Transcript of the testimony of Dr. Dr. Stephen C. Weller, professor, Purdue University to the Domestic Policy subcommittee of the Oversight and Government reform Committee, July 28, 2010.

This transcript and the thoughts herein are in large part based on the manuscript: **Benchmark Study: Perspectives on Genetically-Engineered Glyphosate-Resistant Crops and the Sustainability Of Glyphosate-based Weed Management** authored by Micheal DK Owen Iowa State University, Bryan G Young Southern Illinois University, David R Shaw Mississippi State University, Robert G Wilson University of Nebraska, David L Jordan North Carolina State University, Philip M Dixon Iowa State University and Stephen C Weller, Purdue University. This manuscript is presently in review for publication and is attached as **appendix I** to this document.

The issues before this committee involve genetically engineered, herbicide resistant crops and the environmental impact of the evolution of herbicide resistant weeds. I have been asked to provide testimony on the relationship between adoption of genetically- engineered herbicide resistant crops and the evolution of herbicide resistant weeds; the rapidity with which certain economically significant weeds have evolved their herbicide resistance, the incidence, risk and implications for farming and herbicide usage of multiple herbicide resistance in weeds; and the economic and other consequences for farming and farming practices caused by the evolution of herbicide resistance in weeds. I will do my best related to my area of expertise in weed science.

There is and always has been a need to farm in a manner that allows high production capacity of quality and nutritious food and to farm in a manner that minimizes negative environmental impacts, is sustainable for the long-term and is acceptable to society.
The widespread adoption of genetically engineered (GE) and glyphosate resistant (GR) or GE GR crops on the agroecosystem and for society has been a contentious topic of debate in scientific journals and the popular media. While adopters of GE GR crops experience pecuniary and non-pecuniary benefits such as highly reduced effort needed to implement a weed management system that significantly increases crop production, the risks as perceived by society, must also be given serious consideration. Complexity of assessing benefits and risks of GE GR crops is great and results can demonstrate considerable variability depending on the specific GE cultivar, the production practices and the specific agroecosystem. Below I will summarize and discuss these issues in regard to GE GR crops and their effects with particular attention to the evolution of glyphosate resistant weeds.

Key points relating to GE GR crops.

1. **One of the keys to improved global crop production efficiency is the effective management of weeds.** Global demands to produce more food have increased dramatically in a relatively short period of time and the ever-increasing global population has placed incredible demands on agriculture to produce sufficient yields. Ideally, increased yield will be achieved through sustainable but intensive production practices that allow dramatic increases in food while protecting aquatic and terrestrial ecosystems. There are only two possible solutions in the immediate

future to the dilemma of increasing requirements for food, biologically-based fuel and fiber; improve production efficiency on existing arable land or increase the land area under cultivation. These two options have both benefits and risks that must be addressed. Improved efficiency on land already under cultivation represents the best option but does not represent a simple means to an end. A longer term solutions to the global demands on agricultural production may be to improve crop genetic yield potentials, responses to stress and increased resources utilization efficiency. Genetically engineered (GE) crops are suggested to be an important tool that will allow improved yields and more efficient use of resources thus enhancing crop production efficiency while minimizing risks to the environment (e.g. soil erosion).

Weeds are constantly evolving within the agroecosystem by adapting to high selection pressures imposed by crop production practices and importantly, evolved resistance to herbicides. While eradication of weeds represents the obvious way to eliminate some crop yield loss, the probabilities of accomplishing this goal are extremely unlikely given the ecological adaptability of plant species to fill niches created by agriculture, and the resource and technical issues that affect weed eradication.

2. **GE-GR crops are an important tool to facilitate better weed management and improve yield and allows more efficient use of resources while minimizing risks to the environment.**
3. **Rapid adoption of GE GR crops occurred because glyphosate controls most of the economically important weeds and simplifies weed management tactics.**
4. **Widespread GE-GR technology has facilitated widespread adoption of no-till systems that conserve soil and energy resources as well as improved time management for farmers.**
5. **However, the widespread adoption of GE GR crops resulted in the grower decision to simplify weed management to the applications of glyphosate imposed considerable selection pressure on weed communities which predictably resulted in weed population shifts including the inevitable evolution of weed populations with resistance to glyphosate.**
6. **There are educational and research challenges to implement sustainable GR-based crop systems and paramount is the need to develop consistent and clearly articulated science-based management recommendations that enable farmers to reduce the potential for herbicide-resistant (HR) weeds and to understand better the ecology and genetics of weeds.**

Benefits and Risks Associated with GE GR Crops

Benefits of GR Crops

GR technology has been adopted by farmers with, in most cases, a high level of satisfaction, implying great benefit. Advantages of GR crops include, the simplification of weed control, greater work flexibility and time management, improved success in conservation tillage production systems and favorable economic returns. The environmental impact to GR crops and glyphosate is favorable compared to "conventional" crop production systems (those using non-GR crops), specifically when soil erosion and water quality are considered. Conservation tillage systems, particularly no tillage systems, are more sustainable and environmentally benign, based on the potential for soil erosion and water quality, than crop production systems based on continuous aggressive tillage and GE GR crops have facilitated more consistent management of weeds in conservation tillage systems, particularly winter annuals that were not previously controlled consistently and effectively. Furthermore, conservation tillage has concomitant benefits of reduced time required to produce crops, reduced use of petroleum fuels, reduced production of greenhouse gases (as well as enhanced carbon sequestration in no-tillage systems), improved soil biological health, improved soil physical health and reduced soil erosion. Society also experiences these benefits attributable to the adoption of GE GR crops.

The favorable economics of GR crops is a major benefit and an important consideration for growers. Actual production costs and yields will vary depending on the specific crop and may not always favor the GE GR cultivars. When economics are considered at the farm enterprise level, including the non-pecuniary benefits such as time management, simplicity, and environmental improvement, the GE GR cultivars are strongly favored when compared with conventional crop cultivars.

Risks of GE GR crops

From an actual scientific perspective, potential risks associated with cultivation of GE GR crops can include effects on ecosystems such as decreased species biodiversity, weed spectrum shifts, and the likelihood that weeds will evolve resistance to glyphosate if it is the only product used. It is important to recognize that these risks are no different for conventional crops and all herbicides. The risks are driven, in part, by ecological factors (i.e. species biodiversity) but influenced by agricultural practices such as tillage and herbicide use. There is not a clear direct effect of GE GR crops on these ecological changes and it is likely that any effect of GE GR crops is confounded by other agricultural practices (e.g. tillage). However, "traditional" agriculture (non- GE) has significantly impacted biodiversity historically and these effects occurred irrespective of GE GR crops.

Evolved resistance in weeds to glyphosate

A primary concern for the long-term sustainability of the GR crop system is the extent that GR weeds will evolve or GR volunteer crops will become a pervasive weed problem and how utilization of additional tools for their control are incorporated into the system. Importantly, the evolution of resistance to herbicides in weed populations is not unique to glyphosate and was in fact predicted more than forty years prior to the wide-spread adoption of glyphosate . Furthermore, predictions specifically addressing evolved resistance to glyphosate preceded the actual reports from the field. University researchers, government agency officials and private sector life sciences companies agree that widespread adoption of GE GR crops and concomitant weed management practices has and will continue to change the abundance and types of weed species found in agronomic fields. The full implications of these inevitable changes in weed populations are, in part, a function of the current production practices and resulting changes are not ecologically different than changes that have historically occurred in response to other agricultural and weed management tactics. Given the cumulative hectares of GE GR crops that have been planted in the US and the selection pressure imposed upon weed communities by the use of glyphosate, it is understandable that significant changes in the agroecosystem have occurred as the result of adopting GE GR crops and glyphosate as the primary if not sole tactic for weed control. There is now general agreement that evolution (defined here as: changes in genotype frequencies that result from selection pressure on genetic variation within a population of a weed species) of GR weed biotypes was inevitable, although, again some disagreement exists on the ultimate degree and nature of GR weed impact on agricultural practices. Currently 19 weed species have evolved resistance to glyphosate (Appendix 1, Figure 1 and Table 4). Eleven of these species are found in the US and eight of the GR weed biotypes evolved in conjunction with GR crops. Given the widespread adoption of GE GR crops (more than 80 million hectares in the US in 2009) and the use of glyphosate, often as the only herbicide used, it is not surprising that the ecological risk of evolved glyphosate resistance has resulted in an increasing number of GR weeds that are evolving at an increasing rate (Appendix 1, Figure 1).

The first GR weed in row crops identified in the US was horseweed [*Conyza canadensis* (L.) Cronq.], and its appearance was possibly correlated with the cultivation of GR soybeans. Recently other GR weed populations have been reported (Appendix 1, Figure 2 and 3, Table 4). All these weeds are major economic problems in agronomic crops in the corn, cotton and soybean growing regions of the US and the distribution of glyphosate resistance in these weeds is increasing. GR horseweed is now wide-spread throughout much the US cropland.

It is important to recognize that the impact of GE GR technology on weed communities is not directly attributable to the use of a GE GR crop, but rather an indirect effect of the management of the GE GR crop[78, 83] (e.g. how and which herbicide is applied) which is different from other GE crops (i.e. cultivars that include GE *Bt*). Specifically, the trait that confers resistance to glyphosate in crops does not, by itself, impart any selection pressure on the weed community. The selection pressure is imposed by the herbicide and is a factor only when the grower makes the management decision how and when to apply the herbicide. However, *Bt* trait in the GE crop exerts selection on the insect complex continuously. Regardless, the occurrence of evolved resistance to glyphosate in weed communities represents an important and escalating problem in global agroecosystems.

The speed and frequency of evolved glyphosate resistance in weeds likely reflects a lack of grower understanding about the influence that production practices, notably herbicide use, has on the composition of the weed community . A recent grower survey funded by BASF Crop Protection Corp. provided further insight into this problem. The “2010 Weeds to Watch Poll” was distributed online to growers, retailers, distributors and university experts throughout the US. Weeds reported in the survey have either evolved GR populations or are known to be naturally tolerant to glyphosate. Survey responses suggested the primary weeds of concern in GR systems nationwide included common lambsquarters (*Chenopodium album* L.), horseweed, giant ragweed (*Ambrosia trifida* L.), waterhemp (*Amaranthus tuberculatus* (Moq.) Sauer.), morningglory species (*Ipomoea* spp.) and Palmer amaranth (*Amaranthus palmeri* S. Wats.). Overall, respondents reported that glyphosate resistance in weeds was a major concern in GR crop systems.

Another survey conducted by Farm Progress Company for Syngenta Crop Protection Corp. on farmer concerns for GR weeds, specifically GR giant and common ragweed (*Ambrosia artemisiifolia* L.) (Appendix 1, Figure 2 and 3) suggested that grower awareness of the immediacy of the potential for evolved weed resistance to glyphosate was high and the need for appropriate management tactics great.

FARMER STAKEHOLDER IMPACT ON GR CROP SUSTAINABILITY

I was involved in a survey in 2005 that assessed the implications of farmer knowledge and attitudes on weed management in GR crops in US agriculture. Farmers did not have a high level of awareness of the potential risks to the sustainability of the GR crop systems regarding evolved glyphosate resistance. However, changes in the crop systems have occurred since this survey, Notably, the number of weeds with evolved resistance to glyphosate has increased from nine to 19 (not all of this increase is associated with glyphosate use in GR crops) resulting in an escalation in presentations and information to growers about the implications of evolved resistance to glyphosate in weeds on the sustainability of GR systems (i.e. “The Glyphosate, Weeds, and Crops Series” [www.glyphosateweedscrops.org]). A survey of grower attitudes we are now conducting should provide better information whether growers are aware of and implementing changes in management programs. Herbicide-use practices by growers in GR crops have also changed since the 2005 survey was conducted as the use of a soil-applied herbicide(s) that provides residual weed control has increased in GR corn and soybean (Appendix 1, Figure 4 and 5). Other studies have shown that growers are moving towards a better understanding of the implications of their herbicide-use practices and thus improved sustainability for the GE GR crops and glyphosate. However, glyphosate is still the primary if not sole weed management tactic in a number of crop systems.

Considerations and Programs to Ensure Sustainability of Weed Management in GR Crop Systems

There are numerous opinions on the best approach for designing herbicide-based programs for managing weeds and preventing or minimizing the effect of GR weeds. The best method of herbicide resistance management is to have weed-free fields and this is true from a theoretical resistance management perspective but is not really environmentally or economically practical so other management tools (i.e. other herbicides) must be used. Most current GR weeds have evolved a relatively low level of resistance to glyphosate which it has been argued can be overcome by adjusting the rate of glyphosate applied. This approach would require farmers to adjust the glyphosate rate to target those weeds in their field in hopes of managing the evolution of GR weeds. There is no scientific consensus that this approach is valid, and increasing the rate of glyphosate may expedite the evolution of GR weeds where the resistance is controlled by a single partially dominant nuclear gene. By using a herbicide rate (higher) that is discriminatory between susceptible and resistant biotypes, the population will shift towards resistance.

Even though a herbicide rate adjustment approach is easiest and may work to lessen the probabilities of herbicide resistance evolution in some weeds, the most sustainable and effective approach to GR weed management should include several tactics such as applying tank mixtures of herbicides with different mechanisms of action, tillage, crop rotation, and other integrated weed management approaches. Herbicide resistance in a few weed species to various herbicide types has not made herbicide use impractical or uneconomical in modern agriculture for most other widely used herbicide types. The tank-mix approach appears to be favored by many farmers, but care must be used in following technical recommendations and choosing the specific tank-mix herbicides to avoid selecting for resistance of weeds to other herbicides and causing antagonistic interactions between herbicides that result in reduced weed control. Another important recommendation is to use a soil-applied herbicide(s) that provide residual control of the target weeds.

Considerable research to discover genes responsible for conferring resistance to an array of herbicides and then include these genes in crop cultivars by genetic engineering is ongoing. GE crops with resistance to dicamba, glyphosate, glufosinate, 2,4-D, and acetolactate synthase inhibitors are either commercially available or under development. The concept is that the use of GE crops resistant to multiple herbicides may allow better management of the evolution of herbicide resistance in weeds. When considering this approach, proper management of each herbicide that can be used in the crop with multiple herbicide resistance is important. Consider that some weed species have evolved multiple- and cross-resistance to herbicides that are widely used in the US. The specific characteristics demonstrated by some weeds that result in resistance to multiple herbicides and even the specific mechanism(s) of cross-resistance remain largely unknown. Furthermore, there has been no assessment of the actual risk of multiple herbicide resistant GE crops to agroecosystems. Consider that resistance to ALS inhibitor herbicides evolved quicker and more widespread than resistance to glyphosate. The evolution of herbicide resistance in weeds is not the result of GE crops but rather the management decision to use a single mode of herbicide action as the primary or sole tactic to control weeds. Multiple herbicide resistant GE crops will not be any more or less sustainable unless herbicide tactics are used judiciously.

Role of the Framer in Resistance management

Because farmers are the ultimate decision makers for the use and management of herbicide resistance and GE GR crops, it is important to understand their attitudes and perceptions about the likelihood of selecting for weed resistance to glyphosate. Once farmer attitudes are understood, they need to be coupled with science-based knowledge that guides development of farmer educational programs. These educational programs must increase awareness and knowledge of GR weeds, how to minimize their appearance and how to manage glyphosate resistance when it evolves in weed populations. The educational programs must be robust and provide knowledge that allows farmers to clearly consider other concomitant risks associated with GE GR crops including maintaining long-term sustainability of this technology that will be impacted by their management decisions. A greater educational emphasis on appropriate integrated weed management through the application of best management practices (BMPs) in GE GR crops will help farmers choose diverse weed management tactics that will not lead to a catastrophic loss of chemical weed control tools, while still allowing them to optimize their income from the hectare. The programs must provide a basic background of weed ecology and biology as well as fundamental information about how herbicides work and how herbicide resistance evolves. The programs should be delivered at multiple levels; from internet-based modules to local face-to-face discussions to field demonstrations. It is anticipated that these educational programs will be delivered by the public sector and the life-science companies.

FINAL THOUGHTS

The sustainability of managing glyphosate resistance in weeds is now being tested in millions of hectares of cropland globally, although in a non-scientific, uncontrolled manner. The solution to the sustainability of herbicidal weed management in general and specifically, GR weed management in GE GR crops must involve more than finding new herbicides, and developing new herbicide resistant crops. A truly effective and economically and environmentally sustainable strategy will include an integrated systems approach to weed management based on the inclusion of multiple crop improvement and farm management tools that have been developed over the last 60 years, and driven by science-based knowledge. These strategies must be packaged into educational modules that offer reasonable and attractive choices to farmers that result in consistent and effective weed control while reducing selection pressure for herbicide resistance evolution in weeds. The Benchmark Study will provide important information that supports these educational platforms.