Techno-optimism as a Barrier to Overcoming Herbicide Resistance: Comparing Farmer Perceptions of the Future Potential of Herbicides

Keywords: Agriculture; Technology; Weed Management; Herbicide Resistance; Region;
Glyphosate

Abstract

The purpose of this analysis is to explore how U.S. grower perceptions of the future potential of different weed management approaches is conditioned by faith in technological fixes and how the latter is influenced by the rate and persistence of herbicide resistant weeds (HRW). We ground our analysis in rural studies literature on location and environmental sociological evaluations of techno-optimism. Using a coding typology of techno-optimism, -skepticism, and -dissonance, focus group data show that farmers in Southern states responded with more skepticism and dissonance to the potential of chemical herbicides as a solution to HRW while farmers in Northern states, where there have historically been fewer HRW, have greater optimism in the potential of chemicals to solve the problem. We conclude that (1) the presence of HRWs provides an important context for farmer ideology and (2) those working with farmers in areas with high HRW rates may be able to tap into the skepticism and dissonance farmers feel toward the future potential of chemical herbicide solutions by providing integrated weed management alternatives.

1. Introduction

While the ability of plants to evolve resistance to chemical herbicides is neither a new nor a rare phenomenon, the rapid evolution of resistance by multiple weed species to glyphosate has taken United States agriculture by surprise. Glyphosate was commercially developed and patented by Monsanto in the early 1970s under the name “Roundup.” While highly effective, glyphosate’s use in agriculture initially was limited because it is a broad based herbicide that disrupts the growth of virtually all plants including commercial crops. Glyphosate’s original use in agriculture was in spot spraying, especially before planting or after harvest, because this product kills all plants indiscriminately.

As part of a strategy to expand sales of its patented Roundup product, Monsanto began exploring the possibility of developing a gene that could be inserted into commercial crops that would convey a resistance to Roundup in those crops. Eventually, a Roundup resistant gene was discovered. Roundup Ready soybeans were commercialized in 1996, followed shortly thereafter by Roundup Ready corn and cotton. The adoption of this technological package (seed and herbicide) by farmers was stunningly rapid, due in large part to the fact that “...glyphosate made weed control easier and more effective, increased profit, required less tillage, and did not restrict crop rotation” (Green 2009: 108). For farmers, the decision to adopt Roundup Ready crops was due as much to the way in which the technology made farming easier and simpler as to any other factors (Piggott and Marra 2008). Subsequently, glyphosate sales in the United States expanded tenfold (Green 2009). Today, it is the most commonly used herbicide in the U.S. (Livingston et al. 2015; Fernandez-Cornejo et al. 2014) and the biggest herbicide by sale-volume worldwide (Glover 2008: 9).

Despite scientific warnings that a primary reliance on glyphosate for weed control would result in the evolution of weed species that would be tolerant to glyphosate (Shaner 2000), glyphosate became the dominant herbicide in many cropping systems. Indeed, the argument that there was a lack of evidence showing weeds developing resistance to glyphosate (Bradshaw et al. 1997), may have contributed to popular optimism about the long-term viability of the herbicide. Because of its widespread and consistent use, especially in cropping systems that featured a corn-soybean rotation, environmental conditions were created that lead to the rapid evolution of glyphosate-resistant weeds in the U.S. (Ervin and Jussaume 2014; Harker et al. 2012; Livingston et al. 2015).

Today, glyphosate resistance is extensive, with 14 glyphosate-resistant weed species currently affecting U.S. crops (Livingston et al. 2015). It should be noted that while the use of glyphosate was geographically widespread, the types of weeds that develop weed resistance necessarily varies by region or district because of variable growing and ecological conditions. Additionally, glyphosate is not the only herbicide to which weeds are developing resistance, and resistance to multiple herbicides is on the rise. Consequently, experts including social and natural scientists now agree that farmers should utilize multiple best management practices for controlling weeds, as part of an integrated weed management (IWM) plan (Livingston et al. 2015; Ervin, Glenna, and Jussaume 2010; Frisvold and Reeves 2011; Llewellyn, Lindner, Pannell, and Powles 2004). Such a plan would involve the integration and rotational use of a variety of chemical and nonchemical weed control practices, including preventative, mechanical, cultural, chemical, and biological techniques (Barman et al. 2014) Although recommended, IWM is more cost and labor intensive to farmers, particularly in comparison to a glyphosate-only plan, complicating their support for IWM.

Given the complex challenges that farmers face, and the social, economic and environmental impacts of farmer decision-making, studies of how *farmers themselves* perceive agricultural technologies has become vital (e.g., Kondoh and Jussaume 2006; Guehlstorf 2008; Hall 2008). A deeper understanding is needed of why farmers choose to rely on certain technologies, such as herbicide resistant crops, in lieu of other technologies or alternative cultural management techniques. A growing body of work has begun to examine the level of awareness of glyphosate resistance and experiences with glyphosate-resistant weeds, particularly among U.S. growers (e.g., Gibson, Johnson, and Hillger 2005; Johnson and Gibson 2006; Foresman and Glasgow 2008; Johnson et al. 2009), while a separate line of analysis examining farmer perceptions of modern agricultural technology focuses on innovation adoption and diffusion (e.g., Adesina and Zinnah 1993; Negatu and Parikh 1999; Sinja et al. 2004; Adrian et al. 2005; Chimmiri, Tudor, and Spaulding 2007; Lawson et al. 2009; Gebrezgabher et al. 2015). Our research will contribute to these literatures, focusing specifically on farmers' experiences with glyphosate resistant weeds and related perceptions of modern chemical herbicide technology.

Perhaps the most innovative studies on technology adoption and use among farmers are those that show how the private sphere and Monsanto in particular have played a significant part in endorsing and disseminating pro-technology narratives to farmers in the context of GM seeds (Shah 2005, 2008; Glover 2008; McKinney 2013). For example, Glover (2008) argues that pro-poor and –development and anti-poverty and –hunger discourse surrounding GM crops was an idea strongly, and perhaps firstly, pushed by the private sector, especially Monsanto (cf. Charles 2001). Monsanto was also at the forefront of selling the “farmer’s right to choose” new biotechnology narrative, despite many structural influences that constrain rational choice, to push

for the legalization of new biotechnologies and an individualization of risk (McKinney 2013). There are other social-structural influences on farmer choice of new technologies coupled with industrial narratives. For example, Shah (2005, 2008) details a number of variables that led to the fairly widespread adoption of Bt cotton seed in Gujarat, India, especially among larger growers, stressing its capacity to sustain already existing values and social relations formed by the green revolution (i.e., not just due to industry endorsement). Of particular interest is Shah's (2008: 442-443) finding that growers expressed considerable faith in technological development, particularly the belief that even if there are problems with Bt cotton seeds in the future that industry will supply replacements in time. While we do not have sufficient data to show that growers were influenced by industrial narratives and marketing concerning the benefits of herbicide strategies and development—though, as shown below, techno-optimism is often simultaneously expressed as faith in the chemical industry—, it should be noted that this influence is well-documented in related contexts. We contribute to this innovative literature's focus on the super-individual factors that influence grower perceptions and use of technology, though we focus on biophysical rather than social-structural variables.

While the above bodies of research have made progress in identifying what some farmer behaviors and attitudes toward technologies are, their exploration of the ideological underpinnings that form the foundation for those behaviors and attitudes has been limited. As mentioned above, some studies suggest that industrial narratives from the private sector encourage a techno-optimistic ideology – particularly related to GM technology. However further in-depth analysis of the prevalence and source of farmer's ideologies is needed. The broad goal of our research is to contribute to this literature by exploring grower perceptions of the *future potential* of different weed management approaches and how farmer openness or

resistance to different approaches may be influenced by ideological factors. We focus here on what we refer to as the ideology of techno-optimism and how this ideology is influenced by geographically-relevant biophysical elements – i.e. the rate and persistence of herbicide resistant weeds (HRW). We move beyond previous research on farmer perceptions of chemical use to explore if the spatial nearness or farness of negative technological impacts influence perceptions of the future potential of modern agricultural technology to solve problems caused by those very technologies. We explore, in much more detail than any previous research on weed management decision making, how perceptions of weed problems deriving from physical farmland characteristics influence farmers’ understanding of what solutions may be available to them in weed decision making. In particular, we are interested in how these weed problem perceptions are linked to attitudes toward the possibility of technological fixes to the problem. We expect that a high incidence of HRW contribute to farmers’ doubting the effectiveness of chemical herbicide weed control, with the resulting necessity of moving away from this chemical-dependent weed control; what we call a higher level of “techno-skepticism.” The converse expectation is that low HRW populations would influence farmers’ faith in chemical herbicide weed control, with the consequence that chemically-dependent production is an appropriate use of their farmland; what we call a higher level of “techno-optimism.”

To explore these questions, we compare farmers’ conceptualizations of weeds in Iowa, Minnesota, North Carolina, and Arkansas. Although there are weed species that are resistant to herbicides in all four states, there are several trends that group together Iowa and Minnesota in contrast with North Carolina and Arkansas. Resistance to glyphosate, which is of significant concern given this herbicide’s dominant presence in corn and soybean systems, was first seen in 2006 in Minnesota and 2009 in Iowa (Heap 2016). Currently, three weed species resistant to

glyphosate have been confirmed in Iowa. It is estimated that 50% of all fields have glyphosate resistant waterhemp, and five counties have instances of glyphosate resistant Palmer Amaranth (Eller 2014). Similarly, Minnesota has three weed species that have been confirmed glyphosate resistant.

Moving to the Southern states, North Carolina has four confirmed glyphosate resistant weed species, while Arkansas has six. Their problems with glyphosate resistance both began in 2003 (Heap 2016). It is estimated that in North Carolina glyphosate and ALS resistant Palmer Amaranth infests 70% of all cotton and soybean fields (Heap 2016). In Arkansas, glyphosate and ALS resistant Palmer Amaranth has been identified in all row-crop production counties in the state, with approximately 61% of soybean fields and 80% of cotton fields infested (Coombs 2012). Therefore North Carolina and Arkansas stand out as having dealt with glyphosate resistance for longer than Iowa and Minnesota, as well as having a more severe infestation level. This is in line with previous research which has identified the Southern U.S. as having more extreme herbicide resistance problems due to continuous mono-cropping practices enabled by a consistently warmer climate (e.g. Ervin and Jussaume 2014). Although we by no means suggest that there is a strict dichotomy between Northern and Southern states regarding herbicide resistance prevalence and attitudes, we refer to Iowa and Minnesota as ‘Northern’ states, and North Carolina and Arkansas as ‘Southern’ states throughout this paper. This should be taken as an indication of the general climactic and HRW differences characteristic of these regions of the U.S., rather than an arbitrary division based on the Mason Dixon Line. We posit that the difference in the multitude of HRW in these states may influence how farmers think about the effectiveness and future potential of chemical herbicide weed management. This tests the link between physical characteristics of a region and farmer perspectives on management techniques.

This study makes two contributions – first to the literature on local and embedded forms of farm management and second to the literature on techno-optimism, highlighting how these relate to farmer perceptions and adoption of certain management practices. First, our study takes into account the physical presence of herbicide resistant weeds and how these may influence farmers’ beliefs and associated chemical or integrated weed management plans. This is an important first step in understanding how the physical characteristics of a farm and farming region shape farmers’ land use decisions (Stedman, 2003). We believe the biophysical characteristics of the landscape will play a part in shaping how farmers think about the utility of chemical weed management. In turn, this will influence their level of techno-optimism and shape their land use management decisions. Thus, by asking how the presence of HRW impact farmer’s attitudes towards chemical management, we will start to clarify *how* physical characteristics ultimately shape land use decisions. Second, this study analyzes farmer perceptions of technology as a potential ideological barrier to the future adoption of non-chemical farm management practices. The assumption guiding our latter focus stems from the assertion that “Quick Technological Fixes” are limited and, more specifically, the premise that an IWM program must replace herbicide-dominated management practices. The results of this research will not only make an important contribution to the theoretical literature, but also could shed light on how to work with farmers on the adoption of more integrated weed control programs.

In what follows, we first review research on how location and biophysical elements of farmland shape farmers’ conceptualization of their farm and agricultural technology. Following, we present the case that techno-optimism is a problematic ideology for addressing herbicide resistance. Then we detail our methods and findings.

2. Literature review

2.1 Location Characteristics and Farm Management

The possible influence of biophysical farm characteristics on farmers' beliefs and actions is suggested in Llewellyn et al.'s (2004) research on Australian farmers' weed management practices. They found that farmers who had HRW present on their farm utilized significantly more integrated weed management practices, while farmers without HRW continued to rely on chemical control methods. Supporting these findings, Bonny (2016) discovered that U.S. farmers were much *less* likely to use diverse management techniques when they had no experience with HRW on their own farm. What Llewellyn et al. (2004) and Bonny (2006) have shown is that the presence of weeds on a farm influences actual management practices. However, these analyses do not address whether state-wide presence of HRW have a similar positive effect on adoption of integrated management practices as that seen on individual farms. They also do not specify *why* weed presence impacts the use of integrated management practices – a question our paper seeks to clarify.

As Bonny (2016) found, farmers' management practices were altered specifically when HRW were discovered *on their own farm*. Whether farmers' beliefs and management practices are influenced by HRW at a state level is unclear. More specifically related to region, Kelley, Fernandez-Gimenez and Brown (2013) found that concern over downy brown infestation significantly increased in heavily infested regions of Colorado and Wyoming. Although they did not investigate whether this concern resulted in different management techniques, it is evidence for the impact of regional weed infestation on farmers' beliefs and perceptions of how weeds *should* be managed. Our paper seeks to validate and illuminate these studies by exploring how

HRW intensity impacts not only concern, but ideological leanings that in turn influence actual management practices.

While it is certainly possible that herbicide resistance presence is influencing farmers' meaning-attribution, making this an issue of place rather than space (Gieryn, 2000), we do not have the data to investigate this trend. It was not our initial intention to investigate the role of place in farmer weed management – however during the focus group discussions that were conducted as part of this research it became apparent that responses to HRW problems varied substantially by state. Therefore we include a preliminary discussion of the impact of location, while encouraging future consideration of how HRW influence place-meaning, particularly in light of studies showing how farmers' sense of place can significantly impact their sustainable agricultural practices (e.g. Lincoln and Ardoin, 2015). In our own research, we observed that in locations where herbicide resistance, and particularly glyphosate resistance, has been a longer and more serious problem respondents appeared to express less optimism and more skepticism towards chemical weed control. This may reflect the influence of geographically-relevant biophysical characteristics on farmers' perceptions of how their farm should be managed. In our analysis, we uncover trends across states in which herbicide resistance is more or less prevalent in order to better understand this influence.

2.2 The Problem with Techno-optimism

Alvin M. Weinberg (1966/1981) proposed that remedies to a number of social and environmental problems are available through “Quick Technological Fixes,” in contrast to socially “engineering” (changing) human behavior to address these problems. For example, poverty can be ended through the increased production of goods made available through productive technologies, as opposed to changing the social order in line with egalitarian

demands, or peace can be “imposed” through the mutually assured destruction made available by the H-bomb, as opposed to promoting tolerance between countries. While Weinberg acknowledged that technology can never wholly replace social engineering to solve all social problems, his position, a strong form of what we will be calling “techno-optimism,” is clearly distinct from an approach that seeks to address social and environmental problems through social initiatives: the “social engineer” “asks people to behave more ‘reasonably’,” while the “technologist” “tries to avoid changing people’s habits or motivation.”

Although Weinberg’s version of techno-optimism is strong, weaker forms are prevalent in the environmental sciences and social sciences. Techno-optimists (e.g., Lomborg 2008, 2001; Simon 1981) claim “technological breakthroughs will serve as the means to address each and every environmental problem that arises, allowing society to overcome natural limits and all socio-ecological challenges” (York and Clark 2010: 481). The archetypal example of the techno-optimistic camp in the environmental social sciences is ecological modernization theory, which proposes that new technologies, together with economic reforms, are the foundation for a sustainable society, a society that can be reached without radically altering the current social order (e.g. Mol and Sonnenfeld 2000; Mol 2001). As Mol (2001: 58) put it, “environmental deterioration is conceived of as a challenge for socio-technical and economic reform, rather than the inevitable consequence of the current institutional structure.” Indeed, the “linchpin” of EMT is technological innovation (York and Clark 2010: 483).

There are three broad and fundamental problems of techno-optimism in relation to human-nature relations (York and Clark 2010). First, techno-optimism overlooks the wide body of research showing that environmental problems are influenced by social factors (e.g., power, affluence, poverty) and are often caused (in part) by socio-economic systems (e.g., Schnaiberg

1980; York, Rosa, and Dietz 2003; Myers and Kent 2003; Baland et al. 2010; Freudenberg and Gramling 2011). In contrast, techno-optimists frame environmental problems as technical problems requiring technical solutions. Second, unintended additional environmental problems often follow Quick Technological Fixes, as Weinberg called them. As York and Clark (2010) note, the most glaring example in agricultural history is the unintended human health and ecological consequences of the development and use of synthetic pesticides, as famously brought to light in Carson's *Silent Spring* (1962). Third, techno-optimists ignore the "Jevons paradox," or, that advances in technical efficiency can paradoxically increase the consumption of the limited or risk-associated resources (see York 2006; Polimeni et al. 2008). The limits of the potentials of new technologies are clear in the case of the herbicide glyphosate as well as solutions to HRW.

One goal of this paper is to present evidence that suggests techno-optimism may be an ideological barrier that is impeding farmers' ability to adapt more holistic management systems. There are two reasons that we target techno-optimism as a potential ideological barrier to the adoption of integrated weed management programs. First, and most importantly, there is little reason to think that similar resistance problems will not follow the development of any new "silver bullet" herbicide. In addition, even if multiple herbicides ("herbicide diversity," "multiple modes of action") are used to combat glyphosate resistance, weeds can develop resistance to multiple herbicides (Heap 2011), a problem Harker et al. (2012) argued will increase in the future. Second, no new active ingredients for "major herbicides" have been marketed in two decades (cf. Duke 2011) and "few new herbicides are expected to be available anytime soon" (Livingston et al. 2015: 2; cf. Harker et al. 2012). Thus, social changes coupled with a use of mixed weed management methods is likely a more viable approach for addressing

present and future herbicide resistance in weeds. However, there is reason to suspect that growers may find it challenging to adopt such a strategy in part because of their technologically optimistic hope in the discovery of a new herbicide that will have many of the same advantages glyphosate presented during its early adoption phase.

3. Methods

Research on HRW has primarily focused on economic and biological factors, leaving the sociological aspects of herbicide resistance without a strong empirical understanding, especially in the global North (Fischer, Ekener-Petersen, Rydhmer, and Björnberg 2015). We utilized focus groups with 64 corn and soybean farmers to begin to address this important gap in research because their interactive-exploratory structure is particularly helpful for acquiring a rich understanding of little studied and emerging areas of inquiry (Morgan 1993). Locations of the focus groups were selected based on pre-existing relationships with local university extension agents in states that have, or are beginning to have, herbicide resistance problems. Members of the research team had connections with extension agents in Arkansas, Iowa, Minnesota, and North Carolina –therefore focus groups were conducted within these states. Although selecting these sites based on connections with university extension agents is not representative of the U.S., it provided a valuable cross-section of herbicide resistance sites. Between February and May of 2015, twelve focus group interviews were conducted in Arkansas (two focus groups), Iowa (four focus groups), Minnesota (two focus groups), and North Carolina (two focus groups). Hereafter, specific interviews are referred to using the state abbreviation followed by a number signifying time order (e.g., MN1 signifies the first Minnesota focus group).

Focus groups were kept relatively small, with approximately 6-10 participants, as recommended by Morgan (1993). These participants were recruited through university extension

agents in each state. These extension agents expressed that they had recruited growers whom they considered to be their ‘best’ in terms of management practices, yield, and/or communication with extension. Unsurprisingly, then, our participants often stated that they were attending the focus group because they had a good relationship with the extension agent that requested their presence. Therefore our participants are more likely to be considered ‘good’ farm managers by their extension agents, i.e., farm managers who listen to their extension agent’s advice and are at the forefront of HR weed knowledge and management. Although this sample cannot express views that may be held by farmers who have less knowledge of herbicide resistant weeds, or those who do not have a close relationship with an extension agent, it does reflect the values and ideas of growers who are relatively highly aware of and educated about herbicide resistance.

Most of the focus groups were conducted at a university extension building, with some conducted at community centers or restaurants. Lasting approximately one and a half hours each and audio recorded for accuracy, a primary researcher facilitated discussions and a secondary researcher took notes on general themes during each focus group. The recruiting extension agent was also present at each focus group.

Most of the 64 total participants were white men (60 were white, 62 were male). The median age of participants was 52, with ages ranging from 24 to 79. Seventy percent of participants reported farming with a partner, most often their father or spouse. Ranging from zero to 9,200 acres, the median acreage managed by participants was 1,300. Corn, soybeans, and wheat were by far the most common crops, though some farmers grew other grain, vegetable, or fruit crops. See Table 1 for a summary of demographics by state. While the sample misses some of the diversity of U.S. farmers, it does reflect those that grow mainstream U.S. crops and who are connected to representatives of the land grant system. Regardless of the representativeness

of the sample, the purpose of focus groups is exploring emerging constructs/areas of inquiry, not to generalize findings.

Table 1. Demographics of Focus Group Participants by State

	Minnesota	Iowa	North Carolina	Arkansas
Number of Participants	16	25	11	12
Males	16	23	11	12
Females	0	2	0	0
Age	32 - 68	33 - 77	44 - 79	24 - 73
White	16	25	8	11
Acres Managed	200 - 6,200	110 - 6,000	0 - 1,600	2,200 - 9,200
Acres Owned	0 - 2,600	0 - 1,500	0 - 900	40 - 2,200
Farms with Partner	12	18	5	10
Grows Corn	16	25	8	9
Grows Soybeans	16	25	10	12
Grows Cotton	0	0	0	8

Pre-discussion, participants were informed of the purpose of the study, encouraged to express their opinions during the discussion, even when different, and completed a consent form and short demographic questionnaire. After an ice-breaker question, three consistent lines of questioning were employed: 1) how should/would a farmer react to HRW on their own farm, 2) how should/would a farmer react to HRW on their neighbor's farm, and 3) whether herbicide resistance will be a short- or long-term problem.

Coding of focus groups data was completed in three phases following transcription. First, the three of us independently identified emergent themes by reading completely several transcripts. Next, all transcripts were read closely to code themes into thematic categories while noting representative quotes in the forms of statements and conversations. We met after every two or three transcripts to check inter-coder reliability, refine thematics, and consider any new emerging themes.

After the two phases of initial coding, one researcher focused on re-coding the transcripts with the hypotheses of this paper in mind. Two general perceptions regarding the future potential of herbicides were identified: techno-optimism and techno-skepticism. Although comparable, neither Lawson et al.'s (2009) "positive," "neutral," and "negative" attitudes toward the adoption of GM crops in Denmark nor Hall's (2008) "positive," "uncertain," and "fatalistic" discourses about GM crops in Scotland perfectly captures our coding categories. In the context of herbicides and herbicide resistance, techno-optimism (described above) encompasses the perception that the chemical industry can and/or should develop a new chemistry to replace glyphosate. The term techno-skepticism was chosen over the more common terms "technophobia" (Hellman 1976) or "techno-pessimism" (usually attributed to positions akin to Ellul's 1954/1964) because, as examples show below, these terms are too strong to reflect the ideas being expressed by respondents. Techno-skepticism refers to the following perceptions: significant doubts that the chemical industry is capable of developing a new silver bullet herbicide and/or if the chemical companies do develop a new silver bullet herbicide, farmers will experience the same resistance problems as they do with glyphosate. In addition to these two general themes, an additional coding category was developed to capture the emergent theme of "techno-dissonance." Techno-dissonance refers to the paradoxical co-existence of techno-optimistic and -skeptic perceptions in single statements or in short discussions. For instance, a hope for the chemical industry to come up with a new herbicide may be coupled with the recognition of the potential of new resistance problems should such an herbicide be introduced and used widely. This inclusion resulted in three main coding categories: techno-optimism, techno-skepticism, and techno-dissonance. The relevant quotes and elements comprising each theme were discussed and checked for inter-coder reliability and agreement.

4. Results

As noted above, during coding of the focus group transcripts, three primary themes related to farmers' perceptions of technology were identified. These were techno-optimism, techno-skepticism, and techno-dissonance. While all of these themes came up in multiple focus groups, some were more pronounced or frequently mentioned in certain groups. In particular, techno-optimism was more pronounced in Northern state focus groups (Iowa and Minnesota) and techno-dissonance was stronger in Southern state focus groups (North Carolina and Arkansas). For an interpretive summary of these trends, see Table 2. This reflects our expectations given the relative prevalence of weeds in these four states.

4.1 Techno-optimism

The belief in technology to solve current and future herbicide resistance problems was a consistent theme that occurred in every focus group, although it was more pronounced in Iowa and Minnesota, where resistance problems currently are rarer. This suggests that the biophysical characteristics of these places, i.e. the comparative lack of HRW, may be associated with farmers' perception of technological solutions. In Northern states, techno-optimism came up in the focus groups quite frequently and was discussed at length. In contrast, this theme came up less often in North Carolina and Arkansas, where resistance problems are more intense. This suggests that groups in the Northern states are more optimistic about the potential of technology to solve herbicide resistance issues, while the groups in Southern states express optimistic beliefs in technology to a lesser degree.

Faith in the chemical industry to solve herbicide resistance problems was discussed frequently in terms of the monetary rewards awaiting whichever firm could develop the "next RoundUp" as demonstrated by these farmers from Minnesota and Iowa:

MN1:

PARTICIPANT: That's where the money is so that's where it's going to go. In other words, trying to keep a company keeping new ideas coming, keeping new products moving in the pipeline -- because that's what eventually going to have to happen is... this is never going to go away. You're always going to have an issue with whatever herbicide comes out. So keeping new options coming is more important than really the agricultural practices and all that.

IA2:

PARTICIPANT: I mean the industry's going to have to respond, they're going to have to come out with a new formulization, or they're going to -- and economically, I just feel like that the market will drive some of this change too.

The belief in these Northern focus groups was that when the market demands become high enough, companies will have the necessary incentive to develop new chemical herbicides. The lack of current herbicide development, then, is not conceptualized as a technological limit but rather a financial one. This theme existed in both Northern and Southern focus groups, although in the South growers were more likely to emphasize that companies were working for their own interest so that they could "sell you something," indicating a level of distrust with the chemical industry less prevalent in Northern groups:

AR1:

PARTICIPANT: So, whether it's an American company or a foreign company, they're going to be out there trying to find something to sell us. They're too big of an industry not to. You know, we're growing, what, 88 million acres of soybeans, probably close to the same in corn, it's just such a big industry. There's so much money to be made out there if you have that right thing. They're going to work for them.

AR1:

PARTICIPANT: Now, as this resistance continues, these chemical companies are going to try to find something that they can sell you. And they can't sell it to you unless it works.

Both Northern and Southern focus groups participants took the onus off of technology and put it on the market, specifically on chemical companies who are in the business of

responding to economic incentives. Farmers are therefore able to maintain faith in the ability of technology to solve their current and future herbicide problems, trusting that when the situation becomes truly dire chemical companies will see the economic opportunity and deliver a new technology on demand. The primary difference is that Southern groups tend to emphasize chemical companies' greed more often than the Northern groups, who tended to have a more positive perspective. The term 'greed' was specifically used by members of the focus groups in the South, emphasizing their growing distrust of chemical companies that have, of course, always focused on making a profit.

4.2 Techno-skepticism

Although techno-optimism was a consistent theme across the focus groups, many participants also expressed doubt in the ability of chemical technologies to control or alleviate herbicide resistance. This techno-skepticism occurred the least in Iowa and North Carolina, while higher instances of this theme were observed in Minnesota and Arkansas. The high level of skepticism in Arkansas is in line with the high level of herbicide resistance they are experiencing, while the low level of skepticism in Iowa accords with the relatively lower level of resistance in this state. The prevalence of techno-skepticism observed in North Carolina and Minnesota is opposite for what we would expect given the level of herbicide resistance in these states. Given this, we will investigate quotes from focus groups in these states to further elucidate these trends.

In Minnesota and Iowa, prominent techno-skepticism subthemes included doubt in the ability of chemical technologies to solve resistance, farmer resistance to adopting alternative practices, and the necessity of incorporating these alternative practices. For instance, one farmer in Minnesota had this to say about the future of chemical herbicides:

MN1:

PARTICIPANT: And it's like -- it's -- you saw it 10, 15 years ago with this herbicide, what's going to make Glyphosate any different? What's going to make Pursuit any different? What's going to make any of them any different? They're all going to do the same thing eventually.

Similarly, this grower in Iowa expresses doubt that chemical solutions will be able to "best"

Mother Nature:

IA2:

PARTICIPANT: Well I think the introduction of the Dicamba beans, (inaudible) that's not solving the problem. That's just pushing the resistance problem down the road. Because Mother Nature is going to -- if you use the same chemistry repeatedly, Mother Nature's going to figure out a way to make something grow. So, we're not solving the problem, we're just pushing it down the road.

These growers knew that weeds had developed resistance to glyphosate and other chemicals, and therefore recognized that any new chemicals would be likely to have similar difficulties.

However, in contrast to the Southern focus groups, this resistance was less frequently discussed in terms of farmer overuse of herbicides. Instead, it was based more on biological difficulties and the inherent adaptability of nature – resistance was not seen primarily in terms of a human-created problem as it was in the Southern groups.

In the Southern focus groups, techno-skepticism was largely expressed in terms of growers overusing herbicides, and particularly the potential to repeat this process of creating resistance. To begin with, growers are generally skeptical about how long an herbicide will last before developing resistance:

AR2:

PARTICIPANT 1: Well, they're not called the silver bullet, but anyway, the next option we have. You can tell nobody's happy with it. It's not nothing to be happy about. We're all more or less wondering how bad it's going to be, not how good it's going to be.

MODERATOR: I mean, do you guys expect there to be something that comes out that's like Roundup was? Do you think that's a possibility?

PARTICIPANT 2: (inaudible) I don't see why (inaudible).

PARTICIPANT 1: But then I'm pessimistic. How long will it last? You know, how long before it gets around?

PARTICIPANT 3: That's the second thought every time, is how long is it going to last?

PARTICIPANT 1: Because we're all going to use it.

PARTICIPANT 3: (inaudible) overuse it.

This conversation shows that growers are optimistic that a new chemical can be developed, but recognize that it will not solve the problem in the long term. Particularly, they discuss how farmers will likely use and even overuse such an herbicide should it become available. This sentiment was echoed in North Carolina:

NC1:

PARTICIPANT: And if they come out with a Dicamba-tolerant bean, let's say they're able to get it to where it doesn't volatilize and drift or anything, who's going to put on the farm year after year on the same fields, year after year? Is it going to be ruined again? I know folks right now that ruined this technology again. Everybody does. I mean, they get spoiled too easy.

Interestingly, these comments put the cause of herbicide resistance, at least in part, in the hands of the farmers who overuse the technology and are unwilling to diversify their methods. The skepticism surrounding technology in the Southern focus groups had to do both with the technology itself and with the *human use of* the technology. While it is acknowledged that chemical herbicides will always have the potential to develop resistance, the blame does not fall squarely on the inherent properties of the technology. Instead there is a recognition that farmers' weed management practices also contribute to the declining usefulness of chemical herbicides via persistent overuse and occasional underuse:

AR2:

PARTICIPANT: Well, that's part of the problem. When a company comes out with a chemical, they charge you as much as they can until they think that you will still buy it. So, what do we do, if it works so well, we cut the rates, that adds to our resistance problem. If they would lower the price half as much, we'd use twice as much, and wouldn't have the resistance problem.

Our respondents in the Southern states were not only skeptical of chemical herbicide technologies, but also of farmers' ability to change their practices and avoid overusing or under-using it. This may be a result of the longevity of herbicide resistance in the South, where growers have seen little change in weed management practices despite experiencing herbicide resistance for multiple years (Coombs 2012; Eller 2014; Ervin and Jussaume 2014; Heap 2016).

Although both Northern and Southern growers recognized that non-chemical practices can have benefits for controlling herbicide resistance, they also identified obstacles to adopting them:

MN1:

PARTICIPANT: Some of its cost, and some of its complexity. Glyphosate has been so easy for so long I think guys kind of forgot weed control before that, so they -- maybe they're a little afraid to go out of their comfort zone and try something other than the product that's causing the resistance. And until it's an economic disaster they're probably not going to reach out.

NC2:

PARTICIPANT: I think you just -- you continue to see dependent upon chemicals, because, I mean, field size that we have and the -- you know, you just do the best you can. And I don't see us -- you talk about the margin being so -- profit margin, if there is one, being so narrow that, you know, it's hard for farmers to want to crank a tractor up, and hook up, and go out there and tear everything down a couple of times, you know, just to get a crop of beans out. I think if they put something in the jug, and they can take care of it, that's what most people continue to do.

These observations point to a complicated problematic: While some growers recognize the possibility that chemicals are not the ultimate solution to herbicide resistance, and that alternative

practices can be used to mitigate resistance development, they are tentative about potentially adopting alternative practices due to the complexity of these practices and the familiarity with a simple chemical weed management program. In addition to this complexity, many farmers stated that monetary concerns were a main motivation for using herbicides, as in the following example:

IA2:

PARTICIPANT: I think in this struggle, battle against herbicide resistant weeds of all types, I mean it seems like people will try and go the chemical route at first, because that's going to be simplest, easiest, cheapest short-term way to go about it.

Although techno-skepticism was not particularly more pronounced in the Northern or Southern focus groups, their techno-skepticism tended to stem from different philosophies of technology. While the Northern focus groups emphasized that chemical herbicides can face biological difficulties due to the adaptability of nature, the Southern groups tended to focus on the human problem regarding farmers' overuse of herbicides as a reason for their decreasing longevity.

4.3 Techno-dissonance

Techno-dissonance, which involved single statements or short discussions in which discordant opinions were expressed, was far more prevalent in Southern focus groups than in Northern focus groups. Given Southern groups' lower techno-optimism related to doubt in the chemical industry and associated skepticism related to human error, it is no surprise that their dissonance and questioning of chemical solutions is greater than the Northern groups.

In the Northern focus groups, techno-dissonance was most often expressed in statements following the pattern of, roughly, "Chemical herbicides don't work as well as they should/used

to, *but* they're our only option." In Iowa, for example, this grower discusses the potential for chemical resistance in contrast with growers' dependence on herbicides:

IA2:

PARTICIPANT: As we go away from Roundup, then you're going to have resistance to other chemicals and I mean, that's going to build up. But I think we're going to still be dependent on herbicides, because you can't control it well enough, without herbicides you can't do it with the cultural methods and stuff.

Similarly, this grower from Minnesota recognizes that herbicide resistance will likely be a problem with any new herbicide that is released, but emphasizes continual development of herbicides as a solution over cultural practices:

MN1:

PARTICIPANT: In other words, trying to keep a company keeping new ideas coming, keeping new products moving in the pipeline – because that's what eventually is going to have to happen is...this is never going to go away. You're always going to have an issue with whatever herbicide comes out. So keeping new options coming is more important than really agricultural practices and all that.

This type of techno-dissonance, where chemical herbicides' vulnerability is recognized but simultaneously viewed as the only viable option, was predominant in the Northern states. In contrast, the Southern states had a larger variety of techno-dissonant subthemes. In addition to occurring more frequently, statements of techno-dissonance in the Southern focus groups were more likely to be longer, involve multiple participants, and reference the chemical industry. This greater emphasis on and diversity of techno-dissonance themes supports the supposition that locations with greater biophysical incidence and experience with HRW will express greater doubt regarding possible solutions.

The following discussion between two growers in Arkansas emphasizes that should a new 'silver bullet' herbicide be developed, growers would likely overuse it despite knowing better.

AR2:

PARTICIPANT 1: ...getting that practice though where it's just so easy to do the one thing and not have to – not have to do rig up and do this and do that. And you give me that one bullet where I can use it, hey, that solved my problem.

PARTICIPANT 2: It's cheaper for you.

PARTICIPANT 1: And it's cheaper. (inaudible) it's less everything. And so that's what I'm going to do. *If you give me a silver bullet, I'm going to use it. And I'm probably going to overuse it.* [Emphasis added.]

However, growers in our Southern focus groups were also more likely to be doubtful of herbicides' future effectiveness *and not offer a chemical cure*. While the Northern pattern consisted of “Chemical herbicides don't work as well as they should/used to, *but* they're our only option,” the Southern groups were more likely to follow the script, “Chemical herbicides are our only option, *but* they don't work as well as they should/used to *and* we don't know what will solve it.” This is exemplified by the following conversation:

NC1:

PARTICIPANT 1: Well, controlling bad weeds, you know, that these companies find out about them, they can go right then and experiment, trying to figure a way to take them out, because if they do, and they can get a product that doesn't harm the crop, then they've got some money in the bank.

MODERATOR: Do you have something? No?

PARTICIPANT 2: Everything's so specific now though. All of your chemicals seem to be so, you know, directed to a specific problem that I think that, you know, as you solve one problem another one pops up. I don't know. I mean, I see problems being solved, but at the same time, new ones coming up all along. As far as a cure all, I don't see that happening.

PARTICIPANT 3: Way back, when I was growing up, these weeds didn't have a chance to become a problem, because you had everything in the house out there in the field with hoes. (laughter)

...

PARTICIPANT 1: Sitting on the porch, you make more than you can out there pulling weeds. I mean it's just so expensive to hire people to pull the weeds.

In this conversation we see a movement from faith in the chemical industry to doubt in chemical solutions, followed up by a statement that hand hoeing was a better option but is no longer feasible because of cost. No long-term solution to the herbicide resistance problem is ever offered. While there were discussions in the Southern focus groups that emphasized reliance on herbicides, there were also discussions such as these that problematized chemicals but could not come up with a satisfactory alternative. Aside from frequency, this was a primary difference between techno-dissonance in the Northern and Southern focus groups.

Table 2. Summary of Focus Group Trends by State

State	Techno-optimism		Techno-skepticism		Techno-dissonance	
	Prevalence	Theme	Prevalence	Theme	Prevalence	Theme
Iowa	High	Herbicide resistance will be solved by chemical companies' high financial incentive to develop new herbicides	Medium	Doubt in ability of chemical technologies to solve resistance, particularly due to chemistry of herbicides	Low	Chemical herbicides don't work as well as they should/used to, <i>but</i> they're the only option for controlling herbicide resistance
Minnesota	High	Herbicide resistance will be solved by chemical companies' high financial incentive to develop new herbicides	Low	Doubt in ability of chemical technologies to solve resistance, particularly due to biology of weeds	Low	Chemical herbicides don't work as well as they should/used to, <i>but</i> they're the only option for controlling herbicide resistance
Arkansas	Low	Herbicide resistance will be solved because chemical companies are greedy to make a profit from new herbicides	High	Doubt in ability of chemical technologies to solve resistance, particularly due to overuse of herbicides by farmers	High	Chemical herbicides are our only option, <i>but</i> they don't work as well as they should/used to <i>and</i> we don't know what will solve it
North Carolina	Medium	Herbicide resistance will be solved because chemical companies are greedy to make a profit from new herbicides	Low	Doubt in ability of chemical technologies to solve resistance, particularly due poor farmer management of herbicides	High	Chemical herbicides are our only option, <i>but</i> they don't work as well as they should/used to <i>and</i> we don't know what will solve it

5. Discussion

Based on our focus groups, we found that overall, farmers who we met are techno-optimistic, however this is tempered by techno-skepticism. There are a variety of perceived advantages to chemical weed control, such as economic and labor benefits, that support farmer techno-optimism. However, particularly in the Southern focus groups where HRW have been severely problematic for several years, there is an increasing doubt that such technologies will yield future long-term weed management solutions. These two conflicting beliefs interact to create techno-dissonance wherein farmers are left confused by their own disparate ideations. The result of this is that farmers tend to ‘go with what they know’ and stick with a simple, cheap, and easy chemical weed management plan. This supports our supposition that techno-optimism creates barriers to integrated weed management – it is the fallback position in an increasingly uncertain agricultural production system.

Techno-optimism, -skepticism, and -dissonance were present in all of the focus groups we conducted, indicating their importance as themes guiding farmers’ thinking about herbicide resistance. However, we also saw some interesting variations in these themes between Northern and Southern groups. Although farmers in both regions were techno-optimistic, it was less pronounced in the South and more associated with the greed of chemical companies – as opposed to understanding chemical companies’ actions as normal, our participants specifically stated that they were becoming ‘greedy’. In terms of techno-skepticism, Northern groups tended to emphasize the problem of nature’s adaptability to herbicides while Southern groups spoke more frequently of human-induced resistance. Finally, Southern groups expressed significantly stronger and more varied techno-dissonance than Northern groups, with substantial concern that

ineffective chemicals were their only option. We will discuss each of these trends in turn and propose variables that may explain these differences.

Techno-optimism in the focus groups was largely framed by economic discussions, particularly regarding the financial incentives for chemical companies to produce a new herbicide. Growers believed that eventually the potential demand will be great enough that companies will essentially be forced to cash in on it. Thus farmers' perception of herbicide resistance is characterized not necessarily as a failure of technology, but as a failure of economics/effort on the part of the chemical companies. This allows farmers' continued belief in the power of chemical herbicides – it's not that companies *cannot* develop more/better ones, it's that they currently do not have sufficient incentive.

Northern focus groups, where resistance is less prominent, had stronger themes of techno-optimism. This is associated with belief in the power of chemical companies to come out with new herbicides given enough incentive. Southern groups had less pronounced techno-optimism, although it was still present. The techno-optimism in Southern focus groups was expressed differently than in Northern groups: they tended to believe that chemical companies will produce a new herbicide given enough incentive, but framed this belief in more negative ways, such as companies being essentially greed driven entities “trying to sell you something.”

Techno-skepticism in the focus groups was often expressed in terms of concern related to the longevity of herbicides. Growers, particularly in the South, have seen resistance come up in a variety of weeds and recognize that this trend is likely to continue. This is concerning since they rely so heavily on herbicides, particularly given farmers' own recognition that they are hesitant to adopt alternative practices.

Neither the North nor South stood out as expressing significantly more techno-skepticism than the other. However, types of concern did differ. Northern groups more often stated that chemical herbicides can be problematic, without specifying if this problem stems from something inherent within herbicides or due to their overuse. If anything, they believed that resistance was the fault of nature as opposed to human error. Southern states were much more likely to mention farmers' overuse of chemical herbicides as a reason for herbicide resistance, emphasizing the human element of the problem.

Techno-dissonance was characterized by statements including both optimism and skepticism, wherein growers simultaneously doubted the effectiveness of herbicides in the future while also expressing that herbicides were the best possible option. In the North, this was likely to take the pattern of "Chemical herbicides don't work as well as they should/used to, *but* they're our only option." The Southern groups were more likely to pattern their statements of techno-dissonance in the format of "Chemical herbicides are our only option, *but* they don't work as well as they should/used to *and* we don't know what will solve it". Southern groups seem to be framing a direr situation, expressing confusion and concern regarding the future of weed control. Many growers in this region have *already tried* alternative herbicides to control resistant weeds on their farm, with minimal success. Members of the focus groups specifically mentioned using older (and more dangerous) herbicides, as well as 'new' combinations of older herbicide formulations. There were also several who mentioned switching the brand of herbicide-resistant seed they used to accommodate the use of an herbicide that was new *to their farm*. This direct experience with a biophysical element of their farm then impacts their perception of chemical technology's effectiveness. Importantly, when growers are unsure of what to do next they seem

to be falling back on chemical solutions. When there is doubt and confusion, they go to what they know (or hope for), which is what is cheaper and what they are comfortable with.

Techno-optimism is still prevalent across all focus groups, despite some skepticism. However, this optimism is less pronounced in areas where herbicide resistance has been concentrated for some time. The tension between this optimism and skepticism comes out in the form of techno-dissonance, which is highest in the Southern groups where optimism is relatively lower. Given that the primary difference between these focus groups was their location, it appears that the longer term presence of HRW, and particularly glyphosate resistant weeds, in the South may be impacting growers' perception of chemical technology as a viable solution to herbicide resistance. This points to the influence of physical environmental characteristics, particularly the presence and history of HRW, on farmer perceptions. When resistant weeds have persisted despite farmers' attempts to control them using various chemical methods, faith in the *potential* long-term viability of herbicides decreases with a concomitant increase in techno-dissonance. This, however, does not appear to have resulted in a decrease in the reliance on herbicides to manage weeds. For example, when confronted with this dissonance, farmers in our Northern groups suggested that herbicides were still their best/only option despite their increasing dissatisfaction with these herbicides. On the other hand, our Southern growers were more stymied by future directions for weed management – they still mentioned chemical solutions, but also would sometimes leave the question of future management open. It was extremely hard for them to envision weed control that did not involve primarily chemical herbicides, and while they realized that these herbicides had limitations they rarely came up with an attractive alternative management plan.

6. Conclusions

According to our focus group findings, lack of HRW is associated with farmers' technological optimism, which in turn has an impact on their weed management practices. In particular, the presence of HRW as a biological component of a farming region increases the dissonance farmers are feeling toward chemical herbicide solutions. This is evident in the way that farmers in our Southern focus groups responded with some skepticism to the potential of chemical herbicides as a solution to HRW problems while farmers in the North, where there have historically been fewer resistant weeds, have greater faith in the potential of chemicals to solve the problem.

Our study suggests that where a farm is located geographically does influence how farmers think about technology and its use in farm management – i.e. being in a region that has dealt with herbicide resistant weeds for several decades increases farmers' skepticism and dissonance regarding chemical technological solutions. This is an important contribution, helping us to understand *how* geographically-specific biophysical elements influence management of the environment – that is, through ideology. Although we did not have specific data on farmers' place-related meaning-making, our study provides justification for future research in this vein.

Our findings also echo those of environmental social scientists who argue that the technological mediation of societal-environmental interactions must be understood in social context and that environmental issues are rarely only technical issues that can be easily solved with techno-fixes (e.g., Schnaiberg 1980; York and Clark 2010). Our study contributes to this line of thinking by moving out of critiques of environmental policy and theory (where the discussion tends to stay). Techno-optimism was fairly prevalent among our subjects and should be critically engaged with. In other words, debates about the role of technology in human-nature relations provide fruitful ground for exploring the prevalence of these ideas in the public.

Relatedly, our results also have wider applications for subfields (e.g., the sociology of knowledge) that examine the existential determinants (e.g., class position) of meaning, knowledge, and values. Our results show that biophysical variables should also be taken into account in such studies.

The finding that techno-dissonance increases in areas with higher rates of HRW is the most important finding in terms of policy (e.g., for those working with farmers to develop more holistic weed management practices). On the one hand, this is an unfortunate finding because it may show that farmers will have faith in herbicides and the future potential of herbicides so much so that herbicide resistance becomes a nearly uncontrollable problem (i.e., until HRW populations become too numerous to combat effectively). However, techno-dissonance, unlike techno-optimism, does provide room for change. As stated above, the Southern groups were more likely to pattern their statements of techno-dissonance in the following way: “Chemical herbicides are our only option, *but* they don’t work as well as they should/used to *and* we don’t know what will solve it.” Those working with farmers in areas with high herbicide resistance rates may be able to tap into the skepticism and provide an answer to “we don’t know what will solve it”.

We urge future research on herbicide resistance to expand the testing of other ideological barriers that may inhibit integrated herbicide resistance management plans. As discussed in the introduction, past research shows precedents for industry conditioning pro-technology perceptions among growers. While the focus of this project is different, future research should examine the extent to which techno-optimism in the context of herbicides is an ideology formed and disseminated by the private sphere. Additionally, some have suggested that growers’ sense of individualism may constitute a barrier to action on herbicide resistance (e.g. Ervin and

Jussaume 2014). It will be important to understand the full range of growers' ideology regarding weed management and herbicide resistance, as our research indicates that this can have significant impacts on their conceptualization and use of chemical and alternative management strategies. Second, future studies incorporating quantitative methods would be useful for testing whether our findings hold for growers across the U.S. As an exploratory study concerned with preliminary understandings as opposed to generalizations, this study has certain limitations that can be addressed in future research. The nature of focus groups uncovers a great deal of nuance and detail, but lacks generalizability to a larger population. Third, we focused our questions on perceptions of HRW as opposed to actual weed management behaviors – perceptions do not always predict actions, so it is important to investigate what growers are *actually* doing in regards to herbicide resistance management. This is also an important direction for future research.

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References

- Adesina, Akinwumi A. and Moses M. Zinnah. 1993. "Technology Characteristics, Farmers' Perceptions and Adoption Decisions: A Tobit Model Application in Sierra Leone." *Agricultural Economics* 9(4): 297-311.
- Adrian, Anne Mims, Shannon H. Norwood, and Paul L. Mask. 2005. "Producers' Perceptions and Attitudes toward Precision Agriculture Technologies." *Computers and Electronics in Agriculture* 48(3): 256-271.
- Baland, Jean-Marie, Pranab Bardhan, Sanghamitra Das, Dilip Mookherjee, and Rinki Sarkar. 2010. "The Environmental Impact of Poverty: Evidence from Firewood collection in Rural Nepal." *Economic Development and Cultural Change* 59(1):23-61.
- Barman, K.K., Singh, V.P., Dubey, R.P., Singh, P.K., Dixit, A., & Sharma, A.R. 2014. *Challenges and Opportunities in Weed Management under a Changing Agricultural Scenario*. Chuahan, B.S. & G. Mahajan (eds.). In Recent Advances in Weed Management. Springer Science: NYC, NY.
- Bonny, S. 2016. Genetically Modified Herbicide-Tolerant Crops, Weeds, and Herbicides: Overview and Impact. *Environmental Management* 57: 31-48.
- Bradshaw, Laura D., Stephen R. Padgett, Steven L. Kimball and Barbara H. Wells. (1997). "Perspectives on Glyphosate Resistance." *Weed Science*. 11(1): 189-198.
- Carson, Rachel. 1962. *Silent Spring*. Houghton Mifflin.
- Charles, Daniel. 2001. *Lords of the Harvest: Biotech, Big Money, and the Future of Food*. Cambridge, MA: Perseus.
- Chimmiri, Nagesh, Kerry W. Tudor, and Aslihan D. Spaulding. 2007. "An Analysis of McLean County, Illinois Farmers' Perceptions of Genetically Modified Crops." *AgBioForum* 9(3): Article 3.
- Cochrane, Willard W. 1993. *The Development of American Agriculture: A Historical Analysis*. St. Paul: University of Minnesota Press.

Coombs, Amy. May 20, 2012. "Revenge of the Weeds." *The Scientist Magazine*.

Duke, Stephen O. 2011. "Comparing conventional and biotechnology-based pest management." *Journal of agricultural and food chemistry* 59(11): 5793-5798.

Eller, Donnelle. June 23, 2014. "'Superweeds' Choke Farms." *The Des Moines Register*.

Ellul, Jacques. 1954/1965. *The Technological Society*. New York: Alfred A. Knopf.

Ervin, David E., Leland L. Glenna, and Raymond A. Jussaume. 2011. "The theory and practice of genetically engineered crops and agricultural sustainability." *Sustainability* 3(6): 847-874.

Ervin, David, and Ray Jussaume. 2014. "Integrating social science into managing herbicide-resistant weeds and associated environmental impacts." *Weed science* 62(2): 403-414.

Fernandez-Cornejo, Jorge, Richard F. Nehring, Craig Osteen, Seth Wechsler, Andrew Martin, and Alex Vialou. 2014. "Pesticide Use in US Agriculture: 21 Selected Crops, 1960-2008." *USDA-ERS Economic Information Bulletin* 124.

Fischer, Klara, Elisabeth Ekener-Petersen, Lotta Rydhmer, and Karin Edvardsson Björnberg. 2015. "Social Impacts of GM Crops in Agriculture: A Systematic Literature Review." *Sustainability* 7(7): 8598-8620.

Foresman, Chuck and Les Glasgow. 2008. "US Grower Perceptions and Experiences with Glyphosate-resistant Weeds." *Pest Management Science* 64(4): 388-391.

Freudenburg, William R., and Robert Gramling. 2011. *Blowout in the Gulf: The BP oil spill disaster and the future of energy in America*. MIT Press.

Frisvold, George B., and Jeanne M. Reeves. 2011. "Resistance management and sustainable use of agricultural biotechnology." *AgBioForum* 13(4): 343-359.

Gebrezgabher, Solomie A., Miranda P. M. Meuwissen, Gideon Kruseman, Dora Lakner, and Alfons G. J. M. Oude Lansink. 2015. "Factors Influencing Adoption of Manure Separation Technology in the Netherlands." *Journal of Environmental Management* 150: 1-8.

Gibson, Kevin D., William G. Johnson, and David E. Hillger. 2005. "Farmer Perceptions of Problematic Corn and Soybean Weeds in Indiana." *Weed Technology* 19(4):1065-1070.

Gieryn, T.F. (2000). A Space for Place in Sociology. *Annual Review of Sociology*, 26: 463-496.

Glenna, L.L. and Henke, C.R. 2014. Agricultural Technologies and the Structure of the North American Agrifood System. Bailey, C., Jensen, L., and Ransom, E. (eds.). In *Rural America in a Globalizing World: Problems and Prospects for the 2010s*. West Virginia University Press.

Glover, Dominic. 2008. "Made by Monsanto: The Corporate Shaping of GM Crops as a Technology for the Poor." STEPS Working Paper 11. Brighton, STEPS Centre.

Green, Jerry M. 2009. "Evolution of Glyphosate-Resistant Crop Technology." *Weed Science*. 57: 108-117.

Guehlstorf, Nicholas P. 2008. "Understanding the Scope of Farmer Perceptions of Risk: Considering Farmer Opinions on the Use of Genetically Modified (GM) Crops as a Stakeholder Voice in Policy." *Journal of Agricultural and Environmental Ethics* 21: 541-558.

Hall, Clare. 2008. "Identifying Farmer Attitudes towards Genetically Modified (GM) Crops in Scotland: Are they Pro- or Anti-GM?" *Geoforum* 39: 204-212.

Harker, K. Neil, John T. O'Donovan, Robert E. Blackshaw, Hugh J. Beckie, C. Mallory-Smith, and Bruce D. Maxwell. 2012. "Our view." *Weed Science* 60(2): 143-144.

Heap, I. (2016). The International Survey of Herbicide Resistant Weeds. Online. Internet. Friday, March 4, 2016 . Available at www.weedscience.org.

Hellman, Hal. 1976. *Technophobia: Getting out of the Technology Trap*. New York: M. Evans and Company.

Johnson, William G. and Kevin D. Gibson. 2006. "Glyphosate-resistant Weeds and Resistance Management Strategies: An Indiana Grower Perspective." *Weed Technology* 20(3): 768-772.

Johnson, William G., Micheal DK Owen, Greg R. Kruger, Bryan G. Young, David R. Shaw, Robert G. Wilson, John W. Wilcut, David L. Jordan, and Stephen C. Weller. 2009. "US farmer awareness of glyphosate-resistant weeds and resistance management strategies." *Weed Technology* 23(2): 308-312.

Kelley, W. K., Fernandez-Gimenez, M. E., & Brown, C. S. 2013. "Managing Downy Brome (*Bromus tectorum*) in the Central Rockies: Land Manager Perspectives." *Invasive Plant Science and Management* 6: 521-535.

Kondoh, Kazumi and Raymond A. Jussaume Jr. 2006. "Contextualizing Farmers' Attitudes towards Genetically Modified Crops." *Agriculture and Human Values* 23: 341-352.

Krueger, Richard A., and Mary Anne Casey. 2014. *Focus groups: A practical guide for applied research*. Sage publications.

Lawson, Larty G., Anders S. Larsen, Soren Marcus Pedersen, and Morten Gylling. 2009. "Perceptions of Genetically Modified Crops among Danish Farmers." *Acta Agriculturae Scandinavica, Section C – Food Economics* 6(2): 99-118.

Levins, Richard A. and Willard W. Cochrane. 1996. "The Treadmill Revisited." *Land Economics* 72(4): 550-553.

Lincoln, Noa Kekuwa, and Nicole M. Ardoin. "Cultivating values: environmental values and sense of place as correlates of sustainable agricultural practices." *Agriculture and Human Values*: 1-13.

Livingston, Michael, Jorge Fernandez-Cornejo, Jesse Unger, Craig Osteen, David Schimmelpfennig, Tim Park, and Dayton Lambert. 2015. *The Economics of Glyphosate Resistance Management in Corn and Soybean Production*, ERR-184. United States Department of Agriculture, Economic Research Service.

Llewellyn, R. S., R. K. Lindner, D. J. Pannell, and S. B. Powles. 2004. "Grain grower perceptions and use of integrated weed management." *Animal Production Science* 44(10): 993-1001.

Lomborg, Bjorn. 2001. *The Skeptical Environmentalist*. Cambridge, U.K.: Cambridge University Press.

Lomborg, Bjorn. 2008. *Cool It: The Skeptical Environmentalist's Guide to Global Warming*. New York: Alfred A. Knopf.

Marshall, N. A., S. E. Park, W. N. Adger, Katrina Brown, and S. M. Howden. 2012. "Transformational capacity and the influence of place and identity." *Environmental Research Letters* 7(3): 034022.

McKinney, K. 2013. "Troubling Notions of Farmer Choice: Hybrid Bt Cottonseed Production in Western India." *Journal of Peasant Studies* 40(2): 351-378.

Mol, Arthur P. J. 2001. *Globalization and Environmental Reform: The ecological modernization of the Global Economy*. Cambridge: MIT.

Mol, Arthur P. J. and David A. Sonnenfeld (Eds). 2000. *Ecological Modernisation around the World: Perspectives and Critical Debates*. Frank Cass.

Morgan, David L. 1993. *Successful focus groups: Advancing the state of the art*. Vol. 156. Sage Publications.

Myers, Norman and Jennifer Kent. "New Consumers: The Influence of Affluence on the Environment." *Proceedings of the National Academy of Science* 100(8): 4963-4968.

Negatu, Workeneh and Ashok Parikh. 1999. "The Impact of Perception and Other Factors on the Adoption of Agricultural Technology in the Morel and Jiru Woreda (District) of Ethiopia." *Agricultural Economics* 21(2): 205-216.

Piggott, Nicholas E. and Michele C. Marra. 2008. "Biotechnology Adoption Over Time in the Presence of Non-Pecuniary Characteristics that Directly Affect Utility." *AgBioForum*. 11(1): 1-13.

Polimeni, John M., Mayumi, Kozo, Giampietro, Mario, and Alcott, Blake. 2009. *The Jevons Paradox and the Myth of Resource Efficiency Improvements*. London: Earthscan.

Schnaiberg, A. (1980). *The Environment: From Surplus to Scarcity*. New York: Oxford University Press.

Shah, Esha. 2005. "Local and Global Elites Join Hands: Development and Diffusion of Bt Cotton Technology in Gujarat." *Economic and Political Weekly* 40: 4629-40.

Shah, Esha. 2008. "What Makes Crop Biotechnology Find Its Roots? The Technological Culture of Bt Cotton in Gujarat, India." *The European Journal of Development Research* 20(3): 432-447.

Shaner, Dale L. 2000. "The Impact of Glyphosate-Tolerant Crops on the Use of Other Herbicides and on Resistance Management." *Pest Management Science*. 56(4): 320-326.

Sinja, J., J. Karugiab, I. Baltenwecka, M. Waithakac, M. D. Mianoc, R. Nyikalb, and D. Romney. 2004. "Farmer Perception of Technology and Its Impact on Technology Uptake: The Case of Fodder Legume in Central Kenya Highlands." African Association of Agricultural Economists. Shaping the Future of African Agriculture for Development. The Role of Social Scientists. *Proceedings of the Inaugural Symposium*, Grand Regency Hotel, Nairobi, Kenya, December 6-8.

Simon, J. L. 1981. *The Ultimate Resource*. Princeton, NJ: Princeton University Press.

Stedman, Richard C. 2003. "Is it really just a social construction?: The contribution of the physical environment to sense of place." *Society & Natural Resources* 16(8): 671-685.

Weinberg, Alvin M. 1966/1981. "Can Technology Replace Social Engineering?" Pp. 29-39 in *Technology and Man's Future*, edited by Albert H. Teich. New York: St. Martin's Press.

York, Richard. 2006. "Ecological Paradoxes: William Stanley Jevons and the Paperless Office." *Human Ecology Review* 13(2): 143-147.

York, Richard and Brett Clark. 2010. "Critical Materialism: Science, Technology, and Environmental Sustainability." *Sociological Inquiry* 80(3): 475-499.

York, Richard, Eugene A. Rosa, and Thomas Dietz. 2003. "Footprints on the Earth: The Environmental Consequences of Modernity." *American Sociological Review* 68(2): 279-300.