Crop**	**Location**	**Reference**
Acalypha spp. (copperleaf)	Soybean	—	Owen and Zelaya, 2005; Culpepper, 2006
Amaranthus tuberculatus (waterhemp)	Soybean	—	Owen and Zelaya, 2005
Amaranthus palmeri (Palmer amaranth)	Cotton	—	Culpepper, 2006
Annual grasses	Cotton	—	Culpepper, 2006
Chenopodium album (common lambsquarters)	Soybean	Iowa, Minnesota	Owen, 2008
Commelina communis (Asiatic dayflower)	Cotton, soybean	Midwest, Midsouth, Southeast	Owen and Zelaya, 2005; Culpepper, 2006; Owen, 2008
Commelina benghalensis (tropical spiderwort)	Cotton	Southeast, Georgia	Owen, 2008; Mueller et al., 2005
Cyperus spp. (nutsedge)	Cotton	—	Culpepper, 2006
Equisetum arvense (field horsetail)	Herbicide-resistant crops	—	Owen, 2008
Oenothera biennis (evening primrose)	Herbicide-resistant crops	Iowa	Owen, 2008
Oenothera laciniata (cutleaf evening primrose)	Soybean	—	Culpepper, 2006
Pastinaca sativa (wild parsnip)	Herbicide-resistant crops	Iowa	Owen, 2008
Phytolacca americana (pokeweed)	Herbicide-resistant crops	—	Owen, 2008
Ipomoea spp. (annual morning glory)	Cotton	—	Culpepper, 2006

Growers are already seeing economic consequences from the proliferation of glyphosate-resistant weeds. In Delaware, resistant horseweed has been documented since 2000, and one study showed this increased most soybean growers' costs by at least $2/acre. In a study of 400 corn, soybean, and cotton producers in 17 states, growers estimated that glyphosate-resistant weeds increased their costs by $14-16/acre. To deal with weed problems in these fields, most growers responded that they would increase the frequency of glyphosate applications, apply herbicides with a different mode of action, and increase tillage.

The willingness to increase costs to supplement weed-management tactics in herbicide-resistant crops indicates that growers value the convenience and simplicity of these crops without appreciating the long-term ecological and economic risks attributable to the unvaried tactics they used. That behavioral response might be expected given many farmers' desire to meet short-run financial needs and the fact that other growers may not take similar control actions. However, growers must adopt more diversified weed-management practices, recognize the importance of understanding the biology of the crop system, and give appropriate consideration to more sustainable weed-management programs to maintain the effectiveness of genetically engineered, herbicide-resistant crops. Furthermore, unless growers collectively adopt more diverse weed-management practices, individual farmer's actions will fail to delay herbicide resistance to glyphosate because the resistant genes in weeds easily cross farm boundaries.

The evolution of glyphosate-resistant or tolerant weeds in GE-crop fields could lead to two important changes in practices: use of different herbicides more widely and reductions in conservation tillage. Such changes would increase weed-management costs and reduce producers' profits and could negate some of the environmental benefits to soil and water quality previously achieved. Most glyphosate-resistant weeds of economic importance in row crops are grown in the Southeast and Midwest. The number of weed species evolving resistance to glyphosate is growing, and the number of locations with glyphosate-resistant weeds is increasing at a greater rate, as the decision to spray more acreage with glyphosate continues. Though the number of weeds with resistance to glyphosate is still small compared to other common herbicides,[2] the shift toward glyphosate-resistant weeds will probably become an even more important component of row-crop agriculture unless production practices (such as recurrent use of glyphosate) change dramatically.

The good news is that there are many strategies that can be used to maintain the effectiveness of glyphosate and sustain the glyphosate-resistant crop cultivars. Tank-mixes and

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[2] For example, 38 weeds have developed resistance to some acetyl-CoA carboxylase (ACCase), and resistance to some acetolactate synthase (ALS) inhibitors has been documented in 107 worldwide.

sequences of herbicides could extend the useful life of herbicides. The development of crop cultivars resistant to two or more herbicides would also be useful. Rotating crops and using alternative weed management systems is another strategy. The increasingly common practice of farmers using glyphosate as the primary or only weed-management tactic in rotations of different glyphosate-resistant crops limits the application of the rotation strategy, but if crops can resist more than one herbicide or if varieties of the same crop are developed with resistance to different herbicides, then rotation could be an option. For example, varieties of GE canola grown in Canada have resistance to the herbicide glufosinate while others are resistant to glyphosate. That variation allows producers to include two types of GE canola into a canola–wheat–barley rotation so that canola resistant to glufosinate or glyphosate would be grown only once every 4 years in a particular field. The reduced exposure to the herbicide slows the evolution of resistant weeds.

From the point of view of herbicide-resistance management and the long-term efficacy of GE herbicide-resistant crops, it may be better to engineer a crop for resistance to herbicides that can efficiently control most weeds associated with the crop. If crops that are resistant to multiple herbicides—including ALS inhibitors, ACCase inhibitors, synthetic auxins, and glyphosate—are widely planted, continued use of the herbicides in fields that contain weeds already resistant to some of them could involve a risk of selecting for high levels of multiple herbicide resistance. The ability of weeds to evolve multiple herbicide resistance has already been demonstrated in waterhemp populations in Illinois, Iowa, and Missouri that are resistant to three herbicide mechanisms of action. Evolved multiple resistance will exacerbate problems of controlling some key herbicide-resistant weeds.

In summary, weed problems in fields of GE glyphosate-resistant crops will become more common as weeds evolve resistance to glyphosate or weed communities less susceptible to glyphosate become established in areas treated exclusively with that herbicide. Though problems of evolved resistance and weed shifts are not unique to these crops, their occurrence diminishes the effectiveness of a weed-control practice that has minimal environmental impacts. Weed resistance to glyphosate may cause farmers to return to tillage as a weed-management tool and to the use of alternative registered herbicides with different environmental characteristics. A number of new genetically engineered, herbicide-resistant varieties are currently under development and may provide growers with other weed management options when fully commercialized. However, the sustainability of those new GE crops will also be a function of how the traits are managed. If they are managed in the same fashion as the current glyphosate-resistant crops, the same problems of evolved herbicide resistance and weed shifts will occur. Therefore, farmers of herbicide-resistant crops should incorporate more diverse management practices, such as herbicide rotation, herbicide application sequences, and tank-mixes of more than one herbicide; herbicides with different modes of action, methods of application, and persistence; crop rotation; cultural and mechanical control practices; and equipment-cleaning and harvesting practices that minimize the dispersal of herbicide-resistant weeds. Such practices should be encouraged through collaborative efforts by federal and state government agencies, private-sector technology developers, universities, and farmer organizations to develop cost-effective resistant-management programs and practices that preserve effective weed control in herbicide-resistant crops.

I invite the committee to read the National Research Council's recent report, *The Impact of Genetically Engineered Crops on Farm Sustainability in the United States*, for greater detail on this topic than I have had time to present today. Thank you for your time.