Weeds and Organic Weed Management:
Investigating Farmer Decisions with a Mental Models Approach

Thesis

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By
Sarah Zwickle, B.A.
Graduate Program in Environment and Natural Resources

The Ohio State University
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Thesis Committee:
Robyn Wilson, Advisor
Doug Doohan
Tom Koontz
Gregory Hitzhusen
Weeds are one of the biggest financial, environmental, and social risks in organic farm operations. Experts acknowledge that inherent diversity and site specificity in organic farm systems deter standardization and diffusion of weed management knowledge and long term, preventive strategies. Our data, collected through in-depth, semi-structured interviews with weed scientists, USDA researchers, extension personnel, and 29 farmers in Ohio and Indiana suggests that in the absence of the chemical silver bullet, organic weed management must include a deeper understanding of human decision making systems and agroecosystems. Using the mental models approach, we created conceptual influence diagrams, or mental models, of both weeds and weed management from both perspectives. The models provide a qualitative foundation to understand what organic farmers know about weed management, and, more importantly, how they use their knowledge, experience, risk perception, and emotion to process information and make weed management decisions. This research has both theoretical and practical implications for understanding why farmers, both conventional and organic, make decisions that are beneficial in the short term, but environmentally and economically damaging in the long term. Results show that outreach materials will be more successful if they help a farmer optimize their
experiential/intuitive judgments alongside more analytical processing for efficient and successful long term weed management strategies. Such decisions will help to reduce the immense emotional, ecological, economic, and physical impacts of weeds.
Dedication

Dedicated to the 29 organic farmers in the Midwest who offered their time, insight, and good humor to this research effort. And to my Grandpa Hill and Great Uncle Harold, keep on farming.
Acknowledgments

I am sincerely grateful for the opportunity to contribute to this research project. My advisor, Dr. Robyn Wilson, opened that window for me and has been an especially great advocate and advisor during the last two years. I am also full of thanks for my husband, Adam, my greatest encourager and companion.
Vita

June 1995.................................Goldendale High School, Goldendale, WA

2000........................................B.A. English, University of San Francisco

2009 to present........................Graduate Research Associate, School of

                          Environment and Natural Resources, The

                          Ohio State University

Fields of Study

Major Field: Environment and Natural Resources
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Introduction

“[Weeding] is the process by which we make informed choices in nature, discriminate between good and bad, apply our intelligence and sweat to the earth. To weed is to bring culture to nature—which is why we say, when we are weeding, that we are *cultivating* the soil. Weeding, in this sense, is not a nuisance that follows from gardening (or farming), but its very essence.” (Pollan 2003)

“War, not with cranes, but with weeds, those Trojans who had sun and rain and dews on their side. Daily the beans saw me come to their rescue armed with a hoe, and thin the ranks of their enemies, filling up the trenches with weedy dead…making such insidious distinctions with his hoe, leveling whole ranks of one species and sedulously cultivating another” (Thoreau 2004).

Like Thoreau and countless farmers throughout history, today’s organic farmers are at “war” with weeds economically, emotionally, and physically. Organic farmers’ choice to eliminate chemical inputs from the farm system puts them in much the same position as farmers over one-hundred years ago—finding the right matrix of emotion, motivation, and intelligent management to confront crops’ most persistent competitor. Micheal Pollan, one of the most popular food writers today, concludes that weed management depends on a human’s ability to make informed decisions that bring order to chaos.
In the late 1800’s, the United States Department of Agriculture (USDA) decided to disseminate standardized knowledge about agricultural production methods through land grant universities and Cooperative Extension Services (Lyson 2004). But from their earliest efforts to promote agriculture based on technology, economics, and market demand, the local farmers, rooted in traditional knowledge and culture, have resisted (Lighthall and Roberts 1995; Lyson 2004). During the 1970’s, many farmers began to see the harmful results of industrialized agriculture and chose to return to traditional, organic methods not initially supported by the USDA or the large land grant universities (Buttel 1995).

Because of the original disconnect between science and organic farming, the roots of the organic movement germinated independently from land grant university research and extension services and, as a result, have not been given serious scientific consideration or funding (Allen 2004). This history, combined with a limited understanding or acknowledgement of organic farmers’ experience, knowledge, and beliefs, have proven to be substantial barriers to cooperation between extension services and the organic farm community. The research presented here is an attempt to contribute to the fledgling, but crucial, conversation between organic farmers on one hand and researchers and scientists on the other.

The first chapter presents an expert model of weeds and weed management. It presents both the attributes of the farm (e.g., weed populations, resources, and farm type) and the attributes of the farmer (e.g., knowledge of ecological weed management, risk perception, experience) as crucial factors to understanding weed management decisions. The innovative approach of this model is to include the internal attributes of farmer
decision making as part of the expert model. This highlights the advantage of the model for identifying ways to encourage adoption of ecological weed management. Not only does the model identify three key principles inherent to ecological weed management—recognizing opportunities to manage weeds, utilizing multiple tactics, and managing the weed seed bank—but it also diagrams how the adoption and facilitation of these principles are integrated with the processes of human judgment and decision making.

The second chapter presents the farmer model—a culmination of 29 interviews with farmers in Ohio and Indiana. Through in-depth interviews and the development of conceptual diagrams that represent farmers’ knowledge, beliefs, and risk perceptions, this chapter provides descriptive information regarding organic farmers’ understanding of weeds and weed management. It also includes a comparative analysis with the previously established expert model in order to identify gaps in perception that influence judgment and decisions. The side-by-side comparison of the expert and farmer mental model will focus specifically on three areas: 1) farmer knowledge of ecological weed management, 2) farmer risk perceptions of weeds and weed management, and 3) farmer beliefs and practices regarding the effective use of prevention and control practices.

Finally, the last chapter turns to descriptive models of judgment and decision making in order to describe organic farmers’ weed management decisions. Descriptive models recognize the vital role of risk perceptions, affect, and emotion in the decision making process—all important and prominent attributes of organic farmer decisions—without ignoring the role of analytical processing. Specifically, dual process models describe human decision making as a combination of experiential/emotionally based, or affective, thought processes (system 1) and deliberative, analytical thinking (system 2)
(Damasio 1994; Epstein 1994; Kahneman 2003). System 1 is the first response to a risk, and often includes heuristics, or rules of thumb, based on experience and affect in order to simplify and speed up decisions. We will consider to what extent farmers are using system 1 processing in their weed management decisions.

Each chapter concludes with recommendations, based on the data, to improve collaboration between the organic farm community and the expert community (e.g., weed ecologists, USDA researchers, and extension outreach personnel). If extension agencies and research generated from land grant universities, historically successful conduits for knowledge and innovation transfer to farmers, can facilitate adoption of sustainable weed management practices, it will increase the viability of raising food and fiber without chemicals, and the potential of organic farm systems to create a healthy, diverse, and resilient food system.
Chapter 1

An Expert Model of Ecological Weed Management:

Implications for Farmers

Introduction

Organizational models for improving farm production have a long history of research and application in the United States Department of Agriculture (USDA), the most famous example being Rogers’ Diffusion of Innovation theory (Rogers 1962). Since the late 1800’s the USDA’s Cooperative Extension Services have acted as diffusion conduits between rural farmers and the innovative, agricultural technology developed at land grant universities (Lyson 2004). According to Innovation Diffusion theory, the successful adoption of new technologies requires relative advantage over existing farming systems, less complexity, compatibility, trialability, and observability (Rogers 1962; Brown 1975). The successful spread of innovative weed management practices among conventional farms such as herbicides, GMO crops like Round-up Ready soybeans, and improved machinery, are some examples where disseminating information gives farmers an advantage in the “war against weeds.”

While some organic agribusinesses follow the conventional model of industrial farming, most organic farms rely on ecological systems, rather than chemical and technological inputs, for production (Padel 2001). Farmer collaboration with extension
researchers and scientists could promote the adoption of research based Ecological Weed Management (EWM) practices that save time and labor costs as well as improving cultivation practices that pose risks to soil and water quality. In this ecological partnership, complexity increases, trialability and observability are inconclusive, compatibility is dependent on a diversity of farm resources, and relative advantage cannot be measured solely by the production function (Lyson and Welsh 1995). These factors confound the extension service’s ability to spread replicable solutions for organic weed management (Bastianns, Paolini et al. 2008).

However, like previous attempts to spread best practices for weed and pest control such as Integrated Pest Management and Integrated weed management, adoption among organic farmers has not been successful (Wilson and Tisdell 2001). Diffusion of Innovation theory is apt to describe the a-typical diffusion patterns of weed management on organic farms, but it falls short of a deeper understanding of organic weed management behavior on an individual level. The overall goal of this research is to provide an in-depth study of how beliefs, knowledge, risk perceptions, and experience shape a farmer’s weed management decisions and behavior. The expert model developed in this chapter represents a technical summary of ecological weed management principles that synthesizes the agroecosystem and human decision making system in order to illustrate the attributes of each—farm and farmer—that contribute to certain weed management behaviors.
Ecological Weed Management (EWM) in Organically Managed Agroecosystems

The techniques and strategies of Ecological Weed Management (EWM), often referred to as “many little hammers,” act as filtering mechanisms for weeds and weed seeds at various stages during their life cycle (Gallandt and Molloy; Jackson 1997). EWM increases weed management efficiency without the use of synthetic chemicals, reduces the time and labor required to manage weeds, and provides long term strategies that reduce seed banks and increase biodiversity (Liebman and Mohler 2001; Hatcher and Melander 2003; Gallandt and Molloy 2008; Anderson 2010). Ecological weed management (EWM) has potential to both prevent weeds and improve the health of the environment by increasing diversity in the agroecosystem.

Both the attributes of the farm (e.g., weed populations, resources, and farm type) and the attributes of the farmer (e.g., knowledge of ecological weed management, risk perception, experience) are crucial to understanding weed management decisions. The innovative approach of this research is to include the internal attributes of farmer decision making as part of the expert model. This highlights the advantage of our expert model for identifying ways to encourage adoption of ecological weed management. Not only does our research identify three key principles inherent to ecological weed management—recognizing opportunities to manage weeds, utilizing multiple tactics, and managing the weed seed bank—but it also diagrams how the adoption and facilitation of these principles are integrated with the processes of human judgment and decision making.
making. This paper presents results from the expert model and discusses the three, important EWM principles with the following two questions:

1. Based on results from the expert model, what do experts and weed scientists perceive as the most important risks and benefits of EWM to the farm, the farmer, and the environment?

2. What do experts and weed scientists perceive as the most important principles in EWM for successful organic weed management in the expert model?

Finally, the paper will discuss what the expert model reveals about EWM communication and implementation obstacles in light of judgment and decision making theory.

**Methods**

**Developing the Expert Model: A Mental Models Approach**

*Design.* The mental models approach (Morgan, Fischhoff et al. 2002) has been used as a discernment tool to understand expert and layperson risk perceptions for a variety of risks, including, but not limited to, radon in homes (Bostrom, Fischhoff et al. 1992), climate change (Bostrom, Morgan et al. 1994), and HIV/AIDS (Fischhoff, Downs et al. 1998). There are five elements in the design of mental models research: 1) the expert model 2) mental model interviews 3) the confirmatory questionnaire and 4) development and 5) evaluation of communications. The inner logic of this five-step design is to improve communication directed towards laypeople on how to navigate the risk of a certain phenomena—in this case weeds and weed management.
We use the mental models approach to generate a conceptual diagram of the interactions between weed populations, the agroecosystem, and the decision making process from the expert perspective. This conceptual diagram illustrates how experts structure their knowledge of the complex ecological properties of weeds and weed management in order to optimize agricultural decisions. However, the expert model is more than a diagram of EWM strategies and tactics. It can be used to illustrate how risk perceptions, information processing, and experience influence weed management decisions and may be able to predict what factors contribute to certain types of weed management behavior.

**Procedures.** The expert model was constructed by consulting a community of experts through in-depth, semi-structured interviews and conducting a review of the relevant literature. The literature review creates a foundation for understanding the decision maker (farmer) as well as the decision task (ecological weed management). The interviews collect comprehensive expert knowledge of ecological weed management from a variety of perspectives. There is a plethora of research on the integrated strategies of ecological weed management (Mohler and Johnson 2009; Randal 2009) and preventive strategies (Belz 2007; Gallandt and Molloy 2008; Cardina 2010). However, in order for the expert model to accurately represent the interaction of agroecosystems and farmer decision making, it needs to include how a farmer makes decisions, not just what decision options are available.

For this reason, decision science theory is included as part of the expert model framework. Recent insights into judgment and decision making recognize that decisions are a combination of deliberative, analytical thinking and more intuitive, experience
based thought processes (Damasio 1994; Epstein 1994). Farmers often learn through on-farm trial and error (Bell 2004; Eckert 2006), so including the role of knowledge, experience, risk perceptions, and emotional responses is a crucial link between science-based and experientially-based weed management knowledge.

In addition to the literature review, a total of sixteen experts (e.g., organic farmers, scientists, and extension outreach specialists) were interviewed either by phone or as part of a focus group conducted in Asilomar, CA in the winter of 2010. The members of the group were chosen as representatives of different locations in the United States—the Northeast, the Midwest, and California—and one collaborating scientist from the Netherlands. These experts are recognized in their field for their published research on EWM, their outreach services to organic farmers struggling with weeds, and their direct farming experience with organic weed management. Together, the focus group and phone interviews consist of over thirty hours of narrative data.

The interview protocol for the expert interviews is designed as a semi-structured, open ended interview as recommended for mental model research (Morgan, Fischhoff et al. 2002). It can be imagined as a funnel shaped interview (See Appendix A) that begins with open-ended questions about weeds, weed management, and organic farmers. Once the expert has exhausted his or her knowledge in the open-ended question, the interviewer prompts for more specific thoughts in relation to each topic. Finally, the interview concludes with very pointed questions ranging from weeds and weed management to farmer experiences, risk perceptions, and values. Each expert is given the same interview protocol.
The interviews were transcribed and entered into the qualitative software program MAX Qualitative Data Analysis (MAXQDA). Each interview was coded separately according to a schematic that emerged from the literature review and during the process of analyzing the expert interview transcriptions. The result is a hierarchical coding system based on seven theoretical categories. Each theoretical category consists of one or more conceptual categories with several concepts. Each of these concepts is further broken down into properties and their corresponding dimensions. The qualitative software program is able to track each code back up to its theoretical category, so each comment and phrase in the interview is coded to the level of greatest detail.

For example, the following excerpt was coded to the smallest level of detail (i.e., the dimension) but is traceable back up to its original, theoretical category.

Well I think certainly some weeds are beneficial for erosion. They can protect soil from being bare. They can break up soil. (Researcher D, 25)

The codes assigned include the dimensions of “prevent erosion,” “aerate,” and “cover.” These dimensions describe how weeds benefit the property of “soils.” “Soils” are a property of the “agricultural benefits” of weeds concept located under the conceptual category of “weed benefits.” Finally, “weed benefits” is part of the largest theoretical category in the two models “Perceptions of the Risks and Benefits of Weeds and Weed Management.”
After coding was completed, both theoretical and conceptual categories were analyzed for their importance to experts by the number of times they are mentioned throughout the interviews. Frequency of mention is crucial in mental models research as an indicator of how significant a concept is within the overall structure of the model (Morgan, Fischhoff et al. 2002). In addition, the properties and dimensions of these concepts (fine levels of detail specific to each category and/or concept) were carefully coded. This level of specificity, from a qualitative analysis standpoint, is essential in order to fully portray experts’ conceptualizations of the main categories and how these categories relate to and influence each other (Glesne and Peshkin 1992; Corbin and Strauss 2008; Charmaz 2009). The importance of a particular dimension or property is calculated by the frequency with which it is mentioned as part of its parent concept or category among all the dimensions and properties mentioned by experts.
The completed coding schematic provided the basis for the expert model conceptual diagram (Figure 1). Each category, concept, property, and dimension in the visual model has a corresponding code in the overall schematic. The model was subject to continued, iterative feedback with experts and the decision science literature in order to enhance its validity.

Figure 1. Expert model.
Results from the expert model are reported in three ways. First, an expert’s words will be shown in italics, followed by an anonymous identification and the line in the interview where the quote is found (i.e., Researcher Z, 348). Second, the frequency of mention will be reported in parenthesis (i.e., the number of times that particular category, concept, property, or dimension was coded). Lastly, the frequency of mentions will be reported as a percentage of that particular response within its parent category, concept, or property. The percentages reflect the importance and weight of that particular category, concept, property, or dimension within the experts’ conception of successful, ecological weed management.

**Expert Model Results**

The expert model consists of seven main theoretical categories—four that lead up to a weed management decision and three that represent the outcomes of those decisions. The categories preceding the weed management decision/behavior represent a synthesis of human decision systems and agroecosystems: Farmer Attributes, Farm Attributes, Risk Perceptions, and the Dual Process Filter. The two main categories after the weed management decision—Prevention Strategies and Control Tactics—represent a continuum of possible weed management behaviors. Experience/Trial and Error is included post behavior and feeds back into the internal, experiential attributes of the farmer.

**Before the Weed Management Decision.** Within the seven main theoretical categories, 2,900 separate responses were coded. Among experts, the most discussed
Theoretical category before a weed management decision was Farmer Attributes with 1,061 separate responses coded, over a quarter of the total responses. Within this category, knowledge of EWM was the most discussed conceptual category (333, or 31% of the Farmer Attribute coded responses), and learning about weeds and weed management was the second most discussed conceptual category (311 total responses, or 29%). The robust size of these categories reflects expert’s focus on correct knowledge and farmer learning as crucial for successful weed management.

![Diagram of Farmer Attributes and Farmer Knowledge](image)

Figure 2. Farm and farmer attributes theoretical categories with subsequent conceptual categories. Frequency of response follows the conceptual category heading. Overall percentage of response within its parent category is included in parenthesis.

The second biggest theoretical category was Perception (Risks and Benefits) of Weeds and Weed Management with 741 mentions (Figure 3). These perceptions include conceptual categories that cover the risks and benefits of weeds (167 and 65, respectively) and the risks and benefits of weed management practices (244 and 102,
respectively). The model highlights expert’s risky perceptions of weeds and weed management—over two times as many risks as benefits.

This theoretical category also includes expert perceptions of the mechanisms of weed introduction (59 mentions) and spread (84 mentions). Within these conceptual categories, experts believe that agriculture is the main cause for weed introduction (59 mentions or 86% of total responses to introduction of weeds) and spread (84 mentions or 68% of total responses to spread of weeds). Domains outside of the farmer’s control, such as nature (3 and 8 mentions under introduction and spread respectively), wildlife (9 mentions under spread), society (5 mentions under introduction) or biological mechanisms (12 mentions under spread), were peripheral statements.

The strength of expert responses to agricultural introduction and spread reflects a belief that weed problems originate on the farm with farmer decisions (i.e., spreading uncomposted manure, tilling in waterways, or using off farm straw for mulch). This belief is both good and bad news for farmers. It contends that farmers are the ultimate agents of success or failure when it comes to successful weed management decisions.
Figure 3. Perceptions of weeds and weed management theoretical category with subsequent conceptual categories and concepts.

Following the Perceptions of Weeds and Weed Management, the Dual Process Filter theoretical category models how farmers utilize the prior categories—attributes of the farm, attributes of the farmer, and perceptions—in their information processing. It represents the farmers’ use of analytical and experiential/emotional information in judgments and decisions. According to theories of judgment and decision making, choices are a combination of deliberative, analytical thinking (system 2) and experiential, affective thought processes (system 1) (Damasio 1994; Epstein 1994). These two systems work in tandem, each facilitating and guiding the other during the choice process in unique ways.

Based on this theory, the dual process filter includes information important to deliberation in the Systematic Processing conceptual category. Farm parameters (157
mentions) are one of the most important parts of analyzing weed management options. In the expert view, farm parameters help to define the boundaries of the decision task. These parameters include farm resources (99 mentions) such as cash flow, land ownership, available tools, markets, and labor. Parameters also include regulations that organic farmers must follow to be certified (55 mentions) such as the National Organic Program (NOP) standards, market requirements, and alternative certifiers. Cost benefit analysis was also mentioned by experts and is another key piece of analytical processing.

Dual processing also includes the conceptual category Heuristic Processing (209 mentions). While not identified specifically as heuristics by experts, any time an expert mentioned ways they thought farmers used short cuts to simplify their decisions it was coded as a heuristic. These include emotional reactions to weeds and weed management (78), affective responses to weeds and weed management (2), and heuristic tools (129) such as the use of affect and emotion in the decision making process. Weed tolerance levels were important an important part, or property, of heuristic processing in the expert model (103 mentions). Experts perceived farmers to tolerate (49), tolerate to a certain threshold (33), or have zero tolerance towards weeds (21). These tolerance levels may be influenced by farmer risk perceptions and be used as heuristic decision tools in their weed management decisions. For example, a farmer who tolerates weeds to a certain threshold would calculate the time to take weed management action by waiting until weeds covered at least 20% of his or her field.
The Weed Management Decision/Behavior. There are three main categories after the weed management decision. Control Tactics (226 mentions) include the concepts mechanical (169), cultural (33), and organically approved herbicides (12) (see Figure 4). It is clear that mechanical means of control are most salient to weed scientists and extension personnel. Prevention Strategies (319 mentions) include crop choice/cultivars (22), mulches (29), crop rotation (58), and seed bank management (130). The seed bank management concept includes several filtering techniques for seed rain inherent in EWM such as seed predation, mowing, nutrient management, and appropriate cultivation/tillage. All of these techniques work to capture or filter weed seeds before they enter back into the soil. Experts will often refer to these filters as they describe EWM.

The last theoretical category, Experience/Trial and Error (36), acts as a feedback loop into the internal attributes of the farmer. Specifically, its conceptual categories of
observing a change in weeds (11) and gaining new knowledge through trial and error (14), feed back into the farmer’s expansion or limitation of their next weed management decision. Experience plays an important role in the dual process filter as the basis for short cuts and cognitive biases present in farmers’ choice behavior.

Figure 5. Weed prevention strategies and control tactics (as a continuum) and experience/trial and error theoretical categories.

Discussion

Three Ecological Weed Management Principles

If a farmer wants to succeed in managing weeds, experts agree that he or she must harness ecological processes to benefit the crop rather than the weed. Experts explain that working in partnership with ecological processes requires a holistic understanding of how weeds operate in the agroecological system so that opportunities to manage a weed are optimally utilized. This section summarizes the comprehensive set of measures found in the expert model that are identified as part of EWM and the risks and benefits...
associated with these measures: utilizing multiple practices over time, recognizing opportunities to manage weeds, and managing the seed bank.

1. **Using Multiple Practices: Prevention Strategies and Control Tactics**

**Prevention strategies**

*It’s about the timing and the opportunity to preempt seed rain.* (Researcher F, 502)

According to experts, weed prevention is a long term strategy that reduces the opportunity for weed seeds to be introduced and spread throughout the agroecosystem. Experts contend that farmers have several EWM options to choose from, and these choices have multiple effects in the agroecosystem. The expert model’s conceptualization of prevention strategies illustrates the range of opportunities available.
to farmers at various stages in the production process (319 coded responses). Within this category, seed bank management (40% of coded responses), cover crops (23% of coded responses) and crop rotation (18% of coded responses) were the most discussed. The number and complexity of prevention strategies means that there are plenty of opportunities to prevent weed seeds, but it also increases the opportunities for risk when utilizing these strategies.

**Prevention Risks.**

*If you’re depending on the rotary hoe or cultivation, boy, you’ve got to be out there every day to see when that white stage of those weeds are at peak so that you get those hoed out (Researcher A, 115).*

Prevention risks are divided into four concepts—agricultural, ecological, social, and economic. In each of the four concepts, timing is a critical factor in the success or failure of these strategies. If the appropriate timing for a prevention strategy is not known, taken advantage of, or available, weed seeds will enter back into the soil. As a result, preventive strategies may appear to be ineffective and discourage farmers from adopting them.

Besides designing effective crop rotations and cover cropping strategies, which will be discussed later, the initial opportunity for filtering weeds is during spring tillage. Different types of tillage techniques can be used to prevent the first flush of weeds. For example, no-till methods combine heavy mulching and non-disturbance of the soil to keep weed seeds dormant. Shallow tillage disturbs the top few inches of the soil, leaving weed seeds at greater depths dormant. The stale seed bed technique stimulates weed
seeds on purpose in order to destroy them before they set seed and flush out the seed bank in the top few inches of soil before planting a crop.

The second opportunity for prevention can be done by simply mowing or cultivating weeds before they set seed. The third opportunity for preventing seeds from entering into the seed bank occurs after the weed seed has developed and fallen to the ground, but before incorporation through tillage. If a farmer delays fall tillage, they can encourage weed seed predation by beetles and mice, reducing the weeds seeds that return to the soil.

Each of these strategies is highly dependent on windows of opportunity determined by farm attributes like weather, soil type, and cropping system. For example, when attempting to encourage seed predation, the window of opportunity for delaying tillage may be too short for the predation to take effect. If the farmer plans on introducing a winter cover crop, he or she may need to disturb the ground before predation has a chance to take place in order to establish a good crop stand. Stale seed bed strategies may be hindered by cold, wet springs that delay weed seed germination and inhibit cultivation due to wet soils.

Implementing prevention strategies also poses significant challenges. If prevention strategies are not done with skill, a farmer may actually increase the seed bank and the resulting weed population (see appendices C and D). Economic risks include a poorly sown cover crop that allows weeds to germinate between the desired plants, requiring additional labor and time. In addition, higher seeding rates are costly and organic seed is more expensive. If the cover crop is left in the ground for too long, germinated weeds have time to set seed and increase next year’s seed bank—an
agricultural risk. Denser planting could also decrease air circulation and increase disease—both an agricultural and ecological risk. These are a few examples of the risks of prevention implementation that can add up for the farmer with little benefit to show for it.

In addition to these risks, there is a high learning curve to implementing prevention tactics. Experts emphasized that systems thinking is integral to prevention success, and farmers who conceptualize weeds as part of a complex system will have a better understanding of how to filter out weeds at various stages in their life cycle. In other words, the success of prevention strategies depends on the farmer’s knowledge level and ability to implement the correct strategy in the right place and at the right time.

**Prevention benefits.** It is obvious from the model that prevention strategies involve more agricultural, ecological, economic, and social risks. However, the model also illustrates that prevention strategies provide more long term benefits than control tactics. The model shows that all of the benefits to be gained through prevention strategies depend on correct implementation. In fact, some experts emphasized that implementing prevention strategies can greatly reduce the amount of money and time spent on control tactics throughout the season.

The most prominent concept under prevention benefits is agricultural, with over half of the benefits (51% of coded responses). The benefits include a wide range of ways that prevention strategies improve the health of the farm. Improved soil structure, increased organic matter, improved drainage and aeration to increase cultivation windows, and a reduction in seed rain are just a few of the expert examples.
Prevention strategies are also their own, long-term antidotes to the initial economic risks. Here is one expert’s explanation of the long-term, economic pay off of including hay (an important cover crop for nitrogen replenishment and weed suppression) in the crop rotation:

*And the rotation may be in a few years of a crop that is not as economical, and that's why some people would not want to put hay in the rotation because when they go to sell that product, it's much less value…but if you look at the whole system over 5 or 6 years, the increase of yields in your corn or soybeans would offset the loss of the hay years.* (Researcher G, 103-106)

Experts noted that these benefits may not be immediately obvious. For example, flaming, while perceived to be a waste of fuel, may actually save fuel when compared to hiring labor that has to drive out to the farm. Plastic mulch increases crop yield and saves hours of hand weeding. However, the risk of prevention conceptual category has a larger number of coded responses than the benefits category (118 to 68, respectively), suggesting the risks of prevention are more salient to experts and, in turn, farmers. In order to promote adoption of prevention strategies as part of EWM, experts must be able to communicate EWM in ways that emphasize the long term benefits of prevention strategies over the short term costs.

**Control Tactics**

Control tactics are short term techniques that focus on visible weeds competing with the crop. They are implemented with one goal in mind—to reduce competition for the current season—and are separated into three concepts: mechanical control, organically approved herbicides, and cultural practices.
**Control Risks.** Experts discussed control risks mostly as part of mechanical tactics, and the biggest opportunities for risk in mechanical control are due to ineffective implementation. For example, hand pulling may not remove enough of the plant’s root to discourage its re-growth. Mowing may actually encourage weeds to send out second shoots (or tillers) that increase the amount of seed production for that weed. Tillage can spread weed seed from field to field, and cultivation may not kill the entire plant as well as cause damage to the crop.

In addition, experts talked about weed control success as dependent on timing. If a farmer misjudges or misses a cultivation window due to weather, weeds will have a chance to outgrow the crop and reduce yield. Weather, equipment, and labor may all inhibit the farmer’s ability to be in the field at these crucial cultivation windows.

The second most discussed risk was economic (34% of coded control risks responses). Experts described the economic risks of control tactics solely in terms of time and labor. All 41 of the coded responses dealt with the cost, availability, and intensity of time and labor involved in controlling weeds by hand. The third most salient risk to experts was the ecological impacts of implementing control tactics—most notably, the risk to soil structure and erosion (54% of the coded responses under ecological risks of control tactics).

**Control Benefits.** The benefits of control were coded half as many times as the benefits of prevention (33 and 68, respectively). However, while the benefits of prevention were mostly found in the long-term, the benefits of control techniques have immediate advantages. Tractors are less dependent on weed density, the techniques are
simpler and more obvious when to implement, and correct implementation can reduce seed rain if prevention strategies fail.

Most of the benefits discussed were located in the economic sphere (42% of control benefit coded responses). These had to do with capitalizing on human labor and cultivation/tillage tactics. Such a benefit may only be possible if the farm parameters allow it. A small farm with little cash flow dependent on family for labor would not be able to take advantage of this benefit. The one cultural benefit mentioned frequently was the advantage that tiling offers to widen the windows of opportunity for cultivation.

Mechanical benefits were also mentioned, especially the ability to be precise in weed control, to cover more ground in less time with larger equipment, and to be able to weed in the rain in the case of flaming. Control also offers the immediate satisfaction of looking down a long row and seeing concrete results of hard work, whereas prevention strategies do not offer this type of immediate feedback. The presence of weeds in the farm system is a constant reminder of their impact on yield, time and labor, and even public perception. Implementing prevention strategies and waiting years for them to take effect will not resolve these consequences right away. However, immediate weed control temporarily removes stress and perceived impacts on yield by removing the weed itself. This may be one of the biggest factors in choosing to implement control tactics immediately rather than waiting for prevention strategies to take effect.

**Type, timing, implementing, and locating.** The most illuminating aspect of this component of the expert model is that successful weed management goes beyond simply identifying what type of weed is present in the field. Successful management
decisions for both prevention strategies and control tactics depend on four qualifying features found in each category.

1. **Type** of technique or strategy chosen appropriate to weed reproduction (e.g., type of tillage, type of cover crop, type of rotation)

2. **Timing** of the technique or strategy appropriate to weed life cycles and phenology (e.g., fall tillage, pre-empting seed rain depending on annual or perennial weed cycle)

3. **Implementing** the technique or strategy with skill (e.g., good crop stand, density, and temporal and spatial diversity)

4. **Locating the** appropriate place to apply the technique (e.g., intra and inter-row, field edges) of a mechanical control measure

As a result, even though prevention and control measures will be unique according to weed populations, soil types, and climate, the ecological principles of type, timing, implementing, and locating remain constant. These principles appear in both the prevention and control categories, highlighting the temporal and spatial risks and benefits inherent in ecological partnerships. In addition, the prevention and control categories, while separate in the model, function as a continuous dependent variable. Experts agree that farmers will practice some degree of both prevention and control, but the principles of EWM are mainly found in the prevention strategies. The next two sections discuss crucial attributes that motivate farmers to lean towards more prevention or control techniques.

**2. Recognizing Opportunities to Manage Weeds**

In addition to using multiple prevention and control practices, another principle of successful EWM hinges on a farmer’s ability to recognize when, how, and where to
manage weeds. Recognition is based on three main concepts in the expert model: 1) understanding agroecology, 2) the organic farmer’s ability to identify weeds with their knowledge base, and 3) the contextual (e.g., farm resources) and internal (e.g., risk tolerance, knowledge) attributes of the farm and farmer that determine what measures are available to manage that weed at a particular point in time.

**Concept 1: Understand Agroecology**

*What I’m interested in is listening closely to the ecology of the system and seeing if the ecological interactions between the different components of the agroecosystems suggest methods or practices that haven’t been tried yet.*

*(Researcher I, 384)*

Experts talked extensively about the idea that ecological complexity blurs the cause and effect of weed management practices, making evidence based management hard to come by. In fact, this is the most frequently mentioned (134 separate responses) property of the concept “recognizing opportunities to manage.” Many of the dimensional qualities are concerned with the interconnected effects of farmer management and weed populations. While experts place the responsibility for weed introduction and spread squarely on the shoulders of farm management, they also admit that it is hard to discern which management practices are having what effect on weed populations and density.

Another property of understanding agroecology is the weed/soil relationship. Experts mentioned that agricultural soils invite weeds with their high nutrient content and fine seed beds. They also acknowledged that weeds may be indicative of soil structure. For example, grasses may grow well in compact soils found in the tracks of tractor wheels. What experts do not agree with, however, is the idea that weeds indicate a lack
or presence of soil nutrients. Experts felt this belief was shared by many organic farmers, and while they gave a nod to this idea, were skeptical of any causal link.

If experts, who study the interactions of ecology and farm management in controlled experiments, have a difficult time discerning cause and effect, we can expect that farmers might as well. Experts emphasized the need for patience and systems thinking in order to determine if prevention strategies are, indeed, lowering or raising the seed bank. Approaching weed management with this kind of skeptical curiosity is the first step in recognizing opportunities to manage weeds.

**Concept 2: Weed Identification**

*I mean, that’s the foundation really...understanding the biology of the weed—identifying.* (Researcher A, 115)

Experts emphasized that weed identification includes not only being able to name the weed, but also knowing the weeds’ phenology, biotype, and life cycle. This knowledge helps the farmer recognize it from the earliest to the latest stages of its life cycle. Understanding weed biology, experts said, is a crucial step in understanding when and how to manage a weed. It is also required for success in choosing the right type, time, location, and implementation of EWM tactics.

A biologically based understanding of the weed provides a farmer with the ability to decide when the weed life cycle is optimal for management. For example, experts agree that the most effective times for weed control are the “white thread stage” and the “critical weed free period.” Successful, strategic timing is dependent on this knowledge of the weed’s biology and life cycle.
The type of technique or strategy used to manage a weed also depends on weed identification. Understanding the weed’s reproductive strategies helps a farmer decide on a mechanism that will best prevent further growth. Perennial weeds will need strategic implementation of cover crops and crop rotation to be eliminated from the farm system. Weeds that spread through rhizomes require constant mowing in order to deplete their energy stores. For perennial weeds such as Canada thistle, this strategy is crucial for management success. Annual weeds need frequent, short term treatments such as mowing and short term cover cropping. For example, if a cover crop is left in the field too long before incorporation, annuals will have time to germinate, grow, and set new seed, negating the effect of that particular prevention strategy.

Besides the type and timing of EWM, locating where to use a weed management tactic is important when the goal is to limit a germinated weed’s impact on crop yield. Intra or inter-row cultivation is an example of locating control techniques where they will be most effective at damaging the weed and not the crop. Mowing field edges and ditches is another example of recognizing where to implement control based on the location of the source of new weeds.

The above examples bring to light three crucial ways to identify a weed—how it spreads, if it is a perennial or annual, and where it prefers to grow. These indicators lead directly to knowing when, how, and where to implement the weed management strategy. These three principles can be used by farmers as decision tools when designing their cropping system to combat particularly troublesome weeds such as Canada thistle or foxtail.
Concept 3: The farm attribute, farmer attribute, and farm parameter

matrix. The expert model is structured around both internal and external attributes of the farm and farmer. These attributes are what determine whether a farmer will decide to implement more prevention or more control practices. Experts are particularly attuned to how farm parameters operate in weed management decisions. Farm parameters include on-farm resources and farm regulations. To illustrate this concept, an expert described how available equipment and cash flow (resources) can expand options for controlling a weed:

I saw a great video of a very successful organic vegetable farmer from Pennsylvania...and he said, “I just do NOT have time to worry about my seed bank. I just don’t have time.” And he addresses his weed problem then by making sure that he is really well capitalized to do a good job on the critical weed-free stuff, so he has lots of tractors...as the weed pressure goes up, he buys more tractors. It didn’t work. (Researcher F, Asilomar Session 1, 465)

In this case, the researcher reports that farm parameters expanded the farmer’s options according to his need for efficient weed control, though his capitalized approach to weed management did not guarantee success. Farm attributes enhance or confound the ability of a farmer to implement EWM principles. Researcher F describes a scenario where adding cows to the farm system would diversify the enterprise and provide more filtering opportunities for weeds:

For example, if you had cows, things would really change. Now suddenly you wouldn’t have too much land, you would have a third of your pasture with cows grazing on it and the whole set of options is different. Every time you add an enterprise, the level of complexity and filtering that goes on over time increases.
dramatically and it’s that sort of level of stresses and filtering over time that ends up being the weed pressure that you see (489).

External parameters alone, however, cannot account for successful EWM. The internal attributes of the farmer mediate the successful implementation of management tactics. According to experts, farmer knowledge is the most important concept in a farmer’s internal attributes for managing weeds successfully, but the depth of knowledge increases with each farmer’s experience. Experience increases the farmer’s ability to observe, recognize, and understand the dynamic between management decisions and weed populations.

In combination, attributes of the farm and farmer do, in fact, influence what management options a farmer is able to recognize and implement. These attributes of the expert model flesh out possible management opportunities that result in each farm’s unique weed community. For example, farmers who plan their crop rotation on markets (farm parameters) may have different weeds than farmers who plan their crop rotation based on long-term health of the soil.

[The farmer thinks], I should grow a certain crop on this field this year because that’s better for the soil, better for the whole system, even when the prices are not good. But there is also the other side, the other type of organic farmers here who really keep an eye on the market prices and change the whole rotation…they also have a lot more weed problems and require a lot of manual labor to control the weeds, but on the other hand, they have the resources to hire them. (Researcher D, 333)

Playing the EWM card game. To help understand how weed identification, farm parameters, and key attributes of the farm and farmer influence successful EWM
according to the expert model, imagine these concepts as two separate decks of cards. The first deck contains a card for each weed. This deck is specific to geographical regions of the United States. The second deck—the deck of farm parameters and farmer attributes—is unique to each farmer. This deck includes many different suits; resources, equipment, and regulations, as well as a farmer’s unique set of knowledge, experience, values, risk perceptions, emotions, and personality traits.

The key to playing a successful hand begins with correctly identifying the weed card. Once the weed is identified, will the farmer know all the details of that particular weed’s life cycle? The more knowledge a farmer has about the weed, the more likely he or she will be able to play the most appropriate type of management card, at the right time, in the right place, successfully. Questions the farmer will consider after a weed card has been identified might sound like this. How much of a risk is that weed to my farm? What prevention or control measures do I know that are appropriate for this weed? What kind of equipment is on the farm, and how much labor can I afford? At what time will I implement these measures?

The expert model demonstrates that the more diverse a set of cards the farmer holds, the more possibilities they will have at successfully managing the weed card that is played. Successful, long term effectiveness of EWM is only possible if the farmer’s deck has enough cards to play. The larger a farmer’s deck is, the more filters will be introduced, decreasing a weed’s likelihood of surviving into the next season, or round of the card game.

But success does not depend solely on having diverse options. It also depends on correctly implementing the most effective, available card at the most effective, available
time and location. Events contextual to the game—weather, labor constraints, and markets to name a few—can limit a farmer’s ability to play these cards. But holding more “little hammers” from both prevention and control tactics allows the farmer to adjust more effectively to these uncontrollable elements.

Researcher F explains why a diverse deck of cards leads to more weed management success. The variability inherent in organic farm systems cannot be mediated by sophisticated technology or blanketed by chemicals. Instead, a farmer must build flexibility into his or her management plan.

*On any given day you don’t know what this year’s weed is going to be and you don’t know which tool to pull out to combat it.* (Researcher F, 298)

According to experts, the more a farmer knows about weed identification and management possibilities, the more their hand is expanded and their ability to adapt to external circumstances increases. In addition, the expert model includes experience as a feedback loop into farmer knowledge. Experts agree that experience will improve and expand a farmer’s hand the next time around.

Recognizing opportunities to manage is especially important to farmers who are transitioning from conventional to organic agriculture. Experts, especially outreach extension personnel, talked about the limitations of a conventional farmer’s deck because they have limited experience managing weeds without chemicals. These farmers may not have added much in the way of diversity, resources, or knowledge to their hand in many years because they held the trump card—herbicides. For example, experts often talked about the effect of low knowledge on weed management decisions. Low knowledge may
be an attribute of farmers in transition to organic as well as new organic farmers with little or no agricultural experience.

*When people come to organic farming having been a conventional grower, you’ve got the mindset of; okay, we’ve got a weed problem, we need to react to it, and how can we kill them? And the seedling is the most visible, tangible stage for farmers to deal with the weeds, and so they get out there and they deal. It’s a lack of knowledge of the whole weed lifecycle* (Researcher I, 338)

*It’s a lot more complex system than conventional, so it’s a much more information intensive system.* (Researcher B, 65)

The expert comparison of conventional to organic farm systems highlights the knowledge gaps in a farmer’s deck of “many little hammers” that can effect beliefs about weeds and result in management decisions based more on control tactics than prevention strategies—a suboptimal decision according to EWM principles.

### 3. Managing the Weed Seed Bank

*In the one hand you want people to understand that the seed bank’s important, seed dormancy is important, but that ends up making you [the farmer] feel, oh it’s helpless, they last forever anyway. And it’s not really true because what is true is that half of them will die in that first year* (Researcher F, Asilomar Session 1, 383)

Weed scientists, especially weed ecologists, agree that decreasing the seed bank in agricultural soils is not only possible, but also necessary to reduce the time, labor, and cost of weed management in the long run. However, experts also perceive farmers to hold deeply ingrained myths about the seed bank—that seeds live in the soil for
thousands of years. This fatalistic understanding of the seed bank may be one of the largest obstacles to effective seed bank management.

We have already shown that experts believe that the spread and introduction of weeds and weed seeds are largely a result of agricultural practices. As such, agricultural practices are also responsible for either increasing or decreasing the weed population. Experts contend that if farmers actively manage their seed bank with two of the biggest filters in EWM—crop rotation and cover cropping—the seed bank will gradually decline. In order for these two tactics to be effective at reducing seeds in the seed bank, the expert model emphasizes three evidence-based steps: know your seed bank, coordinate the timing of disturbances, and implement cover crops and crop rotation correctly.

**Step 1: Know your seed bank.**

*You [the farmer] shouldn’t be using long term cover cropping strategies unless your seed bank’s already low and things are in control. If your seed bank is high, and you’re using a full season of red clover, it doesn’t help weed pressure enough, so switch to something that has more disturbance.* (Researcher F, 251)

According to the experts, the first piece of knowledge a farmer must have for proper implementation of crop rotation and cover cropping is their weed seed bank levels. The level of the seed bank should directly influence when and how often a farmer disturbs the soil. For example, research in EWM shows that a high seed bank requires short term crops, whether pasture, cover crops, or cash crops that will be mowed or tilled with more frequency throughout the season. Without frequent disturbance to germinate weed seeds and destroy them before they reproduce, high seed banks will germinate and set seed continuously, exploiting the niche that long term crops provide.
Research in EWM also shows that in soils with lower seed banks, longer term crop rotations and cover crops can be used. However, weeds cannot be allowed to set seed within these long term rotations. Mowing, grazing, and tillage are effective tools for preventing weed seed production in longer rotations. Pasture based systems offer the most flexibility in timing and disturbance during crop rotations. Animals can disturb and destroy weeds at regular intervals, mowing for hay means weeds will not have a chance to set seed, and a larger land base provides more opportunities for crop diversity and long term cover crops.

According to experts, diversity and holistic management of crop rotation and cover crops is cited as the most effective tool for inhibiting weed development. Crop rotation diversifies the plant population to reduce selective pressure on weeds. The more integrated a cropping system, the less likely it will mimic the growth cycle of weeds, discouraging their reproduction. The more diverse the agroecosystem, the more opportunity for designing a farm system that incorporates appropriately timed disturbances. Knowing the seed bank make up and density, and designing the farm system, are two sides of the same coin.

**Step 2: Coordinate timing of disturbances.**

*You could have one [crop rotation or cover crop] that depresses it one year and then explodes the next year and depresses it and explodes, and that’s not really about the crops. It's about the timing of the disturbances and the likelihood for weed control to be sufficiently successful that you prevent seed rain.*

*(Researcher F, 494)*
This quote, and others like it, emphasized the timing of soil disturbance as a key concept for seed bank reduction when deciding the length and type of crop rotations, the length and type of cover crops, and the use of animals or machinery for disturbance. When a production and/or cover crop is planted, it may not be able to out-compete the weeds stimulated through preparation of the seed bed unless the timing of the disturbance is coordinated with ecological rhythms.

For example, experts talked about crop rotations that can be designed to disturb soil at times that benefit crop over the weeds. Diversifying cool and warm season crops prevents the selective pressure of weeds that tend to grow only in certain seasons. Weeds cannot exploit a niche if that niche is constantly being rotated through a diversity of crops, cover crops, and/or pasture.

In addition, experts stressed that disturbance can work for the benefit of the farmer. The stale seed bed technique uses tillage disturbance to germinate weed seeds in the seed bank and then destroy them. Repeating this disturbance several times flushes out germinable seeds. This strategy requires a later planting date, but in the absence of weed competition, the crop will have more access to water and sunlight and be able to make up for lost time.

There are many types and kinds of cover crops, but one of the most important descriptive properties of the cover crop category according to experts is that allelopathy—a chemical property in plants that may inhibit seed germination—alone does not determine efficacy. Allelopathy can account for some of the seed reduction (Belz 2007), but weeds may take just as much of a hit through the timing of disturbance in a bare fallow system as they do in fields of cover crops (Gallandt and Molloy 2008).
Overall, experts communicated that timing disturbance of the soil to stimulate weeds and then pre-empt seed rain with agricultural prevention strategies are the most important factors in reducing the seed bank. Such a concept is not restricted to organic farm systems, but is an ecological concept that can be used in both organic and conventional agroecosystems.

**Step 3: Implement cover crops and crop rotations correctly.**

While timing of disturbance is important, cultural factors need to be implemented at the correct time and with skill for the crop (cover or production) to successfully out-compete the weed. For example, careful nutrient placement will give the crop a head start over the weed, promoting good canopy production. Dense seeding and successful germination of cover crops is crucial for discouraging weed seed germination.

Even after weeds germinate, farmers can use appropriate tillage tactics at the right time to knock back a weed. The white thread stage and the critical weed free period are times during a weed’s life cycle where knocking back the weed will give the crop enough space to out compete. Experts explain that white thread refers to the un-emerged weed seedling that lacks chlorophyll, and the critical weed free period extends from weed seed germination until some point in the future when the crop can no longer grow without being impeded by weed growth. The longer a farmer waits beyond the white thread and critical weed free stages to control the weed, the more difficult it is to do so.

Cultural techniques can give a cover or production crop a boost over weeds even if it was planted too early or too sparsely. The expert model provides insight into how timing of disturbance (i.e, tillage and cover crop incorporation) combined with nutrient
placement, crop choice, and other dimensions of seed bank management result in an increase, decrease, or stabilization of the seed bank. See Figures 5 and 6 for example flow charts predicting how various management choices alter a currently high versus a currently low seed bank.
Figure 7. Cover crop implementation and effect on seed bank.
Optimal crop rotation for weed prevention is based on choosing competitive crop varieties, breaking weed cycles, diversity of warm and cool season crops, and rotations of 4+ years that include forages. Nutrient levels, the placement of nutrients, planting time, timing of disturbance and moisture levels will affect the ability of both the crop and the weed to germinate. Canopy structure is a result of disturbance, timing, nutrient management, and seeding practices at various stages of crop growth, but especially during the critical weed free period where knocking back the weed will give the crop enough space to out compete the weed completely.

Figure 8. Crop rotation/choice implementation and effect on seed bank.
Implications for Extension Communication and Outreach

The expert model of EWM is inherently complex, and successful behavior is dependent on both internal attributes of the farmer and external attributes of the farm—a unique combination of human and ecological systems. This complexity introduces at least three potential obstacles to successful implementation of EWM.

1. Without communicating the benefits of prevention strategies inherent in EWM, farmers may continue to search for shortcuts when making management decisions.

2. Complex interactions between the agroecosystem and the chosen management strategy delay the visible benefits of EWM.

3. The knowledge and long term strategizing required for successful EWM means it will be more dependent on the internal attributes of the farmer (e.g., risk tolerance, risk perceptions, and knowledge) than on prescriptive “best practices” approach commonly used in innovation diffusion.

Short cuts.

*If you’re depending on organic approved herbicides as your control measure, you’re probably less likely to do the other kinds of things that would make your system ecologically strong. I’m much less interested in organic agriculture than I am in ecological management of weeds (Researcher I, 480).*

The limited time and effort organic farmers have to dedicate to understanding the scientific reasons for successful EWM in a complex system may push them to look for shortcuts that simplify such a complex decision-making process. It is understandable that organic farmers look for cheap, immediately visible ways to manage weeds. Organic farmers are not immune to the temptation of shortcuts in weed management. Unlike
conventional farmers, they are short one sure-fire option—chemicals. One of the biggest issues in organic farming is the lack of time and labor to accomplish everyday tasks. This fact may encourage farmers to use heuristics in decision making—making a decision based on the best information a farmer has in the time allowed (Plous 1993). In such a case, short term control measures that offer immediate results and are simpler to execute may be preferred. If organic farmers are still searching for these shortcuts, then the long term strategies so important to EWM will be unpalatable.

For example, experts explain that farmers tend to believe the allelopathic qualities of certain cover crops act as a kind of organic herbicide. According to experts interviewed, allelopathy is only a small piece of cover crop efficacy. Of bigger concern is the need for appropriate plant density and crop stand, leaving the cover crop in for the right length of time, and disturbing the weed seed bank to flush out weeds then destroy them. Without this knowledge, farmers may spend time and money on cover crops that fail to reduce weeds.

Farmers may also feel that capitalization—e.g., buying more tractors or hiring more workers—is the only solution to managing weeds. This mechanized approach may offer immediate short term control, but at what cost? Not all farmers are able to capitalize their operation, and control tactics fail to address the unseen root of the weed problem, the seed bank.

Of particular concern to experts is the trend in organic farming that recommends soil fertility balance as an end to weeds. Many organic magazines and books present a direct relationship between weeds and soil nutrients. Expert scientists and extension personnel do not agree that this kind of relationship actually exists, but have yet to study
it in depth. This is one area where scientists and researchers may be able to focus research on the practical questions of farmers and begin a larger conversation about what makes EWM successful.

**Complexity and the delayed benefits of EWM.**

*Proof* is going to be delayed, that lag period of several years, if you're going to do some type of demonstration well it's going to have to prove itself for a number of years before you're going to convince anybody (Researcher G, 322).

Weeds scientists, USDA researchers, and extension personnel admit that without a chemical “silver bullet,” organic farmers must invest considerable time and labor to manage weeds. The ecological approach to weed management in organic farm systems is a long term process filled with complexity, so immediate results are not an option. There is no “herbicide-like” prescription in EWM. This observation by experts presents yet another risk to adoption of prevention strategies—the often indeterminable cause and effect of long-term management decisions.

The long-term filtering tactics of EWM can be a deterrent to implementation in many ways. In the context of market pressure, little time and labor, and limited resources, the immediate results of control can outweigh the far-off benefits of prevention. In other words, farmers decide control is a more viable option year after year, rather than implementing prevention strategies that may or may not work a few years from now.

Experts recognize there is little evidence-based research to support EWM’s economic, agricultural, and ecological benefits. When experts discussed “science/research” as sources for EWM knowledge (over half of the coded responses),
they emphasized the need for proving the effectiveness of long term planning (23), organizing organic research (19), generating research questions from farmers (19), building more evidence based information (15), and connecting with farmers (10).

Like other studies, our model suggests that in order to promote the adoption of ecologically based weed management tactics, experts must communicate the benefits of EWM to organic farmers in concrete terms (Bastianns, Paolini et al. 2008; Swanton, Mahoney et al. 2008). How much labor will it save over time? What makes a tactic successful? How much will a farm lose in income while waiting for the seed bank to deplete? Will this loss be recovered once weeds are under control?

The first step to answering these questions is providing correct knowledge to farmers not only about what management tactics are available, but also about the risks and benefits of these tactics. For instance, the ecological approach to weed management is encouraging in that there is not just one tactic to get right, but many opportunities to manage weeds over the course of a season and even several years. Implementing prevention strategies now will save labor and time on control tactics in the future.

**The farmer’s role in implementing EWM.** The knowledge intensive qualities of EWM imply that success will be more dependent on a farmer’s internal domain (e.g., risk tolerance, learning style, and experience) than conventional approaches to weed management. If a farmer understands more about a weed (e.g., biology, life cycle, phenology) and knows more options for managing that weed (e.g., when, what implement to use, crop rotation, cover crops), their management options and their ability to succeed will increase.
It is apparent that successful EWM depends on holistic problem solving rather than best practice prescriptions. A farmer’s willingness to patiently observe and decide the efficacy of prevention strategies is an example of how internal factors directly influence EWM behavior. Knowledge, while a key piece in the process of EWM, may not be enough to increase adoption or improve success. According to the experts, increased complexity opens the farm system to increased risks, and diversifying is inherent in risk taking. Farmers who are more risk tolerant may be identified by the amount and type of complexity they have on their farms. Navigating this complexity successfully will require increased knowledge and learning. Those farmers who are risk averse may try to simplify decisions by reducing crop diversity, and thereby eliminating many of the filters inherent in EWM.

Experts believe that the high learning curve required for implementing prevention strategies, especially for farmers from conventional backgrounds, can become a large barrier to implementation. By simplifying the principles of EWM into three main components, this research offers a basis to develop new educational material. Some preliminary examples for this material gleaned from the expert model would be:

1. Disturbance of timing vs. allelopathy in cover crop rotations and modeling of crop interference. These ideas are communicated as part of the integrated weed management (IWM) strategies for conventional farmers, (Swanton and Weise 1991; Davis and Ngouajio 2005; Anderson 2010), but have not been communicated to the organic farm community as part of ecological weed management (EWM) strategies.

2. Organic management strategies to deplete thistle, foxtail, and ragweed. It is not surprising that these very same weeds were the subject of extension bulletins from
the early 1900’s. Organic farmers are dealing with the same weeds, but information has not been updated in a practical way for today’s organic farmers.

3. A cost/benefit analysis of control tactics and prevention strategies that shows specific, economic benefits of prevention strategies. For example, what is the benefit, in numbers, of delaying fall tillage to allow seed predators time to destroy weed seeds? What would it cost to put a field out of production and into hay now, compared to the savings in weed management later? How much yield increase can a farmer expect from a more diverse crop rotation and in what time period? This information would help farmers navigate trade-offs between management and seed burial more effectively. So far, the research that covers this area is very technical and not reader friendly (Swanton and Murphy 1996; Liebman and Mohler 2001; Anderson 2010).

4. The weed seed bank: What is it, and is it possible to eliminate it? Research into this area is robust, but presenting this research at farm conferences or field days may get a better response (Hakansson 2003; Gallandt 2006; Anderson 2010).

5. Are organic herbicides a boondoggle (a pointless practice that appears to be of little value)? Currently there a few, if any, studies into this, though farmers and farm conferences focus on this quite a lot.

6. On-farm threshold demonstrations (Swanton, Weaver et al. 1999). How many weeds can a farm allow before yield loss? How can a farmer determine when the critical weed free period is at an end? What weeds require zero tolerance?

7. The relationship between weeds and the soil: what is it? Do weeds indicate an absence or presence of certain nutrients and what does this mean for weed control? Preliminary investigation of the farmer model shows that farmers believe there is a connection between weeds and soil that may or may not be accurate. This is an area where farmers could be included in the research process in order to confirm or enhance their experiential conclusions. There is some literature about this already (Walters 1999), but it is not endorsed by the experts interviewed in this research.
Although the expert model provides insight into potential decision influences and what experts believe farmers should understand, successful communication of EWM principles requires an assessment of the farmer mental model will need to determine what farmers know and what factors are actually influencing their decisions. A comparative analysis of the two models will highlight gaps in understanding, differences in beliefs about weeds, and the influence of individual farmers’ personalities, values, experiences, and risk perceptions on judgments. These gaps may reveal what kinds of internal attributes will need to be understood and addressed to lead to more prevention measures and adoption of EWM. For example, is farmer knowledge sufficient? Are farmer risk perceptions and emotional response appropriate to the weed? Do farmers perceive prevention strategies as risky as experts? What techniques do farmers currently use and what resources do they have to work with? Where do they get their information about weed management and how can extension personnel develop trust in the organic farming community in order to facilitate communication?

The attributes that may be influencing farmer weed management decisions will be investigated in the next two chapters. This expert model comprises the basis for an interview protocol developed for farmers in California, the Midwest, the Northeast, and the Netherlands that seeks to understand how farmer attributes (e.g., beliefs, risk perceptions, knowledge, and experience) and farm attributes (farm resources, regulations, and enterprise) influence farmers’ weed management decisions and create unique weed populations on organic farms.
Conclusion

Farming is a unique arena where the environment’s risk to humans (weeds in the farm system) and humans’ risk to the environment (over-tillage, erosion, and water quality) coalesce. In the expert view, ecologically based weed management tactics work within agroecosystems to optimally balance these risks while retaining the economic viability of the farm. By nature, a preventative approach requires more thought and effort, but the long term benefits may be more lasting than chemical control and ultimately outweigh the perception that EWM is high risk. If extension agencies, a historically successful conduit for knowledge and innovation transfer to farmers, can communicate and help farmers navigate trade-offs between short term costs and long term benefits of EWM it will increase the viability of raising food and fiber without chemicals, and the potential of organic farm systems to create a healthy, diverse, and resilient food system.
Chapter 2:  
Comparative Analysis of Expert and Farmer Mental Models

Introduction

Both historically and in modern times, one of the biggest risks in organic agriculture is weeds (Cates and Spillman 1907; Cox 1915; Jackson 1997; Cardina 2010). They are often cited as the reason that conventional farmers refuse to become organic (Bastiaans, Kropff et al. 2000; Bastianns, Paolini et al. 2008) and managing weeds in order to maintain cash crops is cited as organic farmers’ most pressing concerns (Mohler and Johnson 2009). At the same time, human choices about how to manage weeds in the agroecosystem can pose serious risks to the environment. For example, the over-use of herbicides in the mid-west has led to widespread concern of herbicide tolerance in weed populations (Martinez-Ghersa, Worster et al. 2003; Nazarko, Van Acker et al. 2005; Johnson and Gibson 2006). Herbicides also pose a risk to food safety and soil and water quality (Wilson and Tisdell 2001; Sass and Colangelo 2006). Even when farmers choose to reduce or refuse chemical applications, they may have to rely more heavily on tillage practices that can increase soil erosion and decrease the farm’s long term productivity (Bastianns, Paolini et al. 2008; Schonbeck 2010).

While knowledge of a risk—in this case weeds and weed management—is important when choosing between management options, current theories of judgment and
decision making argue that knowledge alone does not guarantee the best possible choice. Perceptions of risk, informed by a matrix of individual values, emotion, experience, and knowledge, (Kahan, Braman et al. 2007), play just as important a role in the decision making process as expert or analytical knowledge (Plous 1993; Corselius 2003; Eckert and Bell 2005; Wilson, LeJeune et al. 2008).

The body of scientific knowledge about ecological and integrated weed management is formidable. These long term approaches include diverse crop rotation, cover crops, weed seed bank management, and appropriate mechanical control during critical weed free periods (Liebman and Gallandt 1997; Hatcher and Melander 2003; Belz 2007; Mohler 2009; Schonbeck 2010). However, dissemination and adoption of this knowledge into farming practice has been negligible (Bastianns, Paolini et al. 2008). There is evidence that long term, preventative methods have not been embraced by the conventional farm community (Bastianns, Paolini et al. 2008; Wilson, LeJeune et al. 2008; Doohan, Wilson et al. 2010), and most conventional farmers do not believe that long term prevention of weeds is feasible or possible (Llewellyn, Lindner et al. 2004; Wilson, LeJeune et al. 2008). However, beliefs and perceptions in the organic farm community have not been explored.

It is therefore critical to determine what organic farmers know about weeds from their own experience and how they use this knowledge and experience to judge risk and make weed management decisions. Past research has used the mental models approach to investigate differences in the ways that farmers and experts perceive and make sense of the complex task of weed management (Corselius 2003; Wilson, Hooker et al. 2009). Perceptual incongruity may be one cause for the slow adoption and implementation of
successful, long term weed management in farm systems. Through in-depth interviews and the development of conceptual diagrams that represent farmers’ knowledge, beliefs, and risk perceptions, this research provides descriptive information regarding organic farmers’ understanding of weeds and weed management. It uses the farmer model to generate a comparative analysis with the previously established expert model in order to identify gaps in perception that influence judgment and decisions.

The side-by-side comparison will focus specifically on three areas: 1) farmer knowledge of ecological weed management, 2) farmer risk perceptions of weeds and weed management, and 3) farmer beliefs and practices regarding the effective use of prevention and control practices. The rationale behind a comprehensive examination of knowledge as well as risk perception is based on current, descriptive theories of human decision making. Knowledge informs more analytical processing, while risk perceptions, informed by experiential, intuitive processing, also play an important role in guiding choice (Kahneman 2003). Investigation of these three categories is based on the following research questions:

1. What do organic farmers know/believe about ecologically based weed management strategies?
   a. Is this knowledge different or similar to the expert model, and if so, how is this knowledge utilized in management decisions?

2. How do organic farmers perceive the risks and benefits of both weeds and weed management?
   a. Are there any significant differences in these perceptions with the expert model, and if so, what theories in judgment and decision making might explain the reason for these differences?
What do organic farmers know/believe about control tactics and prevention strategies, and which of these do they use most often?

a. How do they compare with experts in their understanding of what makes these practices successful?

**Methods**

Mental models research conceptualizes and visualizes the knowledge and beliefs of the public in order to design effective communication material that targets gaps in understanding to produce more informed decision makers (Morgan, Fischhoff et al. 1992). The approach has been used to understand expert and layperson risk perceptions in a variety of contexts including radon in homes (Bostrom, Fischhoff et al. 1992), climate change (Bostrom, Morgan et al. 1994), and HIV/AIDS (Fischhoff, Downs et al. 1998). Previous studies have also used mental models to map the knowledge, risk perceptions, and beliefs of conventional farmers about Integrated Weed Management (IWM) strategies (Wilson, LeJeune et al. 2008; Wilson, Hooker et al. 2009; Riemens, Groeneveld et al. 2010). There are five elements in the design of mental models research: 1) developing the expert model 2) conducting (farmer) mental model interviews 3) implementing a confirmatory questionnaire 4) developing and 5) evaluating a risk communication message. The inner logic of this five-step design is to improve communication directed towards laypeople so they have sufficient information to judge the risk of a certain phenomena—in this case weeds and weed management.

This research is designed to compare expert and organic farmer understandings of weeds and organic weed management in order to locate gaps in conceptualization and trace key influential factors in the decision making process from the farmer perspective.
**Organic farmer recruitment.** The farmer model was developed from in-depth, open-ended, semi-structured interviews with twenty-nine farmers over the age of 18 in Ohio and Indiana. A purposeful sample size of 20-30 farmers is sufficient for data saturation in the mental models approach (Morgan, Fischhoff et al. 1992). Interviewees were selected based on their organic farm enterprise, years of organic farm experience, gross farm income, and other demographic considerations. Including farmers from different geographic regions in Ohio and Indiana provides opportunities to compare and contrast their decision making process across farms with varying soil types, climates, and markets. We included both part-time and full-time farmers.

In order to identify a pool of interested farmers from which to strategically sample interviewees, the Ohio Ecological Food and Farm Association (OEFFA) provided access to their list of certified organic farmers in Ohio and Indiana. A recruitment letter was sent asking for interested volunteers to fill out an initial intake card. The potential interviewees were chosen out of this pool of interested organic farmers and contacted to set up an interview in-person. Only one interview was done by phone.

**Development of the interview protocol.** Analysis of the expert interviews revealed seven theoretical categories to investigate in the farmer interviews (Figure 1). These theoretical categories encompass farmer knowledge, how they use risk perception and experience in their weed management decisions, and what weed management decisions they actually make (based on prevention or control). There are four influential categories prior to the weed management decision—attributes of the farm, attributes of the farmer, the dual processing filter, and risk perceptions. The prevention and control
practices post-decision represent the continuum of all possible management options. Farmers’ experience with using these practices is represented by the final theoretical category “experience/trial and error.” This last category acts as a feedback loop into the internal attributes of the farmer, adding to their knowledge and experiential encounters with weeds.

Each of the categories and concepts identified through development of the expert model were used to create the farmer mental model interview protocol. Appendix A depicts how each expert category and its corresponding concepts were converted into the farmer interview protocol. These same categories and concepts are used as the template for coding the farmer interviews (see section on coding, below).

**Interview procedures.** The interview protocol is based on the funnel design suggested for mental models research and informed by an extensive analysis of the expert model. According to the methods described by Morgan et al. (2002), interviews were conducted to uncover farmer knowledge, perceptions, experiences, and emotions in a way that minimized the influence of the interviewer and provided as much freedom of expression as possible. At the same time, responses to questions were prompted in a focused way. For example, an interviewee may respond to the open-ended question “What is a weed?” with a swirling mass of undirected information. Further into the interview, however, the interviewer directs these responses to major areas identified by the expert model. A set of standard phrases is prepared in advance to follow up on the responses and to clarify their answers without questioning their legitimacy. Each farmer is given the same interview protocol. Responses to the open-ended questions are weighted more heavily than prompted responses as they are more salient to the farmer.
The farmer interview protocol also included a ranking and trade-off exercise not included in the expert interviews in order to confirm earlier interview responses and triangulate reasoning behind the decision making process (see Appendix C). Previous mental models research (Morgan, Fischhoff et al. 1992) used picture sorting as a triangulation tool to elicit new information about interviewee’s perceptions of risk. Instead of photos, this ranking exercise asked farmers to order cards that represented various sources of information specific to the organic weed management decision making process. The sixteen options included sources of analytical information (e.g., latest science and research), experientially based information (e.g., what worked in the past), and value based information (e.g., soil health). Farmers were asked to work quickly and rank them from most to least important in their decision making process.

The trade-off exercise asked farmers to draw an X on a continuum from “maximizing profit/yield” to “maximizing ecological partnership” that best represented their current view of their organic farming practices. Again, this interview technique is used at the end of the interview process to elicit further insight into how well farmer’s ideal outcomes or goals align with their self reported weed management behavior.

**Coding.** The interviews were independently transcribed and entered into the qualitative software program MAXQDA (Max Qualitative Data Analysis). Each interview was coded separately according to the hierarchical and theoretical coding schematic developed from the expert model. If a farmer mentioned a concept or property not found in the expert coding schematic, that concept or property was added and marked as a uniquely farmer response.
Over 1,000 individual codes were identified from the expert model, and there were an additional 800 codes unique to the farmer. After the coding schematic was developed, it was tested for inter-coder reliability to examine its potential to produce replicable results. The number of possible codes makes this task difficult. However, it is especially crucial for judging the intuitive logic of the model. Mental models studies expect coders to agreed at least two-thirds of the time (Morgan, Fischhoff et al. 2002). Six of the farmer interviews were coded by an independent researcher. These interviews were then compared with the original coded interviews through MAXQDA’s inter-coder reliability test. The program’s criteria for inter-coder reliability are measured by the number of times a code appears in each document. If the number is the same for each, there is agreement. If the numbers differ, whether it is by 1 or 100 occurrences, there is disagreement. Inter-coder reliability tests revealed between 90% and 96% agreement in each of the six interviews.

Over 5,000 separate responses were coded in the 29 farmer interviews. Each code (theoretical categories, conceptual categories, concepts, properties, and dimensions) in the farmer interviews corresponds directly to the “nodes” in the visual mental models and provides meaningful data points to compare and contrast with the previously developed expert model.

**Coding for Ecological Weed Management (EWM).** The expert model establishes long-term, ecologically based methods as crucial for reducing the risks associated with weeds on organic farms. Rather than asking a farmer directly about the general aspects of EWM, responses were coded when one of the principles was inherent in a farmer response. For example, Farmer S was discussing how he makes a decision to
re-plant corn based on a cost/benefit analysis between the short term cost of seed and the long term cost of an increased seed bank the following years. While he does not identify this specifically as a piece of “ecological weed management knowledge,” the expert model has identified this as one of the four main principles in EWM—seed bank management—so it is coded as such:

*If you have a corn failure, start over. The only thing you have is the cost of your seed. We had two fields this year that we just replanted. If you see in three weeks that “Hey, I’m beat!” instead of fighting it all season long and increasing your seed bank, start over.* (Farmer S)

**Coding for prevention strategies and control tactics.** The prevention/control continuum was developed from the expert model as a way to code farmer responses as either prevention or control focused (Appendix D). Experts recognized that farmers use a combination of control and prevention practices. In order to create a dependent variable that best reflected this combination of management practices, it was critical to represent them as a continuous, rather than a categorical, variable. Based on the experts’ explanation of these two sides of the continuum, some practices are more obviously prevention strategies or control tactics.

For example, diverse crop rotation, cover cropping, and stale seed bed techniques are integrated strategies that require long term planning and are much more obvious as prevention strategies. On the other hand, control tactics such as organic herbicides are short term measures that require yearly application and costly inputs. Several management practices, however, fall somewhere in the middle of this continuum. These
include nutrient management, mowing, and cultivation/tillage. If a farmer discusses these weed management options in terms of sustainability, long term strategizing, saving money in the long-run, and part of a diversity of weed management practices, then their response would be coded as a prevention strategy. If these criteria are missing in the farmer’s response, or if they include such things as high input costs, short term solutions, and stand-alone practices, then the response is coded as control.

**Reporting results.** Results from the farmer interviews are presented in four ways. First, the farmer’s words will be shown in italics, followed by an anonymous identification (i.e., *Farmer Z*). Second, results will be presented as the frequency of coded responses throughout all 29 interviews. Frequency is reported both as the total number of times a category, concept, property, or dimension is mentioned and as a percentage of the number of mentions within its parent category or concept (how many times a dimension was mentioned within a property, a property within a concept, a concept within a conceptual category, or a conceptual category within a theoretical category). For example, farmers mentioned the agricultural benefits of weeds 73 times, or 42% of the total mentions of the benefits of weeds (Figure 9).
Lastly, results may be reported as a percent of agreement among farmers. This helps to identify the most commonly held farmer beliefs and perceptions related to a risk, whether or not this knowledge is technically “correct.” For example, weeds as a “production risk” can be reported as the percent agreement among farmers who mentioned this property (28 out of 29 farmers, or 97%).

Coding the frequency of response is important in mental models (Morgan, Fischhoff et al. 2002). The more often a farmer mentions a category, concept, property, or dimension, the more fully it can be understood as part of their decision making process. If a farmer takes time to explain a concept more fully, it is coded as only one mention, but the details of his or her responses within that concept are coded in detail. If a farmer mentions the same concept later on, it is coded again.
Coding to four levels of detail (category, concept, property, and dimension) provides a way to more accurately compare between groups (farmer to expert) and within groups (farmer to farmer). To give an example, in Table 2, 100% of the farmers agreed that weeds can be beneficial, but this level of detail is useless unless we can determine what kinds of benefits farmers perceive and how this might differ from the expert model. Moving down to the next level, the concept “agricultural benefits” is mentioned 73 times, or about half of the total conceptual category. Since “weed benefits” also includes the concepts of economic, ecological, and social benefits, we can conclude that agriculturally based benefits are one of the most salient in the farmer model (ecological is close with 64 mentions). Becoming even more specific, “soils” are a property of agricultural benefits mentioned most often (44 mentions or 60% of total responses), and there is 62% agreement among the 29 farmers. Four of the dimensions of soil benefits are listed, but “add organic matter” is the dimension with the most mentions overall. The expert and farmer model often align until the finer levels of detail are reached within the hierarchical structure. Here is where meaningful differences in perception or understanding about weeds and weed management can be detected.
Table 2. Example of coding structure reported as percent agreement, frequency, and percentage of mentions within its parent category, concept, and property.

By carefully developing each theoretical and conceptual category through structured coding, it is possible to get a picture of the mental scaffolding that supports the physical practice of weed management (Mace, Morlon et al. 2007). The descriptive results from the farmer mental model provides rich data about the role that knowledge, risk perception, and experience play in an individual farmer’s weed management decisions.

Results
Expert and Farmer Comparisons

After presenting basic farmer demographics, results will focus specifically on presenting and comparing three areas of the expert and farmer models: 1) ecological weed management (EWM) knowledge found within the “farmer attributes” theoretical
category, 2) perceptions of weeds and weed management, and 3) organic farmers’ beliefs and practices regarding the use of prevention and control practices.

**Demographics**

Of the 29 farmers interviewed, 18 were located in Ohio and 11 in Indiana. In 66% of the interviews the only interviewee was male, 10% only female, and in 24% of the interviews both male and female operators were present. The average farmer age was 49, with the youngest being 24 years old and the oldest 68. Experience levels were split fairly evenly with 28% of the farmers new to organic farming (0-4 years of experience), 24% operating organic farms for 5-9 years, 21% for 10-14 years, and 17% for 15+ years.

The farms’ cropping systems were typically diverse, with only two of the farms raising only one type of crop—vegetables. One farmer produced niche greenhouse culinary herbs and exotic plants, but even these seemingly simple operations had diverse rotation systems. The rest of the farms interviewed were a combination of vegetables, field crops, livestock, hay and forage, and dairy. Overall, the split between types of farms was fairly even. Twenty eight percent of the farms included a dairy operation, 24% raised a combination of vegetables and/or field crops, hay, and livestock, 24% raised only field crops and hay, and the last 24% raised some combination of vegetables and/or fruit and herbs (Appendix F).

Just under half of the farms in this study made between $10,001-100,000 gross average income per year—45%. Twenty-eight percent fell into the $100,001-250,000 range, 14% in the $250,001-500,000 range, and 10% in the less than $10,000 range.
1. Knowledge of Ecological Weed Management (EWM) Principles

Knowledge of EWM had the largest number of coded responses in the farmer attributes theoretical category with 427 total mentions (50% of the total coded responses in farmer attributes). Knowledge of EWM principles has four main concepts: managing the weed seed bank (163 mentions or 35% of coded responses in EWM), understanding agroecology (140 or 30%), utilizing multiple management practices (120 or 26%), and recognizing opportunities to manage (41 or 9%).

![Diagram of EWM knowledge concepts]

Figure 10. Comparison of farmer and expert sub-models of the EWM knowledge conceptual categories.

**EWM Knowledge: Managing the Weed Seed Bank.** Experts believe that managing the weed seed bank is both possible and necessary for the long term prevention of weeds in organic farm systems. Depletion of the seed bank through filtering techniques such as timed disturbances (e.g., stimulating the weed and then destroying it),
reduction or elimination of seeds re-entering the seed bank (e.g., harvesting or mowing before weed sets seed), and seed predation (e.g., delaying fall tillage to encourage predators) are all strategies critical for successful seed bank management according to the expert model.

Farmers were asked directly about how they believed the weed seed bank operated, and the property mentioned most often was that the seed bank “needs stimulation” (56 mentions or 61% of coded responses). According to 21 out of the 29 farmers (75% agreement), stimulation is attributed to two things, weather/sunlight/moisture (25% of coded responses), and “management opening up the field to weeds”—specifically, tillage practices (63% of coded responses). These two properties of stimulation are interrelated. Management is often the reason for weather/sunlight/moisture reaching the weed seed. Farmer Z’s comments exemplify the belief that weed seeds are a permanent part of the soil that germinate when stimulated by farmer management:

_I think the weed seed bank presents its ugly face every time you till the ground. Every time you plow. Every time you plow or overgraze you create conditions so that these weeds that have been in the soil for a long time can find a way to grow. One year you will have this one and then one year the next one, and it might have been years since you’ve seen this weed express itself. It’s there are different weed pressures based on timing of tillage, cultivation, and rotary hoeing._ (Farmer Z)

Even farmers who expressed beliefs in weeds as a Biblical curse (21% agreement), perhaps the most uncontrollable origin of weeds, still identified
management’s vital role in weed germination, prevention, and control. Farmer S expresses management accountability despite weeds’ everlasting presence in the soil:

> It’s a curse to the crop. It started that way. It was a biblical curse, but I still think the type of weed that grows is based on management and not the curse. (Farmer S)

Very few, however, thought it would be possible to completely deplete the seed bank. Twenty six percent of the coded responses (24 mentions) included the belief that weed seeds remain viable in the soil for a long time, and of these responses half described their viability as either “forever” or at least 50+ years (12 mentions). The expert model identifies these kinds of beliefs as a myth, but the following excerpts are not uncommon among organic farmers:

> Seven, eight, nine and up to 50 year seed viability, even seeds that have lasted 1,000 years! (Farmer G)

> Sometimes the conditions are ripe, I don’t know why, and a new patch of thistles will just appear spontaneously from an old, old seed bank. Well it would have to be 50 or probably more years old. In the same way I think many seeds lie dormant until they are tilled and they maybe get a little bit of sunlight. I’m not sure. But I know that they are there. (Farmer K)

Farmer A and Farmer K aptly described this tension between the permanence of weeds and striving for effective management.

> I don’t understand a lot about the ability of the seed to be able to be dormant in the ground for 10 years and then start growing again. I think that’s pretty incredible that they can grow consistently and reseed themselves. And you may
not have a problem with it in a rotation, and then you go back to a certain rotation style and then it comes back. (Farmer A)

Those seeds were dormant for 150 years waiting for sunlight and disturbance. So we will never be free of weeds, but there are definitely ways to manage them that they aren’t really that much of a curse. (Farmer K)

Farmers identified many ways to avoid weed seed stimulation. These included tillage depth (e.g., shallow or no-till), rotating tillage type (e.g., inversion tillage, sub-soiling), and avoiding tillage during wet weather (Figure 11). Most farmers did not talk about management possibilities after the weed has dropped seed. Predation of weed seed by macro-organic life was mentioned in the expert model as important, but only 3 farmers mentioned this possibility in the interviews.

Figure 11. Farmer sub-model for the concept of managing the seed bank. Properties and dimensions unique to the farmer model are highlighted in grey.
EWM Knowledge: Using Multiple Practices over Time. While understandings of the viability and origin of weed seeds differed between the two models, both agreed that weeds and weed seeds are largely the result of agricultural practices. As such, agricultural practices are also responsible for either increasing or decreasing the overall weed population. Experts contend that if farmers actively manage their weeds through diverse strategies over a long period of time, the seed bank will gradually decline to the point where farmers can save significant amounts of time, labor, and money. This EWM principle is summarized as “using multiple practices over time” and was coded roughly the same amount of times in both models (112 for the expert model and 120 for the farmer model).

The expert model identified strategic rotation (74% of coded responses under knowledge of EWM principles) as the key player in a diverse set of practices, or filters, for weeds that lead to successful, long term prevention. Sixty-five percent of the farmers interviewed agreed that strategic rotation was an important part of their weed management plan and used it on their farm (50 mentions, or 31% of the “managing the seed bank” concept). The top three properties of strategic rotation were: changing planting times (expert 19% of coded responses, farmer 2% of coded responses), using appropriate tillage/cultivation (expert 14%, farmer 54%), and knowing the seed viability in the soil without falling prey to the “forever” myth (expert 14% of coded responses, farmer 37%). Thirty percent of the farmer responses included the importance of weed seed viability in the soil, but all of these responses included some mention of what expert’s identified as a myth. The large emphasis that farmers gave to appropriate
tillage/cultivation (54% of responses) again points to their understanding of a management-centered approach.

According to the expert model, crop rotation and cover cropping diversify the agroecosystem and reduce weed seeds. Farmers responses reflected this understanding quite well. Eighty percent of farmers mentioned crop rotation as a preventive strategy, and 93% mentioned cover crops and green manures. However, there are some key differences between expert and farmer beliefs about what makes crop rotation and cover cropping successful.

According to the expert model, crop rotations disturb the soil to stimulate weed seeds, then tillage/cultivation destroys and/or the cover crops smother them at the appropriate time (e.g., stale seed beds). Farmer explanations coincided with this understanding, with 50 separate responses coded as “interrupting weed cycles through strategic rotation.” Most of this interruption, as we have seen, was due to correct cultivation/tillage practices (54% of the code). But it also included grazing and strategic mowing (14% of the code), uniquely farmer concepts. Farmer K’s comments summarize farmers’ confidence in tillage/cultivation and grazing as effective management strategies.

*I say with the occasional tillage and with intensive grazing I think it is the best way to control weeds there is in an organic operation.* (Farmer K)

Including hay or pasture with grazing and scheduled cuttings as part of the crop rotation was mentioned more often by farmers than experts (37 codes vs. 10 codes). One farmer even made the astute comment that “the further from alfalfa you get, the more weeds you have.” Many of the weeds mentioned by farmers were also coded as “not a
problem in the pasture.” Farmers highlighted grazing strategies as a buffer against thistle, a weed mentioned as most problematic by 90% of the farmers interviewed.

The expert model does not demonstrate as integrated an understanding of livestock, dairy, and pasture as part of a weed management tactic as the farmer model. Farmers view strategic rotations that include pasture as effective filters for weed seeds because they require constant grazing and mowing, which doesn’t allow the weeds to set seed. Including livestock and/or dairy as part of a strategic rotation also minimizes the economic risk of taking a field out of production to plant into a long-term cover crop such as alfalfa. With livestock as part of the operation, pasture and cover crops provide a source of food throughout the year, as well as a source of weed control.

Lastly, cover crops are viewed by farmers as more beneficial to the soil and the crop than as a weed management technique. Seventy-four percent of the coded responses described cover crops as a benefit to soils, but only 26% as a benefit to weeds. The expert model emphasized cover crops as a way to temporally disturb the soil in order to flush out weeds. Any benefits to the soil were shown as a secondary property of cover crop implementation in the expert model.
Many of the concepts for EWM are interrelated and require a long term, systems approach to management rather than a short term, targeted approach. Experts emphasized long term systems thinking as necessary for incorporating ecological processes into the weed management decision, and farmers mentioned long term strategizing even more often than experts (61% vs. 32% of coded responses). However, examining the types of long term strategizing done by farmers points to a divergence between the two models. Farmers focus more on management choices (e.g., grazing, nutrient management, and soil health) as the source of diversification and success.

Experts, on the other hand, couched their explanations of successful, long term planning as part of an ecologically based strategy to narrow weeds’ window of opportunity to recharge the seed bank (e.g., weed life cycles, phenology, soil disturbances, and predation.

Figure 12. Farmer sub-model for the concept of utilizing multiple tactics over time. Properties and dimensions unique to farmer are highlighted in grey.
by micro and macro-organic life). The perspective may diverge in the two models, but they achieve the same results—a diversified agroecosystem that disrupts weed cycles.

**EWM Knowledge: Understanding Agroecology.** The expert model highlighted that agroecological complexity blurs the cause and effect of weed management practices, making evidence based management hard to come by. The farmer model demonstrated some concern about the indeterminable cause and effect of weed management from year to year (17 responses coded as ecological complexity), but not nearly as much as the expert model. Experts focused on complexity and uncertainty, while farmers focused on finding relationships to help explain these complex interactions.

The biggest incongruity between the two models is the farmer belief that weeds are indicators of soil nutrient levels and “tell” them what type of nutrient management to employ. The indicator concept was quite robust in the farmer model (122 mentions by farmers compared to 57 mentions by experts pointing out its unreliability). Fifty-five percent of farmers stated that the type of weed indicates the type of nutrients and/or minerals that are lacking or present in the soil:

*As we’ve added calcium to the soil the weed populations seem to have decreased. I don’t know how else to explain it.* (Farmer S)

*Adding calcium to the soil loosens it and we’ve seen a decline in dandelion populations.* (Farmer L)

*If you’ve got thistle it’s probably because something not quite in balance with your soil. Sandy’s used that more than any of us here to read the soil. That, combined with soil samples, tells us what we’ve got to do in the soil.* (Farmer A)
You could look at the field and you could say, "I see this weed so it tells me that there’s compaction, or there’s this mineral missing.” I think if we were smart enough and had time to really research it we could learn a lot from our fields. And there are books about it, but we just haven’t had the time to delve into it. (Farmer S)

In order to flush out this farmer belief, the protocol’s question about a relationship between weeds and the soil was careful not to prompt what kind of relationship, allowing the farmers to come to their own conclusion. While experts are skeptical of any causal links between weeds and the presence or absence of minerals in the soil, 50% of the farmers’ coded responses thought this was correct. The following excerpts demonstrate each model’s perspective:

**Expert:** But I don’t think a weed tells you that I’ve got really high calcium. The calcium-magnesium ratio was this kind of a magical thing that farmers were talking about for a long time.

**Farmer:** I believe the calcium affects a weed. I do think that is important. The base saturation of calcium…also the magnesium balance with it.

Farmers utilized this belief as part of their weed management decisions differently. Some tried to implement rules for soil amendments based on what weeds were present in their fields. Others believed there was a relationship, but did not know how to implement this knowledge:

**The more you get to know about weeds or foxtail or thistle it’s probably because there’s something not quite in balance with your soil** and Sandy’s used that more than any of us to kind of read the soil. Combined with soil samples it tells us what we’ve got to do in the soil. (Farmer A)
And the weed that grows usually will indicate. If it’s compaction it will be a certain type of weed, if there’s low lime it will be another type of weed. If we could figure out exactly what it means it will tell us a lot. (Farmer S)

The last two concepts having to do with the relationship between weeds and the soil, besides being indicators of soil nutrients, are “inviting weeds with agricultural soils” and “soil structure.” These two concepts are related. Agricultural soils create high nutrient, fine seed beds that weeds thrive in, and they also create areas of compaction that other weeds, such as grasses, exploit. The detailed properties of this farmer concept include thistles growing in tighter soils, ragweed growing in soils with poor rot conditions, and grasses growing in compact soils.

Again, all of these properties point to management-based solutions. For example, farmers mentioned adding magnesium to loosen soil, sub-soiling, breaking up paths created by tractor wheels to discourage grasses, and tiling or certain crop rotations to drain soils more quickly.
EWM Knowledge: Recognizing Opportunities to Manage Weeds.

Successful weed management behavior is certainly dependent on knowing the type of weeds present on the farm. Both the expert and farmer models indicated that knowing the weed biology, biotype, and phenology are important for recognizing when to manage a weed—separate responses coded for this concept were identical at 37% for both. Fourteen out of the 29 farmers (48%) agreed that knowing the weed was important for correct management of that weed.

To get a general idea of the extent of organic farmer’s ability to identify weeds, they were asked to name all of the weeds on their farm and to elaborate on the ones that were the most and least problematic and the most and least risky. A total of 805 separate
answers were coded in response to this question. No farmer hesitated to name at least four to five weeds on their farm, and analyzing farmer responses reveals that every farmer was able to identify and name several weeds, and most were aware of the weed’s phenology and life cycle. Some farmers openly indicated a lack of knowledge about some of the more uncommon weeds on their farm, but were still able to name or describe it. Table 2 summarizes their responses according to farm type.

<table>
<thead>
<tr>
<th>Weed</th>
<th>Frequency</th>
<th>Veggies/ +Fruit/ Herbs</th>
<th>Field Crops/ Hay</th>
<th>Veggies/ Field Crops/ Livestock/ Hay</th>
<th>Field crops/ Livestock/ Hay/ Dairy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ragweed</td>
<td>71</td>
<td>15%</td>
<td>27%</td>
<td>15%</td>
<td>39%</td>
</tr>
<tr>
<td>Foxtail</td>
<td>39</td>
<td>13%</td>
<td>23%</td>
<td>44%</td>
<td>21%</td>
</tr>
<tr>
<td>Canada Thistle</td>
<td>30</td>
<td>33%</td>
<td>30%</td>
<td>13%</td>
<td>23%</td>
</tr>
<tr>
<td>Lambsquarter</td>
<td>22</td>
<td>50%</td>
<td>9%</td>
<td>0%</td>
<td>41%</td>
</tr>
<tr>
<td>Chickweed</td>
<td>14</td>
<td>43%</td>
<td>14%</td>
<td>43%</td>
<td>0%</td>
</tr>
<tr>
<td>Redroot Pigweed</td>
<td>12</td>
<td>17%</td>
<td>25%</td>
<td>33%</td>
<td>25%</td>
</tr>
<tr>
<td>Velvetleaf</td>
<td>12</td>
<td>17%</td>
<td>24%</td>
<td>17%</td>
<td>42%</td>
</tr>
<tr>
<td>Fescue</td>
<td>11</td>
<td>0%</td>
<td>0%</td>
<td>18%</td>
<td>82%</td>
</tr>
<tr>
<td>Quackgrass</td>
<td>9</td>
<td>67%</td>
<td>11%</td>
<td>0%</td>
<td>22%</td>
</tr>
<tr>
<td>Bindweed</td>
<td>9</td>
<td>33%</td>
<td>0%</td>
<td>33%</td>
<td>33%</td>
</tr>
</tbody>
</table>

Table 3. Frequency of top ten weeds mentioned and percent response by farm type.
2. Perceptions of Weeds and Weed Management

Perceptions of weeds and weed management is by far the largest of the farmer model’s theoretical categories, with 1,489 separate coded responses. Responses were grouped into six conceptual categories: benefits of weed management, mentioned 106 times (or 6%), perception of weed spread (142 or 10%), perception of weed introduction, (179 or 12%), benefits of weeds (176 or 12%), risks of weed management (374 or 25%), and risks of weeds (492 or 33%). The following is an overview of each of these conceptual categories.

![Diagram of Perceptions of Weeds and Weed Management]

Figure 14. Farmer sub-model for the perceptions of weeds and weed management theoretical category with subsequent conceptual categories.

**Perceptions of Weed Introduction:** The introduction of weeds was perceived by both experts and farmers to be mostly due to agricultural practices (86% and 58% of responses to this conceptual category, respectively). Within agricultural sources of introduction, “farmer management behavior” was the largest concept in the farmer model with a total of 46 coded responses (45%) compared to only 5 mentions (10%) in the expert model. The two most important properties of farmer management behavior that
led to the introduction of weeds were an altered soil environment (31 mentions or 67% of the responses in this concept) and dirty seed (14 or 30%), while experts focused mostly on farm inputs as the source of new weeds (e.g., raw manure and compost). “Altered soil environment” includes the belief that 1) previous cropping systems are at fault for new weeds, which is also found in the expert model, and 2) weed seeds are “just there” until management stimulates their germination, which is unique to the farmer model. Farmer S and Farmer M describe this uniquely farmer response:

_“I don’t think somebody just flew in a bunch of seed or some new phenomenon. _I think these seeds were here and we changed the environment of the soil and it allows this particular weed to flourish._ (Farmer S)

_They’re there. They’re there. You just create the right conditions._ (Farmer M)

This perception coincides with farmer understandings of the seed bank—that weed seed stimulation is mostly a result of farmer management. Other farmer perceptions of how agricultural practices could lead to weed introduction were the purchase of dirty seed (15 mentions or 14% of total responses), especially dirty seed from seed companies. Experts did not share this view, and mentioned it just 2 times (4%). Raw manure was cited in both models as one source of weed seed introduction; though the farmer model’s overall percentage of mentions is lower (13 or 12% and 18 or 35%, respectively). Mulches were more important as a source of weeds in the farmer model with 13 mentions or, 13%.

Other sources of introduction according to farmers (Figure 15) were natural occurrences, mentioned 28 times (15% of total responses), wildlife (25 or 14%), and
social factors (17 or 9%). While social factors are not included in the expert model as a source of introduction, the farmers mentioned this concept a total of 18 times, focusing on neighbor’s fields. It is also interesting that 18 of the 29 farmers, without prompting, mentioned birds as the biggest source of weed introduction in the wildlife concept.

Figure 15. Farmer and expert sub-model comparison of conceptual category of weed introduction and spread.

**Perceptions of Weed Spread.** Farmers perceived the spread of weeds to be mostly due to agriculture, and mentioned this 73 (51% of the node) separate times.

Farmers stated that mechanical means and farmer management were most often to blame, with 29 (40%) and 26 mentions (36%), respectively. The expert model also had these
two concepts with 21 (38%) and 13 (24%) mentions. However, while the concepts align almost exactly, the properties in the concepts differ entirely. Experts focused on spread due to contract operators, burying seeds away from predators, and tillage in waterways. Farmers, on the other hand, focused on two entirely different properties—spread due to equipment (e.g., combines, plough, rototiller) with 16 mentions and tillage/cultivation chopping roots and encouraging the spread of rhizomes with 12 mentions.

Biological means of spreading weeds was the second most coded response in the farmer model (46 or 32%), especially the biological traits of seeds, accounting for 70% of this category. The expert model also focused on seed as the mechanism of spread, but failed to mention roots, which the farmer model did 13 times (28%). Natural occurrences, such as wind and flooding, were also mentioned in the farmer model, but were more prominent in the introduction of weeds (12 vs. 28). Wildlife was also mentioned, though it was more prominent in the introduction perception (11 vs. 25). In both the expert and farmer models, birds received fairly equal blame. No social sources of weed spread were mentioned in the farmer or expert models.

**Risks of Weeds.** Farmers were specifically asked about the risks and benefits associated with weeds. Overall, almost three times as many risks (492) were coded as benefits (174). The same is true in the expert model (65 benefits and 169 risks mentioned). Weed risks were combined into four groups: agricultural, economic, social, and ecological. Agriculturally related risks of weeds were cited most often by both farmers and experts (243 or 50% of the farmer coded responses and 95 or 58% of the expert’s), and both were mainly concerned with weeds’ biological ability to compete with
crops. This totaled 74% (180 separate instances) of the farmer responses in this conceptual category and 53% (50 mentions) of expert responses.

After biological competition, the next most frequent agricultural risk in the farmer model had to do with production interference, including harvest and planting operations (36 mentions or 15% of coded responses). Experts mentioned this type of risk only 2 times (2%). This difference in response may indicate a key difference in perspective among scientists and farmers. Scientific investigation and research focuses on reducing biological risk, but not on the later impacts of weeds during harvest. Farmers, on the other hand, deal with weeds throughout the season. Weeds interfere with growth cycles as well as mechanical operations when they become too tall and woody to go through a combine or cultivator. Such risks need to be part of the expert understanding as well.

Another risk of weeds in the farm system mentioned frequently was what we labeled “agroecological entity,” or a weed’s adaptations to agricultural practices that allow it to thrive within the agroecosystem (26 or 11% of the node). Experts cited this risk more often than farmers (35 mentions or 37%), again highlighting the expert focus on biologically based risk factors.

Economic risks of weeds were mentioned most often after agricultural risks in both models. Experts mentioned this concept 50 times (29%) and farmers 151 times (31%). Almost all of the farmer instances of economic risk were related to weeds as production barriers (130 out of 151 mentions, or 86%), again pointing to a management-centered perception of weeds. Experts also cited production risks as 70% (35) of the coded responses. Farmer production risks were much more detailed and specific than those in the expert model, though both mentioned reduction in yield the most (25 by
experts and 47 by farmers). The most frequently mentioned production risks by farmers were interferes/delays harvest (11 mentions or 8% of coded responses) and unpalatable in pasture and feed (5 or 4%). While not large concepts, these responses confirm that farmers are aware of the consequences of weeds from start to finish in pasture systems, a concept experts did not mention very often.

Social risks were mentioned by farmers (89 times or 37% of coded responses in this conceptual category) many more times than experts (15 or 16%). These risks include negative public perception of the farm, personal risks, and risks within their heritage or religious beliefs and communities. By far, the concept with the most responses in the farmer model was public perceptions, mentioned 75 times compared to just 6 times by experts. This concept is defined by properties such as weeds being the sign of a lazy or poor farmer (13 out of 29 farmers agreed), poor aesthetics (11 out of 29 farmers agreed), and difficulty in educating the public that some weeds are OK (8 of 29 farmers agreed). Such beliefs about public perceptions might feed into how farmers decide on the acceptable level of weeds in a field, or their weed tolerance levels. It will also be more difficult for farmers transitioning from conventional backgrounds to accept weeds’ presence on the farm and the public perception that these weeds generate.

The model shows that organic farmers are concerned about how their fields are perceived by others—other farmers and customers. In fact, “ugliness” or “poor aesthetics” was mentioned as a social risk as many times as being a sign of laziness or poor management (18 for both). In the interviews, organic farmers explained that their efforts to manage weeds were much more labor intensive than their conventional counterparts, but they felt that this was not recognized by the public. A feeling of
isolation and fatigue may affect farmer’s attitudes towards weeds and organic farming. Indeed, the dual processing theoretical category shows that organic farmers have several emotional and affective based responses to weeds, and these must be taken into consideration as part of the decision making process (see chapter 3).

The ecological risks of weeds are the least mentioned in both models (5 mentions or 33% of the expert model node and 9 mentions or 10% of the farmer model, respectively). Both experts and farmers mentioned weeds’ ability to host fungi and nematodes as the biggest property in this concept (2 and 4 mentions, respectively).

Figure 16. Expert and farmer sub-model comparison of the conceptual category risks and benefits of weeds.
**Benefits of weeds.** The benefits of weeds also included four conceptual categories: agricultural, economic, ecological, and social. Like the risks, most of the benefits in the farmer model were agricultural (73 mentions or 42% of total coded responses) with ecological following close behind (64 or 37%). These two conceptual categories are reversed in the expert model with ecological benefits mentioned most often (31 or 48%) and agricultural benefits a close second (28 or 43%).

The majority of agriculturally based benefits in both the farmer and expert models deal with soils (44 mentions or 60% of coded responses). Both mention the addition of organic matter most often. Weed root structure also helps to prevent erosion and, according to farmers, can act as a cover crop. Nine farmers also talked about weeds as a benefit to livestock in a pasture-based system (19 mentions or 14% of the concept), while this was mentioned by only one expert.

Ecological benefits in the farmer model (64 or 37% of the benefits conceptual category) included such things as habitat for wildlife and insects (15), biodiversity (12), and food for wildlife (8). Experts agreed that weeds provide habitat and biodiversity, but they did not mention the uniquely farmer concept of weeds as symbols of ecological processes. This concept is mentioned by just under half of all of the farmers regardless of farm type or experience. In fact, Farmer Z, a pasture based farmer who teaches a weeds class at a local community college, mentioned it as much as Farmer M, a cash grain producer who is prone to searching for short cuts and easier ways to manage weeds’ impact on crop yields.
Weeds are an indicator of soil conditions. You can use them as indicators for what your soil is lacking, or what it may be high in. A perfect example in the west is there are certain plants that are called selenium indicators that like to grow in high selenium soil. You can use those as an indicator that we have to be careful about pasturing these animals on this particular prairie. (Farmer Z)

That’s why lambsquarter exists. He’s there to balance the soil. If you give the lambsquarter about 10 years of dying and growing and dying then he’ll cease to exist. Or another example—if you put potassium on your soil like the experts recommend you’ll only get about three years out of your alfalfa crop because you’re putting potassium on the soil. So the alfalfa says, “I’m no longer needed here.” And so it doesn’t thrive. (Farmer M)

Farmers mentioned the social benefits of weeds 28 times compared to experts who only mentioned it 2 times. Most of these instances are due to weeds being edible (13 mentions or 46% of total responses). Farmers also mentioned that weeds are beautiful and, despite being the source of negative public perception, can also be a sure indicator of organic methods. Experts and farmers found few economic benefits to weeds (2 and 7 mentions, respectively), though two of the farmers said they sometimes sell them as part of their salad mix at market.

**Overview of the Risks and Benefits of Weed Management.** Twenty-five percent of the coded responses in the weed perceptions theoretical category were about the risks of weed management (373 mentions), almost four times as often as the benefits of weed management (97 or 7%). This could be due to the interview protocol that tended to focus more on the risks of management practices rather than the benefits. However, the expert model coincides with these percentages, mentioning the risks of weed
management as 33% of coded responses (244 mentions) and the benefits slightly more often than the farmers at 14% of coded responses (or 102 mentions).

The risks and benefits of weed management nodes are split into control risks and benefits and prevention risks and benefits to allow for comparative analysis in the number and type of risks farmers mention in regards to each practice. Farmers mentioned the benefits of prevention almost twice as many times as the benefits of control, a total of 62 times (or 64% of the conceptual category) vs. 35 times (or 36%). Farmers also mentioned risks of prevention less than the risks of control—164 times (or 44% of the conceptual category) compared to 208 times (or 56%). However, the percent agreement among farmers about what constitutes the properties of those benefits and risks is low. The diversity of agroecosystems in the farmer model creates a diversity of perception among farmers about what constitutes the risks and benefits of weed management. Overall, however, the model shows that farmers place more weight on the benefits of prevention and the risks of control.

The expert model coincides with these results quite well. Experts mentioned the benefits of prevention twice as many times as control (68 vs. 33), as did farmers. Control risks are mentioned more often than the benefits of control by both experts and farmers (124 vs. 208). Because the models are similar in the number of responses given to each conceptual category, most of the differences are found in the properties that define each concept within control and prevention benefits and risks.
Figure 17. Expert and farmer sub-model comparison of the conceptual category risks and benefits of weed management.
Comparing the Benefits of Control and Prevention. The benefits of control only show significant differences at the property level. Both farmers and experts agreed that there are mechanical benefits to implementing control strategies as part of the agroecosystem, though farmers talked about it many more times than experts (20 and 5, respectively). Experts focused on the speed and ease of mechanical equipment, while farmers discussed cultivation’s effect on soil properties as a benefit. Farmers talked about cultivate/tillage as a tool that dried out soil, lifted and moved the soil around weeds, and, used in moderation, achieved the desired effects. None of these properties were mentioned by experts. This difference in perspective is reflected throughout the two models, with farmers more focused on the connections between soil conditions and the risks and benefits of weed management. All of the other concepts and categories align fairly evenly across the two models.

Both farmers and experts located the benefits of prevention most heavily in the agroecosystem, and even more specifically, they agreed that these benefits are due to cover cropping. However, farmers mentioned cover crops’ ability to drain soils, suppress weeds and weed seeds, and cover the ground, while expert interviews did not include these responses as part of the benefits of cover crops. Unless we follow each concept out to its various properties, these differences in understanding would remain obscure. Figure 4 illustrates why following each category out to its property is critical for illuminating conceptual incongruities between the two models. There are no other significant differences in prevention benefits between the two models.
Comparing Control and Prevention Risks. Both farmers and experts agreed that the risks of control tactics spread out fairly evenly over three of the four conceptual categories, with mechanical being the largest risk in both models and economic and ecological risks close behind. However, following each concept out to its properties reveals that farmers are much more concerned with the time and labor required to implement several of the control tactics than experts. Experts focused mainly on the cost required for hand labor, perhaps reflecting an expertise in vegetable production in each area of study—the Netherlands, the northeast, the Midwest, and California. In fact, all of the mentions under economic risk (41) fall under hand pulling. Farmers expand this risk
to include not just hand pulling (27 mentions, or 59% of the category), but also cultivation/tillage (12 or 26%), mowing (4 or 9%), and flaming (2 or 4%).

The economic risks of prevention strategies are not mentioned as frequently as the economic risks of control tactics in either the farmer or expert model. The issue of time and labor seem to be less salient as a drawback of implementing prevention strategies. Instead, both models located prevention risks under the concept of how to implement them in the agroecosystem (71 mentions or 61% for farmers and 58 or 76% for experts). The type of prevention strategy that occurred most often under this risk was cover crop/green manure. However, experts focused on a cover crop’s tendency to contribute to the seed bank if not monitored (weed seed sets below the cover crop canopy), while farmers focused on not being able to establish a good crop stand that shades weeds and inhibits their development.

Farmers also mentioned several additional risks not mentioned by experts, the most frequent being the cover crop’s interference with cultivation/tillage and harvest. Again, this is a perception gained from close contact with the soil, the weed, and the crop throughout a growing season and may not be observed by scientists as part of a more specialized approach to understanding weeds’ biological dynamics.

Both the farmer and expert models located a significant amount of risk in timing prevention strategies. They agreed that wet weather is one of the biggest concerns when attempting to cultivate and/or till the ground to prepare a seed bed or incorporate cover crops/green manure. Farmers added low soil temperatures and dry soil as additional risks. Cultivation/tillage was also a risk when farmers could not get in the field early enough for a good planting date, probably due to weather. Farmers who viewed late
spring planting as beneficial for weed control did not share this perception. Farmers also expanded on the timing risks of cover crop/green manures with four additional categories, all concerning their lack of time to implement them. If they did find a window of opportunity in the fall, the germination of cover crops was delayed and sparse, weakening its effectiveness.

One last observation by farmers that is found throughout their model is the benefit of having enough land to rotate into long or short term cover crops without interrupting the crop rotation. Farmer K talks about the concept of increasing the land base to decrease the economic risk of not being able to incorporate a cover crop in time.

*I’m about to give up on that to some extent because of the fact that we don’t have enough acreage that allows us to let it sit all summer and in the spring it is very hard to deal with in a timely fashion. So some of these things that can work for us add other problems, timing problems.* (Farmer K)

3. Organic Farmer’s Beliefs About and Uses of Prevention and Control Practices

Organic farmers mentioned prevention strategies a total of 607 separate times and control tactics a total of 507 times. If we combine these two theoretical categories into the “prevention/control continuum,” individual responses to weed management practices fell fairly evenly between prevention and control (54% and 46%, respectively) with slightly more responses having to do with prevention strategies.

**Prevention Strategies.** Within the prevention strategies theoretical category are five conceptual categories: mulches, crop rotation, crop choice/cultivar, cover crop/green manure, and seed bank management. Seed bank management was defined by
the expert model as any practice that is designed to prevent the entry of weed seeds back into the soil. These practices include tillage/cultivation at critical times, mowing weeds before they set seed, nutrient management that boosts the crop to shade out weeds and inhibit weed seed development, and seeding crops or cover crops close together to create effective canopies.

Of these five prevention strategies, seed bank management and cover cropping/green manures were mentioned the greatest number of times by farmers, with 223 mentioning some type of seed bank management (or 36% of the category) and 212 mentioning cover crops and green manures (or 35% of the category). These were the most discussed categories among experts as well, with 132 mentions (41% of the category) in the seed bank management conceptual category and 74 mentions (23% of the category) for cover cropping.

The two most common methods for implementing seed bank management strategies in the farmer model were cultivation/tillage (119 or 52%) and mowing (44 or 20%). The expert model also mentioned cultivation/tillage (51 or 39%), but mowing was hardly mentioned with only 7 coded responses. Farmers discussed the type of cultivation and tillage in much broader terms than experts, adding six different types of cultivation/tillage to the list. Experts focused on three concepts for successful implementation of cultivation/tillage—rotating the tillage type, busting paths, and tilling/fallowing the edges of the fields. None of these were mentioned by farmers. Instead, farmers talked about the successful implementation of cultivation/tillage strategies as dependent on the skill of the operator. An ability to implement this strategy
well achieves maximum weed damage, buries weeds, and reduces both damage to the soil and trips across the field.

Perhaps the biggest difference in detail in the cultivation/tillage concept is found in the dimension of timing. Farmer responses to timing were coded 30 separate times, and only one of these responses coincided with the expert model—pre-emergent tillage. Experts focused on timing cultivation and tillage before the emergence of weeds or during critical weed free periods, but farmers discussed the conditions of the soil as crucial for improving results and minimizing risks to soil health (16 or 50% of the properties discussed under timing). Farmer K and Farmer M exemplify the balance between preparing seed beds through cultivation/tillage, preserving soil structure, and timely planting of crops:

_**I always keep weeds in my mind and also erosion.** Erosion, you can lose sleep over erosion. (Farmer K)_

_**Timely tillage, when the moisture level is right, and balancing the physical structure, and getting something planted on time.** (Farmer M)_

It is also apparent that weather is one of the biggest frustrations to farmers when it comes to timing. Farmer P is aware that his ideal management plan may be put on hold by the weather:

_I’ve seen a lot of times that I needed to be cultivating, but it was raining. Grass can grow two inches a day when its 80 degrees and you get an inch of rain and all of a sudden I’m behind the eight ball not because I made a bad decision, but because I just couldn’t do anything about it._ (Farmer P)
Mowing is a key concept in the farmer seed bank management category, but it is hardly mentioned by experts (44 and 7 mentions, respectively). *Timing* mowing to pre-empt seed rain is an especially important idea to farmers, making up over half of the coded responses under the mowing concept. Because over half of the farmers have livestock and/or dairy, mowing pasture becomes an important strategy as part of long term pasture/crop rotations. However, even the vegetable farmers, who make up 24% of the total farmer population, produced 23% of the coded responses to mowing. Farmer H is a mixed dairy farmer and Farmer C raises only vegetables for market and processing, but they both discussed the importance of mowing as part of their management strategy:

*When we put in hay it gives us a chance to mow them off before they come to seed.* You know when we put in a hay field we usually mow it four or five times a year. (Farmer H)

*And because we don’t use any chemicals, we don’t let the green beans go on for all season long. The green beans, we mow them off and plow them under after a couple of pickings.* So you don’t usually get any weed seed or addition to the bank from that crop. (Farmer C)
Cover cropping/green manure was the second most mentioned concept under prevention strategies in both models, and it is closely related to cultivation/tillage. The implementation of cover crops and their incorporation into the soil requires soil disturbance that stimulates the seed bank. The expert model suggests that timing of soil disturbance is as important for seed bank reduction as the cover crop or crop, and this timing depends on the seed bank level. High seed banks require more disturbances to flush out weed seeds and incorporate weeds before they set seed. Low seed banks that do not need to be reduced can withstand crops with longer rotations, like alfalfa, without the risk of re-charging the seed bank. Thus, seed banks determine the length and type of crop rotations and the length and type of cover crops (see expert model figures 7 and 8).

Figure 19. Farmer sub-model highlighting seed bank management strategies as part of the prevention strategies theoretical category.
When asked to describe their seed bank, most farmers described it with quantitative language as “healthy,” “very high,” “low,” or “decreasing.” They did not use this information to inform their weed management decisions, but most of the farmers interviewed used short, annual cover crops and crop rotations, which the expert model identified as important for farms with high seed banks. The shorter the amount of time a cover crop or crop remains in the soil, the more often it is disturbed either to incorporate green matter into the soil or to harvest as a crop. Farmers who had livestock and/or dairy used alfalfa as a long term cover crop, but mowed it regularly to reduce weed seed recharge by any weeds present in the pasture. Mowing long season cover crops such as alfalfa is a key timing property mentioned by many farmers, as we discussed above.

There is a slight divergence between the two models when it comes to cover cropping strategies. Although farmers appear to be using this strategy effectively through short rotations with timely disturbance or long rotations with mowing, their understanding of why this works does not coincide with the expert model. Farmers did not mention timing of disturbance specifically as the reason for success. Instead, 69% of the farmers agreed that a cover crop’s ability to smother weeds makes it successful (48 responses or 75% of total responses). Growing a robust crop stand was the most important part of implementing a cover crop according to farmers (30 mentions, or 47% of implementing cover crops concept). Experts agreed with this idea, and focused even more than farmers on the concept that dense seeding improves the effectiveness of cover crops to smother weeds (9 mentions by farmers and 36 by experts). Experts also expected farmers to focus on the allelopathic properties of cover crops as a kind of
“living herbicide,” but only 9% of the farmer responses under implementing cover crops mentioned this.

The remaining conceptual categories under weed prevention were crop rotation (96 mentions, or 16% of prevention strategies), mulches (59 or 10%), and crop choice/cultivars (14 or 2%).

**Control Tactics.** The control tactics theoretical category is comprised of three conceptual categories: mechanical tactics (e.g., tillage/cultivation and hand weeding), cultural tactics (e.g., nutrient management and seeding rates), and organically approved herbicides. Mechanically controlling weeds was the dominant control method mentioned.
in the farmer model (401 mentions, or 79% of the control category), while cultural tactics (73 or 14%) and organically approved herbicides (29 or 6%) were rarely mentioned. Mechanical control also dominated the expert model, with 158 total mentions, or 71% of the responses.

When asked about specific mechanical control tactics, farmers responded a majority of the time with cultivation/tillage (205 or 51%). The most discussed property in implementing successful cultivation/tillage control was to make multiple trips across the field. This would appear to contradict the idea mentioned earlier that organic farmers are concerned with the health of the soil. On the contrary, farmers are still concerned with the risks control tactics pose to soil health (28 mentions or 78% of the total ecological risks of control category), but farmers view the use of control tactics in a weedy field as a trade-off. If weed control is done early and often, farmers feel they can keep the weed seeds from forming and eventually have a low enough seed bank to move into more preventative measures later on. This excerpt from Farmer D’s interview is a typical, well-articulated example of this trade-off process:

So what I’ve been doing is kind of radical. I even agreed with the criticism I’ve gotten, which has been that I’m working the ground too much. My strategy has been to stay ahead of when the weed seeds or, in this case, the tubers re-germinate. So let’s say that’s every three to five days. I need to get out there before I see weed whiskers, which is every five to seven days. Long story short, I’m probably out there once a week lightly disking that ground. I’m hurting the ground by disking as much as I am—oxidizing the soil, carbon and disturbing the microbe life, and soil compaction. But we’re doing that for a reason. What helps me sleep at night is adding compost and sub soiling to try to rectify what
I’m hurting. If I can get caught up on these weeds I don’t have to go out there and disc the ground three or four times before I plant my crop. In years’ time the weeds and discing will slow down. I’ll let crop rotations do the job, graze pastures, and just keep jumping that around—then I’ll get back in the natural balance of things and I won’t have to overwork the soil. (Farmer D)

The data to support the view the farmers are still concerned with soil damage due to frequent trips across a field is supported not only by their risk perceptions, but also by the frequency with which they mention the impacts of timing on tillage/cultivation. The top two properties of timing that made control tactics successful are: when the weeds are small/white thread stage (14 mentions or 29%), and when the soil conditions are right (18 mentions or 37%).

Farmers are also cognizant of their soil type when discussing the type of cultivation/tillage. Farmer R discussed the importance of the soil type and condition when considering what type of cultivation to implement:

So this soil type is Hoytville clay and almost everyone in the state of Ohio will recognize that name. It is right at the top of list for production…it will give you a great yield but you can easily overwork it; that’s the critical part. (Farmer R)

The most popular type of cultivation/tillage in the control category in the expert model was the rotary hoe—22 coded responses, or 47% of the cultivation/tillage concept. The expert model also recognized the growing popularity of the rotary hoe, with about half of the mentions for type of cultivation given to this implement. However, the rotary hoe was specifically questioned by farmers in terms of its economic, agricultural, and ecological benefits. For example, farmer G recognizes the implications of several trips
across the field not just in terms of the cost of time and labor, but also in terms of soil health:

*He said, “Oh if you rotary hoe every 5 days 5 times then you won’t have any weeds.” I’m like, I can’t do that!! If I rotary hoe every 5 days 5 times I won’t have any beans left plus it would be harder than that road out there. **You just can’t run a rotary hoe in this clay ground.** (Farmer G)*

Farmers mentioned a total of twelve more implements than experts, demonstrating that different types of soils and access to different resources can influence the type of implement used for control. Farmers also mentioned a concept overlooked by the expert model, that soil conditions and the type of weed may determine what kind of implement will be most effective for management. Farmers paid particular attention to the way implements covered weeds and moved through soil. Farmer S has several implements so that he can adjust according to these attributes of the agroecosystem:

*There’s a difference in cultivators. We have the Hiniker with that one single wide sweep, that does really good, especially if it dries after you cultivate. If your soil is tilled right, it’s really good. An S tine will make like a wave of dirt, and a small plant can’t handle that. Whereas the single shovel more or less tucks it under gently. (Farmer S)*

Farmer P also talked about using different types of cultivators under different circumstances (time of year, soil condition, type of weed):

*I may use a rotary hoe to break up the surface and break up the clods. If it’s mellower, I’ll use the tine and then maybe use a rotary hoe or not use a rotary hoe at all. Then I would go into row cultivation, and I would use a Danish tine type row cultivator, initially. Then I would use a Hiniker cultivator which has*
broad sweeps on it. The nice thing about those broad sweeps the leading edge is sharp. They look like a delta wing aircraft. They’re angled back and when they slide through the ground these slicing devices can slice that off broadleaves and thistles below the surface. (Farmer P)

Both of these farmers have transitioned from a conventional background into organic row cropping and may be more familiar and interested in cultivators in general. However, through their experiences with organic systems, they have observed, over the years, when and what kind of implements will give them the most success at weed control.

The second most cited type of mechanical control in both the expert and farmer model was hand pulling (138 mentions or 34% of total mechanical control responses for farmers and 45 or 28% of total for experts). Hand pulling is mostly a control measure, and farmers reported that they time this tactic when they see the weed. However, hand pulling can also be a very effective preventive strategy for farmers, especially for the large, invasive weeds such as ragweed. Farmers who had no problems with ragweed all mentioned stopping the tractor to hand pull each one.

Farmers were asked specifically what three weed management practices they used most often. Out of the 29 farmers interviewed, 93% mentioned cultivation/tillage, 48% mentioned mowing, 24% mentioned crop rotation and mulch, and 14% mentioned cover crops and hand pulling.

Assessing the prevention/control continuum with individual farmers: two case studies. The expert model predicted that knowledge of EWM would play one of the largest roles in weed management decisions. The conglomerate farmer model shows that farmers already have a solid base of ecological knowledge and knowledge of
prevention and control techniques. Theories in judgment and decision making also contend that in addition to knowledge, risk perceptions and experiential knowledge will play a role in farmer decision making. According to the parameters outlined by the prevention/control continuum, a farmer who demonstrates long term thinking, knowledge of EWM, and utilizes a diversity of management options should show an increase in how much he or she discusses and uses prevention versus control practices. In addition, their perceptions of weeds and weed management will motivate different types of weed management decisions and behavior.

Do the mental models developed in this research accurately predict if a farmer will be more prevention or control based according to the results of their knowledge, experience, and risk perceptions? The following examples are based on two individual farmer’s mental models. They are exemplary cases that confirm these hypothetical connections between risk perceptions, knowledge, experience, and weed management decisions are indeed present in the mental models.

**Example A.** Farmer K is a life-long farmer who transitioned his land and herd to organic production a few years ago. His interview responses demonstrated a high amount of ecological knowledge (38 mentions, or twice as many as an average response to this category) and an awareness of farm production as a dynamic interplay between human management and ecology. In this example of Farmer K’s agroecological observations, he relates his experiences with the Arctic Poll and weeds, and agriculture’s role in bringing them together:
Then you graze the hay off, but the cows will not eat the ragweed. And that’s when the red polls come in. They love to eat them. They like lambs quarters seeds too. My first flock of Arctic Polls I saw in the neighbor’s hog lot. He had sold his hogs and grew up lambs quarters, and there were the polls. (Farmer K)

Farmer K has a deep understanding of weed biology, and named several obscure weeds such as bulbous buttercup and hedge mustard. He was the only farmer to mention predation (a concept important to experts) and referenced an Ohio State University study about predator beetles.

Farmer K’s coded results showed a balance between his perceived risk of prevention and control (4 and 3 mentions each) and more perceived benefits of prevention strategies overall. His perceptions of weeds in the farm system reflect a healthy mix. He concedes that weeds play a role in the environment, he also has a healthy dislike of weeds:

Farmer K: I don’t think we have any weed that I would be afraid of, except it is just a pain.

Interviewer: So at what point does a weed become a cause of concern to you?

Farmer K: When it begins crowding out the goodness, you know, the good plants. And also, appearance along roadsides. Vanity, vanity, all is vanity.

This dislike, along with his deep connection and familial dependence on land for his livelihood, may explain his intense perseverance and long term strategizing:

We don’t have velvet leaf, not at all, because for 30 years when I saw one plant I would pull it. Once you have it, a full problem, you will never get rid of it. I pulled those problem weeds for the last 40 years, so now my son-in-law and
daughter really have it nice. Like I said, you need to learn to identify your weeds. (Farmer K)

Taken together, his combination of knowledge, experience, and risk perceptions would indicate that Farmer K takes a preventive, long term approach to weed management. The model’s results show that this assumption is correct. Farmer K reports that rotational grazing, along with crop rotation and nutrient management, are the most used and important parts of successful weed management on his farm. He talked about prevention strategies a total of 39 separate times, and control tactics only 20.

Example B. In contrast to Farmer K, Farmer G’s knowledge is mechanical rather than ecological. The interview with Farmer G began with a tour of his shop. It consisted of several weed control implements in various stages of construction and a new tractor with front implement attachment capability. He spent much of his time adjusting these implements in an attempt to increase weed control efficiency and efficacy. Two examples of this included his re-designed “weed whacker” and his modification of an old round-up application implement that used wicks to distribute herbicide, now vinegar, directly onto the plant.

Both of these implements are used only after the weed has grown taller than the crop, by either cutting or burning the weed above the crop level. His rigid dependence on control measures leaves him fewer options to filter out weeds if he misses a window of opportunity during the season. As a result, he is very focused on the unpredictability of the weather as the main cause for his lack of weed control:
I’ve had the flamer hooked up and think “Oh, I’m going to do it,” and then it rains and it was too muddy and couldn’t hold a tractor. Then four or five days later, I can’t do it. It’s too late. I’ve missed my window which is back to the uneven weather and the challenges. (Farmer G)

I couldn’t even see the rows in all the weeds, and it was too wet. By the time I could finally get in the field, then I had to combine wheat and it was just an absolute disaster. (Farmer G)

Farmer G’s crop rotation is very simple and does not include using his livestock, a valuable resource, as part of that rotation. Because he farms alone, Farmer G spends much of his time trying to mechanize his operation. He even talks enviously about those who aren’t organic being able to do this easily. As a result, he prioritizes mechanization over cultural strategies:

I’ve got some major issues right now. I let them (the cattle) lodge in the spring and they cut my fences all to shreds. I spent all my time spreading 150 tons of compost and working on my manure spreader and redesigning it. By the time I got that done it started getting cold. They spend all day at chewing my fence and knock it down instead of me trying to mow. You know, today people just buy a bigger, better mower and a bigger, better sprayer. (Farmer G)

Around here crop rotation is corn—beans—go to Miami, and I can’t afford to go to Miami. So I was substituting wheat for Miami, but that’s not enough. You need to have more than a three way rotation. (Farmer G)

Farmer G understands that his crop rotation and livestock are underutilized, but he is constrained by time and labor. This might explain why he is fixated on finding short cuts to weed management such as the relationship between nutrient management and
weeds. Farmer G talks about this relationship 14 separate times, over three times as often as the average of the farmers interviewed. Farmer K (above) is skeptical of this idea.

Farmer G mentions the risks of weeds 18 times, mostly describing them as biological competitors and economic barriers. He mentions the risks of weed management a total of 23 times, most of these under the concepts of mechanical and economic risk. He mentions the benefits of weed management only once.

After considering the nature of Farmer G’s knowledge and where his risk perceptions are focused, we would expect him to fall on the opposite side of the prevention/control continuum as Farmer K, and his model proves this to be the case. He discussed control tactics a total of 16 times and prevention strategies only 9. The management Farmer G reported that he uses most often and finds indispensable are his weed whacker, which he admits is only a rescue measure:

*The one that’s just out of desperation that’s worked and saved the crops in my beans has been the weed whacker there.* Talk about not being OSHA (Ohio Safety) approved, a 30” blade whirling out in front of a thing with no shields on it! (Farmer G)

The other tactic he described as useful was spraying milk:

*If I was spraying milk right on that row, I’m pretty convinced that I could make that bean field awful good and make that horseweed feel awful sick and the bean might be able to outgrow him.* Plus, the calcium and the biological enzymes and stuff in the milk should really get the bean a kick and get it going. (Farmer G)

These two extreme examples are pulled out to demonstrate that individual differences in the farmer mental models do seem to predict prevention or control
tendencies based on knowledge, risk perceptions, and experiences. Of course there are other attributes that deserve further attention in order to explain examples that may not be as polarized. For example, if a farmer demonstrates a high degree of EWM knowledge but still practices more control tactics, what explains this behavior? Judgment and decision making theories approach this question as part of human’s use of dual processing—the balance between the use of analytical and experiential knowledge in the decision task. The “Dual Processing” theoretical category, explored in the following chapter, takes these theories into account and explores how farmers utilize both kinds of processing in their weed management decisions. These theoretically based codes and explanations for behavior may be even more illuminating for the majority of farmers who fall in the middle of these two, extreme examples and be more generalizable to a wider sample of farmers.

Conclusions and Recommendations

Comparative analysis revealed that experts and farmers knowledge of ecological weed management and risk perceptions, in general, are in fairly sharp alignment. However, the two models demonstrate divergence when it comes to underlying mechanisms. For example, both farmers and experts understand the role that humans play in introducing and spreading weeds. Farmers, however, focus intensely on the role their soil management plays, while experts identify a wider range of sources for seed dispersal, including biological and ecological dimensions. Farmer understanding of the seed bank may be vague compared to experts, but their management practices are
consistent with the expert explanations of ways to effectively reduce the seed bank. These practices include stale seed beds and diverse cover cropping and rotation strategies.

What, then, is contributing to the perceived disconnect between weed ecologists, scientists, extension personnel, and organic farmers? The ecological weed management knowledge of both experts and farmers are quite high, but the source of this knowledge is different. Farmer knowledge is experience-based rather than experiment-based. Farmers encounter and manage the risks of weeds and weed management on a daily basis, and gain knowledge about weeds, their life cycles, and the effects of their management practices through years of observation and trial and error. Experience-based knowledge leads to different risk perceptions, such as the high risk of weed management to time, labor, and resources and the high benefits of weeds to humans and wildlife.

Like scientists, farmers are keen observers that look for patterns to help explain the relationships between their management and the weed populations. This leads to beliefs that scientific observation has yet to explore, such as the relationship between weeds and soil nutrients and the belief that weeds are permanent fixtures in the soil. Farmer conclusions come from working within the complex interactions of the agroecosystem, giving them a more holistic understanding of weeds’ impact in the farm system from season to season over a period of many years.

This initial, exploratory investigation into organic farmers’ mental models can be used to identify ways that can potentially bridge the perceived disconnect between experts and farmers. We discuss three areas for possible integration of expert/farmer knowledge, experience, and risk perception:
1. Integrate knowledge and management

2. Research farmers’ short cuts

3. Acknowledge farmers’ risk perceptions, experience, and values

**Integrate knowledge and management.** The expert model emphasized that a high level of biological and ecological knowledge was needed to implement effective, ecologically based weed management. Weed identification, knowledge of weed life cycles, and understanding agroecology were all important concepts within this conceptual category, and comparative analysis revealed that this knowledge was high in the Midwest organic farm community as a whole. Farmers are not comfortable discussing their strategies as part of an overall plan to reduce the “seed bank,” but they do understand the mechanisms required to reduce it—cover cropping with short season annuals, mowing, cultivating, or hand pulling before seed sets, and diverse crop rotations.

Because knowledge of EWM principles does not seem to be lacking in the farmer mental model, the problem of a high learning curve for implementing EWM may not be as big a barrier to adoption as the expert model predicted. Even farmers who used high levels of control were familiar with the ideal state of crop rotations, cover cropping, and timely mowing. The only farmers to discuss high learning curves were dairy and cash grain farmers who transitioned from conventional to organic operations. They mentioned the absence of guidance during the transition years and some fear about what to expect in the absence of antibiotics and herbicides. Support during this transition period might be addressed by a collaboration of already transitioned farmers and the scientific community with those planning to transition.
The farmer model shows that most farmers in the Midwest have a solid knowledge base from which to start the process of integrating EWM into their management practices. Many of the ecologically based strategies researched by experts are already familiar to farmers—crop rotation, mulches, cover cropping, reduced tillage, and seed bank management—and are perceived to be socially, ecologically, economically, and agriculturally beneficial. In addition, the farmer model reveals that farmers have a high degree of confidence in their management practices to mitigate the social, economic, agricultural, and ecological risks of weeds. Farmers’ belief in their ability to manage weeds successfully may be due to their management-centered approach highlighted by various sections of the model (e.g., benefits of weed management, seed bank perceptions, and risks of prevention and control).

Unlike previous research that showed conventional farmers blamed lack of weed control on forces outside of their personal control (Wilson 2009), organic farmers take responsibility for the type and density of weeds on their farm. Not only do they accept responsibility, but they also believe they have the ability to successfully manage weeds in the organic system. Some farmers even feel this ability is enhanced in an organic system, and that chemicals ultimately fail in the long term to achieve desired results. This management-centered approach is good news for experts. Research and outreach focused on the management based causes of weeds, rather than the ecologically based causes, will resonate with organic farmers’ management focused beliefs.

A management-centered approach, limited by time and resources, might also be what motivates farmers to believe that weeds act as “indicators” for what is lacking in the soil. Studies show that mental models are often used as a blueprint for explaining other
phenomenon in similar domains. If they perceive their weed management to directly influence weed density levels, it would follow that they also believe their nutrient management directly influences the types of weeds present in the field.

This is a major conceptual area where the expert and farmer model diverge. Overall, farmers believe what experts view as a myth—that weeds seeds are forever part of the soil. However, this belief is supported by theories in judgment and decision making—specifically the theory of bounded rationality. Humans have only so much time, memory, and cognitive ability to process the consequences of their actions (March 1994). The more complex a decision task, the more likely a decision maker will rely on past experiences and heuristics to come to a decision.

Farmers beliefs about the connection between weeds and soil nutrients could also be explained by the human tendency to look for purpose and patterns in the physical world that can explain and guide future behavior. This can lead to a perceived relationship between two things that, in fact, do not exist. These illusory correlations are commonplace in studies of judgment and decision making (Plous 1993).

Instead of labeling this prominent farmer perception as a myth, weed scientists could generate research questions in collaboration with farmers’ observation of the links between nutrient management and weeds. Research into this area has not been done by the scientific community, but is highly sought after by farmers. Most farmers cited the use of evidence-based information as important, and would be curious and interested in the results. In fact, the only time farmers deferred to “experts” during the interviews was when they wished they knew more about the weed/soil relationship. Scientists and
researchers are in the unique position of having the ability to confirm or deny the existence of evidence for this belief.

**Research farmers’ short cuts.** Rather than knowledge limitations, the biggest barriers to implementing ideal weed management practices in the farmer model were time, labor, and resources. Along with this perceived barrier comes the inclination to search for short cuts and more effective ways of managing weeds in the time allowed. Instead of viewing the farmer impetus to use simple patterns to guide management decisions as a barrier to prevention strategizing, experts can utilize this heuristic processing to their advantage.

Experts often emphasized the complexity and uncertainty of prevention strategies, but they may need to focus on the three key principles of EWM and develop decision rules for when it is appropriate to apply them. Farmers can then take this information and adjust it to work within their own, unique agroecosystem.

While experts are comfortable with complexity and point out that complexity offers even more filters to deplete the seed bank, farmers do not perceive this as a benefit. Experts can also take advantage of farmers’ desire for short cuts by offering management based seminars that offer evidence-based examples of when, how, and why certain long term prevention strategies work for specific weeds and weed seed bank populations. Some studies already focus on the economic benefits of long term strategies (Liebman and Gallandt 1997; Liebman and Davis 1999; Mohler 2009), but this kind of information needs to be presented to farmers as a way not just to improve weed management, but also as a way to save time and labor in the long run.
Taking a look at areas where farmers may need information to support quicker decisions reveals several potential studies and publications that would interest the organic farmer:

1. What crop rotation is best for a high seed bank and for a low seed bank?
2. How can a farmer find out more about his or her seed bank? (most farmers have the resources to do the test on their own).
3. How many weeds can a farm withstand before yield loss (a rule of thumb) and how can this be determined?
4. Is a rotary hoe actually useful? What kinds of tillage work best for what kinds of soils?
5. What are the costs and benefits of delaying fall tillage?
6. Does predation actually work and what percentage of weeds seeds will be destroyed in predation versus fall tillage?

Most of the farmers interviewed do not have the capital to increase the mechanization of their production methods; rather, they are looking for effective strategies that can save them time and money without risking the economic viability of the farm. In other words, farmers are searching for ways to integrate EWM principles and knowledge into definitive management practices that save them time, labor, and money. If prevention strategies are shown to be cost effective measures in the long term, farmers may be willing to put in the time and effort required to begin the process of incorporating more diversity into their weed management practices.

**Acknowledge farmers’ experience, risk perceptions, and values.** Risk perceptions among farmers and experts aligned across many conceptual categories: the risks and benefits of weeds, the risks and benefits of prevention, and the risks and benefits of control. Like the source of farmer knowledge, farmer risk perceptions are
based on their experience with weed management and the consequences of their decisions on the health of the agroecosystem.

The most prominent example of the connection between experience and risk perception was how much organic farmers in the Midwest mentioned their concern with soil erosion and health. Organic farmers understand and observe how soil conditions effect weed germination and growth, the ability of a plough to roll soil over a weed, and a crop’s ability to compete with the weed. Many of them talked about organic methods increasing their crops’ ability to withstand drought, to drain excess moisture, and to increase the efficacy of their tillage.

Comparative analysis revealed that organic farmers are acutely aware of the risk of over-tillage—a risk emphasized by experts—and are open to practices that would reduce or eliminate tillage. Their intimate connection with soil causes them to constantly question the efficacy and efficiency of their decisions. Their reluctant use of the rotary hoe, their observations that some implements perform better depending on soil conditions, and even their hesitation to disc a field in order to burn up the seed bank are all examples of a constant pull between economic and environmental benefits.

Experts may be able to harness risk perception as a motivator for preventive approaches by acknowledging that weed management doesn’t just affect the weed, but the soil as well. Soil health and weed management coincide in several areas of the expert model: nutrient management, cover cropping and green manures, crop rotation, using appropriate tillage, and even the relationship between healthy soils and healthy micro and macro-organic life that increases weed seed decay and predation. By framing weed
management in terms of soil health, outreach efforts may increase farmer interest and promote greater adoption of preventive strategies.

The farmer risk perceptions brought out in this mental models study point towards another area for further investigation. One of the eminent scholars in human judgment and decision making, Baruch Fischhoff, writes that the decisions we make about risk, “define us as individuals and as citizens, showing what we value and what we accept as our personal responsibility…These choices shape our world, as well as that of people elsewhere on the planet and in future generations—not to mention their effects on the natural environment, which might be seen as having rights independent of our interests” (1997). According to decision science, values play an important role in modifying the correlation between perceived benefits and perceived risks (Siegrist, Cvetkovich et al. 2000; Wilson, Hooker et al. 2009). Organic farmers access other sources of information in their decision making processes beyond the economic bottom line, such as the value of a healthy lifestyle and healthy soils. Environmental stewardship values take management decisions beyond “bottom line” thinking to a more economically “irrational” choice based on health of the soil, people, animals, and crops (Berry 1977).

Descriptive models of judgment and decision making are apt to describe how organic farmers use risk perception, experience, and values in their weed management decisions. According to dual process theory, a balance between two processing systems in the human brain, one analytical and the other experiential/intuitive, is necessary for rational decisions. Both systems provide types of information that motivate and guide the decision making process (Plous 1993; Peters 2008). These current theories define risk as a subjective, human concept created to cope with the uncertainties and dangers in
everyday life (Slovic 1987) and recognize the vital role of intuition, experience, values, and emotion in the decision making process—all important and prominent attributes of organic farmers—without ignoring the role of analytical processing. All of these components of decision making influence decision processes concerning a risk that an individual cares about. In this case, farmers are not only concerned with weeds, but with soil, family, and economic health as well. Further analysis of the farmer mental model will explore the role of dual processing in weed management decisions.
Chapter 3
Organic Weed Management in the Midwest: The Role of Affect, Emotion, and Risk Perception

In a sense, farming might be called a warfare against weeds. Some farmers emerge from the struggle victorious, while others go down to defeat. So powerful are weed enemies in reducing crop yields, while at the same time multiplying labor, that the farmer should at every turn strengthen his position against them. He should bear these invaders in mind in planning the crops he will grow and in deciding on the fields where he will grow these crops, in choosing the implements he will use, in buying his seed, and in many other farm activities...Some men do not attack weeds with enough vigor; they look for rocking-chair methods of work. There is no royal road to weed control. In the main, the old doctrine of “hard work and plenty of it” must be observed, but unless this work is applied intelligently a vast amount of labor may be expended with but little accomplished other than a temporary abatement of the evil.

(Cox 1915)

Introduction

The “war against weeds” has persisted for as long as agriculture has been in existence. The excerpt above is taken from one of several United States Department of Agriculture (USDA) bulletins sent out in the early 1900’s to assist farmers in their struggle to control their greatest “enemy.” Land grant universities continue to disseminate current research to try to increase successful weed management (Cox 1913; Liebman and Mohler 2001; Hakansson 2003; Mohler and Johnson 2009), but weeds are
still one of the most feared and stressful parts of farming (Bastianns, Paolini et al. 2008; Mohler and Johnson 2009).

Today, organic farmers continue to battle weeds economically, emotionally, and physically. Organic farmers’ choice to eliminate chemical inputs from the farm system puts them in much the same position as farmers over one-hundred years ago—finding the right matrix of emotion, motivation, and intelligent management to win the battle, and eventually the war, against weeds. Another early USDA bulletin on thistle—which emerged as still being one of the most worrisome weeds for farmers in this mental models study—stated that any method for keeping thistle top growth down will do, as long as it is done with constant diligence. It concluded that “The man, therefore, is of far more importance than the method” (Cox 1913). Successful weed management is not simply a matter of knowing what management practice to employ. Ultimately, weed management success depends on human elements of judgment and decision making.

Farming is a unique arena where the environment’s risk to humans (weeds in the farm system) and humans’ risk to the environment (over-tillage and excessive nutrient application or loss) coalesce. A farmer’s ability to make good management decisions will determine if he or she is able to minimize the impacts of these risks while also working to sustain or improve the health of the agroecosystem. In the United States, over 40% of the land mass is agricultural and under the direct influence of farmer decisions (United States Department of Agriculture 2007). The well-being of the environment and the health of soil, water, and people is, in part, the result of how each individual farmer perceives the risks of weeds and weed management and decides to act on it. Delving into
the farmer mental model developed in this study offers possible explanations for the affective and emotional motivations behind organic farmers’ management decisions.

**Organic Farmers and Descriptive Models of Decision Making**

Early studies of human decision making emphasized normative models that assumed rational decisions about a risk were devoid of emotion and entirely based on maximizing utility. This perspective of decision making calculates risk with economic utility functions that identify all possible options and their probable consequences (Plous 1993). Normative models are based on the idea that humans are capable of using decision rules to make consistent, rational choices. Risk, in this sense, is a simple calculation of the probability of an outcome multiplied by the consequence.

Modern, chemical and capital intensive agriculture is an excellent example of the normative model of decision making within an agricultural setting. The production function, used by the USDA and other private agribusinesses, measures the risks and benefits of agriculture according to efficiency, replicability, and standardization (Lyson and Welsh 1995) in order to increase crop yield and maximize profit. Weeds, in this domain, are a threat to yield and therefore high risk (Wilson, LeJeune et al. 2008). Management decisions that follow this normative line of reasoning will be based on the most cost efficient way to control weeds and improve yields through technology, chemical applications, and mechanical tillage.

There are two drawbacks to understanding organic management decisions using normative models. The expert model emphasized that ecological complexity blurs causation between management choices and weed populations. An organic farmer cannot
possibly know all the possible outcomes and consequences of weeds and weed management choices. Rational calculations of maximum utility are impossible in this case. Physical attributes of the farm, the farm operation itself, and the farmer all introduce further limitations to maximizing utility. The farm’s limits are resource based (e.g., available equipment, time, labor, and money) and physical (e.g., soil type, geography, and perhaps the most limiting of all—climate and weather patterns), while farmer limitations are cognitively based (e.g., memory, cognitive ability, and attention span).

The second reason to abandon a normative model for farmer decision making is that even normative models of risk cannot be free from the influence of value judgments (Slovic 1987). Judging the consequences of a risk, no matter how scientific or analytically based the assessment may be, involves value-laden judgment (Slovic 1999). Organic farmers may view the risks of managing weeds to extend beyond economic values to include the health of soil, people, animals, and other components of the agroecosystem (Berry 1977; Lyson 2004). Previous mental models studies found that farmers do indeed combine financial and lifestyle domains when making decisions (Eckert 2006). Other, non-economic sources of information in the decision making process are often considered to be as important as the economic viability of the farm.

In light of this research and farmer’s continuous struggle with weeds despite increases in weed management technology and knowledge, we turn to descriptive models of judgment and decision making in order to describe organic farmers’ weed management decisions. Descriptive models recognize the vital role of risk perceptions, affect, and emotion in the decision making process—all important and prominent attributes of
organic farmers—without ignoring the role of analytical processing. In this paper, affect is defined as a feeling of “goodness” or “badness” about weeds and weed management built up over time through each farmer’s experience. Dual process models describe human decision making as a combination of experiential/emotionally based, or affective, thought processes (system 1) and deliberative, analytical thinking (system 2) (Damasio 1994; Epstein 1994; Kahneman 2003). System 1 is the first response to a risk, and often includes heuristics, or rules of thumb, based on experience and affect in order to simplify and speed up decisions.

According to dual process theory, a balance between system 1 and 2 is necessary for rational decisions. Both systems provide types of information that guide and motivate the decision making process (Plous 1993; Kahneman 2003; Peters 2008). In the absence of experience and/or emotional system (system 1), a decision maker would be unable to choose efficiently between different options in simple decisions (Damasio 1994; Hsee 1996), while the absence of the analytical system (system 2) would cause an individual to become narrow minded and fail to consider more beneficial options. These two systems influence decision processes concerning a risk that an individual cares about, in this case, weeds and weed management.

This paper investigates what types of information processing (system 1 or 2) are dominating organic farmers’ weed management decisions. After a brief overview of the dual processing results from the farmer mental model interviews, this paper will discuss organic farmers’ use of system 1 processing, specifically, the role of affect in their weed management decisions.
Methods

Twenty-nine farmers from Ohio and Indiana were interviewed in the fall and winter of 2010-2011. For a detailed account of the interview protocol and analysis, please refer to chapter 2. The very first question in the interview (What is the first thing that comes to mind when I say the word “weed?”) was designed to illicit a farmer’s immediate, affective reactions and emotions to weeds. Follow-up questions focused on specific agricultural, ecological, economic, and social impacts of weeds in the farm system. Farmers were also specifically asked about the risks and benefits of weed management.

In addition to the interview questions, farmers were asked to complete an additional ranking task. Previous mental models research (Morgan, Fischhoff et al. 2002; Scholl and Binder 2009) used picture sorting as a triangulation tool to elicit new information about interviewees’ perceptions of risk. Instead of photographs, each farmer was asked to arrange a set of sixteen note cards from the most important to the least important things they considered when managing weeds (Table 1).

The note cards reflected risk factors in the weed management decisions as well as experiential/affective reasons for weed management and analytical considerations. Overall, the note cards were split evenly between system 1 and 2 processing, with eight in each. Farmers were asked to work fairly quickly in order to simulate the time constraints experienced on the farm (Finucane, Alhakami et al. 2000).
Interview Results

Heuristic Processing. The heuristic processing conceptual category (system 1) includes the farmers’ affective and emotional responses towards weeds and any heuristic tools that exemplify system 1 processing. Farmers mentioned some kind of heuristic processing a total of 444 separate times, or 85% of the total dual processing category, making it a substantial concept. Within this conceptual category, use of heuristic tools, or a need for short cuts, were mentioned 285 times (64% of the total conceptual category).

Farmers’ affective responses were coded by weighting their initial response to the very first question, “What comes to mind when I say the word ‘weed’?” as either negative or positive affect. Twenty-eight out of the 29 farmers interviewed had a negative affect towards weeds.

The most prominent concept within heuristic tools—the weed tolerance continuum—had 183 mentions (64% of the total heuristic tools mentioned). Its properties range from tolerating weeds to zero tolerance for weeds. Organic farmers referred to weed tolerance a total of 183 times in the 29 interviews, which is a substantial amount. “Tolerating weeds to a certain threshold” was discussed by farmers most often, with a total of 94 mentions (51% of the weed tolerance conceptual category). Farmers may not have specifically defined their decision rule as a “threshold,” but it was coded this way if it included a visual, economic, or experience based cue for action. Zero tolerance and tolerating weeds were 20% and 30% of the mentions in this concept, respectively. The use of weed tolerances as a heuristic tool will be discussed later in this chapter.
Experience plays a role in system 1 processing because it increases intuitive response and decreases the amount of time it takes to make decisions (Damasio 1994), but it is separated out from the dual processing filter theoretical category, which focuses specifically on systematic and heuristic processes. In this farmer model, Experience/Trial and Error is located after the management behavior as a feedback loop that can either solidify current management practices or challenge previously held knowledge and assumptions and alter management in the future.

**Systematic Processing.** The systematic conceptual category (system 2) includes concepts that are deliberative and analytical. Two main concepts, cost/benefit analyses and the parameters of the farm were identified. Overall, references to systematic processing were mentioned a total of 79 times, or only 15% of the dual processing category. This could be due to the fact that these concepts were not in response to specific questions and represent unprompted examples of systematic thinking. In order to assess whether or not the low response rate to system 2 processing is due to the interview protocol or the fact that farmers rely more on system 1 processing, farmers were asked to participate in a ranking exercise, which will be discussed later in the chapter. Preliminary results show that farmers do indeed rely more on system 1 processes.

The largest concept within the systematic processing category is farm parameters. These parameters include available resources such as time, land ownership, equipment, labor, and cash flow. They also include any rules or regulations that organic farmers must follow to be certified organic, such as the National Organic Program (NOP) standards. The need for short cuts based on the limitations set by the farm parameters—mostly time and labor—were mentioned by over half of the farmers (25 mentions).
without prompting. References to cost/benefit analysis (27 mentions) make up the rest of this conceptual category.

While not included as part of the systematic processing concept, knowledge of Ecological Weed Management (EWM) Principles is one of the largest conceptual categories in the entire farmer model. As experience is to heuristic processing, so EWM knowledge is to systematic processing. It requires a slower, more deliberative approach to weed management based on ecological understanding. Long term planning, understanding agroecology, weed seed bank management, and recognizing opportunities to manage weeds—all concepts within EWM knowledge—exemplify properties of system 2 processing and inform a farmer’s accurate use of analysis in their management decisions.

**Risk perceptions of weeds and weed management.** Perceptions of risk are influenced by a farmer’s experiences with weeds as well as their affective and emotional responses to weeds. For a detailed analysis of the results of farmer risk perceptions see chapter 2. Here, risk perceptions will be discussed in relation to system 1 processing.
Figure 21. Expert model with dual process filter highlighted.
Results from the ranking exercise showed that farmers use a majority of system 1 processing in their weed management considerations (Table 2). Five out of the first 8 top-ranked considerations were system 1 processes, suggesting that organic farmer decisions are largely dominated by value orientations, experience, and affect. The top four considerations included three system 1 processes and one system 2 process.

“What worked in the past” was the most important consideration for farmers according to this exercise. Time and labor, the type and timing of the weed, and soil health were the next three highest ranked considerations (Table 4). Three of the four value orientations were ranked in the top eight considerations: soil health (4), crop yield (5), and environmental/ecological health (8). Public perceptions of the farm were talked about often during the interviews, but ranked quite low in this exercise (13).
<table>
<thead>
<tr>
<th>Consideration</th>
<th>Overall Rank</th>
<th>Type of Information Processing</th>
<th>Processing System</th>
</tr>
</thead>
<tbody>
<tr>
<td>What worked in the past</td>
<td>1</td>
<td>Experiential</td>
<td>1</td>
</tr>
<tr>
<td>Time and labor</td>
<td>2</td>
<td>Constraint</td>
<td>1</td>
</tr>
<tr>
<td>Type/timing of weed</td>
<td>3</td>
<td>Analytical</td>
<td>2</td>
</tr>
<tr>
<td>Soil health</td>
<td>4</td>
<td>Values based</td>
<td>1</td>
</tr>
<tr>
<td>Crop yield</td>
<td>5</td>
<td>Values based (economic)</td>
<td>1</td>
</tr>
<tr>
<td>Farmers w/ similar soils/crops do</td>
<td>6</td>
<td>Experience (second hand)</td>
<td>1</td>
</tr>
<tr>
<td>Markets/consumer demand</td>
<td>7</td>
<td>Analytical</td>
<td>2</td>
</tr>
<tr>
<td>Env. and/or ecological health</td>
<td>8</td>
<td>Values based</td>
<td>1</td>
</tr>
<tr>
<td>Immediate control</td>
<td>9</td>
<td>Affective Response</td>
<td>1</td>
</tr>
<tr>
<td>Respected farmer’s advice</td>
<td>10</td>
<td>Analytical (knowledge)</td>
<td>2</td>
</tr>
<tr>
<td>Family and worker health</td>
<td>11</td>
<td>Values based</td>
<td>1</td>
</tr>
<tr>
<td>Cash flow</td>
<td>12</td>
<td>Analytical</td>
<td>2</td>
</tr>
<tr>
<td>Public perception</td>
<td>13</td>
<td>Values based</td>
<td>1</td>
</tr>
<tr>
<td>National Organic Program standards</td>
<td>14</td>
<td>Analytical</td>
<td>2</td>
</tr>
<tr>
<td>Latest research and science</td>
<td>15</td>
<td>Analytical</td>
<td>2</td>
</tr>
<tr>
<td>Extension recommendations</td>
<td>16</td>
<td>Analytical</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4. List of note cards for ranking exercise and the corresponding processing system.
Discussion

Simplifying management decisions. According to the expert model, one of the biggest risks to implementing successful weed management based on ecological principles is the lack of a clear cause and effect mechanism between a weed management strategy and its outcome. It is clear, however, that organic farmers are forced to make decisions in a very complex environment under rigid time, labor, and resource restraints. While the scientific community can afford to be comfortable with complexity as part of the challenges of research, farmers must search for patterns and relationships, either consciously or unconsciously, that might help to save them time and simplify their operations in order to stay viable. Heuristic, or system 1 processing, plays a large role in simplifying their weed management decisions.

The theory of bounded rationality explains that humans may intend to be rational and consistent, but their judgments and decisions are bound by time, resources, and limited attention and memory (March 1994; Kahneman 2003). As a consequence, humans often use heuristics, or rules of thumb, to help simplify the decision making process (Kleindorfer 1999). In the face of both complexity and constraints, farmers are often forced to simplify the decision making process. On the one hand, farmers are participating in the complex and unpredictable rhythms of the agroecosystem, while on the other hand available resources, regulations, and the physical properties of the farm restrict their options within this system.

Farmers talked openly and often about the risk weeds pose to time and labor in several categories of implementing control tactics (flaming, mowing, cultivating, and
hand pulling) and prevention strategies (mulch, cover crops/green manure, tillage). These constraints directly influenced their decisions. In the following excerpts, each farmer talks about their ideal management strategy being thwarted by time and labor constraints:

*What do you have time for? What can actually be accomplished versus what you desire to get done? (Farmer G)*

Hay is a very labor intensive crop, so once we start getting over 200 acres of hay it's just way too much. We have to sometimes take out really good fields. (Farmer D)

*You really have to be on top of it. Working by yourself, it's hard for me to get help at the right time. (Farmer R)*

In spite of these constraints, a farmer’s perception of what constitutes a time saving practice varied according to the size and type of the farm. Farmer P discussed mechanization as labor saving only at certain scales. His decision to keep returning to manual cultivation is due to the amount of time it takes to calibrate equipment as well as the risk of not calibrating correctly and, as a result, damaging the crop:

*So then you're like, “Oops, I'm going to stop 'cause I don't have the time right now to screw this crop up, but I know manual works.” So guess what, I'm going to grab my scuffle hoe or my grass weeder, my rotary hoe or the glacial wheel hoe which we purchased this year and I love it.*

Often, farmers talked about wanting to simplify and ease their operations in order to find a management tactic that was “good enough” under less than ideal conditions:
I’ll look at the task. If it looks like it’s something pretty easy and quick I’m more inclined to do it than not. I tend to put off the more arduous ones. (Farmer M)

Do I have equipment? Can I find the equipment? Can I make the piece of equipment? Do I have enough money to hire Hispanics to come out here and do it? How much money am I going to get from my crop? (Farmer G)

What I can do with the equipment that I have and the amount of time I have to best utilize it? (Farmer W)

Because conditions set by the farm parameters and farm attributes are less than ideal, farmers exhibit clear use of satisficing in their decision making process. Satisficing describes choice behavior as one that only satisfies an individual’s most important concerns (Simon 1959), whether those concerns are economic, ecological, social, or agricultural.

The following two examples demonstrate satisficing on different attributes of weed management—one economic and the other ecological. Farmer G is concerned about the economic stability of his farm. Cognitively, he knows that a longer crop rotation would help with weed pressure (reflecting system 2 processing), but he feels it is too risky economically to take a field out of production. In this case, satisficing leads to a decision that is based on short term economic gain:

You know corn, soybean, wheat is not a good enough rotation. There needs to be more than a three way rotation, but you know we’re so starved for money that you feel like you can’t do that, but yet when you lose your crop [to weeds] you feel you should do that, you know. You’re saying, “Man, I can’t do that
because I just can’t lay a third of my ground out or a fifth of my ground out for a year.”

Farmer L’s decision to get into organic no-till is based on two concerns, a desire to care for the soil naturally while minimizing time spent in the field. For him, implementing a no-till roller/crimper into the farm system is a kind of satisficing that reduces the risk of running out of time and labor while taking care of the soil. This particular example, unlike the previous one, leads to a decision that requires more deliberative, long term planning:

This is kind of why we are leaning towards organic, because that is how we feel that the ground is supposed to be cared for is naturally. You just get a sense of pride that comes from having a chemical-free field. The only thing I didn’t like about the idea of organic was that I don’t have the time to cultivate beans and have cultivation be the only source of my weed control. So we got into no-till.

Other examples of satisficing from farmers are based on ecological values that trump more economic considerations. By delaying his hay cutting, Farmer K risks a decrease in his hay’s economic value and nutritional quality. He talked about trying to explain this decision to his neighbors:

“Why aren’t you cutting hay?” They ask, and I had the “lame” excuse that the bobolinks are nesting. “Bobolinks are nesting!” I said. “Well you don’t worry about bobolinks” they said. “Well, yes I do.”

All farmers satisfice to simplify their decision making process, but the tools available for satisficing differ according to the attributes and parameters of the farm as well as the internal attributes of the farmer (i.e., risk tolerance, values, and perceptions). If satisficing leads to outcomes that are good enough for the farmer, then using it in
decision processes is beneficial. If, however, satisficing only temporarily meets a need at the expense of more important, long term goals, then satisficing is a detriment to the economic and ecological sustainability of the farm.

**Using affect in weed management decisions.** Satisficing is one example of how farmers use system 1 information processing to speed their management decisions. Affect, unburdened by cognition, can also be used as a mental short cut in weed management decisions. Affect is an automatic response to stimuli—in this case weeds—that provides the basis of system 1 processing. Decisions motivated by affect are quick, easy, and more efficient in complex decision environments.

Farmers develop affective responses towards weeds and weed management over time as they build associations between weeds, management choices, and expected outcomes (Slovic, Finucane et al. 2003). As their experiences with weeds and weed management accumulate, this sense of “good” or “bad” deepens and influences future judgments and decisions. Some farmers described weeds as “evil” or “a pain in the butt,” but most had the general impulse that weeds are “bad” because they cost time and effort. Farmer S and Farmer K describe their immediate response to Giant Ragweed and velvet leaf. It leads them both to stop whatever they are doing and pull them:

*I mean, there are certain weeds that we try harder to get out. A giant ragweed is one that we have to stop the tractor and pull. That one we dare not let get started. (Farmer S)*

*They just bug me. I’m not fanatic, but if I walk through a neighbor’s field and I see a velvet leaf I will pull his weeds. I have always refrained from doing it on*
Sunday, but occasionally I couldn’t help myself. I say Lord forgive me, but I’m going to pull this weed. (Farmer K)

Harnessing negative affect as motivation is ideal for managing invasive weeds that need to be eradicated early and with diligence. If, however, negative affect is not instilled quickly, a farmer may not be as aroused to the weed’s presence and leave it in the field. This lack of experience could lead to poor management choices. Farmer M is a prime example of what happens when the negative affect motivation is absent:

*We accepted an enormous amount of weed pressure on the farm when I took it over, and I accepted it too. But now I realize that this is crazy.* (Farmer M)

Without the presence of affect, a decision maker may not be able to choose efficiently between different options (Damasio 1994; Hsee 1996) and end up taking no action. This may be the case with new farmers, organic or not, who have had few weed encounters and are not able to associate weeds and their weed management choices with expected outcomes. Without sufficient negative affect, an inexperienced farmer may allow certain weeds to remain. As a consequence, the seed bank will increase over time, stressing both the crop and the farmer.

Affect can also blind a decision maker to other possible options. The farmer model presents two cases that compare and contrast the different uses of affect in weed management decisions. In the first example, Farmer K uses affective information and corresponding emotions to motivate vigilance and perseverance. Not only does he integrate long term, rotational grazing into his farm system to “outsmart” the weeds, but he also hand pulls particularly invasive weeds with intense diligence:
When I cultivate corn I keep a hoe on the cultivator and I stop. If I see a dock plant I get off, and if I can’t pull it then I pull out the hoe and it’s gone. By the time I’ve cultivated 12 fields, I may have left the cultivator 50 times to get a dock plant… I pulled those problem weeds for the last 40 years. So now my son-in-law and daughter really have it nice. (Farmer K)

On the other hand, an overly negative affect might focus a farmer’s attention on short term management practices that satisfy strong emotional reactions but are ineffective as long term strategies. Farmer G’s interview was ripe with negative affect and emotional responses based on the uncontrollability of weather, weeds, markets, and cash flow. All of his energy goes into designing implements for control tactics that maximize crop yields instead of designing long term cropping strategies that minimize the risks of weeds. In this excerpt he demonstrates negative affect, high economic risk perceptions, and disappointment in his choices.

Weeds can bite you and take over a corn crop or a bean crop. With organic I think you’re hanging it out there—more variables and things that can get you…When the organic market died and my regular cost of diesel fuel, insurance, and light bill went up, I got caught in a squeeze. I’m hurting. (Farmer G)

The two examples above are exemplary. They demonstrate affect’s motivating qualities, but in two different directions. In the first example, Farmer K uses negative affect to increase diligence and holistic farm management. He harnesses his affective and emotional reactions towards weeds in order to motivate more long term thinking and planning in organic weed management by using it to focus a farmer’s attention on a long term weed management strategy.
At the other extreme, Farmer G uses negative affect as a motivator to design short term weed control tactics. He would like to implement more long term thinking, but his negative affect overpowers more deliberative, system 2 thinking. Some farmers may be unable, either through lack of knowledge and experience, or because of overpowering emotions stimulated by affect, to engage the analytical side of information processing that increases deliberation and focuses attention on other, more preventive-based, weed management possibilities.

**Weed thresholds: balancing system 1 and 2.** Dual process theory describes analytical, or system 2 thinking, as sensitive to scope and experiential, or system 1 thinking, as sensitive to the presence or absence of a risk (Plous 1993). In light of this theory, a farmer who has strong negative affect and emotional responses to weeds may come to a weed management decision based on the simple presence of weeds. If, on the other hand, a farmer is able to use more analytical thinking, their weed tolerance will be more appropriate to the scope and type of weed present. Heuristic tools that provide rules of thumb for when a management effort is required according to the scope and type of weed will be extremely important in this case. One such tool found in integrated weed management literature is utilizing thresholds, or how much weed pressure a crop can withstand before yield loss (Maxwell 1992; Swanton, Weaver et al. 1999).

Weed thresholds are economic equations based on cost/benefit analyses that determine the minimum amount of herbicide or pesticide use necessary to maintain optimal yields (Myers, Curran et al. 2005; Sanyal, Bhowmik et al. 2008) and are a prime example of analytical (system 2) processing in weed management. However, recent studies have found that threshold approaches to herbicide reduction are often trumped by
the perceived benefit of herbicide use (Llewellyn, Lindner et al. 2004; Wilson 2009). Our farmer model investigates how organic farmers create, adjust, and use thresholds in weed management decisions. While yield and profit play a large role in determining weed thresholds, they also fluctuate according to a farmer’s experientially based affective and emotional responses to weeds and their resulting risk perceptions.

In the farmer model, thresholds are represented by the “weed tolerance continuum” that ranges from zero tolerance, to threshold tolerance, to tolerating. The weed threshold continuum is actually a “range” of dual processing between zero and complete tolerance, with a tolerance based on thresholds being the ideal balance of analysis and affect. The ends of the continuum represent tolerance levels based more on the presence or absence of affect and the resulting emotional reactions to weeds. In both of these cases, affect drives risk perceptions that are either very high or non-existent. Farmers that fall on either end of this continuum are more likely to satisfice their decisions based on attributes that are important in the short term but detrimental in the long term.

For example, farmers who demonstrate a high tolerance for weeds talked about prioritizing other chores or personal health and sanity ahead of weed management. Their affective reactions to weeds are lower, and they tend to have less experience in organic farming overall, usually 0-4 years.

*Weeds aren’t all bad. You’re going to have some weeds, and I suppose a lot of them have a wildlife benefit. You see a lot of them along the edge of the fields and right now I’m sure there’s a lot of weed seed being eaten.* (Farmer W)
Farmers with zero tolerance for weeds prioritized eradication and the aesthetics of the farm. Their risk perceptions of the social and economic impact of weeds are higher, and they satisfice their management decision according to short term benefits such as a clean field and minimizing yield impact, despite the extra time and labor required to do so. For example, Farmer J is a new organic farmer struggling with the concept of weed thresholds and trying to find a balance between the time she spends on weed management and its effect on yield. Her recent experiences with weeds have increased her risk perception and blocked her desire to explore thresholds:

> *Sometimes I wonder if we are overzealous in trying to control weeds and if there is a balance that we can strike with them. At this point we feel like there isn’t a balance. We feel like we have to control them all.* (Farmer J)

Farmers who had more experience (typically 9-15+ years) described their tolerances as based on “thresholds.” They have learned to balance their emotional and affective responses with more analytical processing in order to develop an appropriate weed tolerance.

> *I realize my hate is stronger than the harm that it does.* (Farmer C)

> *Definitely weeds rob yield, but it always looks worse than they really are.* (Farmer D)

These more experienced farmers base their risk perceptions on deliberative thought processes that act as decision rules for when to implement management:

> *So if you have 20% weeds in a field, no big deal. I don’t even think you’ll have crop loss. Like I was saying before, if I had 80% crop, 20% weeds it’s not going to affect what I’m trying to grow.* (Farmer M)
A little bit of weeds that aren’t affecting yield so much isn’t a major problem. But when they are choking out the crops and you go through and you have 20 acres of beans and you get 400 bushel, that tends to be a problem. (Farmer J)

One study done with farmers found that farmer experiences could develop and reinforce existing mental models of farming. It was also discovered that an “activating event” such as a bad experience with chemicals or sick animals might shift or change a mental model in some way (Eckert 2006). Other mental models studies describe experience as a feedback loop that “resets” the parameters of the lay person model (Morgan, Fischhoff et al. 2002). Consistent with these studies, the farmer model revealed that farmers in the Midwest use experience to modify their risk perceptions of weeds, to determine their level of tolerance, and to choose appropriate management strategies according to these new parameters.

For example, Farmer L recently transitioned from conventional to a no-till organic production system. He spoke eloquently about shifts in his mental model, specifically weed thresholds, due to experience. He learned to tolerate weeds, navigate public perceptions, and implement effective crop rotations. Ultimately, these experiences lowered his risk perception of weeds so that even using chemicals seemed riskier than having a weedy crop:

That was my biggest thing is that I couldn’t stand weedy fields. That was going to drive me nuts, I thought, the most. Now that we are into it, the only thing that we’re really struggling with is the small grains and keeping weeds out of those. Every time we’ve had corn so far we’ve followed it with alfalfa—two to four years of mowing alfalfa has really kept those weeds at bay. We’ve had a
pretty amazingly clean corn because of it...I guess when you see big agriculture you see a clean field and you think, well it must be okay because it’s clean and everything. When you see weeds it looks dirty. You know? A guy told me at a conference a couple of years ago that he was talking to a chemical farmer, and this guy transitioned over like 5 or 6 years, like how we are doing. He said to the chemical farmer, “I’ll eat my weeds if you drink your chemicals.” I would much rather chew on lambsquarter than use chemicals. (Farmer L).

Farmer tolerance levels are a balance between how “bad” the weed looks—an affective response—and its actual effect on crop yield—an analytical response—through experience. Appropriate use of weed thresholds is a prime example of a successful balance between system 1 and system 2 processing. As experience and knowledge increase over time, farmers balance analytical thinking with affective and emotional responses to weeds in order to implement successful weed management strategies.

**Recommendations**

One of the main goals of this research project is to re-establish successful communication between the scientific research community, extension agencies, and organic farmers to improve weed management decisions and reduce the risk of weeds to the farm and the farmer. The expert and farmer models are invaluable tools for understanding what relevant information needs to be exchanged that will encourage collaboration and lead to increased success of weed management.

While the experts’ understanding of successful weed management focuses on ecological principles that reduce the seed bank through knowledge-based, long term strategies, the farmer model highlights that correct knowledge is only partly used by
organic farmers in their weed management decisions. In addition to knowledge, experience, affect, emotion, and risk perceptions are the kinds of information being processed.

The strength of this mental models research is that it clearly points to several areas in the farmer decision making process that are important to farmers and used most often to make decisions. Research and extension outreach personnel must recognize farmers’ use of system 1 processing so they can directly address what is dominating farmer decision making behavior with relevant research. Without knowing what particular biases and heuristics to address, the formidable amount of research being generated by land grant universities and the USDA will continue to be irrelevant to the organic farming community.

For example, farmers are very concerned about soil health. Presenting weed management as part of a holistic management plan to improve soils will resonate with farmers and may be more accepted. Farmers’ search for relationships between weeds and the soil is another area ripe for an influx of scientific investigation, perhaps conducted in partnership with interested farmers. System 1 processing also introduces biases into the choice process, such as affectively fueled decisions with short term benefits (aesthetics) but long term consequences (yearly inputs of time, labor, and resources). This is where evidence based information provided by the research community can work to de-bias the farmers’ decisions and improve their overall weed management behavior. The farmer model shows that organic farmers think about these relationships constantly as a way for saving time and labor, so addressing these needs and patterns of behavior is crucial for the research community.
Clearly listing attributes of different weed management options side by side can help organic farmers navigate what they feel are the most important attributes of a choice without falling prey to affective responses and time pressures that may lead to poor decisions. This may help farmers choose management options that are longer term, more consistent, and more in line with their values and long term goals (Plous 1993).

The following table is a hypothetical example of how attributes might be presented across different management options. Experts can provide the evidence-based information necessary to accurately represent cost/benefit considerations (i.e., yield loss at different weed thresholds, the cost of putting land out of production and into a cover crop, and how much time and labor is saved through diverse crop rotations). With this information in hand, farmers are able to weigh these attributes according to their own values and needs, providing a more deliberative process for considering various management options in combination with their experience-based information.

<table>
<thead>
<tr>
<th>Weed Management Option/Attribute</th>
<th>Long-term prevention strategies</th>
<th>Mix of prevention and control</th>
<th>Short term control tactics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost: fuel, seed, land out of production</td>
<td>Fuel: low Seed: high Land: 30% out production</td>
<td>Fuel: medium Seed: medium Land: 15% out</td>
<td>Fuel: high Seed: low Land: 0% out</td>
</tr>
<tr>
<td>Length of rotation</td>
<td>5 years</td>
<td>4 years</td>
<td>3 years</td>
</tr>
<tr>
<td>Yield loss</td>
<td>1\textsuperscript{st} year: 15% 5\textsuperscript{th} year: 0%</td>
<td>1\textsuperscript{st} year: 15% 5\textsuperscript{th} year: 0%</td>
<td>1\textsuperscript{st} year: 15% 2\textsuperscript{nd} year: 15%</td>
</tr>
<tr>
<td>Yield gain</td>
<td>1\textsuperscript{st} year: -15% 5\textsuperscript{th} year: +10%</td>
<td>1\textsuperscript{st} year: -15% 5\textsuperscript{th} year: 0%</td>
<td>1\textsuperscript{st} year: -15% 5\textsuperscript{th} year: -15%</td>
</tr>
<tr>
<td>Weather vulnerability</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Time and labor</td>
<td>1\textsuperscript{st} year: medium 5\textsuperscript{th} year: low</td>
<td>1\textsuperscript{st} year: medium-high 2\textsuperscript{nd} year: medium-high</td>
<td>1\textsuperscript{st} year: high 2\textsuperscript{nd} year: high</td>
</tr>
<tr>
<td>Soil health</td>
<td>High</td>
<td>Medium</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Seed bank result</td>
<td>Low</td>
<td>Stable</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 5. Hypothetical example of trade-offs in chart form.
Conclusion

Investigating farmer decision making in light of the dual processing model reveals the motivating mechanisms behind their decisions that researchers and scientists can use to support and improve farmers’ choice behaviors. Internal and external constraints force farmers to use rules of thumb, or heuristic processing, in their weed management decisions. Heuristic processing can be beneficial (without affect, farmers may lack the motivation necessary to sustain their efforts) or harmful (too much affect can lead to short term decisions that fail to reach their long term goals). Farmers show obvious use of experience, affect, and emotions as they navigate the complexities of raising food in ways that support both human and non-human communities. Weed management is a valuable example of how the integration of human and natural systems involves both analytical assessment and the use of experience, affect, and emotion for the benefit of both the environment and the farmer.
References


Appendix A: Expert Interview Protocol
The goal of this focus group is to map out both the knowledge that is necessary for organic farmers to have in order to make informed weed management decisions, as well as the factors that may influence weed management decisions on the farm. We are interested in how organic farmers make management decisions? What these decisions look like? And why they make the decisions that they do?

Icebreaker: What factors describe an organic farmer? How are they different from other alternative farmers? Conventional farmers?

1. Weed and Soil Science
   a. What is a weed?
   b. What characteristics define a weed in an organic farming system?
      i. What are the risks and benefits of weeds in the system?
   c. What role do weeds play in the agro-ecosystem?
      i. What is the relationship between weeds and the soil?
   d. How are weeds introduced and/or spread in organic farming?

2. Weed Management

3. What strategies are available to manage weeds?
   a. Follow-up with how each particular strategy should ideally be implemented on an organic farm.
   b. Follow-up with what are the specific risks and benefits associated with each strategy.

4. What strategies are most important when trying to manage in a diverse and integrated manner? What is good enough? What determines what is good enough?
5. What strategies are actually used by organic farmers? Why?

6. Who is responsible for weed management?

7. What are the desired outcomes of weed management?

Weed Management Decision

8. Why do organic farmers make the management decisions that they do?
   a. What leads them to identify a weed as a threat?
   b. What leads them to adopt or fail to adopt a new strategy/technology?

9. How do organic farmers make a particular weed management decision?
   a. Intuition? Reason? What is the role of experience in weed management?

10. What factors do you think influence organic farmer weed management decisions?
   a. Individual characteristics/factors?
      i. What role does socio-economic status play?
      ii. What role do individual worldviews play?
      iii. What role does individual risk tolerance play?
   b. Societal/cultural characteristics/factors?
      i. What role do social networks play?
      ii. What role do markets play?
      iii. What role does tradition play?
      iv. What role does culture play?
   c. Regulatory characteristics/factors?
      i. What role does past/current policy play?
   d. Bio-physical characteristics/factors?
      i. What role does weather play?
ii. What role does geography play? Location and physical make-up?

iii. What role does the type of crop play?

11. To what degree do you think science/research plays a role in organic weed management decisions?

Communication

12. How do organic farmers access information? Through what channels?

13. When do they seek out information? Why? What motivates them?

14. Who are the best sources of information? Most trusted?

15. What determines the quality of information?

Perceptions of Self in Relation to Farming System

16. How would you describe yourself in an alternative farming system?

17. How would you describe researchers and scientists in alternative agriculture?
Appendix B: Development of Interview Protocol
<table>
<thead>
<tr>
<th>Major content area</th>
<th>Subcontent area</th>
<th># of concepts</th>
<th>Description of concepts</th>
<th>Primary Influence Question</th>
<th>Prompts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer Attributes</td>
<td>knowledge of ecological weed management</td>
<td>4</td>
<td>ecologically based, integrated strategies for long-term prevention of weeds</td>
<td>Coded according to individual responses to several content questions.</td>
<td>describe the weed seed bank on your farm? Is there a relationship between weeds and the soil? Why?</td>
</tr>
<tr>
<td></td>
<td>risk tolerance</td>
<td>2</td>
<td>Self-reported perception of their tolerance to risk on the farm</td>
<td>Compared to other organic farmers, are you more risky or more cautious?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>farmer values</td>
<td>6</td>
<td>values thought to contribute to a farmer's orientation to farming and overall goals of the enterprise</td>
<td>Why did you decide to farm organically?</td>
<td>What makes an organic farmer successful? What are the barriers to being certified organic? How did you alter the practice? Why did you alter the practice?</td>
</tr>
<tr>
<td></td>
<td>experience</td>
<td>4</td>
<td>trial and error of weed management practices built up over time in organic systems</td>
<td>Changed, altered, or given up a mgt practice in the last two years?</td>
<td></td>
</tr>
<tr>
<td>Farm Attributes</td>
<td>weeds on the farm</td>
<td>12</td>
<td>the type, number, and density level of weeds on the farm, including the most and least risky</td>
<td><strong>What weeds do you have on your farm?</strong></td>
<td>What are the most problematic/risky? least problematic/risky?</td>
</tr>
<tr>
<td></td>
<td>farm enterprise</td>
<td>3</td>
<td>The type/diversity of crops grown, including livestock and dairy, farm scale, geography/climates/soils</td>
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<tr>
<td>Perceptions</td>
<td>Weeds/Weed Mgt</td>
<td></td>
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</tr>
<tr>
<td>Weed Intro</td>
<td>agricultural</td>
<td>11</td>
<td>Introductions that result in movement of seed or plants through farming practices</td>
<td><strong>How are weeds introduced to the farm?</strong></td>
<td>any other ways?</td>
</tr>
<tr>
<td></td>
<td>social</td>
<td>3</td>
<td>Introductions that result from movement of seeds or plants outside of the farming operation</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>natural occurences</td>
<td>3</td>
<td>Introductions of plants or seeds that occur as a part of natural, ecological processes</td>
<td></td>
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<tr>
<td></td>
<td>wildlife</td>
<td>3</td>
<td>Introductions of plants or seeds that occur due to movement of wildlife</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed Spread</td>
<td>agricultural</td>
<td>11</td>
<td>Spread encouraged by on-farm operations such as combines or livestock</td>
<td><strong>How are weeds spread on the farm?</strong></td>
<td>any other ways?</td>
</tr>
<tr>
<td>Comprehensive Technical Model</td>
<td>Farmer Interview Protocol</td>
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<tr>
<td>biological 2</td>
<td>Spread encouraged by the biological traits plants and seeds on the farm</td>
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<tr>
<td>natural occurrences 3</td>
<td>Spread encouraged by natural occurrences such as flooding or wind</td>
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<tr>
<td>wildlife 3</td>
<td>Spread encouraged by animals outside of the farm operation</td>
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<tr>
<td>Benefits of Weed Prevention 6</td>
<td>Impacts of prevention strategies that increase yield or save money in the long run</td>
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<tr>
<td>economic</td>
<td>What makes a weed management practice successful or beneficial on your farm?</td>
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<tr>
<td>agricultural 7</td>
<td>Impacts of prevention strategies that benefit crop and/or livestock production</td>
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</tr>
<tr>
<td>social 3</td>
<td>Impacts of prevention strategies that benefit the farmer, farm community, farm worker, or society</td>
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<tr>
<td>ecological 4</td>
<td>Impacts of prevention strategies that benefit the environment or the agroecosystem</td>
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<tr>
<td>Risks of Weed Prevention 1</td>
<td>Consequences of prevention strategies that decrease yield and/or cost time, labor, or money</td>
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<tr>
<td>economic</td>
<td>Are there any risks to specific weed management strategies?</td>
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<tr>
<td>agricultural 11</td>
<td>Consequences of prevention strategies that impact crop and/or livestock production</td>
<td></td>
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<td>social 1</td>
<td>Consequences of prevention strategies that impact the farmer, farm community, farm workers, or society</td>
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<tr>
<td>ecological 4</td>
<td>Consequences of prevention strategies that impact the environment or agroecosystem</td>
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<tr>
<td>Benefits of Weed Control 2</td>
<td>Impacts of control tactics that increase yield and/or save time, labor, and money</td>
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<td>economic</td>
<td>What makes a weed management practice successful or beneficial on your farm?</td>
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<tr>
<td>agricultural 1</td>
<td>Impacts of control tactics that benefit crop and/or livestock production</td>
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<tr>
<td>Mechanical 3</td>
<td>Impacts of control tactics that coincide with benefits from the farm's implements and/or other mechanical resources</td>
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<tr>
<td>Comprehensive Technical Model</td>
<td>Farmer Interview Protocol</td>
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<td>ecological 2</td>
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<td>Impacts of control tactics that benefit the environment or the agroecosystem</td>
<td>Are there any risks to specific weed management strategies?</td>
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<td>Impacts of control tactics that benefit the farmer, the farm community, farm workers or society</td>
<td>Are there any risks to specific weed management strategies?</td>
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<td>Risks of Weed Control</td>
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<td>mechanical 5</td>
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<td>Are there any risks to specific weed management strategies?</td>
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<td>economic 1</td>
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<td>Consequences of control tactics that cost time, labor, or money</td>
<td>Are there any risks to specific weed management strategies?</td>
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<td>ecological 3</td>
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<td>Consequences of control tactics that impact the environment or agroecosystem</td>
<td>Are there any risks to specific weed management strategies?</td>
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<td>Consequences of control tactics that impact the farmer, farm community, farm workers, or society</td>
<td>Are there any risks to specific weed management strategies?</td>
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<td>Benefit s of Weeds</td>
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<td>economic 1</td>
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<td>Impacts of weeds that benefit a farmer's income and/or yield</td>
<td>Are there benefits of weeds on your farm?</td>
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<td>agricultural 3</td>
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<td>Impacts of weeds that benefit crop and livestock production</td>
<td>Are there benefits of weeds on your farm?</td>
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<td>ecological 5</td>
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<td>Impacts of weeds that benefit the environment or agroecosystem</td>
<td>Are there benefits of weeds on your farm?</td>
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<td>social 2</td>
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<td>Impacts of weeds that benefit the farmer, farm community, farm worker, or society</td>
<td>Are there benefits of weeds on your farm?</td>
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<tr>
<td>Risk of Weeds</td>
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<td>economic 2</td>
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<td>Consequences of weeds that impact a farmer's income and/or yield</td>
<td>Are there risks of weeds on your farm?</td>
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<td>agricultural 3</td>
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<td>Are there risks of weeds on your farm?</td>
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<td>ecological 4</td>
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<tr>
<td>Consequences of weeds that impact the environment or agroecosystem</td>
<td>Are there risks of weeds on your farm?</td>
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<tr>
<td>Social 3</td>
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<td></td>
</tr>
<tr>
<td>Consequences of weeds that impact the farm, farm community, farm workers, or society</td>
<td>Are there risks of weeds on your farm?</td>
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<tr>
<td>Process</td>
<td>Comprehensive Technical Model</td>
<td>Farmer Interview Protocol</td>
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<td></td>
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<tr>
<td><strong>Dual Processing</strong></td>
<td>cost/benefit analysis</td>
<td>5</td>
<td>Use of cost/benefit analysis in the decision making process</td>
<td>At what point does a weed become cause for concern?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>new knowledge</td>
<td>3</td>
<td>use of new knowledge in the decision making process</td>
<td>Where do you learn about weed management practices?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>farm parameters</td>
<td>2</td>
<td>the resources and regulations that define the farm operation and limit decisions</td>
<td>What do you consider when deciding what weed management practice to use?</td>
<td></td>
</tr>
<tr>
<td><strong>Filtering</strong></td>
<td>affective marker</td>
<td>2</td>
<td>a good/bad reaction to weeds</td>
<td>What's the first thing that comes to mind when I say &quot;weed&quot;?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>behavioral</td>
<td>3</td>
<td>use of hueristics in decision process (e.g., weed tolerance, simplification, past experience)</td>
<td>Has your tolerance for weeds changed over the years?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>emotional</td>
<td>7</td>
<td>emotionally based reactions to weeds that may influence decision making and behavior</td>
<td>What happened to cause this change? Does this effect how you mg. weeds now?</td>
<td></td>
</tr>
<tr>
<td><strong>Prevention Strategies</strong></td>
<td>mulches</td>
<td>2</td>
<td>Any barrier to weed seed germination</td>
<td>What are all the ways you can think of to manage weeds?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>crop rotation</td>
<td>9</td>
<td>A diverse rotation with long and short term crops, timed disturbances, and part of a weed management strategy</td>
<td>Do you use crop rotation specifically for managing weeds?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>crop choice/cultivars</td>
<td>5</td>
<td>Choosing competitive varieties of crops that germinate early and compete with weeds</td>
<td>What makes crop rotation successful at managing weeds?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cover crop/green manure</td>
<td>11</td>
<td>Using short or long season crops to cover the soil, time disturbances, and part of a weed management strategy</td>
<td>Do you use cover crops specifically for managing weeds?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>seed bank management</td>
<td>10</td>
<td>A diverse set of strategies that eliminate or reduce the amount of seed entering the seed bank</td>
<td>What makes cover cropping successful at managing weeds?</td>
<td></td>
</tr>
<tr>
<td><strong>Control Tactics</strong></td>
<td>mechanical</td>
<td>3</td>
<td>Short term tactics used on visible weeds as part of immediate response</td>
<td>What are all the ways you can think of to manage weeds?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>organically approved herbicides</td>
<td>2</td>
<td>Any substance used to destroy emerged weeds as part of immediate response</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>cultural</td>
<td>6</td>
<td>Diverse tactics used as an immediate response to weed pressure</td>
<td></td>
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</tr>
</tbody>
</table>
Appendix C: Midwest Farmer Interview Protocol
I. Weeds in the Farm System

1. What is the first thing that comes to mind when you think about weeds? Anything else?

2. What makes a plant a weed? **Prompts (leave blank for not prompt, X for prompt):**
   - Do they have any biological traits that make them weedy?
   - Do they have an economic impact?
   - What role do they play in the environment, or their ecological characteristics?
   - Do they have any philosophical purpose or symbolic meaning?
   - Do weeds say anything to the public about your farm?

3. How are weeds introduced to the farm?

4. How do weeds spread on the farm?

5. Tell me about weeds on your farm
   a. Type:
   b. Most problematic / least problematic:
   c. Most risky / least risky
   d. Has there been a change in weed type / density over the years or w/ change in cropping system?

6. Are there benefits of weeds on your farm? How did you come to this conclusion?

7. Are there risks? How did you come to this conclusion?

8. At what point does a weed become cause for concern? How did you come to this conclusion?

9. Is there a relationship between weeds and the soil? If so, what kind? How did you come to this conclusion?

10. How would you describe the weed seed bank? How does the weed seed bank work on your farm?
II. Weed Management Behavior

(List their answers, then ✓ the ones they believe are the most effective and ★ the ones they use most often—write the “why” next to each answer)

1. What strategies are available to manage weeds—list every one you can think of? (List their answers)

2. Of these strategies, which ones are the most effective? Why?

3. What strategies do you use most often? Why?

4. What makes a strategy or strategies successful or beneficial on your farm?

5. Are there risks to specific weed mgt. strategies (may have to remind them)?

6. Do you use crop rotation for managing weeds? (If already mentioned, skip to a. below)
   a. What makes a crop rotation successful at managing weeds?

7. Do you use cover crops for managing weeds? (If already mentioned, skip to a. below)
   a. What makes a cover crop successful at managing weeds?

8. Have you changed, altered, or given up a weed mgt. strategy in the last two years?
   a. How did you alter the strategy?
   b. Why did you decide to alter your technique?

9. Where do you get information on weed management strategies? Which ones are the most useful?

III. Weed Management Decisions

1. What do you consider when deciding what weed management strategy to use? (List their answers)

2. Of the factors that you mentioned, which ones influence your weed management decisions in the short term? (✓ each one)
3. Which ones influence your **long term** weed management decisions? (*Circle each one*)

4. Has your tolerance for weeds changed over the years? What happened to cause this change? Does it change how you manage weeds now? How?

5. *Written on these index cards are some of the factors that you might take into consideration when making weed management decisions. Working fairly quickly, put them in order from most important to least important. What factors are most important to you when you are making weed management decisions on the farm?*

6. *When you are making a decision about weed management, where would you place yourself on this continuum? Draw an X where you feel it best reflects your motivations.*

   Does your position ever change? Why or why not?

7. Compared to other organic farmers, do you view your farm management practices as more risky or more cautious? Can you give an example of why or why not?

8. What makes an organic farmer successful? Why?

9. What do you think are the biggest barriers to becoming certified organic? What changes do you think need to happen in order to increase adoption of organic farm practices?

*See Appendix C

IV. Visible Values and Identity Creation

1. Why did you become an organic farmer?
   a. Can you explain that further?
   b. Did values play a part in that decision? What kind of values (cultural, religious, etc)?
   c. Where did those values originate?

2. How would you define a value?

3. How do you balance your values with the everyday realities and tasks of farming?
4. What main goal do you have for the farm?

5. What role do you see your farm playing in the community?

6. Is there anything else we haven’t covered that you would like to tell me?

7. Do you have any questions for me or feedback about the interview?

8. Thank you...the next step will be in the spring...if I have any follow up questions or clarifications?
Appendix D: Ranking and Trade-Off Exercise
Here are a set of note cards with sixteen different things you might consider when making weed management decisions. Working fairly quickly, order them from most to least important:

<table>
<thead>
<tr>
<th>Concept</th>
<th>Dual Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public perception</td>
<td>Values</td>
</tr>
<tr>
<td>Family and worker health</td>
<td>System 1</td>
</tr>
<tr>
<td>Environmental and/or ecological health</td>
<td>Experiential/</td>
</tr>
<tr>
<td>Soil health</td>
<td>Affective</td>
</tr>
<tr>
<td>Respected farmer’s advice</td>
<td>System 2</td>
</tr>
<tr>
<td>What worked in the past</td>
<td>Analytical</td>
</tr>
<tr>
<td>Immediate control</td>
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<tr>
<td>Extension recommendations</td>
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<tr>
<td>Latest research and science</td>
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<tr>
<td>National Organic Program standards (USDA)</td>
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<tr>
<td>Crop yield</td>
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<td>Cash flow</td>
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<td>Time and labor</td>
<td></td>
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<td>Markets and consumer demand</td>
<td></td>
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<tr>
<td>Type/timing of weed</td>
<td></td>
</tr>
<tr>
<td>What farmers with similar soils/crops do</td>
<td></td>
</tr>
</tbody>
</table>

**Max ecological partnership**

**Max profit/yield**
Appendix E: Prevention Control Continuum
<table>
<thead>
<tr>
<th>Prevention Strategies</th>
<th>Control Tactics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop Rotation</strong></td>
<td><strong>Cultural Practices</strong></td>
</tr>
<tr>
<td><strong>Crop Choice</strong></td>
<td><strong>Cultivation/Tillage</strong></td>
</tr>
<tr>
<td><strong>Cover Cropping</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Mulches</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Seed Bank Mgt.</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Criteria for coding the middle practices as either a prevention strategy or a control tactic:

- Long term
- Sustainable, renewable
- Implemented at invisible stages
- Planning ahead 2-5 years
- Ecologically based
- Diversity increases
- Other agroecological benefits
- More cost effective long term

- Short term
- Input dependent
- Only when weed visible
- Yearly without planning
- Mechanically based
- Diversity decreases
- Economic benefits only
- Yearly costs

*The most important distinctions between prevention and control practices are:

- WHEN (e.g., before seed rain, white thread, critical weed free vs. after seed rain or when weather permits)
- WHAT action is taken (e.g., diverse vs. simple rotation, cover crop vs. organic herbicide)
- WHERE it is taken (e.g., edges and borders vs. spot mowing)
- HOW EFFECTIVE the management is (e.g., dense seeding vs. light seeding rates, excessive vs. appropriate tillage).

(These concepts are coded in the expert and farmer models under the properties of timing, type, location, and implementing).
Appendix F: Farmer Interviewee Demographics
<table>
<thead>
<tr>
<th>Farm</th>
<th>Gender</th>
<th>Age</th>
<th>Years Farming Organic</th>
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<tr>
<td>1</td>
<td>M/F</td>
<td>38</td>
<td>5-9</td>
</tr>
<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>F/M</td>
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<td>0-4</td>
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<td>M</td>
<td>65</td>
<td>10-14</td>
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<td>5</td>
<td>M</td>
<td>68</td>
<td>15+</td>
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<tr>
<td>6</td>
<td>M/M</td>
<td>67</td>
<td>15+</td>
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<td>M/F/M</td>
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<tr>
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<tr>
<td>9</td>
<td>M</td>
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<td>5-9</td>
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<tr>
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</tr>
<tr>
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<td>F</td>
<td>36</td>
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<td>29</td>
<td>M</td>
<td>60</td>
<td>14-19</td>
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</table>

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Cropping System</th>
<th>Average Income</th>
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<tbody>
<tr>
<td></td>
<td>Growth</td>
<td>Hay and Forage</td>
</tr>
<tr>
<td></td>
<td>Field Crops</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

24% M/F
66% M only
10% F only

1. Veggies Only/Herbs 24%
2. Field Crops/Hay 24%
3. Veggies and/or Field Crops/Hay 24%
4. Field Crops/Livestock/Hay/Feed 20%