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A Wicked View

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In a recent essay, Harker and coauthors stated that considering herbicide resistance as a wicked problem "without clear causes or solutions" ignores what weed scientists know about the biology and management of herbicide-resistant weeds. In this response, we argue that this misrepresents what is meant by "wicked" and that the wicked problem concept is valuable in understanding the multifaceted nature of herbicide resistance as a human-caused phenomenon.
Key words: Herbicide resistance, weed management, wicked problem.

It is always gratifying when publications that one is associated with stimulate thought and discussion, so we were pleased to read "Another View" by Harker et al. (2017). The authors raise several points in this article with which we agree. However, they also make other points that reflect a misunderstanding of why we consider it useful to consider herbicide resistance as a "wicked problem."

In their essay, Harker et al. state that because a wicked problem is "without clear causes or solutions," considering herbicide resistance to be "wicked" ignores the fact that resistance as a biological response is well understood by weed scientists, as is the need for diverse weed management tactics to address it. This misrepresents two recent publications (Barrett et al. 2016; Shaw 2016) cited by Harker and coauthors. The authors of these publications are not claiming that weed scientists fail to understand the evolutionary basis of resistance, nor do they suggest that weed scientists are unable to recommend best management practices to slow this evolutionary process. On the contrary, several of these same authors contributed to a key publication describing best management practices adopted by the WSSA as an official society position (Norsworthy et al. 2012). Indeed, the fact that weed scientists understand so much, and yet the problem of herbicide-resistant weeds continues to worsen, indicates that herbicide resistance IS a wicked problem. When we broaden our perspective beyond evolutionary biology, we see that many additional factors—social, cultural, economic, and climatic—contribute to the spread of herbicide-resistant weeds across the North American landscape. We encourage readers to consult the seminal article by Rittell and Webber (1973) to understand the full set of wicked problem characteristics that make an adaptive management path to progress so vexing. Successful implementation of best management practices for herbicide resistance will need to address ALL these factors, and the concept of a wicked problem helps us to see this important complexity in its entirety.

Weed scientists know that weeds adapt to selection pressures imposed by any control measures, whether chemical or nonchemical (Vencill et al. 2012). There is also general agreement on best management practices for reducing herbicide selection pressure (Norsworthy et al. 2012). While best management practices must be adapted to specific local weed management situations, the clear message is that sustainable weed management systems need to diversify beyond sole or even primary reliance on herbicides. This message has been consistent in WSSA educational efforts: for example, the herbicide resistance training modules that Shaw and many others on the WSSA Herbicide Resistance Education Committee developed, and other initiatives such as the Take Action outreach material sponsored by the United Soybean Board and written by WSSA members. However, the continuing increase in herbicide-resistant weeds demonstrates that educational efforts alone have been insufficient.

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Our central argument is that this undesirable trend stems from failure to recognize the need for interdisciplinary approaches that combine social science with sound weed science. Weed scientists have defined best management practices and clearly articulated them in educational messages, yet human behavior has not changed sufficiently to overcome the problem. We have come to appreciate that to truly address the herbicide resistance problem, we must better understand the drivers behind and the structural conditions surrounding grower decisions. Many people influence weed management decisions, including academics, grower associations, consultants, landowners, lenders, and industry, and thus all bear responsibility in decisions to adopt more diverse tactics. To understand this decision-making process, weed scientists must work with sociologists, economists, and other scientists from a variety of disciplines. To that end, WSSA has sponsored several initiatives, including the Second Herbicide Resistance Summit, the *Weed Science* special issue on human dimensions of herbicide resistance, and the recent regional herbicide resistance listening sessions held around the United States. The intent of these activities and others is to reinforce the notion that herbicide resistance is not just an evolutionary problem but simultaneously a human problem that is wicked in nature. Saying that herbicide resistance is a simple problem with a simple solution is like saying climate change, cardiovascular disease, and hunger are simple problems that can easily be remedied by forgoing the use of fossil fuels, exercising and eating fewer fats, and growing more food.

We agree with Harker et al. that industry faces a challenge in promoting stewardship programs that would also limit herbicide sales. This will require a great deal of creative thought in registration and marketing programs on the part of industry and government agencies. However, some initial attempts are being tested, such as the recent Environmental Protection Agency (EPA) proposal for herbicide resistance management to include time-limited herbicide registrations. Through the required monitoring and reporting, if herbicide resistance to new products occurs and is not contained, then the registrations could be allowed to lapse—removing the products from the market. The EPA also recently approved a registration (Zest™, nicosulfuron use on Inzen™ sorghum) that requires crop and herbicide mechanism of action rotation (Anonymous 2016).

We disagree with the statement by Harker et al. that the need for more diversified cropping systems and reduced reliance on herbicides has not been "the consistent message coming from WSSA or its flagship journals." As we have already described, WSSA has been involved in multiple herbicide resistance initiatives in recent years, including two summit conferences cosponsored with the National Research Council, herbicide resistance management recommendations to the U.S. Department of Agriculture and EPA, two special issues of *Weed Science*, and the development of diverse educational outreach materials. In all of these efforts, WSSA has emphasized the importance of diversification in weed management. We would also point out that the goal of the WSSA journals is to publish quality peer-reviewed research and scholarship that reflect diverse aspects of weed science; it is not the function of WSSA journals to convey any officially sanctioned "consistent message."

We also take exception to the assertion by Harker et al. that WSSA is biased by "heavy industry representation" and therefore fails to function as a professional scientific society. The numbers simply do not support this statement. Of the 18 current WSSA board members, just two are employed in industry (details of all WSSA members serving on the board of directors are publicly available at http://wssa.net/society/directories/#C2). Further, donations from industry to support the WSSA annual meeting and other programs comprised only 10% of the society's 2016 revenue ($77,932 out of $767,767 total annual revenue) and will comprise 12% of society revenue in 2017 ($90,050 out of a projected $760,083 total annual revenue). WSSA membership is open to all who work with or are interested in weeds and invasive plants, regardless of where they are employed. Industry is an acknowledged part of the community responsible for and dealing with herbicide resistance and will need to be part of workable solutions: we note that Mortensen et al. (2012) called for "stronger partnerships between industry, universities and government" to foster integrated weed management through "more effective education and extension efforts." The presence of industry members in WSSA is one avenue to forming these partnerships.

To conclude: How is the problem of weed resistance wicked? Some examples we have heard over the past several years include: barriers to on-farm diversification from lack of access to markets for alternative crops, bankers who limit crop loans based on crop prices, and landowners who do not allow crop rotation by tenants; federal incentive programs that limit weed management options, such as restrictions on tillage; sales incentive programs that encourage use of

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a single company's product line rather than a diversity of appropriate herbicides; and farmers believing that a new herbicide mechanism of action is just around the corner, if only EPA would approve it. Such examples reinforce our conviction that herbicide-resistant weeds must be understood as a multifaceted socioeconomic problem, not merely a biological phenomenon. Harker et al. are correct that herbicide resistance is a predictable evolutionary response to selection imposed by herbicide use. However, we also contend that this selection is entirely human caused and therefore must be considered in a human context. Failure to do so guarantees that lack of progress in addressing the issue will continue.

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