

# **Organic Weed Management in Ohio and Indiana: A Report on the Knowledge, Perceptions, and Experiences of Farmers and Experts**



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“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...leveling whole ranks of one species and sedulously cultivating another.” (Thoreau, *On Walden Pond*, 1854)

“[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, *Second Nature: A Gardener’s Education*, 2003)

## INTRODUCTION

Like Thoreau and all farmers throughout history, today’s organic farmers struggle against weeds. Despite new tools such as chemical herbicides and technologically advanced farm equipment, weeds continue to threaten crop yields and cost farmers time, labor, and stress. Organic farmers’ choice to eliminate chemical inputs from the farm system puts them in much the same position as Thoreau over one-hundred years ago—finding the right matrix of resources, motivation, and intelligent management to manage crops’ most persistent competitor.

This research, funded through the United States Department of Agriculture’s (USDA’s) Organic Agriculture Research and Extension Initiative (OAREI), investigates the largely unexplored interface between weeds on organic farms and farmer decisions about how to manage them. By delving into how farmers think about weeds and weed management, we aim to uncover the internal (i.e., cognitive, emotional, and experiential) and external (i.e., soil type, cropping system, and available tools) factors that influence their management decisions in order to target specific areas that might contribute to more informed, effective choices.

Through in-depth interviews with both the research community (e.g. weed ecologists, scientists, and extension personnel) and organic farmers in Ohio and Indiana, we compare how knowledge, perceptions, and beliefs contribute to how weeds are managed on organic farms. The interviews provide a qualitative basis for identifying gaps in understanding that may frustrate effective communication and collaboration between experts and farmers and hinder more successful weed management.



## RESEARCH QUESTIONS

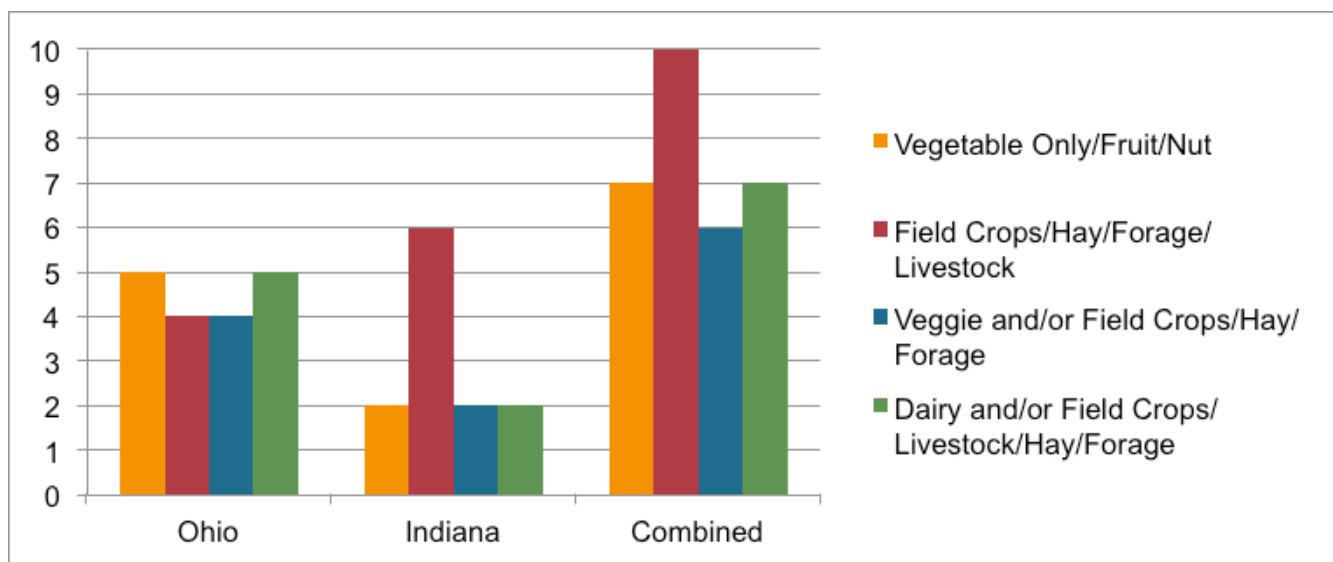
1. What knowledge do experts (e.g., weed scientists, ecologists, and extension personnel) and organic farmers share (or not share) about weeds and weed management in organic farm systems?
2. What are the perceived risks and benefits of weed management according to experts and organic farmers?

## WHO ARE THE FARMERS WE TALKED TO?

A total of 29 farmers in the Midwest were interviewed for this research. Seventeen were located in Ohio and 12 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 one type of crop—vegetables—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 (Figure 1).

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.



**Figure 1.** Number of farms by type of operation.

## RESULTS

### Successful Weed Management is Ecological Weed Management (EWM)

The aim of this research was to develop a model of successful weed management grounded in literature from the fields of weed management and decision making as well as in-depth interviews with 16 experts in the areas of weed ecology, weed biology, and organic farming. These experts included five weed scientists, five extension personnel, four farmers identified as very experienced by the research community, and two researchers involved with organic agriculture.

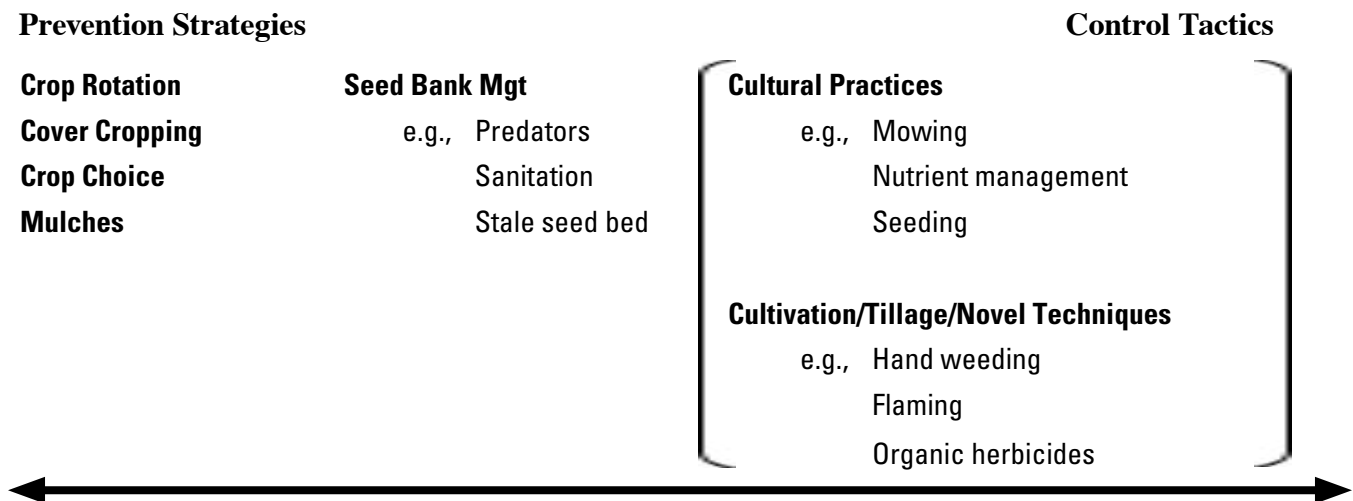
In summary, the expert interviewees explained that successful weed management on organic farms is a long-term, diverse, and integrated set of strategies that harness ecological processes to benefit the crop rather than the weed. These strategies (Figure 2) are encompassed by the term Ecological Weed Management (EWM) and act as a suite of filtering mechanisms for weeds and weed seeds at various stages during their life cycle.

EWM increases weed management efficiency without the use of synthetic chemicals, reduces the time and labor required to manage weeds, reduces seed banks, and increases biodiversity (Liebman and Mohler, 2001; Hatcher and Melander, 2003; Gallandt and Molloy, 2008; Anderson, 2010). According to weed ecologists, EWM has the potential to both prevent weeds and improve the health of the environment by increasing diversity in the farm system.

### The Prevention/Control Continuum

While successful EWM focuses on prevention strategies, experts recognized that farmers use a combination of both control and prevention practices (see Figure 2). For example, diverse crop rotations integrated with cover crops require long-term planning and are defined as prevention strategies. Short-term measures, such as organic herbicides, that require yearly application and more costly inputs, are defined as control tactics.

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 (Expert I, 480).



**Figure 2.** Weed management as a range of practices. Those on the far left are long-term strategies that reduce seed banks over time. Techniques on the far right of the continuum (noted in parenthesis) may be prevention or control based depending on the goals of the farmer for implementing them.



Several management practices (i.e., mowing, flaming, and hand weeding) could be used for either prevention or control. In these cases, experts outline the most important distinctions for determining whether a particular practice is prevention or control-based (see Table 1). The difference between a control tactic and a prevention strategy is largely due to four qualifications: timing (e.g., before seed rain, white thread stage vs. after seed rain or when weather permits), type (e.g., diverse vs. simple rotation, cover crop vs. organic herbicide), location (e.g., between the rows vs. within the rows), and implementation (e.g., dense seeding rates vs. light seeding rates, excessive tillage vs. appropriate tillage).

**Table 1.** The criteria for distinguishing when a particular practice is being used as a preventive strategy versus control tactic.

<b>Prevention Strategies</b>	<b>Control Tactics</b>
Long term	Short term
Sustainable, renewable	Input dependent
Implemented at invisible stages	Only when weed visible
Planning ahead 2-5 years	Seasonal
Ecologically focused	Mechanically focused
Diversity of tactics increases	Diversity of tactics decreases
Other agroecological benefits	Weed management only
Implemented with skill	Poor implementation
More cost effective long term	Yearly costs

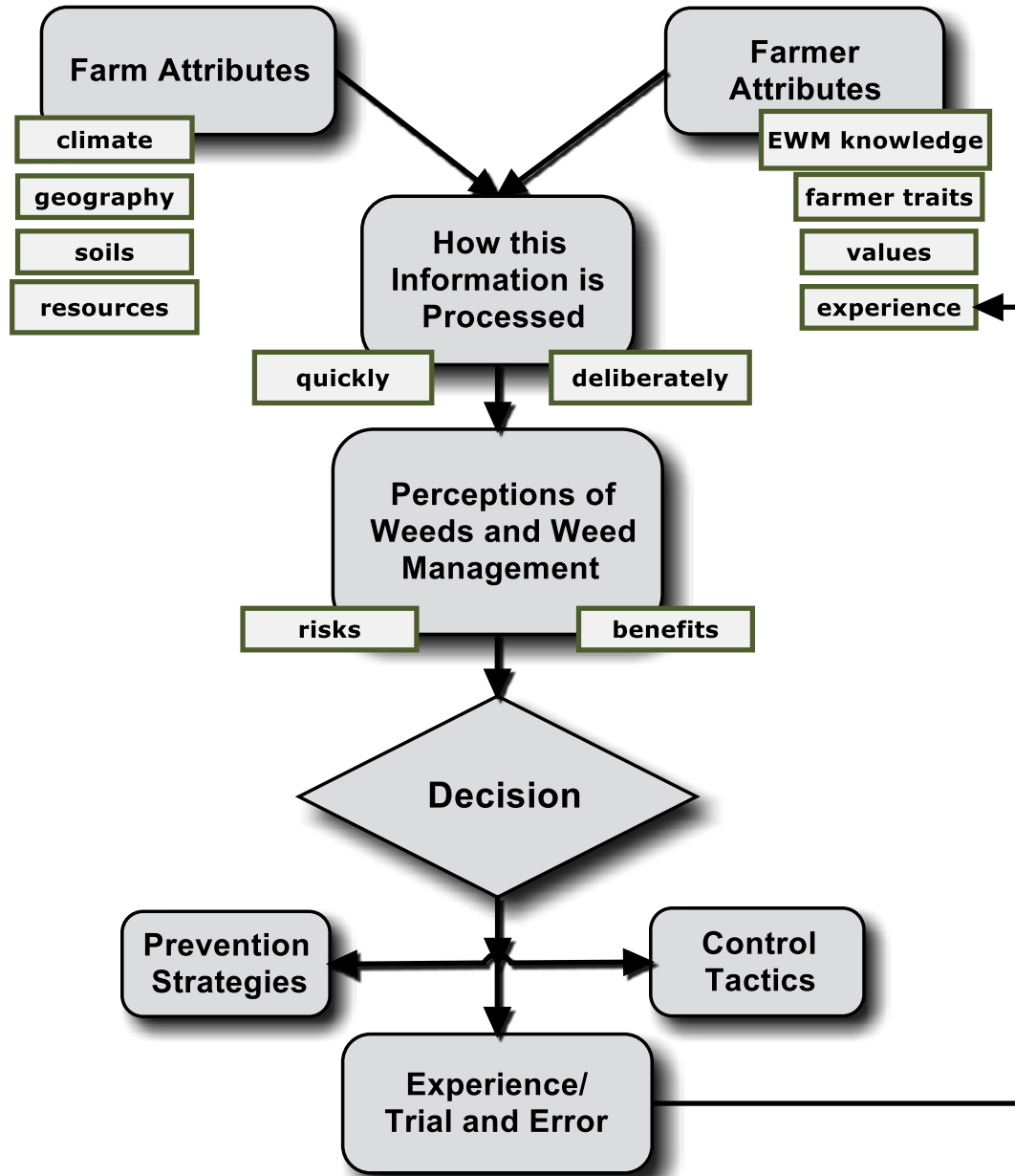
The prevention/control continuum is critical for being able to determine whether or not organic farmers interviewed for this study focused more on long-term, prevention-based management strategies or relied on short-term control tactics that are less than ideal, according to experts.

In addition, there are other critical factors involved in a weed management decision before the prevention/control choice is made. Interviews with experts and studies of how people make decisions led to the development of a large, conceptual model that shows what factors are present in a weed management decision and how these factors influence each other. This conceptual diagram represents a synthesis of weed science and ecology, the decision sciences, and expert assessments of the factors that influence farmer weed management decisions (Figure 3).

Based on the expert interviews and current literature, we concluded that farm attributes (e.g., soil type and geography), farmer attributes (e.g., knowledge and experience), how farmers process the information provided by these attributes, and their risk perceptions of different weeds and weed management choices, influence weed management behavior.

The farmer interviews were based on exploring the categories in this conceptual model and a summary of their responses are given in the next section.





**Figure 3.** Conceptual mental model of weed management derived from the expert interviews.

### What do Farmers Know about EWM in Ohio and Indiana?

Experts believed that knowledge of EWM was a key to long-term success in weed management. Knowledge of EWM includes these four concepts: manage your seed bank, understand agroecology, use multiple management practices over time, and recognize opportunities to manage weeds. Farmers also covered each of these concepts in great detail (a total of 427 separate times in the 29 interviews) as part of their weed management decision process. We cover the two most discussed concepts: manage the seed bank and understand agroecology.

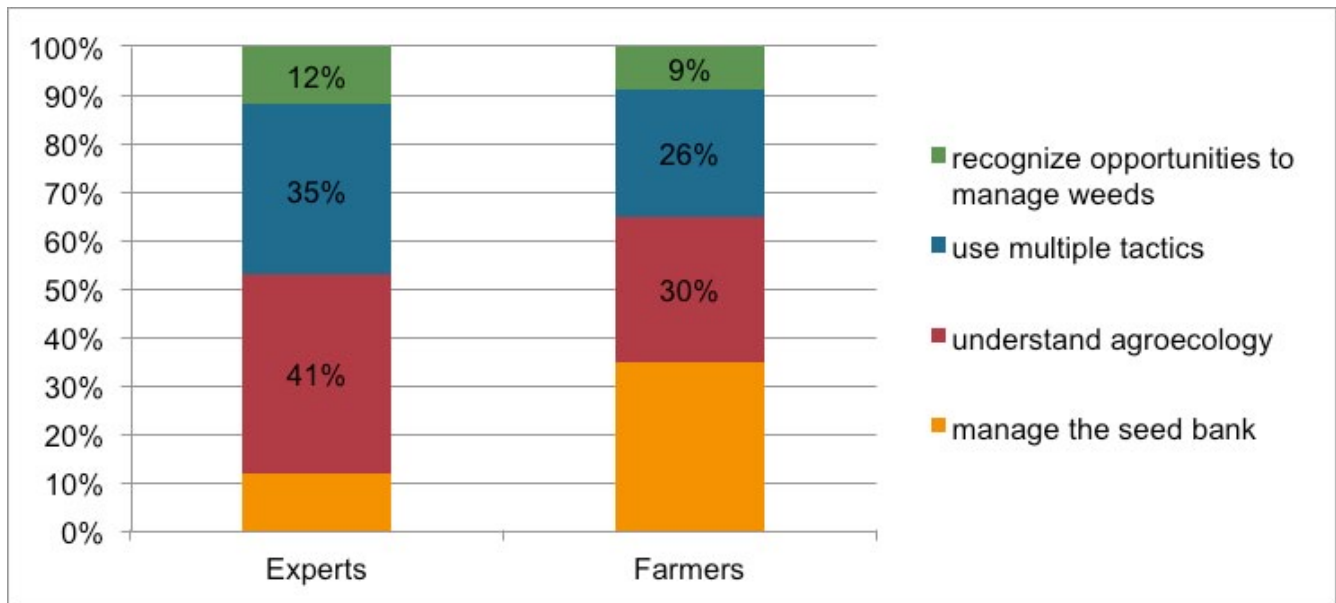


### Manage the seed bank

*I think the weed seed bank presents its ugly face every time you till the ground. **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. (Farmer 7)*

Of the four principles, farmers discussed seed bank management the most and almost twice as many times as the experts (Figure 4). There was a specific question that asked how the seed bank operated, which could account for the large number of responses. However, the seed bank was certainly a salient subject to the farmers and important in their weed management decisions. This group of organic farmers felt strongly that their management practices “opened the field” for weed seeds to germinate from the seed bank. Rather than blame weeds on circumstances outside of their control (i.e., wind, floods, and birds) farmers took responsibility for the type and density of weeds on their farm. Farmers are extremely aware of the effect of their decisions on the seed bank. For example, the following quote demonstrates a farmer’s willingness to replant corn in order to avoid increasing the seed bank for the following year:

*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 22)*



**Figure 4.** Expert and farmer mentions of the four principles Ecological Weed Management by percentage of total mentions of EWM.

### Understand agroecology

***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 12)*

Both the expert and farmer models indicated that knowing weed biology, biotype, and phenology were important for recognizing when and how to manage a weed (Figure 4). It is especially important for removing weeds early, such as velvet leaf and giant ragweed.

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 or five weeds on their farm. Some farmers openly indicated a lack of knowledge about some of the more uncommon weeds, but were still able to name or describe it. Table 2 summarizes their responses according to farm type.

**Table 2.** Frequency of top ten weeds mentioned and percent response by farm type.

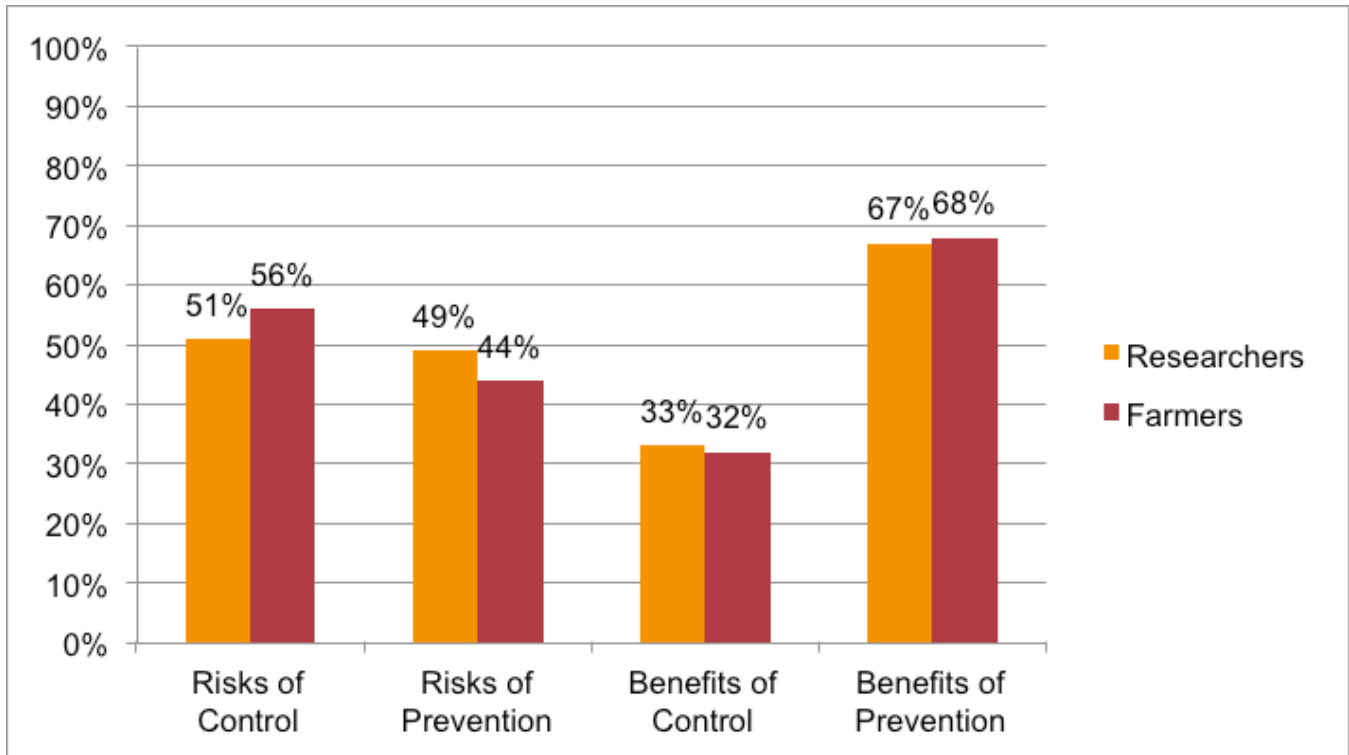
Weed	Frequency of Mention	Veggies/Fruit/Herbs	Field Crops/Hay	Veggies/Field Crops/Livestock/Hay	Field crops/Livestock/Hay/Dairy
Ragweed	71	15%	27%	15%	39%
Foxtail	39	13%	23%	44%	21%
Canada Thistle	30	33%	30%	13%	23%
Lambsquarter	22	50%	9%	0%	41%
Chickweed	14	43%	14%	43%	0%
Redroot Pigweed	12	17%	25%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

### The Risks and Benefits of Weed Management

*[T]here are different weed pressures based on timing of tillage, cultivation, and rotary hoeing.*  
(Farmer 12)

It is clear that both experts and farmers perceived weed management to be risky overall. The risks of weed management had almost four times as many mentions as the benefits (Figure 5). This could be due to the interview questions that tended to focus more on the risks of management practices rather than the benefits. However, both farmers and experts talked about the benefits of prevention over twice as often as the benefits of control and much more than the risks of prevention, even though the interview questions focused on risk.

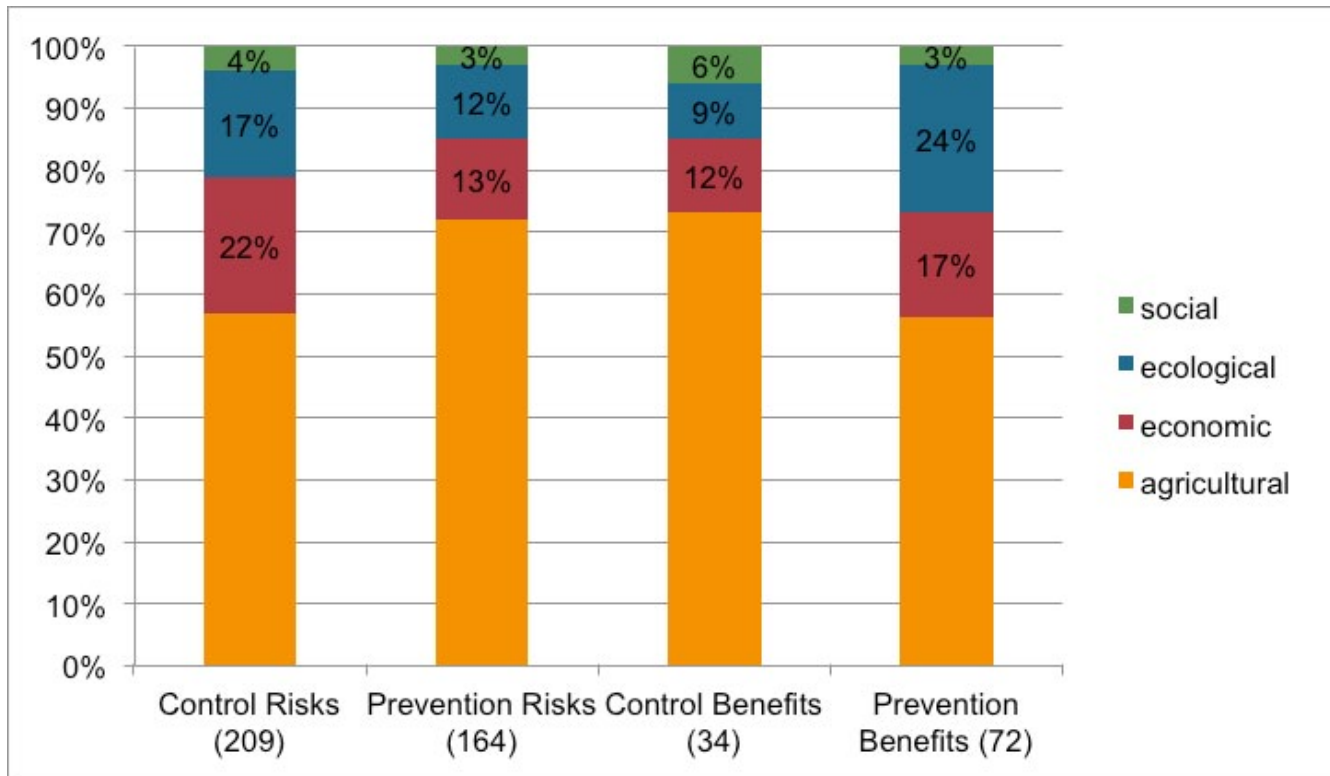
The risks and benefits of weed management were split into the risks and benefits of control tactics (e.g., organic herbicides, hand pulling after seed has set) and the risks and benefits of prevention strategies (e.g., cover cropping and mulching) based on the expert’s model of weed management (Figure 1).



**Figure 5.** Expert and farmer responses to the risks and benefits of control tactics and prevention strategies as a percentage of their overall responses to the risks and benefits of weed management.

Each of the prevention and control risks and benefits are broken down into agricultural, economic, ecological, and social categories (Figure 6). The vast majority of risks and benefits mentioned were agricultural and economic in nature. In addition, each of these categories is further broken down into four qualifying features that points where prevention or control practices could result in a risk or a benefit—in the type, timing, implementation, or location of the weed management practice. For example, experts talked about the risks of implementing cultivation as potential crop damage. However, if cultivation is implemented with skill, it is a great tool for removing weeds. Getting into the field to cultivate was dependent on the unpredictability of the weather—a timing risk. In contrast, timing cultivation with the white thread stage of a weed can greatly benefit the crop and boost its early growth. In summary, here are the four ways that prevention and control practices can result in a benefit or a risk:

1. **Type** of technique or strategy chosen appropriate to weed and weed seed bank levels (e.g., short term control tactics such as cultivation or long term prevention strategies such as cover cropping and crop 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 or longer term prevention strategy.



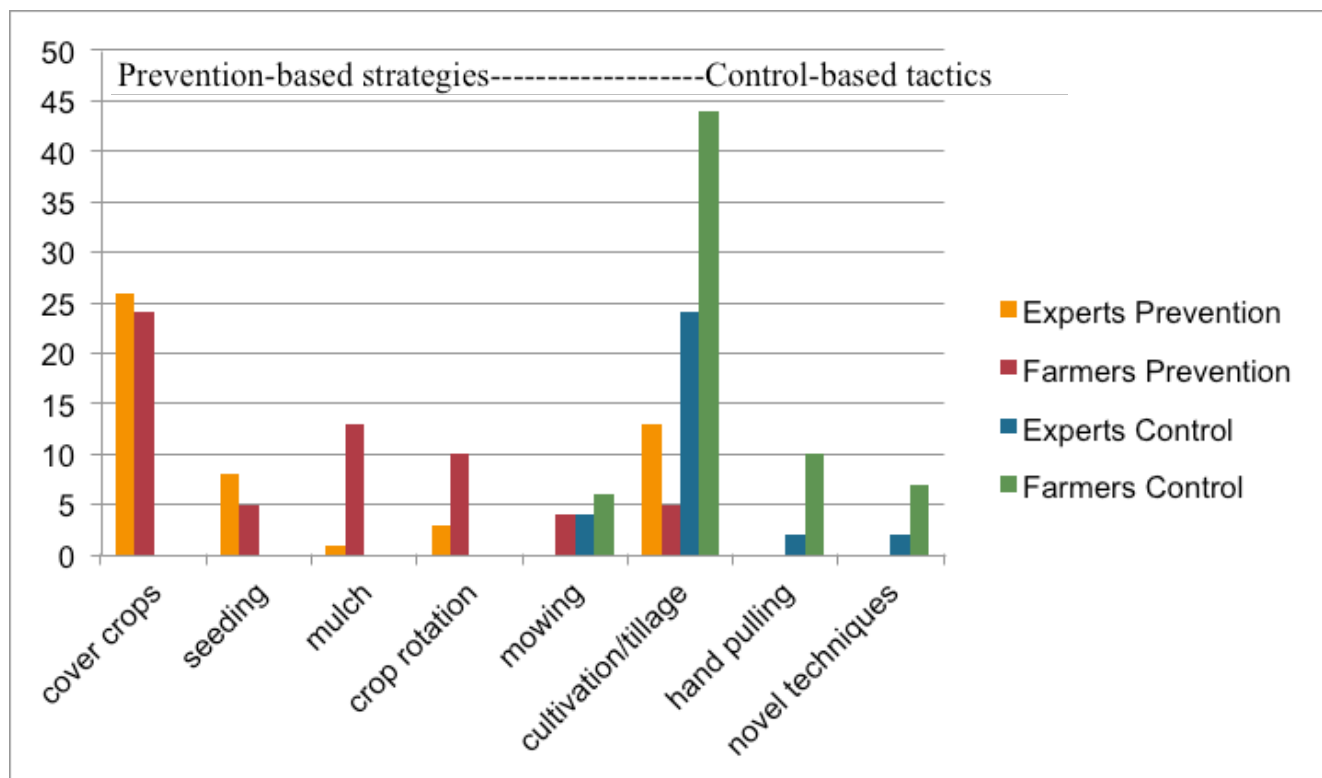
**Figure 6.** Farmer mentions of the risks and benefits of both prevention and control practices and their subcategories by percentage of total mentions.

### *The Risks and Benefits of Prevention Strategies*

Both farmers and experts felt that implementation of prevention strategies posed the greatest agricultural risks to the farm—specifically, cover crop implementation (Figure 7). If cover crops are not seeded thickly enough, if there is poor germination, or if they are not incorporated often enough, they may allow weeds to grow, set seed, and increase the seed bank. The expert interviews provided detailed information about how the timing, implementation, and location of cover and production crops lead to different levels of weed seeds (Appendices A and B).

The prevention strategies that required good timing were also problematic. Experts and farmers agreed that wet weather is one of the biggest concerns when attempting to prepare a seed bed or incorporate cover crops. Timing was also difficult for cultivation/tillage if farmers could not get in the field early enough in the spring for production crops or in the fall for cover crops. Farmers who viewed late spring planting and delayed fall tillage as beneficial for weed control did not share this perception.

*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 26)



**Figure 7.** Comparison of the number of times experts and farmers mentioned the types of agriculturally-based prevention and control strategies they felt were risky to implement.

Prevention strategy implementation posed a unique set of risks. Cover crops were especially problematic to farmers, who were concerned with poor germination and bad crop stands as well as increased seed rain once the cover crop was established. In addition, some farmers felt they could not afford to put land into cover crops if it meant taking land out of market production.

***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 20)***

The risks of mulching were mentioned more often by farmers than experts. Organic mulches brought in new weed seeds, and plastic mulches required weed control in the pathways as well as some hand weeding in the plastic.

The benefits of prevention strategies were mentioned more than the benefits of control by both experts and farmers. In addition, both farmers and experts agreed that most of these benefits are due to the biggest prevention risk—cover crops, highlighting a strategy that is believed to be both high risk and high benefit, posing a difficult tradeoff. Farmers mentioned cover crops' ability to improve soils through drainage, weed suppression, and ground cover. Experts, on the other hand, focused on cover crops' ability to break weed life cycles. The benefits of cover crops also included ecological benefits such as reducing erosion, which is a major concern for farmers in Ohio and Indiana.

Economically, the only significant prevention strategy that saved time, labor, and money according to farmers was the use of plastic mulch. Experts emphasized that prevention efforts reduced the amount of money needed for control each year, but most farmers did not mention this benefit.

### *The Risks and Benefits of Control Tactics*

The agricultural risks related to mechanical cultivation and tillage were the most talked about control risks among farmers. The risks associated with the implementation of mechanical control tactics were possible damage to crops and encountering weeds too big for equipment to effectively handle. In such a case, weeds continue to grow despite a farmer's efforts. In addition, relying on cultivation and tillage as the only means of weed control puts the farmer at the mercy of the weather. Missing a cultivation weather window—a timing risk—was mentioned over 40 times during the interviews.

*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 20)

After agricultural risks, economic and ecological risks were of concern to farmers. The cost of time and labor was mentioned over 40 different times by farmers. Damaging soils was also a major concern for farmers when using mechanical means as a way of controlling weeds. They are particularly keen to avoid any damage to soil structure that might lead to an increase in erosion.

While experts focused on the speed and ease of mechanical equipment as a benefit of control tactics, farmers discussed cultivation's beneficial effects on soil properties. Cultivation and tillage can be used as a way to dry out the soil, lift and move the soil around weeds, and, when used in moderation, achieve the desired effects for weed control. None of these ideas were mentioned in the expert interviews. Farmers emphasized the ability to cultivate with skill as crucial for successful weed control. It maximizes weed damage and minimizes trips across the field.

***A good tillage to start with I think is huge.** Make sure that what is growing there is dead. Don't let your grasses take off again.* (Farmer 4).

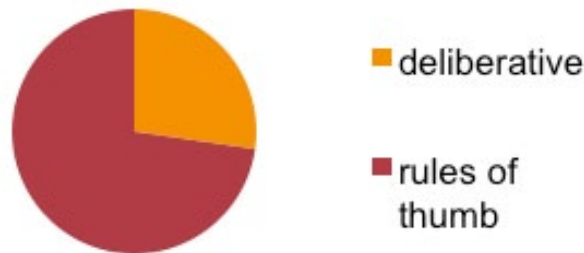
### **Weeds: Hate Them, Live with Them, or Both?**

***It's tempting to react and feel the stress of how to manage a weed problem short term. I'm learning that is exactly what it is. It is a stress reaction.** But it's much more complicated than just saying, "Oh there's a weed, I better go get it out." **The health and the fertility of my farm, certain things that are within my control such as the type of rotation...are beginning to become more of a long term strategy for me. I'm learning patience. I'm learning that since I don't have chemicals I can't get the quick fix, and I need to quit putting so much pressure and having the expectation of any short term fixes. I'm learning to live with the weeds.*** (Farmer 29)

The 29 farmers interviewed talked about emotional responses to weeds almost 100 times. Most farmers called them a plant out of place, but words such as evil, pain in the neck, enemy, work, and bad were, not surprisingly, used often. The questions we asked farmers explored how much of their decision might be dominated by initial, emotional responses to weeds, and how much of their decision would be a more deliberative, thoughtful process. These two approaches to decision making are embodied in the dual processing theoretical category (Figure 1 and 8).



## Dual Processing



**Figure 8.** Farmers use more rules of thumb in their management decisions, including their own tolerance level for weeds.

While farmers may correlate weeds with strong emotions, their approach to weeding was much more nuanced. Farmers had a range of tolerance levels for weeds that informed their decisions about when and how to deal with them. Farmer tolerance levels change based on the type of the weed (i.e., difficult to manage, poisonous) and the time of year (i.e., if it appears when people are coming to the farm, if there is labor and time to manage it). While farmers would like to have no weeds on the farm, most learn to live with a few either out of necessity or because they do not perceive them to be a risk to the crop.

Thirteen of the 29 farmers had zero tolerance for certain weeds at certain times during the season. Weeds would be managed aggressively, not allowing them to become a problem in the first place. Over half of the farmers completely tolerated weeds at some point in time, either because they were not a top priority or they felt that the weed had a place on the farm.

Finally, almost all farmers (25 out of 29) used some kind of threshold to determine their tolerance level. Despite their dislike of weeds, farmers often based their management decision on the size, type, spread, and perceived impact of the weed on the crop. The threshold could be visual (i.e., once the weed becomes too tall or takes over 25% of the field), related to its life cycle (i.e., until it begins to set seed), or economic (i.e., until it hurts yield or impacts the ease of harvest).

We view these thresholds as “rules of thumb,” or short cuts to help farmers decide when and how to act. They are based not only on a farmer’s knowledge of weed life cycles, but also on their past experiences with weeds that informs how they perceive its impact on their crop. Many times a farmer must take into consideration how much time, labor, and tools they have available to manage a weed in order to determine their threshold for weed tolerance.

*It [seeing clean rows] doesn't feel like that is right. It feels like, what poison is on there to keep the other stuff from growing? **It doesn't feel right. So you never really say, "Oh good, there's weeds." But to actually see the clean between rows of mature corn....*** (Farmer 4a)

*Yeah, there needs to be a little bit of life. I don't want them going to seed, but I want something alive down there in that cornfield. **Don't hurt my yields and don't go to seed.*** (Farmer 4b)

Tolerance levels were especially prevalent in farmers who had transitioned from conventional to organic agriculture. These farmers talked often about their shifting attitudes from one of zero tolerance to one of learning that a few weeds would not impact the yield or quality of the crop.



***That was my biggest thing is being organic I couldn't stand weedy fields. That was going to be the thing 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. I think we can get over that with some intercropping, like some clovers or something in the early spring. We haven't raised enough of them to know how it's going to work. Once I got into it I was actually kind of surprised that I was able to control it in the corn and stuff. (Farmer 27)***

***The tolerance I guess is something that we just had to change because I can't get a perfectly clean field and so over time it's just watching the yield. I've realized that we're getting very similar yields to what we used to conventionally. So the weeds must not be making that much of a difference. (Farmer 6)***

### The Most Important Factors in Weed Management Decisions: A Ranking Exercise

In addition to the interview questions, farmers were asked to complete a ranking task. Each farmer was asked to arrange a set of 16 note cards from the most important to the least important factors they considered when managing weeds (Table 3). Overall, what worked in the past and the time and labor required for a certain management practice were the most important factors in making a weed management decision. The type and timing of the weed was also near the top, reflecting farmers' use of knowledge in weed management decisions. Soil health and crop yield came in 4th and 5th, reflecting farmer values and goals for implementing certain weed management techniques. The last three considerations were the National Organic Program (NOP), the latest research and science, and extension recommendations.

**Table 3.** Farmer ranking of most to least important consideration when making a weed management decision.

<i>Consideration</i>	<i>Overall Rank</i>
What worked in the past	1
Time and labor	2
Type/timing of weed	3
Soil health	4
Crop yield	5
Farmers w/ similar soils/crops do	6
Markets/consumer demand	7
Env. and/or ecological health	8
Immediate control	9
Respected farmer's advice	10
Family and worker health	11
Cash flow	12
Public perception	13
National Organic Program standards	14
Latest research and science	15
Extension recommendations	16



## What are Farmers Using for Weed Management?

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.

## DISCUSSION

### Knowledge is Not the Limiting Factor in Successful Weed Management

Each of the farmers interviewed had a sophisticated and intimate knowledge of their own farm system—its weeds, soil type, resources, and history. In addition, they demonstrated enthusiasm and curiosity about trying new weed management techniques and learning through trial and error. As a result, many of the ecologically-based strategies discussed by weed scientists and ecologists are already familiar to farmers—crop rotation, mulches, cover cropping, reduced tillage, and seed bank management—and were perceived to be socially, ecologically, economically, and agriculturally beneficial.

Experts emphasized that a high level of EWM knowledge was needed to implement effective, ecologically based weed management. Weed identification, knowledge of weed life cycles, seed bank management, and understanding agroecology were all important concepts of EWM, and our interviews revealed that this type of knowledge was present in the Midwest organic farm community as a whole.

What, then, is contributing to the perceived disconnect between experts and organic farmers and the perceived lack of EWM among the organic farm community? This initial, exploratory investigation into organic farmers' mental models identifies three key factors in farmer weed management decisions that diverge from the expert understanding and may contribute to this perceived disconnect: saving time and labor, improving soil health, and experience-based management.

### Saving Time and Labor Crucial to Farmers

***[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.*** (Expert G)

Organic farmers are forced to make decisions in a very complex environment under rigid time, labor, and resource constraints. In such a complex environment, farmers look for ways to simplify their decision making. Their desire to find a straightforward answer for the presence of certain weeds in their field and how to get rid of them may be what motivates over 50% of the farmers to believe that weeds are “indicators” for what is lacking in the soil. For example, some farmers believed thistle signaled a lack of calcium in the soil and would remain, drawing that nutrient into the soil through its roots, until it was no longer needed.

***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.*** Farmer 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 17)

Weed scientists could generate research questions in collaboration with farmers' observation of the links between nutrient management and weeds in order to scientifically investigate their observations. 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.

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 save them time and simplify their operations in order to stay viable. The farmer's need for information that would support quicker decisions reveals several potential studies and publications for the research community to address.

1. What is the relationship between soil nutrients and weeds? Does adding specific nutrients deter specific weeds from growing?
2. How can cover crops (perceived to be both a risk and a benefit) be implemented effectively despite the risks of poor germination and weather?
3. What crop rotations are best for a high seed bank vs. a low seed bank? What crop rotations are best for certain types of weed populations (e.g., pasture based systems for the control of thistle, or short term cover crops for a high seed bank)?
4. How can a farmer determine the level of his or her seed bank? (Most farmers have the resources to do a seed bank test on their own.)
5. How many weeds can certain crops withstand before yield loss (a rule of thumb for thresholds), and how can this be determined?
6. What types of tillage/cultivation implements work best in what kinds of soils and what skills are needed to operate them? This question is one that farmers may be better equipped to answer than experts.
7. What are the costs and benefits of delaying fall tillage to encourage seed predation by macro-organic life such as beetles?
8. Does predation actually work, and what percentage of weeds seeds will be destroyed in predation vs. fall tillage?
9. Do organically managed soils with high organic matter decay seeds more quickly than conventionally managed soils?

In general, a farmer's mental model of weed management utilizes rules of thumb, or heuristics, to help them make decisions that will save time and labor. However, they may only be saving time and labor in the short term, requiring them to repeat the same measures year after year. By providing farmers with the above information, experts can help them navigate their decisions toward long-term strategies that improve weed management decisions and permanently save them time, labor, and money.

### **Soil Health is a Top Priority for Organic Farmers**

Farmers and experts are in sharp alignment when it comes to their perceptions of the risks of weeds and weed management, but farmers weigh the risks of weed management much more heavily in soil health than experts. The risk to soil health often forces farmers to make management trade-offs such as bare fallowing combined with heavy cover cropping, or initial stale seed bed techniques followed by longer rotations that allow the soil to rest.

Soil health also informs a farmer's choice and use of tillage equipment, which he or she understands on a much more nuanced level than some of the scientists interviewed. The following excerpt highlights farmer tradeoffs between weed management and soil health:



*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 discing that ground. I'm hurting the ground by discing 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 16)

Farmers' on-farm experience plays a large role in how they understand the connection between weed management and soil health. Organic farmers are not just thinking about weeds, they understand and observe how soil conditions affect weeds, implement usage, and crop growth. Many of them talked about organic methods improving their soils and increasing their crops' ability to withstand drought, drain excess moisture, and increase the efficacy of their tillage.

*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 18)

Organic farmers were acutely aware of the risk of over-tillage—a risk emphasized by experts as well—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. Many farmers would like more information on the capacity for no-till management in organic systems.

Experts may be able to harness risk perception as a motivator for the preventive approaches ideal to EWM by acknowledging that weed management doesn't just affect the weed, but the soil as well. According to experts, soil health and weed management coincide in several areas: nutrient management, cover cropping and green manures, crop rotation, and using appropriate tillage. By framing weed management in terms of soil health, efforts to promote greater adoption of preventive strategies may be more successful.

### Experience-based Management

Farmers make weed management decisions based on experiential knowledge. This was evident in the interviews and in the ranking exercise that showed "what worked in the past" was the number one factor in a weed management decision. On many levels, experience-based knowledge coincided quite well with scientific knowledge, even though farmer understanding of mechanisms behind certain practices may not have been the same.

For example, experts believed 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.

***[O]n 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.***  
(Expert F)

Very few farmers, however, thought it would be possible to completely deplete the seed bank. Over half of the farmers interviewed believed that weed seeds remain viable in the soil for a very long time, and of these responses half described their viability as “forever.” Rather than using research to inform their seed bank management, farmers turn to local knowledge and their own experiences. As a result, farmers use short, annual cover crops and diverse crop rotations appropriate for depleting high seed banks. Even long term cover crops are mowed regularly to prevent seed rain. In other words, experts and farmers often come to similar conclusions—one through experiments and the other through experience, whether it's their own or that of other farmers.

*Well I remember back when I was a kid when there was no chemicals. Dad farmed and it would be in alfalfa or hay or something for two years or three years, and then he would plow it under and he would put it in corn the first year. The second year would be soybeans, and then the third year would be either oats or wheat after the soybeans. Then he would sow clover in the wheat, and then keep that a year or two, and then plow it under and go back to corn. **We done that for many years. We didn't have grass problems. [Now] it just seems like every year further away from the alfalfa you get more and more weeds.*** (Farmer 25)

The farmer model also reveals a high degree of confidence in management to mitigate the social, economic, agricultural, and ecological risks of weeds. This belief is based in the long term experiences of organic farmers who, like scientists, are acute observers of how their decisions affect the agroecosystem.

***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 4)

***One thing we learned the last two years is wait two weeks before you plant after you till in green manure. You can till down the woody material, the carbon material, but if it's living material then wait 2 weeks and let it break down before you plant or [the crop] will not sprout. ..It's a new phenomenon with the rotavators that we didn't used to have. When you have a plow, you plow down 6" deep or 7". Your breakdown process is beneath the seed zone. By the time the two weeks pass and your roots get down into it, your breakdown process is completed. The bacteria that break it down are a pathogenic bacteria to the seed. They can break down the seed as well.*** (Farmer 4)

Unlike previous research that showed conventional farmers blamed lack of weed control on forces outside of their personal control (Wilson 2009), organic farmers in Ohio and Indiana take responsibility for the type and density of weeds on their farm. Not only do they accept responsibility, but they also believe in their ability as farm managers to be successful in weed management. 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.

***[H]ow is it that he has phenomenal weed pressures every year? Because the weeds are adapting to the sprays and are putting out seed and they're surviving. I find that the organic controls are long term more effective than chemical controls. We don't have ragweed here anymore. He still has, after 50 years; he still has ragweed in his fields from using strictly cultivation and chemical controls. The biggest limitation [in organic agriculture] is time. It takes more time and diligence.***  
(Farmer 9)



This management-centered approach is good news for the outreach community. 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.

### Areas for Further Investigation

One of the eminent scholars in human judgment and decision making, Baruch Fischhoff (1997), writes:

*[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).*

"Values" is often put at the heart of the debate between conventional and organic agriculture, but what do organic farmers really value and what role do they play in their weed management decisions? This research shows that 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, wildlife on the farm, and healthy soils.

*"Why aren't you cutting hay?" The lame excuse that the bobolinks are nesting. "Bobolinks are nesting! Well you don't worry about bobolinks." Well, yes I do... My son-in-law—I have to give him credit for it, because I think Ralph Waldo Emerson says "A man standing in his own field is unable to see it" and there is a lot of truth to that—he said why don't we graze that field lightly every week or so up until the 1st of July and just emulate the prairie where the bison walk through there? And it works wonderfully. **So in that field we would not go for the max profit and yield; we go for the ecological partnership with the bobolinks.** But we have horses and we have heifers, so that hay is not wasted. (Farmer 12)*

Our interview data has the potential to begin a thorough investigation into the role of values in organic farmers' management behavior. Weed management is more than applying correct knowledge to a problem; it is a dynamic matrix of risk perceptions, beliefs, and values that will directly influence the agroecosystem a farmer manages.

### CONCLUSION

The research presented here is an effort to enhance the relevance of research and outreach in weed biology, ecology, and analyses of various weed management tools (e.g. cover cropping, mulch, and cultivation) by providing an in-depth study of how an organic farmer's beliefs, knowledge, risk perception, and experience shape his or her weed management decisions and behavior.

While knowledge of a risk—in this case weeds and weed management—is important when choosing between management options, this research shows that knowledge alone does not inform organic farmers' weed management choices. Perceptions of risk, informed by a matrix of individual values, emotion, experience, and knowledge play just as important a role in the decision making process as expert or analytical knowledge.

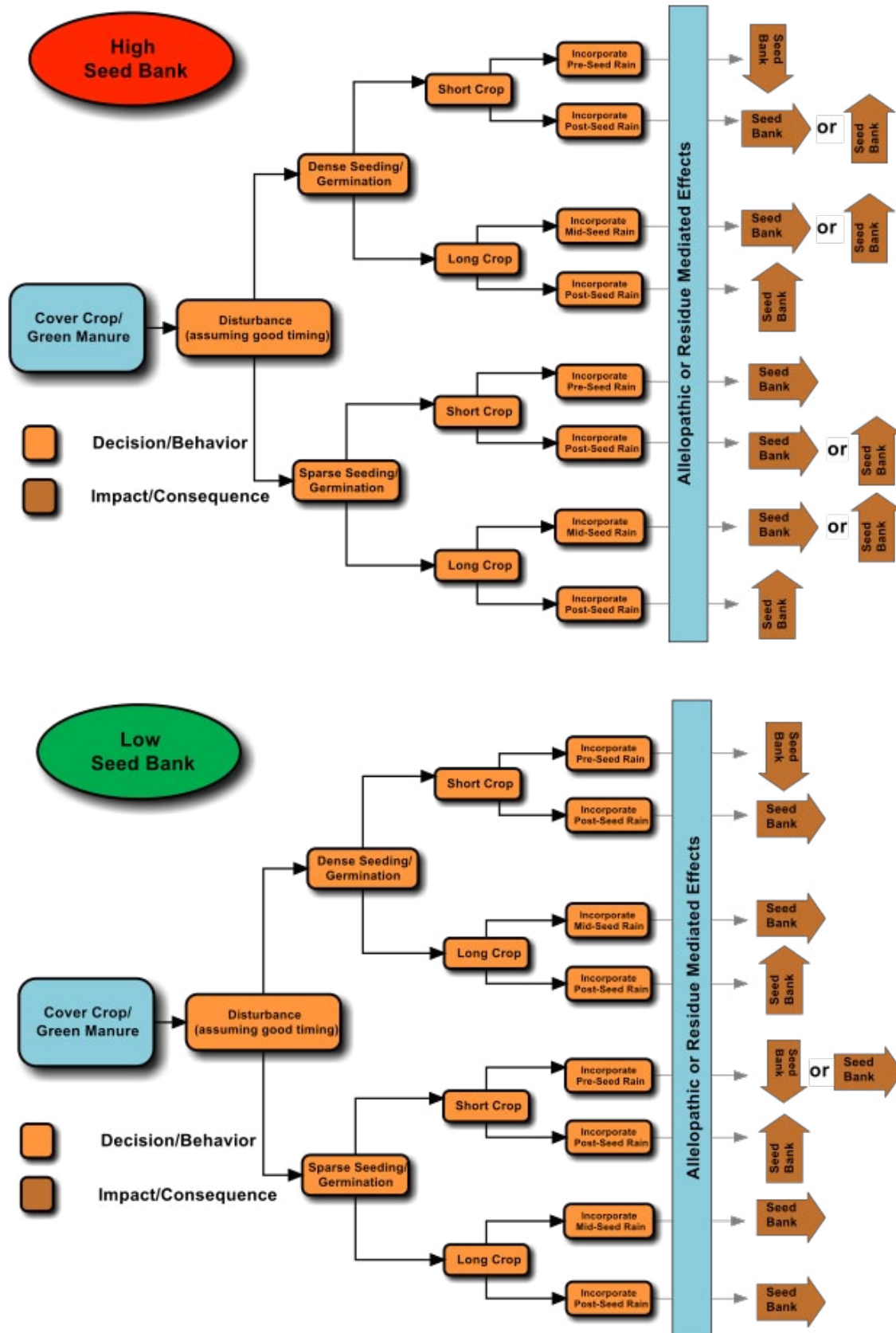
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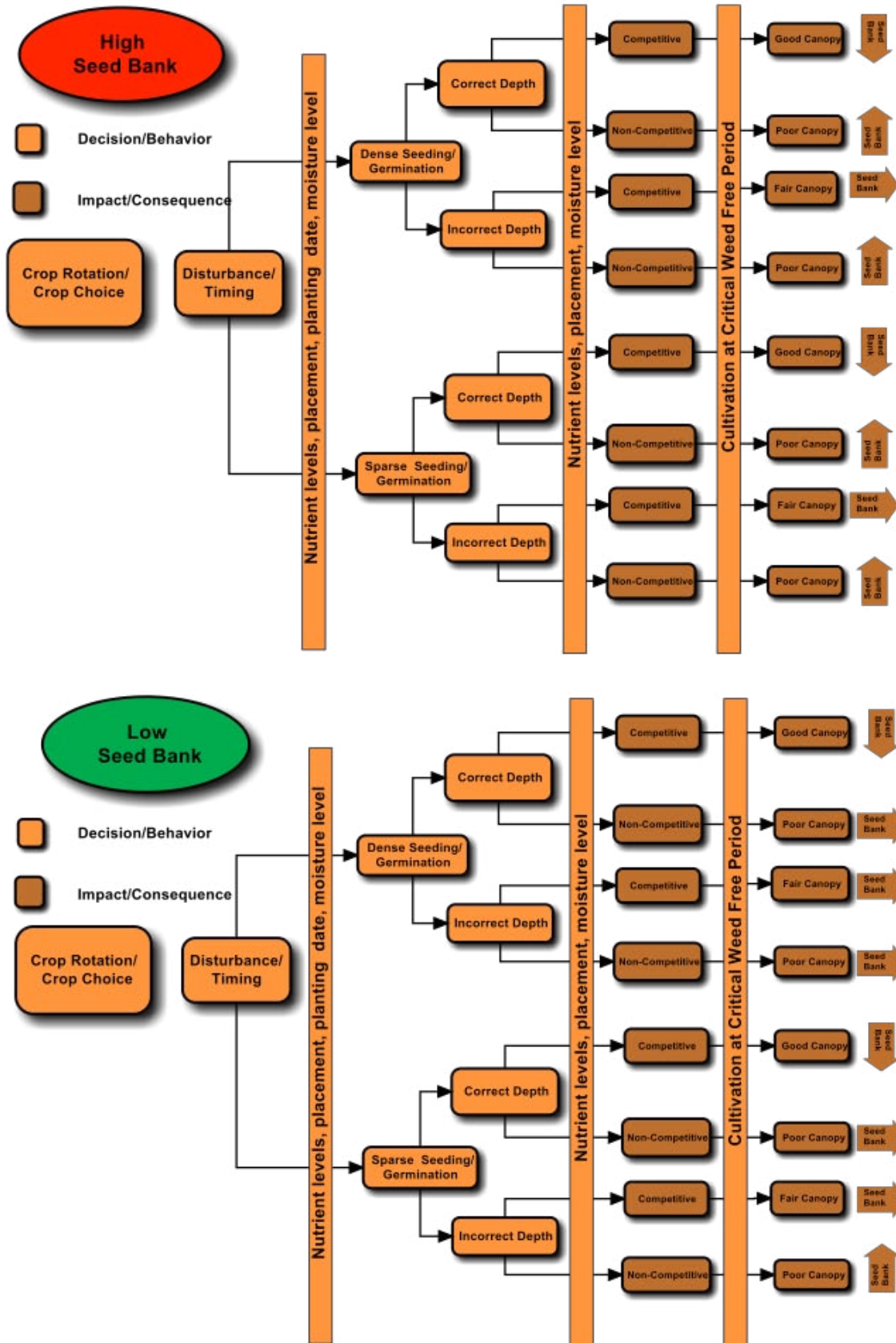
### Appendix A. Decision tree for cover crop implementation and effects on seed bank.







**Appendix B. Decision tree for crop rotation/choice implementation and effects on seed bank.**





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