Discovery, The Student Journal of Dale Bumpers College of Agricultural, Food and Life Sciences

Volume 14 Article 15

Fall 2013

Herbicide-Resistant Soybeans in Arkansas: Lessons Learned and Future Direction

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Interdisciplinary Creative Projects

This is the inaugural year for an exciting new addition to *DISCOVERY*: The "Interdisciplinary Creative Projects" section. This portion of the journal will be reserved for an assortment of papers, some authored by teams and others by individuals, that give a taste of the creative, interdisciplinary, hands-on interactive projects that are a part of many unique opportunities our students participate in throughout Bumpers College.

This year, we feature the work of students from the Leadership in Food Policy Special Topics Course.

Herbicide-Resistant Soybeans in Arkansas: Lessons Learned and Future Direction

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ABSTRACT

In Arkansas Delta soybean production, glyphosate resistant (GR) Palmer amaranth has significantly impacted weed management. The incidence of herbicide resistant (HR) weeds has far-reaching crop science, economic, and communications implications, which have been explored by the corresponding expertise of our research team members to form a comprehensive literature review. The review was used to develop policy recommendations to address current and future HR genetically modified (GM) crop use and the associated issues. The review of crop science research indicated an overall increase in herbicide application, as well as an increase in weed management programs focused around glyphosate rather than the application of multiple herbicides. The review also revealed some management methods have potential to resolve the problem, including alternating herbicide application, avoiding sub-lethal rates, using "burn down" herbicides prior to planting, crop rotation, tillage, and zero tolerance weed policies. The use of fewer herbicides rather than multiple types creates a monopolistic edge for the companies producing those few herbicides, allowing greater market control. Crisis communication methods, including developing internal readiness, conducting needs assessments, developing a relevant message, and conveying the message through appropriate channels, can be used to develop a response to the issue that will best communicate necessary information to the target audience. The team used these findings to formulate policy recommendations, which include management, economic, and communication plans that may provide a starting point to address the issue.

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LEADERSHIP IN FOOD POLICY COURSE

Many students want to be change agents in our industry, with their goal being to economically and environmentally sustain the agriculture industry. The Leadership in Food Policy Course allows students the opportunity to get out of the classroom and put their desire for change to work. The 2012-2013 course focused on studying the impacts of glyphosate resistant palmer amaranth. Students spent the Fall semester listening to professionals from all aspects of the issue, from farmers affected by glyphosate-resistant Palmer amaranth to soil scientists. After obtaining a clear background, the class was able to break the issue into three sections: Agronomic, Economic, and Communication. Once broken up, the groups did their own research on the background of resistance rising in palmer amaranth in soybean fields in Arkansas. Once complete, the team used their literary research to make recommendations from political, managerial, and environmental standpoints. Finally, the team presented their findings to Stratton Seed Company, a seed-provider based in Stuttgart, Arkansas instigating talk of what is to come in Arkansas soybean production if resistance continues to impact production.

MEET THE STUDENT-AUTHOR TEAM

Amy May West

I am the daughter of Michael and Nancy West of Gravette, Arkansas, and a Junior majoring in Agriculture Business with a focus in economics. Active in student government, I was a member of Fresh H.O.G.S., Senator for the Dale Bumpers College, and will serve as the Chair of Senate for the 2013-2014 academic year. I have served as a College Ambassador for Dale Bumpers College, Vice-President of Ag Business Club, Jr. Panhellenic Delegate for Kappa Kappa Gamma Fraternity, Director of Awards for the Honors Student Board, and am a member of the AgriBusiness/Ag Econ Quiz Bowl Team. In order to gain agriculture-based experience in research, I work for Dr. H.L. Goodwin as a research assistant. After my freshman year, I studied abroad in Belize, working with farmers to enhance their business plans. Interested in Ag Policy, I interned in Washington, D.C. this summer for Senator Boozman and the National Rural Electric Coop in their Governmental Affairs Department. I intend to pursue a career in policy areas of agriculture.

Raven Anai Bough

I am a proud native of Fayetteville, Arkansas and graduated from Fayetteville High School in 2009. The following fall semester, I began studying Horticulture at the University of Arkansas. To gain supplemental skills and experience necessary for a career in research, I also pursued a minor in biology, worked as a lab-assistant for the Department of Horticulture, worked at a local plant nursery and retail center, and completed an internship funded by the National Science Foundation Research Experience for Undergraduates at the non-profit Donald Danforth Plant Science Center.

I plan to attend graduate school in California, the heart of United States fruit production, to pursue a career in horticultural plant breeding for crop improvement. Ultimately, I hope to attain a Ph.D. and manage my own laboratory and research programs in either a university or industry setting.

MEET THE STUDENT-AUTHOR TEAM

I am a newlywed from Ozark, Arkansas. I am a graduate of the University of Arkansas with a degree in Agricultural Education, Communication and Technology, as well as a minor in Agricultural Business. Upon completing my bachelor's degree, I began my graduate assistantship with the Agricultural and Extension Education Department. My research currently focuses on the Arkansas Cooperative Extension Service and the impacts of social media on agriculture. I would like to thank my mentor and graduate advisor, Dr. Leslie Edgar, for her help on this project. I would also like to thank Drs. Michael Vayda and Curt Rom, as well as Michele Helton for their guidance throughout the semester. This unique research opportunity allowed me to examine data from different aspects than my normal areas of focus. The collaboration of our classmates, mentors, and instructors was invaluable to the success of this project.

Hayley Jernigan

I am a graduate of the University of Arkansas with degrees in agricultural business and poultry science. I am a former Bumpers College Ambassador and former president of Collegiate Farm Bureau. I served as the 2012-2013 Chair of the Senate in the Associated Student Government and in that role directed the legislative and policy agenda for the student government. In my time at the University, I have studied abroad at the London School of Economics, received an Arkansas Department of Higher Education Student Undergraduate Research Fellowship to conduct research with Dr. Lanier Nalley, and completed an internship with the World Cocoa Foundation in Accra, Ghana. I am currently a summer intern at the White House and plan to work in Washington, D.C. for a few years prior to attending graduate school as a 2012 Harry S. Truman Scholar.

Mike Norton

I am a junior and the daughter of two Mobile, Alabama natives, William and Linor Thomas. In 2007, my family relocated to Quitman, Arkansas, where I graduated from Quitman High School in 2011. I came to the University of Arkansas the following fall to pursue both a B.S. in Agricultural Education, Communication and Technology and a B.A. in Drama. I hope to graduate in May of 2015 and continue on to seek a Master's degree in Agricultural and Extension Education. After earning my degrees, I intend to pursue a career in either publication or documentary filmmaking.

I am currently employed as a communications specialist with the Experiential Learning Lab, an organization based within the Agricultural and Extension Education Department that provides clients with various professional communications services. I also serve as the 2013 president of the University of Arkansas' chapter of Sigma Alpha, a professional agricultural sorority that is focused on scholarship, leadership, and service.

Katie Beth Thomas

INTRODUCTION

Today, the appearance of glyphosate-resistant (GR) weeds has greatly reduced the advantages of using the Roundup Ready genetically modified (RR GM) system. In Arkansas, over 94% of soybeans planted are RR GM crops (Scott and Smith, 2010). In the past few years, over 30 counties in Arkansas have reported GR *Amaranthus palmeri*, commonly known as Palmer amaranth, which is an exceedingly prolific weed whose properties include continuous germination, rapid vegetative growth, and production of high seed numbers (Scott and Smith, 2010). Because the composition of GM crops is similar to national percentages, Arkansas can act as a model state to examine the effects of GM technologies, especially herbicide-resistant (HR) RR crops.

Interviews with Delta farmers, local business owners, and experts that specialize in these areas were fundamental to the development of the main hypothesis of this comprehensive literature review, which states that RR GM soybean crops have an impact on GR Palmer amaranth in the Arkansas Delta. With soybeans comprising over 25% of Arkansas's farmland, this study focuses on the impacts of RR soybeans in Arkansas (FSA, 2012). Because of the controversial nature of GM technologies, this study focuses on synthesizing objective, scientific evidence to frame the issue. The study is broken into specialized areas including effects on crop management, the environment, social aspects, and economics. The appearance of GR Palmer amaranth emphasizes the influence of GM technology in Arkansas and will provide key answers for management recommendations involving current and future technologies.

AGRONOMIC TRENDS

The focus of soybean cultivar development has somewhat shifted since the introduction of GM crops in private versus public sectors due to rapid adoption of GM technology. Due to transgenic product protection under intellectual property laws, private breeders at larger companies perceive a greater value for investment in GM technology than conventional breeders and therefore focus on developing new GM traits (Miller-Garvin et al., 2010). Yet, large companies still rely on private breeders at small companies and public breeders for access to soybean germplasm for non-GM traits. Specifically, public breeders, such as those at the University of Arkansas, have increased breeding efforts for non-GM soy varieties with an emphasis on disease resistance, protein and oil contents, yields, and general germplasm enhancement (Miller-Garvin et al., 2010).

Herbicide-resistant GM crops have also shifted cropping practices. Larger farms have become more prevalent in Arkansas, and the number of farms greater than 2,000 acres has increased by 30% (Scott and Smith, 2010). Conservation tillage, where at least 30% of the soil surface is covered with crop residues after planting, has become widely adopted since weeds could be controlled after emergence with glyphosate (National Research Council, 2010). Genetically modified soy producers are also twice as likely to use conservation tillage or no-till practices than non-GM producers (National Research Council, 2010).

Before widespread adoption of HR GM crops, farmers utilized a variety of herbicides for weed control. It is estimated that HR soybeans have increased herbicide use by about 0.62 kg/ha per year (Benbrook, 2009). This trend may be attributed to the rising occurrence of GR weeds.

Widespread use of a single herbicide, glyphosate, has exacerbated the problem of HR weeds due to a large acreage of RR crops, making herbicide resistance a bigger problem than ever before. Generally, the more a herbicide is applied, the higher the proportion of HR phenotypes in a weed population that will arise due to increased selection intensity (Diggle and Neve, 2001).

In response to GR weeds as an effect of immense reliance on RR soybeans, agricultural companies are developing new GM cultivars with different herbicide resistance traits. Dicamba (Monsanto) and 2,4-D (Dow) resistant soybean crops are both undergoing development, with scientists stating that HR weeds will not be a problem with these GM crops (Mortensen et al., 2012).

TRENDS IN DIFFUSION AND DISSEMINATION OF COMMUNICATION

The Smith-Lever Act created the Cooperative Extension Service to assist in diffusing useful and pragmatic information (Rasmussen, 1989). Today, the Extension Service is diverse and widely distributed, offering the largest adult education system in the United States (Franz and Townson, 2008). "Having the ability to create, host, and facilitate access to educational materials and information over the Internet creates many new opportunities for Extension educators" (Rich et al., 2011).

Extending the reach of Extension is a need that must be met in the age of digital media and distance education. "People want their information delivered in smaller chunks. We've conducted focus groups who claim to still want fact sheets, but if you look at what they're actually using, it all relates to digital media and small bits of information," (K. Ballard, pers. comm.). "Berlo's SMCR (Sender; Message; Channel; Receiver) model is unidirectional and focuses on the source's attempts to manipulate the receiver's beliefs, attitudes, and behaviors" (Jandt, 1974). To understand the model, consider the Extension Service. They act as a media source that sends messages to farmers, the receivers. Feedback manifests in the form of altered practices.

Crisis communication management is crucial to the issue of GR Palmer amaranth (Edgar et al., 2012). When this occurs, "communication professionals must be prepared to manage the people involved with the crisis and reduce negative impacts," (Edgar et al., 2012). In the event of a crisis, one reliable spokesperson should be identified and provided with clear talking points that should address facts about the problem, how the problem will be addressed, and responses to foreseeable objections (L. Edgar, pers. comm.). Specific to the case of HR weeds, Extension should be considered.

ECONOMIC TRENDS

Since 1996, soybean farmers have seen positive changes in production resulting from GM seeds, with both increasing yields and decreasing production costs (National Research Council, 2010). However, after over a decade of RR technology in soybean production, the economic benefits of producing RR soybeans may be declining in areas such as yield and weed management efficiency (Nichols et al., 2008).

In 1997, RR soybeans only produced 13.1 bushels per hectare more than conventional fields (Fawcett, 1997). Yields have, as a trend, continually increased since 1980. Since 2004, yields have continued to increase but at a decreasing rate (USDA-NASS, 2011). There are three possible causes for this change: forces outside of management have affected yields; the current technology of RR soybean seeds is losing efficiency; or Palmer amaranth has reduced soybean yields. The answer may be found in a combination in all three of the above hypotheses (Mills, 2012).

An average GR Palmer amaranth infestation can cost farmers 27.2 bushels per hectare and farmers can spend close to $222 per hectare once the infestation becomes severe. Assuming these values, a GR Palmer amaranth infestation costs farmers $424.03 per hectare overall. This is the opportunity cost that farmers incur when producing RR soybeans (Klingman and Oliver, 1994). Minimal research has been conducted to determine how many Palmer amaranth plants per acre are considered an infestation, although the literature suggests that it does not take long for a pigweed infestation to go from being a small problem to a large problem (Ray, 2008).

Overdependence on a single mode of action can amplify an HR problem. Currently, the seed market uses a form of partial integration with contracts and licensing agreements by joining seed, chemical, and genomic roles into a singular company (Goldsmith and Sporleder, 1998). It appears that the trend will always exist towards vertical integration, yet this approach does not account for the costs associated with an increasing firm size (King, 2001; Chataway, 2001; Bijman, 2001a,b). Some biotechnology companies initially tried to incorporate an additional pharmaceutical role; however, most have divested that portion, illustrating that transaction costs act as a natural defense to complete vertical integration (King, 2001; Chataway, 2001; Bijman, 2001a,b).

Nevertheless, cohesion at some level between a firm and its suppliers or customers allows for better forecasting for both cost and revenue. By contracting with or directly owning plant breeders, genetics-based companies internalize the profits that would be lost without any vertical integration. Biotechnology development requires numerous processes. Integration enables access to cross-licensing and multiple patents, increasing the odds of completing research and development (R&D) and taking a product to market. Thus, there is an incentive for mergers and acquisitions, which leads to greater intellectual property rights for the larger post-merger organization.

If fewer pesticides are being used with the introduction of GM crops, firms producing these inputs have gained market power and leverage. But, given the availability of non-GM hybrid varieties that act as market competitors, the demand for seeds is still elastic as no one firm can exercise legitimate monopolistic power (Lin et al., 1995). Cooperatives, which were originally formed by farmers to combat supplier price opportunism within small or isolated markets, could provide increased seed genetics competition by investing directly in biotechnology research and development (Goldsmith, 2001).

RECOMMENDATIONS

Recommendations were analyzed using a cost-benefit analysis, both economically and environmentally, understanding that the primary weaknesses of Palmer amaranth are a shallow emergence depth, a short seed life and a high light requirement for germination. Using these few plant characteristics, producers can make economic and environmental decisions for their operation by listing costs associated with each recommendation, and then, based on the benefits and costs, make decisions related to financial and ecological management.

Best Management Practices

Pre-Planting. The first step to decrease the probability of HR weeds in HR soybeans is to begin with weed-free fields (Monsanto, 2012; Norsworthy et al., 2012; Smith et al., 2012). This is accomplished through a combination of methods, including tillage or a burn down with fire or herbicides (Norsworthy et al., 2012; Smith et al., 2012)

To further prevent the likelihood of HR weeds from arising or to diminish existing HR weed populations, it is crucial to establish a diverse herbicide program through multiple modes of action and application methods (e.g. foliar, soil, etc.) (Ervin et al., 2010; Norsworthy et al., 2012, Smith et al., 2012). It is also highly recommended to apply herbicides at full application rates to avoid sublethal rates that could result in selection for HR weeds that can survive those rates (Monsanto, 2012; Norsworthy et al., 2012; Smith et al., 2012).

Seasonal Non-Herbicide Weed Control. To acquire maximum HR and non-HR weed control, herbicide weed management programs should be supplemented with non-herbicide weed control methods, which often involve manipulation of weed biology. For prolific weeds such as Palmer amaranth, it is important to prevent weed seed production in order to reduce the weed seed bank (Ervin et al., 2010; Norsworthy et al., 2012; Smith et al., 2012). Employing the zero tolerance strategy significantly reduces the weed seed bank, and is accomplished through increased scouting and subsequent spot herbicide sprays as well as physical removal of the weed (Mortensen et al., 2012; Norsworthy, et al. 2012; Price et al., 2011).

Palmer amaranth seed is short-lived with an initial viability of 96% that decreases to 44-61% (shallow to deep burial, 1.25 cm and 40.64 cm, respectively) after a year, to 19-37% after two years, and to 9-22% after three years (Sosnokie et al., 2013). The Palmer amaranth seed bank and other short-lived, small seeded weeds can be further reduced by tillage (Norsworthy et al., 2012; Scott and Smith, 2010; Smith et al., 2012). Denser soybean rows can prevent light-activated germination of many weeds, including Palmer amaranth, by minimizing light penetration to the soil. This effect can be maximized by using early leafing soybean cultivars that are capable of forming a dense canopy before the germination of summer weed seeds occurs (Norsworthy, et al., 2012). Early planting also enables soybeans to become established and be more competitive against summer weeds (Mortensen et al., 2012; Norsworthy et al., 2012).

Long-Term Non-Herbicide Weed Control. Crop rotations, such as to rice or the Liberty Link HR soybean system in rotation with the RR HR soybean system, ensure a variety of herbicide modes of action between successive years (Norsworthy et al., 2012; Smith et al., 2012). Rotations including the Liberty Link HR soybean system provide ease of use similar to the RR HR system; whereas a rice-soybean rotation actually increases yields rather than continuous soybean cropping. In an 8-year study, soybeans grown after 1 or 2 years of rice had a 9.3 bu/acre yield increase with a $57.01 increased net return compared to continuous soybean cropping (Kurtz et al., 1993). Cover crops prevent winter weeds during their life cycle and (Norsworthy et al., 2012; Teasdale et al., 2007) may also provide additional profit as in the case of winter wheat. Though annual single soybean cropping has larger yields and lower production costs than double-cropping winter wheat after soybean, the double-cropping system provides a larger net profit over a year (LeMahieu and Brinkman, 1990). Based on more recent average five-year commodity prices, the double-cropping system had a net average profit of $255/ha; whereas single cropping had a net profit of $176/ha (Browning, 2011). Leftover winter wheat straw residues can be shredded via combine attachments or a rotary chopper after seed heads are harvested, enabling direct seeding of soybeans into residues (Minor and Wiebold, 1998).

Allelopathic plants are particularly useful as winter cover crops and summer residues, ultimately reducing herbicide input (Norsworthy et al., 2012). One study found a 94% emergence decrease of GR Palmer amaranth in cotton from the physical barrier and allelopathic effects of rye residue without tillage (Price et al., 2011). Other studies combining minimal tillage and rye residues cited 85% (DeVore et al., 2009) and 75% (Culpepper et al., 2011) decreases in emergence of Palmer amaranth. These three studies demonstrate the effectiveness of using cover crop residues in row cropping.

Field Border Weed Management. Weed management of HR soybean should also extend to surrounding vegetation and field borders (Norsworthy et al., 2012). Herbicide burn down or tillage maybe employed; however, repeat burn down applications would be necessary and tillage causes the soil to be more susceptible to erosion and invasive plant species (Buffin and Jewell, 2001). Establishing native grass stands is a more viable option, which will be less costly over the long term (Norsworthy et al., 2012). Other benefits of using switchgrass in a border stand are the creation of wildlife habitats, erosion control, flood management, and filtration of runoff from a soybean crop (Renz et al., 2009).

Soybean Breeding

Genetically modified breeders should not rely on stacking multiple HR genes to avoid increasing selection pressure for weeds expressing multiple herbicide resistance. Though the probability of multiple HR weeds occurring as a resulted of stacked HR genes is very low, immense soybean acreage, existing HR weeds, and past incorrect predictions for the appearance glyphosate-resistant weeds indicate that stacked HR GM crops will ultimately result in multiple HR weeds (Mortensen et al., 2012). Genetically modified and non-GM soybean breeding should develop soybean characteristics such as early maturation, faster maturation, dense canopy formation, and dense spacing tolerance. These characteristics would enable soybean cultivars to mature before weed flushes and limit soil light penetration, resulting in more competitive cultivars (Norsworthy et al., 2012). Faster turnover rates of GM cultivars, especially those that are HR, would be beneficial to producers by expanding growing options and enabling diversified crop rotations. Currently, it takes about 6-15 years for a new GM crop to be released commercially due to cultivar trials, evaluations, and the USDA approval process (Pocket K No. 17, 2012).

Cooperatives or completely public breeding programs (through Extension) could increase HR crop competition and help ensure crop rotation and multiple modes of action. Although some concerns lie with the property rights protection afforded to many biotechnology firms, decreasing patent protection may lead to more biologically excludable forms of trait development such as V-GURTS (variety genetic use restriction technologies, or self-terminating seeds), which would not reduce the HR issue since it focuses on patent protection, not on diversification between modes of action (Kvakkestad, 2009). Instead, property rights should only be lessened if they are coupled with increased public funding for breeding. Once developed, publicly developed traits could be transferred to the market through an auction system (Kvakkestad and Vatn, 2011).

Communications Management

A concise publication would be useful for farmers experiencing GR Palmer amaranth in their soybean fields. The North Central Soybean Research Program (http:www.ncsrp.com) offers publications, ranging in length from 2 to 16 pages, on managing similar issues such as white mold and sudden death syndrome. Currently, the University of Arkansas Extension's "MP44: Recommended Chemicals for Weed and Brush Control" and "MP197: Arkansas Soybean Handbook" are over 100 pages each, making quick reference difficult (Scott et al., 2012; SCC-UADA, 2012).

Policies

The emergence of GR weeds with high reproductive rates in Arkansas RR GM soybean fields, particularly Palmer amaranth, has resulted from a lack of education and infrastructure to ensure best management practices for HR crops. In order to preserve the short- and long-term effectiveness of current and future HR traits, it will be necessary to implement new policies and regulations. Such new regulations can be modeled after EPA mandated Insect Resistance Management (IRM) plans, which have been successful in preventing large scale insecticide resistance in insects to *Bacillus thuringiensis* (*Bt*) (EPA, 2012b). *Bacillus thuringiensis* corn and cotton are GM crops that express insecticidal proteins from a soil bacterium and were first released in 1996, followed by rapid adoption parallel to that of RR and other HR crops (Alexander, 2007).

Environmental Protection Agency regulations on *Bt* corn and cotton include the following components: 1) preliminary grower agreements, 2) required non-GM insect refuges, 3) grower compliance programs, and 4) resistance monitoring (EPA, 2012a). When purchasing GM *Bt* seed, farmers must sign a contract agreement that EPA regulations will be followed. Educational materials or workshops must also be supplied by the seed company (Weiss, 2000). For any *Bt* corn hybrids, farmers are required to maintain at least 20% of their total corn acreage as non-*Bt* corn for insect refuge (Cullen et al., 2008). The use of *Bt* cotton requires at least 50% of total acreage to be non-*Bt* (EPA, 2012a). Non-*Bt* refuge areas decreases the probability of mating between solely *Bt*-resistant insects, ensuring that *Bt* susceptibility is retained in populations (Cullen et al., 2008). There are several field configurations possible for both *Bt* corn and cotton, though a refuge area must be within 0.80 km of the *Bt* planting (Cullen et al., 2008).

Seed companies that are registered to sell *Bt* seed are required to establish a grower compliance program to identify and address noncompliance that includes field and planting record inspections through the EPA (Cullen et al., 2008). Methods used by seed companies to ensure compliance are anonymous phone surveys, on-farm visits, and complaint programs through phone or digital means (Cullen et al., 2008). Farmers that do not comply with the IRM refuge are initially given a warning from the seed company and required to have a compliance assessment the second year. If the farmer fails to meet compliance the second year, they are denied access to *Bt* seed the third year. Repeated noncompliance results in revoking the right of a farmer to grow *Bt* seed.

In the case of *Bt* corn, 32% of farmers indicated they would not plant a refuge if it were not required, 37% were undecided, and only 30% stated they would plant a refuge regardless of regulation (Alexander, 2007). This perception indicates that best management practices may not be followed by a significant number of farmers without regulation. Regulations similar to the EPA mandated IRM program would be beneficial to a sustainable use of HR cropping systems by requiring good stewardship.

With IRM as a model, a herbicide resistance management program should first require a license or contract that includes an education component for HR crop best management practices in the form of an examination, training, or a workshop. Literature should also be provided to each HR crop grower for best management of HR crops. Growers should be required to maintain a proportion of their field as non-HR to ensure the existence of herbicide susceptible weeds that can decrease HR populations. Additionally, a diverse herbicide program should be required that includes different methods of application, modes of action, and crop rotation. Refuges and diversified herbicide programs can be enforced by the submission of plans along with a license or contract and by assessments, surveys, and anonymous phone tip-lines similar to the IRM program. Non-compliance should be initially penalized by a warning, followed by probation, and ultimately revocation of the privilege to plant HR seed if non-compliance continues. Herbicide-resistant weed monitoring should also be implemented.

For highly prolific weeds, such as HR Palmer amaranth, it may be necessary to implement a zero tolerance law with fines for non-compliance. Oklahoma's Noxious Weed Law and Rules regarding Canada, musk, and Scotch thistle eradication can be used as a model (ODAFF, 2000). This law requires landowner control to prevent the mentioned thistle species from going to seed, with fines being bestowed for up to $1000 per day for each violation. Violations are investigated based on complaints that can be submitted anonymously to the Oklahoma Department of Agriculture, Food, and Forestry.

CONCLUSIONS

In Arkansas Delta soybean production, GR Palmer amaranth has significantly impacted weed management. This incidence of HR weeds has far-reaching crop science, economic, and communications implications, which have been reviewed by the corresponding expertise of our research team members. The team has used findings to formulate recommendations that address agricultural management, economics, and communications and provide a starting point to address the issue. The appearance of GR Palmer amaranth emphasizes the influence of GM technology in Arkansas and provides implications for establishing economical best management practices, enhancing communications, and developing policies that will ensure short- and long-term viability of current and future GM technologies.

ACKNOWLEDGMENTS

The Leadership in Food Policy Team would like to acknowledge Stratton Seed Company for their support and funding. We would like to thank Michele Helton for her assistance as a mentor, H.L. Goodwin, Kenneth Korth, Nilda Burgos, Pengyin Chen, Jason Norsworthy, Cynthia Sagers, and Joel Cape for their assistance, and John C. McClendon, Boyce Johnson, and Bill Hawkins for allowing us to visit their farms.

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