Written Statement
Prepared for the
Domestic Policy Subcommittee of the Oversight and Government Reform Committee by

Dr. David A. Mortensen
Weed Ecologist, Department of Crop and Soil Sciences
The Pennsylvania State University

Background. Weeds more than any other agricultural pest type (than insects and disease for example) are widespread and because they overwinter in the soil their emergence each spring is quite predictable. It is not surprising that weed management is a serious matter for farmers. While weed management almost always comprises several tactics, herbicide use is central and accounts for 70% of all pesticides used in agriculture (1).

Since the mid-1990s, adoption of genetically engineered (GE) crops resistant to the herbicide glyphosate has been widespread and herbicide resistant crops are now grown on over 143 million acres of cropland internationally (2) with 92% of the US soybean crop planted to glyphosate resistant varieties. Genetic engineering makes it possible to take a crop that was formally susceptible to glyphosate and genetically transform it to be resistant to the plant-killing effects of the herbicide. The adoption and widespread use GE herbicide resistant crops has greatly changed how farmers manage weeds, enabling them to rely solely on a single tactic approach to weed management (application of glyphosate). Unfortunately, this single-tactic approach has resulted in an unintended, but not unexpected, problem: a dramatic rise in the number of weed species that are resistant to glyphosate (3) and a concomitant decline in the effectiveness in of glyphosate as a weed management tool (4).

Adoption of genetically-engineered herbicide resistant crops and evolution of herbicide-resistant weeds. Not unexpected, the "massive adoption of transgenic glyphosate-resistant crops has meant excessive reliance on glyphosate for weed control. In evolutionary terms, widespread and persistent glyphosate use without diversity in weed control practices is a strong selection pressure for weeds able to survive glyphosate" (5). This over-reliance on single-tactic management has led pest management scientists to question whether integrated pest management is still practiced in such systems (*see* Is Integrated Pest Management Dead? (6)). During the period since the introduction of glyphosate resistant crops, the number of weedy plant species that have evolved resistance to glyphosate has increased dramatically, from zero in 1995 to 19 in June of 2010 (3). This list includes many of the most problematic weed species, such as common ragweed (*Ambrosia artemisiifolia* L.), horseweed (*Conyza Canadensis* (L.) Cronq.), johnsongrass (*Sorghum halepense* (L.) Pers.), and several of the most common pigweeds (*Amaranthus palmeri* S. Watson and *A. tuberculatus* Moquin-Tandon) many of which are geographically widespread (3,7,8). In practice, the problem of glyphosate resistance goes far beyond a species count. There is no question the number of species evolving resistance to glyphosate is increasing at a steady rate of 1-2 species per year. As the recent PNAS report points out (9), this is a conservative estimate as there is no formal, coordinated monitoring and reporting system in place. More importantly, perhaps, is the dramatic increase in acreage infested with glyphosate resistant weeds. The reported extent of infestation in the U.S. has increased dramatically since just November of 2007, when glyphosate resistant populations of eight weed species were reported on no more than 3,251 sites covering up to 2.4 million acres. In the summer of 2009, glyphosate resistant weeds are reported on as many as 14,262 sites on up to 5.4 million acres, and the most recent summary indicates 30,000 sites infested on up to 11.4 million acres (10). In a period of three years, the number of reported sites infested by glyphosate resistant weeds has increased nine-fold, while the maximum infested acreage increased nearly five-fold. There is reason to believe this trend will continue into the future. Of the 41 reports of resistant biotypes, 32 were reported as expanding in acreage, only two were not expanding, while information was unavailable for seven reports.

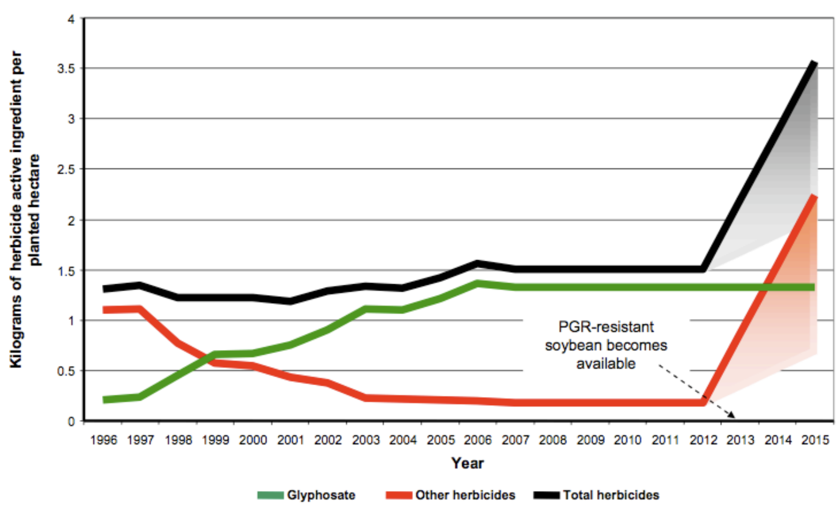
Multiple herbicide resistance. As the recent NRC report on genetically modified crops (9) rightly points out, adoption of glyphosate resistant crops, increasing glyphosate use and reduced tillage are correlated. As tillage is reduced, reliance on herbicides for weed control increases. If glyphosate continues to be used repeatedly within a season and over consecutive seasons, the likelihood for selection of multiple resistance will be high. Resistance can arise from a range of physiological properties of plants from highly specific point mutations to more general physiological processes like enhanced degradation or limited uptake and translocation. Multiple resistance arises when one or several of those processes occur in a plant. For example, *Lolium rigidum* was found to be resistant to glyphosate, paraquat and to ACCase inhibiting herbicides (three unrelated classes of chemistry). While point mutations were the cause of the ACCase resistance and one form of the glyphosate resistance, both glyphosate and paraquat resistance was also attributed to reduced translocation, a much more general physiologic process in plants (11). The fact that more generic physiological processes can work across herbicide modes of action is underscored in the herbicide resistance management section of some herbicide labels. For example, Dow AgroSciences' FirstStep herbicide label (a product containing glyphosate and florasulam, an ALS herbicide) states "FirstStep Herbicide Tank Mix contains a Group 2 and a Group 9 herbicide. Any weed population may contain plants naturally resistant to FirstStep Herbicide Tank Mix and other Group 2 and/or Group 9 herbicides. The resistant biotypes may dominate the weed population if these herbicides are used repeatedly in the same fields. Other resistance mechanisms that are not linked to site of action, but specific for individual chemicals, such as enhanced metabolism, may also exist" (12).

Already, in the Midwest, waterhemp (*Amaranthus tuberculatus*) is resistant to glyphosate and several ALS herbicides (10). While another recent report documents multiple resistance in this species to three unrelated herbicide active ingredients from three distinct modes of action (glyphosate, thifensulfuron, and lactofen)(13).

Economic and other consequences on farming and farming practices caused by the evolution of herbicide resistant weeds. USDA's Agricultural Research Service (ARS) estimates that up to 25% of annual US pest (weed and insect) control expenditures are attributable to pesticide resistance management (14). The cost of forestalling and controlling herbicide-resistant weeds therefore costs farmers approximately .9 billion dollars each year (13% of $7 billion). This cost mirrors the acres infested with glyphosate resistant weeds from the North American Herbicide Resistant Weeds survey (10). If the upper estimate of 11.4 million acres is representative of the spatial extent of glyphosate resistant weeds and those fields are managed at an additional cost of $10-20 per acre and the equivalent of three times that area in close proximity to those fields is also managed to control resistant weeds, then some 45.6 million acres of farmland would be managed at a cost of $.45-.9 billion each year.

In addition to production costs, resistance is manifesting itself in other ways. A worrisome trend is evident in how herbicide and germplasm development companies are responding to the glyphosate resistance problem (15). A new generation of genetically engineered crops are under development where glyphosate resistant cultivars are being engineered to have additional resistance traits introduced into the crop's genome. These additional gene inserts will confer resistance to other herbicide active ingredients, including 2,4-D and dicamba (16-18). For a variety of reasons, it is quite likely that such crops will be widely adopted (15). Conservative estimates of adoption would result in a significant increase in herbicide use in soybean and cotton; disturbingly, through the use of older higher use-rate herbicides. If glyphosate and 2,4-D or dicamba (PGR herbicides) are adopted in the way I expect they will, herbicide use in soybean would increase by an average of 70% in a relatively short time after the release of these new genetically engineered herbicide resistant cultivars (see figure below).

Figure 1. Total herbicide active ingredient applied to soybean in the United States*.



*Data from 1996 to 2007 are from the US Department of Agriculture, National Agricultural Statistics Service; modified from Figure 2-1 In *Impact of Genetically Engineered Crops on Farm Sustainability in the United States,* Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability; National Research Council, National Academies Press (2010). To forecast herbicide rates from 2008 to 2015 we assumed the acreage of glyphosate-resistant soybean, rates of glyphosate applied and rates of "other herbicides" remained constant at 2007 levels until 2013 (when PGR-resistant soybean varieties are expected to become available). Yearly increases in PGR herbicides (increases in "other herbicides") were calculated by assuming a 33% annual adoption rate of PGR-resistant soybean from 2013-2015 such that by 2015, 92% of U.S. soybeans would be PGR and glyphosate-resistant. We further assume that adoption of PGR herbicide use in soybean would mirror adoption of the resistant soybean. Our estimates encompass low (.57 kg ha^{-1} or .5 lb $acre^{-1}$) and higher (2.24 kg ha^{-1} or 2 lb $acre^{-1}$) use rates; a range in use-rate typical of other PGR tolerant crops (19-20).

Expanded use of these PGR herbicides is unprecedented during this time of the growing season (later and warmer than other uses). Vapor drift of PGR herbicides has been implicated in many incidents of crop injury (17, 21, 22), and may have additional impacts on natural vegetation interspersed in agricultural landscapes. A comparative risk assessment that included glyphosate as a benchmark found the relative risk of non-target terrestrial plant injury was 75 to 400 times higher for dicamba and 2,4-D respectively (23). A growing body of work indicates non-crop vegetation supports important ecosystem services that include pollination and biocontrol (24, 25). Ironically, the comparative risk ecological risk assessment cited above (23) concluded the adoption of glyphosate tolerant wheat would enable farmers to move away from environmentally troublesome herbicides like 2,4-D and dicamba.

Taken together, the herbicide and seed breeding industry is moving to address the problem of resistance with crops that have been engineered to be resistant to multiple herbicide active ingredients. If these new GE crop introductions occur as reported (16-18) we should expect to see herbicide use continue to increase and a significant proportion of those added herbicides will be older, less environmentally benign compounds (23).

The role of federal regulation in forestalling the further development of herbicide-resistant weeds. The following is a list of steps that could significantly improve the sustainability of weed management practices in American agriculture.

1. The U.S. Environmental Protection Agency (EPA) and APHIS should require that registration of new herbicide/transgene crop combinations explicitly address herbicide resistance management (26).

2. When a new GE resistance trait allows for an old herbicide to be used in new crops, at new rates, and in novel contexts, EPA and APHIS should work in a coordinated way to insure that a thorough reassessment of the herbicide active ingredient occurs in the context of its expanded and novel use. This reassessment should include explicit consideration of weed resistance and should be regionally relevant and recognize the spatial heterogeneity of fields, farms, and crops produced (27, 28).

3. Limit repeated use of herbicides in ways that select for resistance or that result in increased reliance on greater amounts of herbicide to achieve weed control. In the same way that Bt is regulated at the farm level, it's entirely feasible to consider farm-level herbicide management planning to limit practices that accelerate herbicide resistance.

4. Provide environmental market incentives (possibly through the farm bill) to adopt a broader integration of tactics for managing weeds. Increasingly, farmers are adopting cover crops, crop rotations and novel selective methods of cultivation for weed suppression.

5. Transgene seed and associated herbicides should be taxed and proceeds used to fund and implement research and education aimed at advancing ecologically-based integrated weed management (IWM).

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